SHELL OFFSHORE INC.

BEAUFORT SEA REGIONAL EXPLORATION OIL DISCHARGE PREVENTION AND CONTINGENCY PLAN

SHELL OFFSHORE INC.

ANCHORAGE, ALASKA

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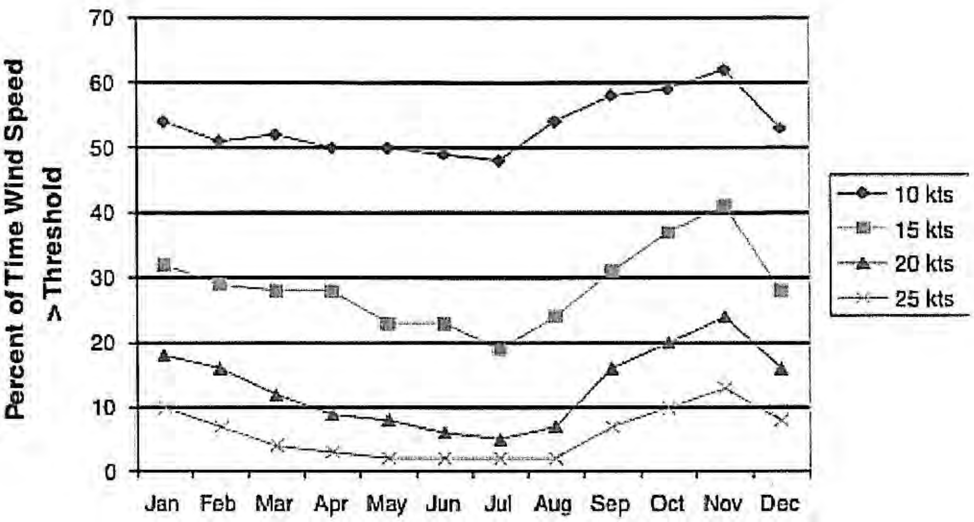
FIGURE 3-3-3-4
MONTHLY WIND SPEED EXEEDANCE



VAUDREY (2000) BASED ON LONG-TERM DATA FOR THE PRUDHOE BAY AREA

states during the period of maximum open water (mid-August to mid-October) can be estimated from this standard relationship. For example a moderate breeze of 11 to- 16 knots (Force 4) will result in a wave height of 3.5 to 5 feet, a condition which would be exceeded approximately 30 percent of the time in September (Figure 3-34), – the month with the maximum extent of open water off the Alaskan Beaufort Sea coast.

In the event that a storm surge occurs, critical drilling operations would be curtailed and continuous monitoring of the weather forecast would ensue. For specific limitations on response equipment due to sea states, see ACS *Technical Manual*, Tactic L-7.

3.4.3 In Situ Burning Response Measures in Ice

Introduction

One of the most important factors that influence drilling activities is the movement and amount of sea ice in the Beaufort Sea. Sea ice can pose a significant challenge for spill response; however, experience has shown that low temperatures and ice can often enhance spill response and reduce environmental impacts. For example:

- Low air and water temperatures often result in greater oil equilibrium thicknesses, thereby reducing spreading rates and areas of coverage. These reductions greatly reduce the potential for impact with natural resources while providing the potential for much higher oil encounter rates for mechanical recovery and burning operations.

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- Evaporation rates are reduced, leaving the lighter and more volatile components in the oil longer, thereby enhancing the ease with which the oil could be ignited.
- The wind and sea conditions in the Beaufort Sea are considerably less dynamic than most open-ocean environments; and the presence of ice can actually dampen wave action and limit the fetch over which winds might otherwise create large waves.
- While ice, even in low concentrations, can preclude the effective use of oil containment boom, responders may still operate with short boom extensions and skimmers to maneuver among ice pieces and intercept oil.
- When ice concentrations preclude the use of any boom, the ice will often serve as a natural barrier to the spread of oil and help concentrate the oil for pocket-recovery operations with stationary skimmers. The natural containment of oil against ice will often result in thicknesses that could significantly enhance the efficient removal of oil with burning.
- When high ice concentrations (very close pack) and/or continuous stable ice conditions prevail, any spilled oil (especially from a subsea blowout) will likely become immobilized and encapsulated within the ice and, therefore, isolated from any contact with airborne or waterborne resources.
- Oil locked up and captured within the ice will be preserved physically and chemically so that its unweathered state upon release (deliberately exposed, or naturally released during break-up) will support combustion.

In addition to the above environmental factors, there are other spill source considerations that should be recognized ~~as~~ because they influence the full potential for elimination of spilled oil with burning:

- The spill scenarios associated with Shell's operations in the Beaufort Sea involve the release of oil and gas from a subsea blowout (in contrast to an above-water release such as from a fixed drilling structure). Oil would therefore be released to a relatively small area on the water with initial slicks with widths of typically a few hundred meters or less. Even with the gas-induced flow of oil and water toward the surface and the resulting radial spread of oil outward from the source, the initial area of involvement will be localized and relatively easy to contain and/or deflect with booms.
- Because of the likely release of large quantities of natural gas and vapors from the surfacing oil, it is likely that early ignition of that gas would be desirable as soon as the drillship~~ing rig~~ is moved off location. The vapor cloud could be readily ignited using standard ignition procedures, thereby eliminating the accidental ignition of the source when vessels are in close proximity. The early ignition of the source would not only be prudent for safety reasons, it is possible that significant quantities of oil could be eliminated through combustion at or ~~/~~near the source.
- With or without ignition of the blowout, prevailing atmospheric conditions in the Beaufort Sea will support safe operating conditions at or beyond a few hundred meters downwind of the source.

To summarize key points: the nature of oil released to the surface; the oil's limited spread due to reduced temperatures (and possible ice); and the potential for responders to access the oil before it moves far from the source and begins to weather, all enhance the potential for successful recovery and/or burning operations.

Key Combustion Processes

The following discussion summarizes the current state of understanding the scientific principles and physical processes involved with in situ burning of oil on water and ice.

For an oil slick on water or ice to become ignited, the oil must be thick enough to insulate itself from the water beneath it. The igniter can heat the surface of thickened oil to the flash point temperature at which the oil produces sufficient vapors to ignite. The rules of thumb for minimum ignition thickness are listed in Table 3-6.

TABLE 3-6
MINIMUM IGNITABLE OIL THICKNESS ON WATER
(ADAPTED FROM BUIST ET AL., (2003)

OIL TYPE	MINIMUM THICKNESS
Light Crude and Gasoline	1 mm* (0.04 inches)
Weathered Crude and Middle-Distillate Fuel Oils (Diesel and Kerosene)	2 to 3 mm (0.08 to 0.12 inches)
Residual Fuel Oils and Emulsified Crude Oils	10 mm (0.4 inches).

*mm – millimeters

The oil removal rate for in situ oil fires is a function of fire size (or diameter), slick thickness, oil type, and ambient environmental conditions. For most large (greater than 3 meter m diameter) fires of unemulsified crude oil on water, the "rule- of-thumb" is that the burning consumption rate is 3.5 millimeters mm per minute (mm/min). Lighter fuels burn faster while heavier oils and emulsions burn slower, as shown in Table 3-7.

TABLE 3-7
BURN REMOVAL RATES FOR LARGE FIRES ON WATER
[(ADAPTED FROM BUIST ET AL., (2003)]

OIL TYPE/CONDITION	BURN/REMOVAL RATE
Gasoline >10 mm (0.4 inches) thick	4.5 mm/min (0.18 in/min*)
Distillate Fuels (diesel and kerosene) >10 mm (0.4 inches) thick	4.0 mm/min (0.16 in/min)
Crude Oil >10 mm (0.4 inches) thick	3.5 mm/min (0.14 in/min)
Heavy Residual Fuels >10 mm (0.4 inches) thick	2.0 mm/min (0.08 in/min)
Slick 5 mm thick[1]	90 percent of rate stated above
Slick 2 mm thick[1]	50 percent of rate stated above
Emulsified oil (percent of water content)[2]	Slower than above rates by a factor equal to the water content percent
Estimates of burn/removal rate based on experimental burns and should be accurate to within ±20 percent.	

* inches per minute

1. Thin slicks will naturally extinguish, so this reduction in burn rate only applies at the end of a burn.

2. If ignited, emulsions will burn at a slower rate almost proportional to their water content (a 25-percent water-in-crude-oil emulsion burns about 25 percent slower than the unemulsified crude).

Burn rate is also a function of the size of the fire. Crude oil burn rates increase from 1 millimeter per minute (mm/min) with 3-foot diameter fires to 3.5 mm/min for 15-foot fires and greater. In situ burns on meltwater pools typically consume oil at 1 mm/min. For very large fires, on the order of 50 feet in diameter and larger, burn rates may decrease slightly because there is insufficient air in the middle of the fire to support combustion at 3.5 mm/min. As fire size grows to the 50-foot range, oil type ceases to affect burn rate for the same reason.

An in situ oil fire extinguishes naturally when the slick burns down to a thickness that allows enough heat to pass through the slick to the water to cool the surface of the oil, below the temperature required for sustained combustion. The thickness at which an oil fire on water extinguishes is related to the type of oil and initial slick thickness. The rules of thumb are presented in Table 3-8. Other, secondary factors include

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environmental effects such as wind (winds greater than 20 knots preclude in situ burning in most cases) current herding of slicks against barriers, and oil weathering.

TABLE 3-8
FIRE EXTINGUISHING SLICK THICKNESS
[(ADAPTED FROM BUIST ET AL., (2003)]

OIL TYPE/INITIAL SLICK THICKNESS	EXTINGUISHING THICKNESS
Crude Oil up to 20 mm (0.8 inches) thick	1 mm (0.04 inches)
Crude Oil 50 mm (2 inches) thick	2 to 3 mm (0.08 to 0.12 inches)
Distillate Fuels any thickness	1 mm (0.04 inches)

With an estimate of the initial thickness of a fully contained slick, or a measure of the burn time, it is relatively easy to estimate oil removal efficiency by burning. If not all of the slick area is on fire; the calculations need to account for this.

Oil-removal efficiency by in situ burning may be summarized as a function of the following key factors:

- Initial thickness of the slick,
- Thickness of the residue remaining, and
- Amount of the slick's surface that was on fire.

The water current maintains the oil thickness in the apex of a fire-resistant boom under tow, or against an ice edge in wind. When burning in a current, the fire slowly decreases in area until it reaches a size that can no longer support combustion. This herding effect can increase overall burn efficiencies, but it extends the time required to complete each burn.

The residue from a typical, efficient (greater than 85 percent removal) in situ burn of crude oil 10 to 20 mm thick is a semi-solid, tar-like layer that has an appearance similar to the skin on an old can of latex paint that has gelled. For thicker slicks, typical of what might be expected in a towed fire boom (about 150 to 300 mm), the residue can be a solid. Burn residue is usually denser than the original pre-burn oil, and usually does not spread due to its increased viscosity or solid nature.

Most unburned oil or burn residue following combustion would be transported from the vicinity of the blowout by wind or currents.; sShould any residue remain on the surface in the immediate area, it could be recovered by various means, including the use of booms in open-water conditions downstream of the burn area, or by response personnel using nets, poles, or other simple equipment over-the-side of small work-boats, subject to safe working conditions, weather, and available time. Disposal of any recovered residue would be in accordance with Appendix D.

Tests indicate that the burn residues from efficient burns of heavier crude oils (less than <32 degrees API gravity°API) may sink once the residue cools, but their acute aquatic toxicity is very low or nonexistent. The "*In Situ Burning Guidelines for Alaska*" (ADEC, U.S. Environmental Protection Agency ([EPA]), and U.S. Coast Guard (USCG), March 2001) state, "The environmental advantages of in situ burning outweigh the potential environmental drawbacks of burn residue, including the possible environmental harm if the burn residue sinks. Therefore, the on-scene coordinators do not consider the potential impacts of burn residue when deciding whether to authorize an in situ burn." As required under 18 AAC 75.445-(h) and 18 AAC 75.425(e)(3)(G), Shell will also submit an "RRT Regional Response Team In Situ Burn Application Form" to the Unified Command (See Section 1.7), which will includes its plans for residue collection and disposal.

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Compared with unemulsified slicks, emulsions are much more difficult to ignite and, once ignited, display reduced flame spreading and more sensitivity to wind and wave action. Stable emulsion water contents are typically in the 60 percent to 80 percent range with some up to 90 percent. The oil in the emulsion cannot reach a temperature higher than 100 degrees Celsius (°C) until the water is either boiled off or removed. The heat from the igniter or from the adjacent burning oil is used first, mostly to boil the water rather than heat the oil.

The following points summarize the effect of water content on the removal efficiency of weathered crude emulsions:

- Little effect on oil removal efficiency (i.e., residue thickness) for water contents up to about 12.5 percent by volume;
- A noticeable decrease in burn efficiency with water contents above 12.5 percent, the decrease being more pronounced with weathered oils;
- Zero burn efficiency for emulsion slicks having water contents of 25 percent or more; and
- Some crudes form meso-stable emulsions that can burn efficiently at much higher water contents; Paraffinic crudes appear to fall into this category.

Fortunately, emulsion formation is slowed dramatically by high ice concentrations and may not be a significant operational factor in planning in situ burns on solid ice or naturally contained in higher concentrations of broken ice.

SL Ross et al. (2003) provides guidelines for burning thin slicks in broken ice with brash and slush, particularly relevant during the break-up and freeze-up shoulder seasons. General rules for minimum ignitable thickness and oil removal rates for burning thin slicks of crude oils on brash and/or slush with broken ice are as follows:

- The minimum ignitable thickness for fresh crude on frazil ice or small brash ice pieces is up to double that on open water, or about 1 to 2 mm.,
- The minimum ignitable thickness for evaporated crude oil on frazil ice or small brash ice pieces can be higher than on open water, but is still within the range quoted for weathered crude on water, about 3 mm with gelled gasoline igniters.
- For a given spill diameter, the burn rate in calm conditions is about halved on relatively smooth frazil/slush ice and halved again on rougher, brash ice. Wave action slightly reduces the burn rate on open water, but the halving rule seems to also apply in waves.
- The residue remaining on broken ice in calm conditions is about 50 percent greater than that on open water, or 1.5 mm. The residue remaining on brash or frazil ice in waves is slightly greater than in calm conditions, at about 2 mm.

In summary, in situ burning of oil is efficient and rapid in broken ice conditions under the following conditions:

- The spilled oil is thicker than the minimum required for ignition (a thickness of 2 to 3 millimeters mm results in 50 to 66 percent removal efficiency: 10- millimeter mm thickness, a typical thickness for wind-herded slicks on melt ponds on ice, gives 90 percent removal efficiency);
- Larger areas can be ignited – (a 100-square foot slick on a meltwater pool will burn at 3.5 barrels of oil per hour (boph);, a 50-foot diameter, 10-mm thick slick will burn at 300 boph; and a 100-foot diameter slick will burn at 1,200 boph);
- The oil is not more than 25 percent emulsified; and

- Herding in a current and enlarging fire diameters can increase burning rates.

The potential for efficient oil spill response (with or without burning) is strongly tied to the nature and amount of ice present. The following section addresses the seasonal ice conditions in Shell's area of interest in the Beaufort Sea during the proposed drilling season.

Seasonal Ice Conditions

The following general description of the ice environment applies to the nearshore and offshore marine environments in the Alaskan Beaufort Sea, from shore out to the approximate 100-foot isobath representative of Shell's drilling locations. Descriptions cover typical conditions ~~as well as~~ and the variability in ice coverage and timing of the seasonal ice cycles. The focus is on a chronology most applicable to Shell's exploration program, starting with the first evidence of ice melt and clearing along the coast, and ending with the establishment of a stable fast ice cover nearshore and very close pack (9/10 or more) offshore in the November/December period. A brief description of the overall morphology and dynamics of winter ice conditions offshore is provided for completeness. See Dickins and Oasis (2006), Vaudrey (2000), and Atwater (1991) for further details.

May

The major river systems (Colville, Kuparuk, Sagavanirktok, and Colville) overflood the nearshore sea ice between mid-May and early June (average last week in May), based on 16 years of analysis presented in Atwater (1991). In any given year, the different rivers tend to flood within three to four days of each other. The maximum seaward extent of the floodwater reaches the 20-foot isobath between Stump Island and Northstar and the 10-foot isobath off Endicott and Niakuk.

The ice overflood along the coast triggers a rapid progression of local ice decay and break-up, fanning out in shallow water east and west from the major river ~~D~~deltas and eventually leading to an almost continuous open corridor from Harrison Bay to Camden Bay (see June below).

Ice concentrations in the offshore area (outside of the fast ice zone) in May are classified as very close pack ice of 9 to 9.5/10 (90 to 95 percent ice coverage). Recent analysis for the period 1996-2004 by Eicken et al. (2006) shows water depths at the fast ice edge in May off Flaxman Island ranging from 56 feet to more than 150 feet (averaging 98 feet). At this time, a broad open flaw lead often separates the fast ice inshore from the mobile pack ice offshore. This lead is highly variable in width and ~~E~~east/~~W~~west extent and tends to become much less prevalent towards the end of May, and into June and July.

June

June 1 to July 15: Within the overflood zones, previously bottom-fast (grounded) ice in shallow water (less than 6-foot depth) lifts off the seabed and rapidly melts in place. The sea ice over-flood often peaks at this time curtailing routine ice road operations. The influx of relatively warm water discharge into the inshore lagoons leads to early opening along shore in June, several weeks ahead of break-up offshore. First open water appears offshore of the Sagavanirktok and Kuparuk ~~R~~rivers in the period June 6 to June 13 and expands to include the lagoon side of West Dock (PM1) by June 17 on average. Fast ice beyond the overflood zones and outside the Barrier Islands is still intact at this time and often more than 5 feet thick in the first half of the month. Melt ponds usually cover less than 10 percent of the floating fast ice.

June 15 to July 25: Nearshore lagoon areas between Oliktok and West Dock, and in shallow waters off the Sagavanirktok delta, are mostly free of ice, and ice is starting to fracture and open south of the Endicott causeway. Further to the east, the initial clearing associated with flooding from the Staines and

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West Canning Rrivers expands around Brownlow Point to become contiguous with the much larger clearing off the Canning Ddelta. This connection generally occurs by late June.

The fast ice, still intact outside of the Barrier Islands gradually melts but is typically still 4 to 5 feet thick in many areas. The soft ice surface at this time is often 25 percent covered by melt-water pools that are rapidly deepening and expanding, with visible cracks and fractures. Ice deterioration is accelerated in areas where the surface is contaminated with dirt either left from drainage of overflood waters, or windblown off the nearby land (Vaudrey 2000).

Air temperatures at this time of year average 35 degrees °F and range from 20 to 40 degrees °F. The wind is variable, but blows 60 percent of the time from the E east and NEnortheast, averaging 10 knots.

The fast ice can still support heavy equipment and low ground-pressure response vehicles up to the third week of June. The ability to achieve continued mobility on deteriorating sea ice with specific equipment is illustrated in ACS *Technical Manual*, Tactic L-7, based on field trials by Coastal Frontiers (2001).

The offshore area (100-foot water depth and beyond) still experiences 9/10ths or greater ice concentration until the last week of June in most years.

July

July 1: By the beginning of July, the open-water areas, which that originated from the Colville and the Kuparuk Rrivers typically join to form a continuous band of open water stretching from the south shore of Atigaru Point in Harrison Bay to West Dock (Dickins and Oasis, 2006). By this time, the open water areas, which initially formed off the Shaviovik, Kadleroshik, and Sagavanirktok Rrivers further west, have also joined to become a continuous coastal pathway of open water. The last nearshore area to clear (one to two weeks later) tends to be the coastal section between Point Thomson and Bullen Point (a coastal area not directly impacted by river overflood). The fast ice at this time is broken and mobile with drifting thick floes of variable concentration out to approximately 5 miles from shore.

In deeper water (Northstar vicinity or 30-foot water depths and beyond), the fast ice is still intact but badly deteriorated and vulnerable to break-up and fracturing by wind action. The ice at this time can still be 3 to 4 feet thick with many visible cracks and approximately 40 to 50 percent of the surface covered by meltwater pools and holes.

July 1 to July 7 (Typical): Break-up begins with fracturing and movement in the remaining floating landfast ice outside the Barrier Islands. The onset of break-up with fast ice in a severely weakened state is usually triggered by a wind event acting on parts of the sheet separated by natural lines of weakness indicated by a series of deep melt ponds or old thermal or stress cracks (Vaudrey in Dickins et al. 2000).

Pack ice concentrations in deeper water offshore (100 feet and vicinity) are typically in the range of 7-8/10ths, a 20-percent reduction from the full winter concentration.

July 8 to July 12: Remaining fast ice remnants outside the Barrier Islands, off the Sagavanirktok River Ddelta and in Prudhoe Bay, survive as drifting floes in less than 7/10ths concentration. As the winds shift direction, the broken ice floes and pans move back and forth in belts and patches of varying concentrations, all the while melting with a reduction in average floe size. First-year ice continues to deteriorate and break into smaller floes, creating large, highly variable openings in the remaining ice cover (Dickins *et al.* 2000).

July 15 to July 30: Ice-free water exists from shore out to Northstar and sites in equivalent water depths off the Endicott causeway and further east into Mikkelsen Bay. Ice invasions in the nearshore areas after this date are possible, but unlikely (Vaudrey, 2000). Ice concentrations in deeper water steadily diminish

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through melting and wave and floe interactions over a period of two to three weeks. Remaining broken ice at this time moves back and forth in response to wind shifts, in belts and patches of varying concentrations. By the end of July or the first week of August, the study area typically becomes open water (defined as less than 1/10th ice concentration) out to water depths in the 40- to 65--foot range. Nearshore ice floe diameters rapidly shrink as the remaining fast ice decays and clears, starting out at 500 to 1,000 feet in the early stages and becoming ice cakes 30 to 40 feet in diameter by the third week in July.

Conditions in deeper water sites in the last half of July are highly variable, ranging from open water in unusually mild years (2two years in ten) to a more typical condition of 7 to 8/10ths thick first--year ice with floe sizes in the medium to big category (300 to- 1,500 feet to and 1500 to -6500 feet). Periods of intermediate concentrations (4 to 6/10ths) can occur in mid- to late July, but these conditions tend to be short lived.

August to September

Offshore, the first half of August typically encompasses the last stages of break-up, with open drift ice concentrations ranging from 2 to 6/10ths. Extreme years can see variable patches of close pack ice in high concentrations during this period. Floe sizes range from small to medium for the predominantly first-year ice (60 to -300 feet to and 300 to- 1,500 feet). Multi-year ice is often present in trace amounts (a few percent in coverage or much less than 1/10th) and rarely occurs in significant concentrations in the vicinity of Shell's drilling locations at this time of year (maximum reported 4/10th in two of the last ten years;. (Source: Canadian Ice Service charts). Summer multi-year floe sizes tend to be larger than the surviving first--year pack (up to thousands of feet in diameter).

The nearshore area previously covered in stable ice, the winter fast ice zone, is completely open by the beginning of August in most years. Once established, open--water conditions in the coastal nearshore lagoon areas and adjacent to the Barrier Islands (typically in less than 10--foot water depths) generally prevail until freeze-up (see below). For example, there are no reported instances of drift ice entering the lagoon areas between Brownlow Point and Bullen Points during the summer months of August or September. The median duration of open water in the lagoon areas is 12 weeks, with a variability of up to two weeks representing summers better or worse than average in terms of break-up and freeze-up (Dickins, 1984). Immediately outside of the Barrier Islands (out to approximately the 50-foot-ft water depth), the duration of open water drops by about two weeks, and in some summers can be further reduced by several weeks through temporary pack ice invasions.

In the vicinity of the Shell's drilling locations, the average duration of open water (defined as 1/10th or less pack ice) is 7.5 weeks, with the most consistent period of continuous open water beginning mid-August and ending with first complete coverage of new ice in deep water in mid- to late October (based on a review of historical ice charts from 1997 to 2006).

Air temperatures average 40 degrees °F in July and August, dropping to 30 degrees °F in September. Wind blows from the E east and NE northeast 50 percent of the time, and Wwest and southwest/SW 20 percent of the time, averaging 13 knots.

October

Freeze-up begins along shore in shallow water on October 4, ±8 days (Vaudrey, 2000). Ice becomes fast for the season within one week following freeze-up in the nearshore lagoons and at coastal locations such as Point McIntyre 2 and Niakuk. In deeper water north of the Barrier Islands (10 to 50 feet), the first continuous sheet forms on average by October 15 (Dickins and Oasis, 2006). By late October, ice movements inshore of the 30-foot water depth are infrequent, and the sheet is considered relatively

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stable. Air temperatures at freeze-up range from 5 °F to 15 degrees °F. Daylight in October is typically 9 to 10 hours per day (longer if twilight is included).

Additional time is required for the young fast ice sheet to gain sufficient thickness and stability to be judged safe for over-ice operations. Depending on location, the total time from initial freeze-up to being able to commence on-ice operations with response equipment ranges on average from 40 to 43 days at coastal or nearshore locations such as Niakuk and Endicott, to 55 days at the Northstar Production Island (Vaudrey, 2000).

November to December

An expanding fast ice zone, increasing in stability as the ice grows, characterizes this period. The young floating fast ice sheet outside the Barrier Islands is still vulnerable to break-up by storm events and positive surges in water levels until December in extreme years. At the nilas stage (defined as new ice less than 10 centimeters cm thick) a moderate storm with winds over 20 knots can quickly break up the entire ice sheet.

For grey and grey-white ice between 4 and 12 inches, there is potential for break-up and/or substantial deformation and movement in strong winds over 27 knots. Storms of this severity in October and November are uncommon, on the order of two events during a ten-year period (Vaudrey, 2000).

The risk of substantial ice movements decreases sharply once the ice is greater than 12 inches. Extreme cases have been documented where portions of the land-fast ice have experienced substantial movement in early winter, but these are considered rare events. Vaudrey (2000) recounts only one year in 12 when a 20-inch thick ice sheet (a condition reached by late November in most years) moved 100 to 200 feet in the vicinity of Northstar. Movements of this magnitude would not result in visible open water, with the ice motion being absorbed by ridging and rubble formation.

During December when the floating fast ice reaches between 1.5 to 3 feet thick, ice motions are reduced to a range of 10 to 15 feet, based on measurements in 20 feet of water off the Barrier Islands to the west of Prudhoe Bay (Vaudrey, 1996).

The fast ice edge in early winter expands seaward from an average water depth of 15 feet in October and November, to 40 to 45 feet in December. (Eicken et al., 2006 based on data at 146 deg W Long.).

Beyond the fast ice edge and active shear zone, the pack ice can be divided into a highly active, often constantly deforming transition zone (seasonal pack) comprised of mostly first-year ice of highly variable age and thickness, and a more homogeneous polar pack with predominantly old (multi-year) ice. The polar pack edge (50 percent or greater coverage of multi-year ice) occurs in much deeper water well north of all of the proposed drilling locations.

In the early winter period (November to December) the transitional pack ice zone in the vicinity of the 100-foot water depth is comprised almost totally of first-year ice. No multi-year ice beyond trace amounts (much less than 10 percent coverage) was reported in the October to December time frame over the past ten years (1997-2006). The early winter pack ice consists of a mix of ice ages, from young ice less than 12 inches thick to thin first-year ice up to 27 inches. Once the ice begins to raft and rubble in November, level ice becomes the exception and much of the ice surface will represent some form of deformation process including the active formation of pressure ridges in December.

Pack ice moves in a meandering, net westerly drift in response to wind and currents. As the winter progresses and the pack becomes thicker and more consolidated, there are periods when little or no ice movement occurs in deep water. For example, a long-term ice drift record over 7 seven seasons shows that the monthly incidence of no ice motion typically increases from around 20 percent in November to

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between 30 and 40 percent in December (Melling and Reidel, 2004). During these periods of static offshore ice, the boundary between the fast ice and pack ice zones can become blurred and indistinct. In these situations, mapping the boundary becomes a matter of interpreting the significance of a particular lead or crack.

When the pack ice is in its more typical dynamic drift mode, the fast ice boundary is clearly defined by a zone of massive shear and compression ridges stretching for hundreds of miles off the Alaskan North Coast. Many of these ridges can be grounded in water depths out to 80 feet with dramatic surface elevations up to 50 feet in some cases. The most active shear zone of severe ice deformation tends to be fairly narrow and concentrated between about 50 and 70 feet of water with no distinct east/west trends in severity (in some years it can extend into greater depths). In some areas a string of known shoals (e.g. Stamukhi off Oliktok) act to nucleate islands of grounded ice with dramatic fields of severe ridges and rubble (Kovacs, 1976; Reimnitz, 1984).

January to April

During the winter period of active ice growth, the fast ice continues to expand seaward reaching beyond 70 feet of water by February. The maximum fast ice extent occurs during the months of March to May when the water depths at the average edge position (off Flaxman Island) reach 100 feet, much deeper than the 60 feet boundary often discussed in earlier references (Eicken et al., 2006).

During the winter, east/west oriented leads (shore following) are common within the seasonal pack ice zone in water depths from 100 to 150 feet. Many of these leads will have widths ranging from hundreds of meters to miles and continue without blockage for long distances. In one study (Dickins, 1979), over half of all satellite images collected in the March to May time period showed distinct leads in this zone, becoming more frequent from west to east. Eicken et al. (2006) provides an extensive analysis of lead distributions, orientations, and dimensions within the pack ice zone.

The net mid-winter pack ice drift off the North Slope is to the west. On an hourly basis, pack ice motion tends to be episodic and meandering. In general, ice speeds are at a maximum (5 to 7 nm per day) with large expanses of young ice offshore in November and December, and decrease as the ice pack thickens and becomes more consolidated through January and February. Average pack ice drift speeds reach their minimum in March and April with typical values of 1.5 to 2.7 nm per day (Melling and Riedel, 2004). Four buoys were deployed by the USCG in the Beaufort nearshore between 1980 and 1985 in the winter period with high ice concentrations. Most of the buoy drift tracks of interest fell between 142°W and 150°W Llongitude in water depths from 60 to 200 feet. Results are summarized in Dickins (1984). The general movement trend and net drift was predominantly to the northwest, but there were also substantial periods when the buoys moved in other directions. For 40 to 60 percent of the recorded periods, the ice appeared to move without a persistent sense of direction (wallowing, meandering, or static). Vaudrey (2000) summarized the available historical ice movement data from a range of sources utilizing satellite drifter buoys from 1975 to 1996. Table 3-9 below shows daily averages fro for longer-term ice movements. Short-term ice drift speeds (over periods of 2 to 6 hours) can be significantly higher, in the range of 1 to 2 knots using 4 to 5 percent of the wind speed, as a rule of thumb.

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TABLE 3-9
EXCEEDANCE PROBABILITY DISTRIBUTION OF ICE DRIFT SPEEDS

	PERCENT > NET DAILY ICE MOVEMENT RATE (knots)							AVERAGE
SEASON	**>0.2**	**>0.4**	**>0.6**	**>0.8**	**>1.0**	**>1.5**	**>2.0**	**SPEED (knots)**
Freeze-Up	50.0	17.7	8.1	3.8	1.9	0.4	0.3	0.3
Break-Up	34.0	14.4	6.2	2.8	0.8	0	0	0.2

Operational Preparedness

Shell ~~Oil~~ and its contractor, ASRC ~~Environmental~~ Energy Services (AES), together with ~~Alaska Clean Seas (~~ACS~~)~~ maintain a comprehensive inventory of equipment to initiate and sustain in situ burning operations throughout the proposed drilling season. The Shell *Beaufort and Chukchi Seas Regional Tactics Manual*~~AES' Response Tactics Manual~~ and the ACS~~'~~ *Technical Manual* contain specific tactical guidelines for the offshore operations with and without ice. Many of these tactics (e.g., Regional Tactics OR-1B, OR-2B, and OR-4B ~~from AES~~ and ACS Tactic R-20 ~~from ACS~~) illustrate ways to intercept oil with an open-apex U-boom configuration so that thin or scattered oil slicks can be concentrated for recovery or captured downstream of the open-apex for burning within a fire boom.

Some of the tactics within each manual are specific with guidelines for implementing and sustaining burning on open water and in the presence of ice (e.g., ~~AES'~~ Regional Tactic OR-7 and ACS~~'~~ ~~t~~Tactics B-3, B-4, B-5, B-6 and B-7). These tactics are incorporated ~~in Shell's Beaufort Sea Regional Exploration Oil Discharge Prevention and Contingency Plan~~here by reference ~~here~~, along with shoreline concepts for burning nearshore in Section 1.6.12, ~~(~~Shoreline Cleanup~~) of the Shell C-plan~~.

ACS conducts in situ burn training seven to eight times a year at different North Slope locations. Typical courses involve at least ~~an~~ one hour of classroom instruction and ~~an~~ one hour of field exercises involving basic combustion theory, guidelines for safe operating procedures, and gelled fuel mixing and Heli-Torch deployment. Shell/AES personnel are also instructed on these same guidelines and procedures as they relate to the potential use of controlled burning offshore. ACS and AES maintain an inventory of specialized response equipment to support a large-scale burn operation as follows:

TABLE 3-10
INVENTORY OF IN SITU BURNING EQUIPMENT (ACS AND AES)

EQUIPMENT	QUANTITY
ACS	
Fire Boom (20", 30" and 40" skirts)	19,000 feet
Heli-Torch (55 gal.)	6
Heli-Torch (300 gal.)	2
Heli-Torch SureFire gel	1,200 lb.
Air Deployable Igniters	>-1,400
Heli-Torch Batch Mixers (gelled fuel)	2
AES	
HydoFire Boom (500' per system)	2
Cooling Water Pumps and Hoses	2

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In addition, ACS and AES maintain all appropriate logistical support for controlled burning, including boom~~-~~-tending vessels, helicopters, and vessels to transport and deploy equipment and ignition systems~~,~~ and fire extinguishers.

Regulatory approval must first be obtained before using in situ burning, depending on whether the burning operations will be conducted in federal or state waters. The ACS *Technical Manual* (Tactics ~~Description~~ B-1) contains steps that should be followed in reaching the decision to use in situ burning. As part of the approval process the "~~Alaska~~ Regional Response Team ~~Application for~~ In Situ Burning ~~ing~~ Application Form" will be submitted to the Unified Command according to the ARRT Unified Plan for Alaska, Appendix~~.~~ 2, Annex F, *In Situ Burning Guidelines for Alaska*. An incident-specific burn plan is contained within the application.

Once relevant state and federal approval have been obtained, the following steps are normally taken to implement the response:

- Use towed open-apex boom configuration(s), as necessary, to concentrate and release oil directly into fire-resistant booms. Conventional boom may be used for this operation.
- Collect and contain the oil using fire-resistant booms. Re-locate the contained oil a safe distance from the open-apex configuration and other vessels.
- In light ice cover (with ice-deflection/management support), collect and contain oil using fire-resistant booms.
- In higher ice concentrations, locate naturally occurring pools of thick oil.
- As appropriate, use fire monitors and/or prop-wash to gently direct oil into heavier concentrations against ice floes or densely packed ice cakes. Wind may provide such desired herding of oil naturally.
- Ignite the oil using the Heli-Torch or hand-held igniters, following established safety procedures to avoid flashback or ignition of any ongoing spill source.
- Monitor the burn, maintaining constant watch on the fire and smoke plume. Maintain a careful assessment of fire boom condition (if used) and other safety hazards and issues as appropriate.
- Make every effort to recover and dispose of the burn residue.

Safety procedures and planning in accordance with established guidelines are emphasized throughout the training, preparation, and conduct of in situ burning operations.

In situ burns are monitored to ensure ~~that~~ fire does not spread to any uncontained oil nearby and ~~that~~ burns are conducted at safe operating distances from all vessels and personnel on location. Personnel and equipment used in conducting the operation are kept at safe distances from the spill source (ongoing natural gas normally already ignited). The safe working distances from an in situ fire on water depend on the size of the fire and the exposure time, and are summarized in Table 3-11.

TABLE 3-11
SAFE WORKING DISTANCES FROM THE FIRE

PERSONNEL EXPOSURE TIME	PERSONNEL MINIMUM DISTANCE FROM FIRE (FIRE DIAMETERS)
Indefinite	4
30 minutes	3
5 minutes	2

Aerial ignition with gelled fuel from a Heli-Torch, or with other ignition devices, is coordinated, taking into account prevailing weather conditions, oil pool size and distribution, and the need for strict adherence to established safety practices.

ACS and AES personnel practice the techniques involved with controlled in situ burning at sea that could involve several vessels and aircraft working in close proximity.

Effectiveness of In Situ Burning in Open Water and in Ice

The consensus of research on spill response with in situ burning of oil on open water and with ice is that burning is an effective technique with removal rates of 85 ~~percent~~ to 95 percent in most situations (Shell et al. 1983;~~,~~ SL Ross 1983;~~,~~ SL Ross and DF Dickins 1987~~,~~; Allen 1990~~,~~; Allen 1991;~~,~~ Allen and Ferek 1993~~,~~; and Singsaas et al. 1994). A considerable amount of research has demonstrated the success of in situ burning in broken ice. The research includes several smaller-scale field and tank tests (SL Ross et al. 2003;~~,~~ Shell et al. 1983~~,~~; Brown and Goodman 1986~~,~~; Buist and Dickins 1987~~,~~; Smith and Diaz 1987;~~,~~ Bech et al. 1993~~,~~; and Guénette and Wighus 1996) and one large field test (Singsaas et al. 1994). Most of the tests involved large volumes of oil placed in a static test field of broken ice resulting in substantial slick thicknesses for ignition. Tests in unrestricted ice fields or in moving ice have indicated that the efficacy of in situ burning is sensitive to ice concentration and dynamics, and thus, the tendency for the ice floes to naturally contain the oil, the thickness (or coverage) of oil in leads between floes, and the presence or absence of brash or frazil ice which can absorb the oil.

The feasibility and efficiency of burning oil from a subsea blowout in the Beaufort Sea will depend in large part ~~up~~on the nature of the oil as it surfaces and upon the nature and amount of ice present (if any). Studies within Shell have revealed that oil and gas from a subsea blowout (best represented by gas and oil flow rate characteristics from nearby reservoirs) could result in the atomization of oil due to turbulence from the gas plume. With this type of release, small droplets of oil would rise, along with the expanding gas, toward the surface where induced currents would then carry the oil droplets out radially from the source. Little, if any, emulsification is expected during the transport of oil toward the surface; however, within hours (depending upon the actual oil, wind/sea conditions) emulsification could reach levels that would make ignition difficult to impossible. The potential emulsification of the oil, together with the initial distribution of the oil droplets are factors that must be considered as one considers the potential use of in situ burning for the elimination of oil at or immediately downstream of the blowout.

The following information addresses the practicality of burning in open water and with varying concentrations of ice while recognizing the effects currents (primarily wind-driven) could have ~~up~~on the distribution of oil and, therefore, the feasibility of collecting and igniting the oil.

Open Water with Current

The initial distribution of the surfacing oil droplets in open water could involve a surface area with a diameter of several hundred meters. The outer reaches of this area would involve a relatively small percentage of the total blowout release as the largest droplets would surface more quickly near the center; and the smallest droplets would rise more slowly, riding with the induced currents to the outer regions of the slick. Depending on the current moving over the blowout, the oil droplets could surface into a clean (or relatively clear) water surface, where their initial spread would result in slicks that are too thin to support combustion (likely on the order of a tenth of a millimeter). Under these conditions (open water with current), combustion could effectively consume the free gas surfacing at the blowout; however, the relatively thin slicks would not support sustained combustion of the oil (typically requiring a 2 to 3 mm layer thickness). Authorization for ignition of the gas cloud directly over the blowout would normally be

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requested as early as possible to avoid any risk of exposure to personnel on location and any accidental ignition that could expose personnel and equipment to fire.

Burning of the oil in this situation would require containment or deflection with boom to concentrate and thicken the oil while it is relatively fresh and unemulsified. Towed open-apex boom configurations could be used downstream of the blowout to thicken and release concentrated bands of oil into fire boom being towed in a U-configuration. Once such fire booms reach their holding capacity, they could be moved a safe distance from the open-apex, where ignition and sustained combustion could be quite successful. While burning the contained oil, a second fire boom could be positioned downstream of the open-apex to collect oil for a second burn. The elimination of oil at the first boom could easily be completed in time to relieve the second collection effort before the fire boom reaches its holding capacity.

Open Water with Little or No Current

Should oil and gas be released from the seabed with little or no current, it is likely that authorization would have been secured (as in the previous scenario) to ignite the free gas directly over the blowout to avoid harmful exposures to personnel and any accidental ignition of the gas plume. Without current to sweep surfaced oil away from the blowout, there would be an accumulation of oil droplets at the surface allowing for the build up and re-coalescence of those droplets into a layer that could support combustion. In this case, it is likely that the heat generated by the burning of free gas would be sufficient to ignite vapors from the surfacing oil, thereby enlarging the burn area and removing a substantial portion of the blowout.

In this situation, it would not be necessary to use fire boom or to position personnel and equipment anywhere near the surfacing oil. The efficiency of removal by burning, however, could be improved if it was safe to deploy fire boom in a U-configuration at and immediately downstream of the surfacing oil and gas. The positioning of fire boom in this mode could be carried out safely if there was at least a light wind and/or a slight current that could carry the burning oil back into the apex of the U-configuration. Two boom-towing boats could be positioned well upstream of the surfacing oil and gas (using longer than normal tow lines) at a distance that would preclude any unsafe exposure to heat and smoke from the fire. Effective burning could be carried out without personnel, boats, and boom when the surfacing oil is held naturally at and near the spill source. In fact, the heated air rising above the blowout would produce a thermally-induced wind along the surface working radially in toward the fire. Even a very light breeze of this kind could help reduce spreading of the oil and maintain oil thickness for improved combustion. If currents less than 1 knot and/or light winds were available to move the burning oil away from the source, boom-~~-~~tending boats could work at a safe distance from the burning source, and substantially improve the efficiency of burn.

Low-to-Moderate Ice Concentrations (with and without current)

Even at ice concentrations of a couple of tenths, there could be sufficient ice (depending ~~up~~on the size and distribution of the ice pieces) to reduce the effectiveness of conventional ~~or~~ fire booms for the collection of oil. If the distribution of ice is such that ice could not be avoided or deflected away from the opening of a boom configuration, and ice could therefore accumulate to high concentrations within the boom, then boom could not be used effectively. Often, however, low ice concentrations are present as discontinuous wind-consolidated strips separated by broad open-~~-~~water areas that may allow for the limited use of boom to capture oil. In more scattered ice concentrations, responders could access oil at low speeds and encounter rates between ice floes. At such low ice concentrations, there are times when burning could be conducted with fire boom.

Should broken ice (from as little as 2 to 3/10ths to as high as 7 to 8/10ths concentration) move into and over the blowout, the ice could actually help in a number of ways. The ice would tend to dampen waves, reduce surface spreading radially over the blowout, and promote re-coalescence of the surfacing oil droplets in the reduced water surface between ice cakes or floes. Under these conditions, there would be an increased potential for the accumulation of oil on water at thicknesses that could support sustained combustion.

As long as the ice concentrations do not become excessive (>greater than 8 to 9/10ths) and/or the ice iscome under pressure, there should remain sufficient oil-on-water area to support combustion. AndAlso, as in the previous open-water scenarios, if water movement over the blowout drops to little or no current, the increased accumulation of oil between oil floes would only enhance the overall efficiency of burn. Induced radial currents over and adjacent to the blowout may prevent much of the oil from sticking to the underside of ice cakes and small floes. Most oil would therefore be exposed for combustion while it is fresh and relatively unemulsified. Should the natural floes be large enough to entrap some of the oil beneath them and keep the oil from surfacing, efforts could be initiated with icebreakers well upstream of the blowout to break such ice into smaller pieces or deflect large floes away from the blowout. Ice management is a proven technique that can completely modify the composition of the ice moving over a drilling location. For example, the successful 2004 coring program at 88°N saw two icebreakers work to maintain the drillshiping vessel on location in high concentrations of 7- to 9--foot ice. Floes drifting towards the drill site were over 3,000 feet in diameter. By the time they arrived, the icebreakers had reduced the average ice piece size to between 35 and 43 feet (Keinonen et al., 2006). In addition to managing the floe sizes, oil could be dislodged from the underside of ice (before it becomes encapsulated within the ice) using prop-wash from vessels on location.

Another approach that could enhance combustion with moving ice concentrations involves the use of large ice deflection barriers such as a barge with tug assist or a vessel with dynamic positioning. Shell has conducted extensive mathematical and ice-tank modeling efforts to show that such large-scale deflection of ice appears safe and feasible for the creation of a relatively ice-free surface downstream of the deflection operation. Pending the results of full-scale trials with ice, it is likely that moving broken ice and early freeze-up ice (new ice, nilas) could be deflected with a barge or vessel positioned side-ways to the current/ice flow. Temporary paths of relatively open water several hundred feet wide could be created downstream of the deflection system to facilitate the use of conventional containment and recovery tactics and/or the use of fire boom in a conventional burn mode.

High Ice Concentrations and Continuous Layers of New Ice in Early Winter

The movement of a continuous layer of new ice or very high ice concentrations of ice over a subsea blowout could reduce the effective use of in situ burning. There could be a reduction in the air/water surface area to accumulate oil and allow for efficient sustained combustion. This could be remedied in two ways: one involving the natural processes, and the other involving ice management. Experience has shown that large gas accumulations beneath ice will accumulate and rupture continuous ice layers (Dickins and Buist, 1981) during early freeze-up. The ice would likely break up, and move out and away from the blowout, rafting and accumulating to create a natural barrier within which burning of the oil and free gas could take place. The other remedy involves the use of large ice deflection systems upstream of the blowout as described above. Such deflection would provide an opening for burning on ice until prevented by excessive ice thickness. If the ice was continuous (even at relatively thin layers of say 3" to 6" inches) tank test results suggest that it would be necessary to use ice-breakers forward of the deflection system. As long as the ice could be broken, and it is not too thick or pressured, it is possible that a relatively ice-free path could be opened just forward (or upstream) of the blowout. Oil (even widely scattered particles) surfacing within the cleared path downstream of the deflection system would soon be trapped within the downstream opening bounded on each side by ice. Even if bounded by broken ice and

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