

**Evaluation of Cleanup Capabilities for Large Blowout Spills  
in the Alaskan Beaufort Sea During Periods of Broken Ice**

for

**Alaska Clean Seas  
Anchorage, AK**

and

**Department of the Interior  
Minerals Management Service  
Anchorage, AK**

on behalf of the

**North Slope Spill Response Project Team**

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## **Executive Summary**

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### **1. Background**

This study was performed for Alaska Clean Seas and the U.S. Minerals Management Service, acting on behalf of the North Slope Spill Response Project Team (NSSRPT)<sup>1</sup>, a task group formed to develop comprehensive oil spill response plans for petroleum operations on the North Slope of Alaska. The objective of the study was to evaluate the capabilities to recover spilled oil from very large oil well blowouts occurring during broken ice conditions in the southern Beaufort Sea. The study team was to consider six well-defined oil well blowout scenarios and determine quantitatively:

- whether the mechanical cleanup systems that are currently available on the North Slope are adequate to satisfy Alaska State requirements for cleaning up spills from blowouts in broken ice conditions;
- whether additional resources would significantly improve the existing mechanical recovery capability, and to what extent; and
- what the maximum cleanup capabilities might be for dealing with blowout spills in broken ice if all possible cleanup techniques were considered

The scenarios cover two locations (Point McIntyre and Northstar Island) in three ice concentrations (30, 50 and 70% respectively). For Point McIntyre the scenarios are 12,000 barrel-per-day spills during spring break-up conditions. The Northstar Island scenarios are 15,000 barrel-per-day spills that occur during fall freeze-up.

The study describes in detail the behavior and fate of the six blowout scenarios and the likely effectiveness of countermeasures in recovering the resulting spills on water and ice. First, the effectiveness of the mechanical recovery systems that exist on the North Slope is assessed. Then the possible benefits are evaluated of adding more mechanical systems to the response, and of adding the countermeasures of dispersant use and *in situ* burning to the mix of response options available. Also discussed is the potential benefit of igniting and burning the blowout at source and thus preventing a major marine spill from occurring in the first instance. The results are summarized as follows.

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<sup>1</sup> *The NSSRPT members include Alaska Clean Seas, Alaska Department of Environmental Conservation, Alaska Department of Natural Resources, Alyeska Pipeline Service Company, British Petroleum Exploration (Alaska) Inc, North Slope Borough, US Environmental Protection Agency, and US Minerals Management Service*

## 2. Effectiveness of Existing Mechanical Countermeasures

Results are summarized in the Table S-1. Effectiveness is defined as the percentage of the blowout flow over the 15-day period that could be recovered by existing response systems. A second effectiveness number is also shown; it takes into account the reduction in blowout volume due to evaporative losses – fixed at 20% for all scenarios – and losses due to tiny-particle drift – estimated to be 10% of the total blowout flow. This second effectiveness number is therefore the percentage recovery of the oil that is estimated to land in the marine environment, that is, 70% of the total blowout flow.

**TABLE S-1**  
**Summary of Recovery Effectiveness for Six Scenarios**

Scenario Parameters	Freeze-up			Break-up		
	Ice Coverage			Ice Coverage		
	30%	50%	70%	30%	50%	70%
Estimated 15-day recovery as a percentage of total blowout	5.9	2.2	0.6	18	12	4.4
Estimated 15-day recovery as a percentage of total blowout that reaches ice/water surface	8.5	3.1	0.8	25	18	6.3

Major factors affecting the results are discussed below.

### Effects of Ice

The major effects of the ice are that (a) a certain percentage of the blowout lands on ice and is thus unavailable for containment and recovery based countermeasures; and (b) as the ice coverage increases, it becomes more and more difficult to operate containment boom to concentrate oil for recovery. Particularly for the spills in 70% ice coverage, attempting a containment and recovery response would be almost pointless.

### Initial Slick Conditions

Each blowout produces a thick, relatively narrow band of oil directly down drift of the blowout source, with a much wider relatively thin slick on each side of the thick slick. It is estimated that about 60% of the oil that eventually reaches the surface will land in the thick portion of the slick. It was also estimated that (a) 20% of the total blowout flow would evaporate from the droplets in the air; and (b) 10% of the droplets would be so small that they would remain suspended in the

atmosphere. In total, an estimated 70% of the blowout flow will eventually reach the ice/water surface. This means that only about 40% of the total blowout flow (60% x 70%) will reach the surface and form a thick slick. About 30% of the total blowout flow (40% x 70%) will reach the surface, but in a relatively thin slick for which a containment and recovery response would be relatively ineffective, whether in broken ice or open water conditions.

#### Daylight Hours

It was assumed that recovery operations would be conducted only during daylight hours, for reasons of worker safety and due to difficulties in positioning containment equipment relative to the slick. For the freeze-up scenarios, with daylight hours ranging from 8 to 12 hours, this causes a decrease in effectiveness to only one-third to one-half what it otherwise could be. There is no such reduction in effectiveness in the spring break-up scenarios given the 24-hours of daylight at that time of year.

#### Delays in Response during Freeze-up

The ice conditions during freeze-up at West Dock, where the primary equipment and marine logistics are located, means that the response time would be 60 hours as opposed to the 12 hours used in the break-up scenarios. Over the 15-day period, this translates into a loss in effectiveness of 17%.

#### Weather Limitations

Considering the negative effect of weather (mostly sea state and visibility) on countermeasures effectiveness, it was calculated that containment and skimming equipment could be operated 77% of the time during freeze-up and 66% during break-up.

### **3. Advantages of Adding More Recovery Equipment and Vessels**

In all spill cases, the entire width of the thick slick could be encountered using one or two systems with a total boom length of no greater than 720 feet. Similarly, there are a number of skimmers stockpiled with (derated) recovery rates that exceed the rate at which oil would be encountered in the thick slick, so the capability of recovery equipment should not limit the operation. Finally, there is adequate logistical systems to support the containment and recovery operation, including the storage and transfer of recovered fluids.

In each of the scenarios, consideration was given to the possible effectiveness of additional containment and recovery systems. In each case it was found that any such equipment would be limited to chasing relatively thin slicks of oil – either that which originally landed outside the thick portion of the slick or that which was lost past containment due to ice problems – and would contribute little more to the overall effectiveness.

#### 4. Alternative Countermeasures

For each of the six blowout scenarios the potential effectiveness of alternative countermeasures was also examined. This includes the use of dispersants, *in situ* burning, and igniting the well to burn off the oil as it is emitted from the well. The results are summarized in Table S-2. In each case, effectiveness is defined as the percentage of the blowout flow over the 15-day period that could be dealt with by the particular technique.

**TABLE S-2**  
**Summary of Recovery Effectiveness for Alternative Countermeasures**  
 (as a percentage of total blowout flow)

Scenario Parameters	Freeze-up			Break-up		
	Ice Coverage			Ice Coverage		
	30%	50%	70%	30%	50%	70%
Existing Countermeasures	5.9	2.2	0.6	18	12	4.4
Dispersant - Use	4.2	0	0	0	0	0
In-Situ Burning <sup>1</sup> - on-water	3.4	2.2	6.4	0	14	7.1
- on-ice	0	0	0	15	25	33
Well Ignition	99			74		
1. Note that ISB on-water effectiveness is for comparison with existing containment and recovery effectiveness; ISB on-ice effectiveness would be in addition to either containment and recovery or ISB on-water effectiveness.						

#### Dispersant Use

The use of dispersants is an attractive option for dealing with blowout-type spills, particularly those that are relatively close to centers of logistic support, as are the spills in these scenarios. The modest daily spill rate combined with the ability to deliver the required quantities of dispersant while the oil is relatively thick means that there are good opportunities for application. Also, a dispersant operation as described here could be mounted relatively quickly, within 12 hours as opposed to the 60 hours estimated for containment and recovery in the freeze-up scenarios. Unfortunately, the presence of ice tends to dampen any wave action which is required for effective dispersion. In this

evaluation, it is assumed that dispersants would be only 25% effective in 30% ice. For the 50% and 70% ice scenarios dispersant-use is assumed to be ineffective due to the limited wave energy, although treatment might be attempted.

Another problem, not related to the ice coverage, is the properties of the oil chosen for the break-up scenarios. Although the 24-hours of daylight would have otherwise made these scenarios attractive to a serious dispersant effort, the oil is of a viscosity that is resistant to dispersant effectiveness. It should be noted that the Pt. McIntyre oil used in the break-up scenarios has a viscosity that is atypical of North Slope crudes, and that most other oils could be much more amenable to dispersion

#### In situ Burning

For the freeze-up scenarios at low and medium ice concentration, in-situ burning offers little advantage over containment and recovery techniques. Because the slicks emanating from the blowout are below burnable concentrations, containment is required to concentrate and thicken the oil before it is burned. As in the evaluations of booming and skimming, in-situ burning is limited in these scenarios by both the inability to effectively contain oil among broken ice and the fact that there is only 10-1/2 to 12 hours of daylight.

For the freeze-up scenario in 7/10ths ice, there is a potential to contain and burn oil using the area of open water -- or wake -- that is likely to be present down drift of the production island. In this situation, a batch-type contain-and-burn operation is estimated to burn off up to 6.4% of the total blowout flow, well in excess of the predicted effectiveness of a containment and recovery operation.

For the break-up scenarios, burning on water using fire containment boom provides an effectiveness that is approximately equal to that afforded by containment and recovery. Because of the above-freezing temperatures, oil that lands on ice will tend to be herded into concentrations that may allow burning using only the natural containment provided by the ice. In this situation, burning the oil that lands on floes and concentrates in melt pools offers an oil removal capability that would supplement either the on-water burning operation or containment and recovery.

#### Well Ignition

The possibility and potential effectiveness of intentionally igniting the blowing well was briefly examined. Based on previous studies on this subject, it is estimated that up to 74% for the Pt. McIntyre scenarios (break-up) and up to 99% of the Northstar scenarios (freeze-up) would be consumed in such a fire.

## 5. Report Addendum

Subsequent to the preparation of the draft report of this study it was decided to re-analyze the situation using more realistic conditions instead of the unvarying winds and ice concentrations that were used originally. The spring break-up and fall freeze-up situations were examined separately by two different study teams. The spring break-up situation at Pt. McIntyre was re-analyzed by the original study team and is reported here as an addendum

The first step in the re-analysis was to prepare a sequence of weather and ice events that would typify a 15-day blowout spill during the break-up period. This included two days of relatively stationary ice, followed by increasing ice movements and decreasing ice concentrations, and finally an increase in winds leading to a near-open water situation. Next, the blowout deposition modeling was redone to account for the varying ice movements and concentrations. Finally, the countermeasures options were re-examined for their potential effectiveness.

For the first two days of the scenario, the ice is relatively stationary, leading to pooling of oil close downwind of the blowout. In this situation, *in situ* burning of oil on the ice would be the preferred countermeasure and would likely be very effective. For the next 10 days of the scenario, *in situ* burning could be accomplished, using fire-resistant boom to concentrate oil amongst oil and also by igniting oil that accumulates in melt pools. On the last two days of the scenario, the response tactics would include a combination of containment and recovery from amongst the light ice concentrations, and *in situ* burning to deal with oil that lands on the ice.

The table below summarizes the estimated effectiveness for each of the 15 days of the scenario. The highest effectiveness values are for Days 1 and 2 when the oil pools in a thick layer on the relatively stationary ice and can be removed through *in situ* burning. The lowest value is for Day 12 where the moving broken ice reduces the effectiveness of cleanup operations. The average effectiveness over the 15-day period is 38% of the total 15,000 barrel/day blowout flow, and 52% of the oil that lands on the ice and/or water surface.

**Summary of Response Tactics and Estimated Effectiveness**

Day	Main Response Tactics	Estimated Effectiveness	
		of total blowout flow	of oil that lands on ice/water surface
1	<i>in situ</i> burning of oil on ice	63%	87%
2	<i>in situ</i> burning of oil on ice	63%	87%
3	<i>in situ</i> burning of oil amongst and on ice	41%	57%
4 - 6	<i>in situ</i> burning of oil amongst and on ice	37%	51%
7 - 11	<i>in situ</i> burning of oil amongst and on ice	31%	43%
12	<i>in situ</i> burning of oil amongst and on ice	25%	35%
13 - 15	containment and recovery and <i>in situ</i> burning	35%	49%
Average		38%	52%

Note. the estimated volume of oil that lands on the ice/water surface takes into account the assumed 20% evaporative loss and the further 10% of oil drops that are so small when discharged from the well that they remain in the air and never land



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# **1. Introduction**

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## **1.1 Industrial Setting**

This study focuses on the problem of major oil spills that might occur during oil development activities that are now taking place in the offshore waters of the Alaskan North Slope, in the southern Beaufort Sea. Readers not familiar with the industrial setting can refer to Appendix A which presents a brief history of oil development on the Slope. This will help in understanding the following discussions of oil fields in the area that have been selected for special analysis.

## **1.2 NSSRPT Goals**

This study was performed for Alaska Clean Seas and the U.S. Minerals Management Service on behalf of the North Slope Spill Response Project Team (NSSRPT), a task group formed in 1997 by the Alaska oil industry and federal and state regulators<sup>1</sup>. The team's objective was to develop a comprehensive oil spill response plan that could be used for all exploration and production operations on the Alaska North Slope. Such a plan was needed to:

- assure adequate spill response capability in meeting federal and state laws;
- minimize duplication of effort through effective planning including shared use of spill response equipment and expertise; and
- foster timely and efficient review of contingency plans for new and existing operations.

The following goals were set by NSSRPT to reach their objective:

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<sup>1</sup> The NSSRPT members include: Alaska Clean Seas, Alaska Department of Environmental Conservation, Alaska Department of Natural Resources, Alyeska Pipeline Service Company, British Petroleum Exploration (Alaska) Inc., North Slope Borough, US Environmental Protection Agency, and US Minerals Management Service.

- Develop an efficient Slope-wide response capability, including, but not limited to, efficient and effective use or integration of response personnel, communications or logistical needs to support spill response for North Slope operations;
- Develop an ACS Response Plan, the design of which would meet, to the extent possible, the format and substance requirements of the federal/state sub-area plan;
- Use the ACS Response Plan as a base document to support the individual facility contingency plans of North Slope operators;
- Develop a sufficient number of generic oil spill response scenarios, whether located on land, near shore or offshore;
- Develop as a first priority oil spill scenarios necessary for State approval of contingency plans for the Pt. McIntyre and Badami fields (Endicott, Naikuk and Milne Point facility plans are also affected); and
- Identify additional spill response equipment needs as a product of developing the spill response scenarios. This is to be done sufficiently in advance to ensure timely approval of contingency plans for new fields.

### **1.3 Past Regulations regarding Broken Ice: Tier 1 and Tier 2**

The difficulty of the NSSRPT mission is complicated by the problem of "broken ice", a marine situation in which ice floes are scattered and in motion on the water surface. The cleanup of oil spills in broken ice conditions has been a concern in Alaska ever since oil exploration and production began to move into the nearshore and offshore areas of the Alaskan North Slope. Although oil spill cleanup methods are well established for spills in open water and for spills on solid, landfast ice, it has been recognized for some time that spills in broken ice conditions are more problematic.

Oil drilling restrictions during broken ice conditions in the Alaskan Beaufort Sea have been the subject of debate for over twenty years. The main environmental concern is that a large oil well blowout might occur and have a serious impact on the bowhead whale, an endangered species whose fall migration route north of the barrier islands is close to drilling sites. In 1978, the State of Alaska restricted drilling to the ice-covered period from November 1 through March 31 each year, and in May 1982 a complex two-tiered restriction became effective. Tier 1 kept intact a prohibition on

drilling activity below a predetermined threshold depth during: 1) periods of broken ice; 2) outside the barrier islands during the open water period; and 3) during the fall bowhead whale migration Tier 2 of the decision would allow drilling during periods of broken ice, and during periods of open water outside the barrier islands once a lessee "...demonstrates compliance with applicable laws and regulations, including the theoretical and physical capability to detect, contain, cleanup, and dispose of spilled oil in broken ice conditions".

In February, 1982, a joint agency/industry Steering Committee and Technical Committee were formed to address the criteria for Tier 2 approval. In February 1983, the oil companies notified the State that they were ready to demonstrate their capabilities. After consultations with State, Federal and North Slope Borough officials, the companies prepared a document entitled "Oil Spill Response in the Arctic" summarizing their views on the current state-of-the-art for cleaning up spills in broken ice (Industry Task Group, 1983). The regulatory agencies agreed with many of the views but questioned others, particularly those claiming an adequate capability in about 3 to 5 oktas (3/8ths to 5/8ths or 37.5 to 62.5%) ice coverage. On the basis of these questions, field tests were designed to demonstrate cleanup capability in this ice cover range. These demonstrations were conducted by the oil companies during June and July of 1983 in the Beaufort Sea area, and witnessed by a team of State, Federal and local officials and technical consultants. The field trials included demonstrations of:

- In-situ burning of oil in scattered ice
- Burning of oil in fire containment boom
- Operation of the ARCAT (a purpose-built skimming vessel) in broken ice
- Operation of tugs and barges in broken ice
- Operation of rope mops from a barge in broken ice and open water
- Boom deployment in moving broken ice

Based on these demonstrations and the recommendations of the consultants' report (SL Ross 1983), the State issued its "Tier 2 Decision" in June 1984 which stated that adequate capability exists to clean up spilled oil in broken ice and during open water outside the barrier islands for exploratory drilling if:

- the lessee complies with all laws and regulations,
- the lessee participates in a five year R&D program, and
- drilling personnel are trained in well control techniques.

In addition, it was decided, if well control were not possible, that the oil well could be ignited. However, lessees were not allowed to drill exploration wells outside the barrier islands prior to and during the fall bowhead-whale migration, but were allowed to drill on and inside the barrier islands if there were a whale monitoring program in place.

The agencies issuing the Tier 2 decision said that the decision was based on the following factors:

- Low probability of a large spill
- Industry's extensive contingency planning efforts
- Availability of spill cleanup equipment (barges, tugs, helicopters, storage tanks, front-end loaders, camp facilities, and small boats)
- Short periods of broken ice
- Effectiveness of recovery and burning at the wellhead and of *in situ* burning

#### **1.4 Current Regulatory Situation and Related Questions**

In 1990, the State of Alaska reiterated the Tier 2 decision and issued a seasonal drilling policy for exploration drilling in the Beaufort Sea. That policy is still in effect, but does not address production drilling.

Subsequent to the Tier 2 work, the state of Alaska implemented detailed spill response regulations. These regulations require that operators plan to be able to *mechanically* contain and recovery, within 72 hours, a "response planning standard" (RPS) volume of oil. For an exploration or production facility, the RPS from an uncontrolled blowout is a minimum of 5,500 barrels of oil per day (if well data indicates a higher production rate, the RPS is adjusted accordingly). Burning, which was recognized as an effective tool in the Tier 2 work, cannot presently be considered in addressing the state RPS.

This then begs the question as to what the current capability might be in broken ice with mechanical systems only. In the Tier 2 exercise it was made clear that there were severe technological and logistical limitations to mechanically recover oil spilled in broken ice. Has the situation changed substantially over the past 15 years?

An equally important question is: What is the current cleanup capability with respect to other countermeasures in broken ice, such as *in situ* burning, and have these improved substantially since Tier 2?

The final question worth asking is: Do we have a better understanding today of the meaning and actuality of "broken ice" in the Alaskan Southern Beaufort Sea, and, if so, should not regulations and contingency plans both be modified to take this into account?

The expression "broken ice" that is used in regulations and in industry plans really has no scientifically-acceptable, quantitative definition. The Tier 2 exercise was concerned with ice break-up during springtime only, so the broken-ice definition used at that time was expressed in spring break-up terms as any ice condition from decaying ice at 8 okta (100 percent) ice coverage at the beginning of spring breakup to widely scattered ice at 1 okta (12.5 percent) coverage at the end of breakup (SL Ross 1983). For the Tier 2 exercise it was assumed that this broken ice period lasted about 12 weeks. As mentioned above, for the Tier 2 regulators, the condition of concern in this "broken ice" period was the 3 to 5 okta (37.5 to 62.5 percent) ice coverage period, which is known to last for a much shorter period, perhaps a few days only. It is clear that this study needs to address the realities of "broken ice" in the Beaufort Sea, in both physical and temporal terms, and in both spring break-up and fall freeze-up periods. This must be done before attempting to analyze how to deal with spills in such ice.

### **1.5 Terms of Reference of Study**

The terms of reference for the study were developed by NSSRPT. The objective of the project was to consider six well-defined oil well blowout scenarios and determine in quantitative terms:

- whether the mechanical cleanup systems that are currently available on the North Slope are adequate to satisfy Alaska State requirements for cleaning up spills from blowouts in broken ice conditions;
- whether additional resources would significantly improve the existing mechanical recovery capability, and to what extent, and
- what the maximum cleanup capabilities might be for dealing with blowout spills in broken ice if all possible cleanup techniques were considered

The scenarios cover two locations (Point McIntyre and Northstar Island) in three ice conditions. For Point McIntyre the scenarios are to consider spills during spring break-up conditions with ice concentrations of 30, 50 and 70% respectively. For the Northstar Island scenarios, the spills will occur during fall freeze-up during ice concentrations of 30, 50 and 70% respectively. The parameters for the six spill situations or scenarios are in Table 1-1.

**TABLE 1-1**  
**Parameters for Six Blowout Scenarios in Broken Ice**

Oil volume.	Northstar - 15,000 BOPD for 15 days minus 20% evaporative loss Pt McIntyre - 12,000 BOPD for 15 days minus 20% evaporative loss
Type of blowout	Oil is exiting the casing under high pressure and being sprayed into the atmosphere
Oil type.	Alaska North Slope (ANS) crude oil
Ice concentrations	Assumes 1 <sup>st</sup> year ice only, with no multi-year incursions. Ice concentration will not vary during the scenario duration. For example, a 30% ice concentration will remain constant throughout the 30% ice scenario.
Weather conditions:	The mean weather conditions for the North Slope, based on historical information, will be used during the applicable time periods for both freeze-up and break-up
Equipment recovery efficiencies:	Lori brush skimmer                      217 barrels per hour Oleophilic skimmers                    20% of nameplate capacity Weir skimmers                            20% of nameplate capacity



The above parameters are used exactly as indicated throughout the study. The only exception is that the oil type considered is not ANS crude, which is a blend of North Slope crude oils. Rather two other, more relevant crude oils have been selected for study: Pt. McIntyre crude oil itself and Milne Point crude oil, an oil known to have properties close to that of crude oil from the Northstar field

## **1.6 Structure of Report**

This introductory chapter is followed by four chapters, Chapters 2 through 5, that set the scene for the main job in Chapter 6 of developing and evaluating the six blowout scenarios.

**Chapter 2** presents a detailed description of actual broken ice conditions in the study area, then presents simplified broken ice models that can be used in the scenario evaluation work. **Chapter 3** provides a general description of blowouts and marine spills, with a particular emphasis on the problem of oil spilled in broken ice.

**Chapter 4** presents an overview of response options for dealing with marine oil spills, especially oil spills in ice, and **Chapter 5** discusses in greater detail the three main methods of mechanical recovery, dispersant use and *in situ* burning that exist in Alaska for responding to spills in the North.

**Chapter 6** describes in much detail the behavior and fate of the six blowout scenarios and the likely effectiveness of countermeasures in recovering their spills. First, the effectiveness of the mechanical recovery systems that exist on the North Slope is assessed. Then the possible benefits are evaluated of adding more mechanical systems to the response, and of adding the countermeasures of dispersant use and *in situ* burning to the mix of response options available. Also discussed, but not on a scenario-by-scenario basis, is the possibility and benefits of igniting and burning the blowout at source and thus preventing a major marine spill from occurring in the first instance. The long chapter ends with a tabular summary of the evaluation and a mass balance of the spill in terms of evaporation losses, losses due to tiny-particle drift, and amounts of oil that can be physically recovered, burned and dispersed.

**Chapter 7** ends the report with conclusions and recommendations.

## **1.7 Limitations of Study**

The study has certain limitations as noted below:

1. In the terms of reference for the study the following subjects were explicitly excluded:
  - sourcing of manpower requirements
  - disposal (water, recovered oil, debris)
  - command infrastructure
  - wildlife response
  - source control
2. The subject of spill prevention is not addressed. This issue requires separate analysis.
3. The study focus is on the cleanup of spills very close to source. Less attention is paid to the response phase of "chasing slicks" that have escaped near-source countermeasures. Predicted recovery efficiencies in this report refer only to the recovery of oil on the water and not to the subsequent collection of oil that has somehow reached and stranded on shorelines.
4. The study is not a contingency plan for responding to large spills in the area, nor is it a countermeasures manual. The oil spill cleanup measures described are not necessarily the ones that will be adopted by industry in fighting spills in the area. The study simply attempts to evaluate spill cleanup capabilities in broken ice in the area.
5. The hypothetical oil spill scenarios developed in the study were designed for illustrative and evaluation purposes only. They should not be considered to be probable events. The hypothetical spills should also not be used to predict the general behavior of spills in the area. There are infinite possibilities; the selected scenarios are but six.
6. There are a number of assumptions made in the scenarios to simplify the analysis. Examples include: having all spills evaporate the same amount regardless of spill circumstance; keeping

ice concentrations fixed over the duration of each scenario; and keeping oil discharge rates constant over the period of the blowout. These are not realistic, but they serve the purposes of the study.

7. Finally, the issue of spill probability is not addressed, although this is surely a very important consideration for both regulators and industry. The maximum spill size in the study, 225,000 barrels (15,000 barrel-per-day blowout x 15 days), is close in size to the *Exxon Valdez* spill. Despite the still-fresh memory of this spill, it should be understood that oil well blowouts are far less probable than tanker spills. To help put this into perspective, Appendix G has been prepared; this is a quick analysis of the probability of blowout spills of the size considered in this study.

### **1.8 Addendum to this Report**

When the first draft of this report was completed in April 1998 it became clear to members of the North Slope Spill Response Project Team (NSSRPT) and other reviewers that one of the terms of reference for the study (detailed in Section 1.5 above) was particularly unrealistic. This was the requirement that wind and ice conditions for each scenario remain fixed over the entire 15-day blowout period. To explore the significance of this restriction, NSSRPT requested that the scenarios be re-analyzed using realistic conditions instead of the unvarying winds and ice concentrations that were used originally. The spring break-up and fall freeze-up situations were examined separately by two different study teams. The spring break-up situation at Pt. McIntyre was re-analyzed by the original study team; the results are presented in Appendix H of this document. The fall freeze-up situation at the Northstar location was studied by a task group set up within NSSRPT; the results of this study are available in a separate report. Except for Appendix H, no other references to this additional work is made in the following chapters or appendices.

## **2. Ice and Other Environmental Conditions**

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### **2.1 Introduction**

The ice conditions and other key environmental parameters associated with the six spill scenarios are documented in this chapter. The scenarios include spills in 30%, 50%, and 70% ice concentration in each of the following broken-ice situations: (1) freeze-up at the Northstar Development production island and (2) ice break-up at the Pt. McIntyre Development on the West Dock Causeway.

The behavior of ice during the break-up and freeze-up periods needs to be characterized and delineated for the purposes of: (1) estimating quantitatively the distribution and fate of oil from each blowout scenario and (2) evaluating the applicability and effectiveness of spill countermeasures. Unfortunately, the behavior of ice during these transition periods is a complex phenomenon which varies greatly from year to year. Ice is constantly converging and diverging in response to wind shifts, and running up against physical boundaries such as shorelines, islands, and the offshore pack. Belts and patches of varying concentrations are common during break-up, while during freeze-up the young ice often breaks into large floes which quickly drift out of the area, leaving open water which in turn refreezes in a matter of hours.

To deal with this natural variability in assessing cleanup capability it becomes necessary to make simplifying assumptions in characterizing ice conditions for each scenario. One helpful assumption is to keep the ice concentration fixed for a given length of time. It is important to emphasize that such assumptions are not meant to be realistic; rather they are simply meant to serve our purpose of "testing" and evaluating the effectiveness of spill countermeasures techniques and systems in specific ice concentrations.

The following steps were taken for describing ice and environmental conditions in the study area, starting with the situation in real terms and ending with a simplified model of the situation that can be used for assessing spill countermeasures quantitatively and objectively.

- An overview of year-round ice dynamics in the southern Beaufort Sea is presented;
- historically-accurate, detailed descriptions of freeze-up at Northstar and break-up and Pt. McIntyre are presented; and then
- simplified ice scenarios are presented, including mean values of ice conditions and other pertinent environmental parameters; these are summarized in tabular form for use in subsequent oil fate-and-behavior and countermeasures analyses.

## **2.2 Overview of Ice Conditions in the Alaskan Beaufort Sea**

Petroleum activities in the southern portions of the Alaskan Beaufort Sea are occurring on gravel islands and structures, which in winter are surrounded by solid, immobile, landfast ice. By late April or early May the ice will have grown to a maximum thickness of about 5 to 6 feet. The ice during this period is subject to various types of stress cracks resulting from rapid temperature changes, tidal action, and storm surges. These cracks quickly re-freeze to form a continuous layer of ice.

During the months of May and June, the ice is warmed by increasing air temperatures and lengthening periods of sunlight. Surface melting and river outflows adds to the deterioration of the ice rendering it increasingly susceptible to deformation, cracking and movement. The increased absorption of solar radiation in water as compared to snow and ice, causes accelerated melting in puddled areas. The ice thickness beneath these melt pools decreases more rapidly than the surrounding ice, in some cases resulting in holes through the ice.

During this period of decay, typically about six weeks, 100% ice coverage persists until the ice deteriorates to the point of breaking up under the influence of winds and currents. Following the onset of breakup, the ice cover begins to shift, crack, and deteriorate further into a field of ice cakes and brash ice (<65 feet across) combined with small to medium floes (65-1600 feet) and large floes (>1600 feet). Giant floes exceeding 5 nautical miles normally break up rapidly depending on the wind and the sea.

After the initial massive breakup, the ice cover typically requires two weeks or less to pass through the 75% to 90% ice coverage stages. During this period many of the ice floes are still relatively large and the floes and ice cakes are generally touching.

The next phase of breakup (from an operational standpoint) involves ice coverages between 75% and 25%. Depending again upon the weather, this phase lasts for one to two weeks in many of the areas that are the subject of drilling activities. Floe sizes continue to decrease during this period, while the distances between floes increase. Rarely do floes exceed 1600 feet once the ice concentrations reach about 40% or less in early August.

The 75% to 25% ice coverage portion of breakup is frequently characterized by extensive regions of heavier ice concentrations seaward of the barrier islands. At the same time, there are often areas of open water nearshore and in the lee of the barrier island chains. Depending on the weather, the water depths, and the proximity to natural or man-made islands, the actual ice cover frequently drops considerably below the 75% to 25% coverage in many of the operational areas.

Once the average ice concentrations reach about 25% or less, open water conditions begin to prevail. Such conditions normally exist for approximately two months prior to the onset of freeze-up in October. During this summer period, usually the months of August and September, the waters of the Beaufort Sea remain relatively free of ice except for short periods of ice incursions due to northerly winds.

The rapid drop both in daylight hours and average air temperatures in October is generally accompanied by the formation of frazil ice and grease ice nearshore and in inshore and backwater areas. Depending on the wind and sea conditions, young ice forms offshore and develops into thin areas and/or pancake ice. Eventually, the creation of solid ice cover begins and builds to a 10- or 12-inch layer, normally in November. Beyond this time only a major storm will cause significant disruption of the ice growth process. Currents beneath the ice decrease to 0.1 knots or less and remain at that level in most regions until spring breakup.

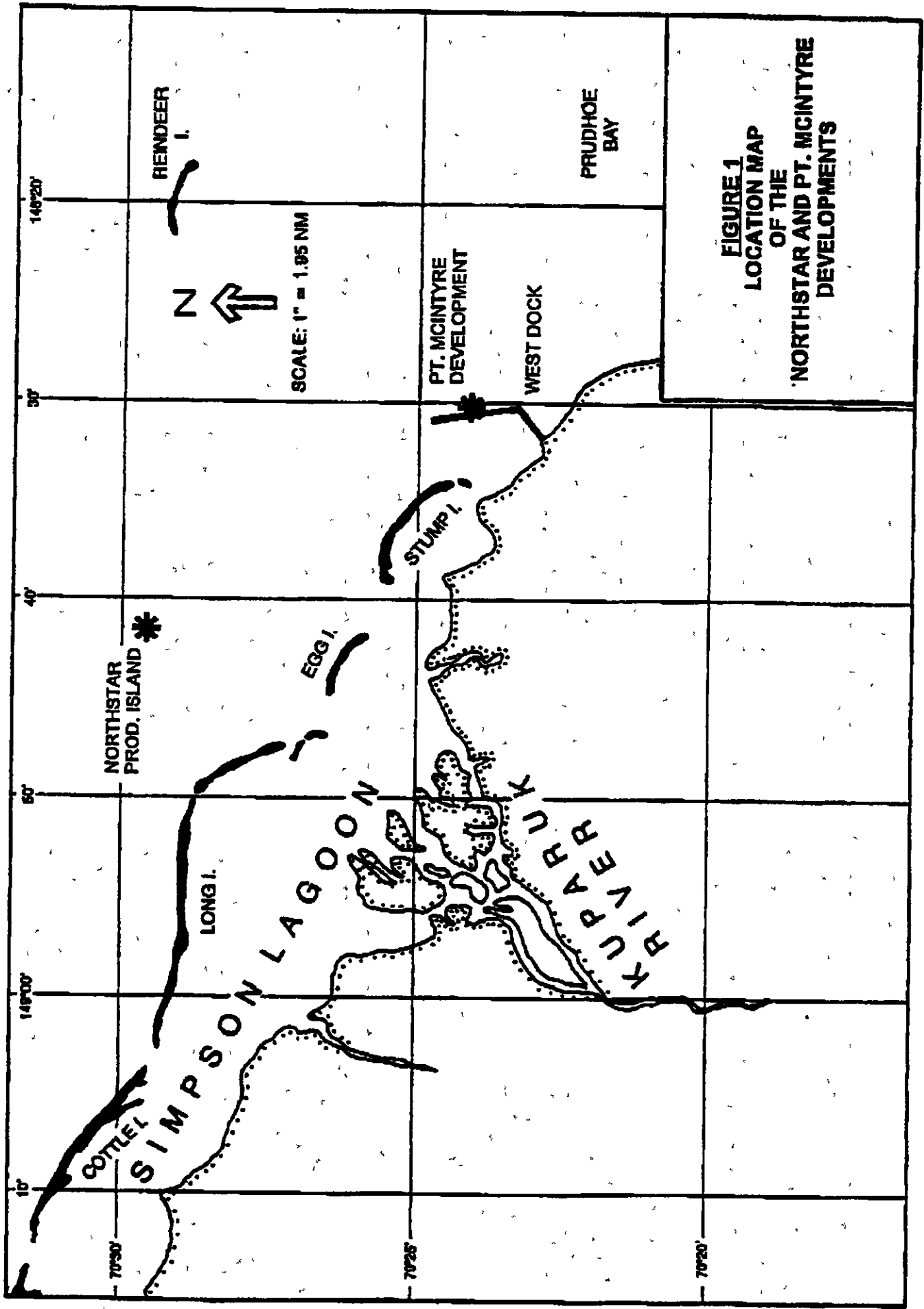
### **2.3 Descriptions of Freeze-up at Northstar**

**October.** Freeze-up occurs first in the calm, shallow water of the protected bays and lagoons, such as Prudhoe Bay and Simpson Lagoon south of Long and Stump Islands (see Figure 1). The average date of freeze-up for the Northstar location is October 6, with a range from the third week in September to the fourth week in October. The young ice cover spreads rapidly offshore into deeper water. Most of the lagoons become entirely ice covered within one week after freeze-up begins.

This young, first-year ice is only 6 to 8 inches thick and very susceptible to movement and deformation by storm winds in October. On October 19-20, 1982, for instance, the 8-inch thick ice that was present moved more than 10 nautical miles past Seal Island, driven by a 30 to 40 knot westerly storm. However, at the same time the ice in Simpson Lagoon and around West Dock moved very little (on the order of 50 to 75 feet). Such storms may produce ice ride-up and pile-up along the gently sloping beaches of the barrier islands and create ice rubble around man-made gravel islands and offshore structures, such as the Northstar production island.

**November.** Ice movement will be very small (1 to 2 feet) to nonexistent in Simpson Lagoon, after the ice becomes 1.5 feet thick, typically in mid-November. However, there is a small, but finite, risk of large ice movements (100 feet or more) in the corridor between the Northstar production island and Stump Island or West Dock during the late freeze-up season (from mid-November to late November) when the ice thickness is 1.5 to 2.0 feet. Based on six freeze-up studies from 1980 to 1985, five years of satellite imagery collected during freeze-up (1987 to 1991), and personal observations by K. Vaudrey in 1995, there was only one year (out of 12 years) in which there was an ice movement greater than 100 feet during mid-to-late November. This occurred in 1983 when 20-inch thick ice moved 100 to 200 feet, creating a 10 to 12 foot high pile-up on Stump Island.

It is clear that any storm wind that might create a broken ice condition in November would have to be very strong indeed. In addition, such a storm would have to be a southwesterly wind in order to produce a large-scale ice movement at the production island. This combination must be considered an unlikely possibility.



**FIGURE 1**  
**LOCATION MAP**  
**OF THE**  
**NORTHSTAR AND PT. MCINTYRE**  
**DEVELOPMENTS**



**December.** Typically by mid-to-late December (when the first-year ice sheet becomes about 2.5 to 3 feet thick), the ice in the vicinity of the Northstar production island becomes relatively stable, and the region becomes part of the stable landfast ice zone. During this period only small ice movements are likely to occur. For example, ice motion measured during 1995-96 at a wireline station located 5 miles east of the Northstar pipeline route in 21 feet of water, produced ice movements on the order of 10 to 15 feet. Exceptions to little ice movement do occur, however. For example, a 90 to 100 knot southwesterly storm in late February, 1989, removed most of the "landfast" ice north of the barrier island chain and drove it 20 to 30 nautical miles offshore.

**January.** After January 1 the risk of ice movement and the magnitude of ice movement is reduced significantly as the ice sheet becomes thicker and more stable. It should be remembered, however, that there still is a small chance of a major ice movement event occurring during the winter, as documented during the late February storm in 1989. The wind speeds measured during the storm were the largest ever measured (94 kts) and close to the 100-year maximum wind speed for Barter Island (98 kts), according to the Climatic Atlas (1988).

It should be noted that multi-year ice invasions (of 1 tenth concentration or greater) can occur during freeze-up at a rate of once every 3 to 4 years, but multi-year ice is not part of this study.

#### **2.4 Descriptions of Break-Up at Pt. McIntyre**

Break-up usually occurs inside the barrier islands and around the West Dock Causeway (WDC) between the last week of June and the second week of July, with an average date of July 4. Break-up is defined as the time when the ice concentration goes from 10 tenths to 9 tenths or less. The break-up season usually lasts for approximately three weeks, from the time of initial break-up until first open water occurs.

In the period before break-up, in mid-May, the ice starts to deteriorate to a point where ice roads can no longer support over-ice operations. Water in the Kuparuk River typically reaches the coast in late May or early June and begins to overflow the sea ice in Simpson Lagoon. Within a few days after the flooding begins, the water flows out of Simpson Lagoon (to the north between Egg Island and

Stump Island and to the east between the coast and Stump Island) and over-floods the ice along the entire west side of the WDC. During years of heavy flooding, the water can extend to a portion of the east side of the WDC by coming around the north end of WDC and by flowing through the 650-ft breach.

The overflow water on top of the floating landfast ice (in water depths of 6 to 20 feet) quickly drains through holes and cracks. The overflow water on top of the bottom-fast ice (frozen to the sea floor) loosens it and allows the ice to pop up to the surface. In both cases, the top of the ice in the overflow zone is usually covered with a thin layer of silt deposited by flood water. Within a period of 2 to 3 weeks after the flooding has ceased, most of the landfast ice within the overflow zone will have melted in place from a combination of the fresh, relatively warm, water and the increased heat absorption by the dirty ice.

Thus, by early July when break-up typically occurs, there may be little or no ice in eastern Simpson Lagoon and along the west side of the WDC; in contrast, it is likely that a completely intact, 10 tenths ice cover will exist on the east side of the WDC. Of course, the sheet ice along the east side of the WDC and around PM2 pad will be very deteriorated, with approximately 40% to 50% of its surface covered by melt ponds.

At this time in late June or early July, any 20-knot wind that begins to blow will probably initiate break-up. If break-up is caused by an easterly wind, the broken ice will stack up along the eastern shoreline of the WDC and will remain 10 tenths coverage for a distance of a few miles offshore. In outer Prudhoe Bay and south of Reindeer I. and Cross I., it is likely that open water will exist. If break-up is caused by a westerly wind, then open water will probably exist at the eastern shoreline of the WDC, with 5-6 tenths ice in outer Prudhoe Bay and 8-9 tenths ice near the barrier islands. As the winds shift from one direction to the other, the broken ice floes and pans will move back and forth across the lagoon in belts and patches of varying concentrations, all the while melting rapidly. The broken ice inside the barrier islands moves at about 0.3 to 0.5 knots during the short break-up season, but peak rates may reach 0.8 to 1.0 knot. Usually, within 2 to 3 weeks of break-up, the region around the WDC and most of the bays and lagoons, such as Prudhoe Bay and Stefansson Sound, will become open water (1 tenth or less ice concentration).

## 2.5 Persistence of Broken Ice

The detailed descriptions in the previous sections of freeze-up at Northstar and break-up at Pt. McIntyre suggest that ice at either location will rarely be in the form of ice floes that cover the water surface uniformly at fixed concentrations of 30%, 50% or 70%. The reality of the situation is that broken ice in any selected area will be in the form of closely packed ice in one part of the area and open water in the other. The average ice concentration for the area at any given time might be some value in the range of 30 to 70%, but generally the area is not uniformly distributed with ice floes. There can be a transition period following a storm or other disruption where the ice is redistributing, and where there is indeed ice concentration of ice floes of 30 percent or whatever, but this transition period is very short-lived, in the order of hours. This is explained in the following discussions.

**Freeze-Up at Northstar.** The most likely scenario for freeze-up at Northstar is that a young solid (10 tenths) ice sheet will grow until a storm wind of sufficient strength and duration occurs. The sufficiency requirement will depend primarily on ice thickness and confinement of the ice sheet (which in turn depends on the previous storm sequence). For example, an easterly storm creates an open water lead offshore of the Northstar production island and makes the ice sheet surrounding the island susceptible to movement from a westerly storm. When the young (thin) solid ice sheet at Northstar moves as a result of a storm wind, typically large (1000s of feet across) ice floes will break free of the coastline or landfast ice edge and move quickly away from the area. This will create an open water condition, not a broken ice condition, around the island. Depending on how cold it is, the open water will start to re-freeze, usually within a few hours to one day. This scenario may be repeated several times during freeze-up (October through mid-November), depending on the ice thickness, storm intensity, and wind direction. The broken ice condition that occurred when the ice cracked and movement started is relatively short-lived and within a few hours an open water lead (one to several miles across) is formed.

**Break-up at Pt. McIntyre.** The most likely scenario for break-up at Pt. McIntyre is that the deteriorated, melting sheet ice (solid 10 tenths ice concentration) on the east side of West Dock becomes susceptible to movement during a moderate storm wind from the west (e.g., 15-20 kts). Any such wind during late June or early July is likely to cause break-up of the sheet ice. When break-up

occurs, the 8-9 tenths ice concentration immediately begins to pull away from West Dock and moves quickly to the southeast, east, or northeast, leaving an open water lead along the east side of the Dock. The open water condition typically will extend offshore of the Dock for several miles, where the ice concentration abruptly changes from no-ice to 5 tenths or greater ice as the broken ice floes (50 to 100s of feet across) start stacking up on each other as they pack up against the eastern side of Prudhoe Bay or against the barrier islands (e.g., Reindeer or Cross).

For either location, a broken ice condition, meaning a situation in which floes of ice are distributed over the surface in concentrations ranging from 30 % to 70%, is more likely to occur during mid-to-late summer (August or September) when an ice invasion may occur. One or more such invasions of 3 tenths or 5 tenths ice concentration have a 56% or 35% chance of occurrence, respectively, at Northstar. Summer ice invasions are less likely, but certainly do occur, in and around West Dock.

## **2.6 Other Ice Features Affecting Broken Ice Spill Response and Logistics**

**Boundary Conditions.** During a storm or strong wind condition one can imagine that "broken ice" in concentrations of 30 to 70% can flow past either site for as long as the wind condition lasts. Typically, however, ice movement that occurs at Northstar during freeze-up or at Pt. McIntyre during break-up cannot go on indefinitely due to constraining boundary conditions. Any ice motion to the east, south, or west from the Northstar area is significantly restricted by the barrier island chain or West Dock. Larger movements to the east-southeast can occur, but are eventually constrained by the shallow water of Prudhoe Bay. Similarly, ice motion to the north and northeast is constrained by shoals. However, ice motion to the northwest (from a southeasterly or easterly wind) may continue almost indefinitely (as long as the duration of the storm wind) due to the absence of natural obstructions for a distance of some 30-40 miles.

Given that the west side of West Dock at break-up is likely to be in open water, the only ice movement at break-up will occur on the east side of the Dock. Any ice motion occurring at West Dock during break-up will be constrained by the barrier islands to the northeast and the shallows of Prudhoe Bay to the southeast. Even ice movement to the east in Stefansson Sound may be impeded by the Endicott Development and the shallows offshore of the Sag. River delta. Again, the only

direction which remains relatively unrestricted is to the northwest where ice floes at break-up have been observed or tracked moving as far as Harrison Bay within a few days of leaving the Prudhoe Bay area.

***Open-Water Wake.*** An open water wake has frequently been observed when close pack ice (7/10 or more) moves past gravity based drilling structures and artificial islands in the US and Canadian Beaufort Seas. This wake may extend for a distance of 2 to 3 island diameters or approximately 1000 to 1500 feet and will be as wide as the island diameter or about 500 feet.

New ice will start to form almost immediately in the open water wake, with the grease ice and nilas moving with wind to build up a slush dam against the ice floes at the downwind side of the wake. This wake effect is accounted for in developing the freeze-up scenario with 7/10 ice at Northstar. In lighter concentrations, individual floes are free to close in quickly behind the island as the ice drifts past; consequently, a wake as such does not exist in those cases. At break-up, the scenarios are located to the east of West Dock which forms an extension from the shore. By definition, with open water already present to the west of West Dock in July, there is no ice upstream to create a wake effect, even if the configuration of the drilling pad allowed ice flow on both sides.

***Fast Ice Nearshore.*** While the freeze-up broken ice scenarios are applicable to the Northstar production island, logistics for any oil spill response will undoubtedly be based at West Dock. It is anticipated that freeze-up storms (greater than 20 kts) in October, when the ice thickness is less than 12 inches, can create a broken ice condition at the Northstar production island but retain a 1-2 mile wide zone of landfast ice around West Dock. Response vessels will have to negotiate a solid ice cover (6"-12" thick) over a distance of 1 to 2 miles in order to reach the broken ice described in the simplified scenarios presented below.

## **2.7 Simplified Models for Freeze-Up and Break-Up Scenarios**

Simplified models are developed here to define ice break-up and freeze-up conditions for the purposes of spill response evaluation.

**Introduction.** The terms of reference or parameters for this study, as stated in Chapter 1, focus on six blowout scenarios, each of which is to take place in an given ice coverage, either 30% 50% or 70%, which is to remain constant throughout the blowout scenario period of 15 days. The ultimate objective is to determine what capability exists for cleaning up spills in these broken ice conditions, however long the conditions last. It is clear from the discussions in this chapter that such ice concentrations might occur, but only for a relatively short period, in the order of hours for most situations. Regardless of this, it remains important to know whether or not a reasonable capability exists for dealing with spills in such broken ice conditions.

In terms of satisfying the objective of the study, and at the same time remaining reasonably true to the reality of the situation, the following is proposed. First, the oil spill cleanup capability that exists when operating in fixed, "broken ice" conditions will be calculated. Then it will be assumed that these conditions last a full 15 days. This is a less reasonable thing to do, but it will be done nonetheless. Because the spills are continuous discharges, the spill characteristics at and near site should be the same at the beginning stages of the blowout as at the end, for constant broken-ice and environmental conditions. Therefore, once the daily spill cleanup capabilities for a given broken ice condition are established, it becomes simple to calculate the overall 15-day capability for that blowout situation.

In summary, the following approach will be taken in conducting the evaluation of spill countermeasures.

- Broken-ice scenarios will be developed in which ice floes cover 30%, 50% and 70% of the water surface.
- The scenarios will be used in modeling and delineating the distribution of spilled oil onto the surrounding water and ice.
- The ice and oil spill scenarios will be used to analyze countermeasures capability in 30%, 50% and 70% ice concentrations, on a daily basis and over the 15-day blowout period.

**Simplified Broken Ice Scenarios.** Based on ice studies, climatic data, and personal observations, typical environmental parameters are developed for spill response scenarios at the Northstar production island during freeze-up and at the Pt. McIntyre location at West Dock during break-up. The parameters are presented in Tables 1 and 2 (at the end of this section) for the specified ice concentrations of 30%, 50% and 70%. Appendix B provides supplemental data on ice and climate parameters which can be used to determine the percentage time that a particular condition may exceed the values used in the scenarios.

The following briefly outlines the sources used to generate the climate and ice parameters that are in the tables. Reference numbers in the text identify sources in the attached list.

**Ice Conditions** (Concentration variability, ice thickness, floe size, and snow on the ice, melt pool coverage): As discussed earlier, there is considerable variability in establishing the range in ice concentrations which could actually be encountered in each scenario. Although the regional concentration averaged over a few square miles may be 30, 50 or 70% the actual concentrations on distance scales of hundreds of feet may range from open water to solid ice (a large floe being equivalent to 100% ice coverage within its perimeter). Average or median values for the ice parameters shown in Tables 1 and 2 were extracted from a combination of References 2, 4, and 9

through 19 and extensive personal experience in the area during break-up and freeze-up (Ref. 9 through 20).

Ice Drift Speeds: Realistic ice drift speed and direction values are derived from a combination of a percentage of wind speed and actual nearshore ARGOS buoy measurements (References 3, 5 through 8, and 20, 21) where applicable. As explained below, wind speeds used in the scenarios are not necessarily representative of the means.

Metoccean Conditions (winds, air temp, precipitation, sea state, visibility, and ceiling height): mean values for these parameters are extracted from Reference 1; with atmospheric icing estimated by ERA Helicopters who are the only operator to have maintained an operations base in the Prudhoe Bay area continuously for the last 25 years.

Wind Speed And Direction: During break-up, the scenarios for 3 and 5 tenths (30% and 50%) ice coverage are defined by average wind speeds of 8-12 kts. However, the 7 tenths ice concentration scenario is assumed to occur sometime during or immediately after the initial break-up event, when the landfast ice undergoes a rapid transition from 10 tenths to a broken ice condition; therefore, the wind speed in this case is represented by a moderate "storm" wind (15-20 kts) which would be necessary to initiate the break-up event.

During freeze-up, the scenario for 3 tenths ice coverage represents the median wind speed (12-15 kts) for October. The other scenarios are represented by higher wind speeds, reflecting the frequent occurrence of storms during freeze-up (scenarios with higher concentrations are more likely to occur during or on the tail of a storm event). The logic here is that over a 72-hour period spill response teams will likely encounter moments of sustained above average winds. Based on the frequency distribution of wind speeds shown in Table B-2 in Appendix B, the winds shown in Table 1 will be exceeded 20-30% of the time for the 50% ice concentration scenario and 10-20% of the time for the



70% ice concentration scenario (amounting to between 7 and 22 hours out of 72-hour response period).

Wind directions at freeze-up were chosen as the most likely direction, based on wind direction occurrence presented in Table B-2. Directions at break-up are dictated by the somewhat artificial situation created by the West Dock causeway. For example, winds from the ENE in July would lead to the oil plume falling in open water on the west side of the causeway. Consequently, the wind directions used in Table 2 were deliberately chosen as westerlies to carry the oil into the broken ice remaining on the east side of the causeway. Such winds are common in July; strong winds needed to initiate break-up in Prudhoe Bay are most often from the west.

**TABLE 1**

**Typical Environmental Parameters for Northstar during Freeze-up**

<b>Ice Parameter</b>	<b>Ice Concentration (tenths)</b>		
	<b>3</b>	<b>5</b>	<b>7</b>
Local variability in concentration	0 to 0.4 at island, but 10/10 landfast ice near West Dock	0.2 to 0.6 at island, but 10/10 landfast ice within 1 to 2 NM of West Dock	0.3 to 0.8 at island, but 10/10 landfast ice within 1 to 2 NM of West Dock
Date (from-to)	10/10 through 10/12	10/19 through 10/21	10/29 to 10/31
Daylight hours (incl. twilight)	12	10.5	8
Floe ice thickness (ft)	0.4 to 0.6	0.6 to 0.8	1.0 to 1.2
Floe size (ft)	100's to 1000's	100's to 1000's	100's to 1000's
Snow thickness (in) on top of the ice	1 to 2	2 to 4	5 to 6
Ice drift speed (kt)	0.3 to 0.4, up to 1.0	0.7 to 1.0, up to 1.5	0.8 to 1.2, up to 1.8
Ice direction (to)	NW	E	NE
Wind speed (kts)	12 to 15	18 to 20	20 to 25
Wind direction (from)	E	WSW	SW
Air temp. (day) - °F	23	18	13
Air temp. (night) - °F	13	8	3
Precipitation (snow) (inches)	1	1	1
Sea state height (ft)/period (sec)	84% of time < 3 ft with periods of 6 to 8 s	N/A	N/A
Visibility (NM) (helo ops)	5% of time < ½ NM (~3 to 4 hr in 3 days)	5% of time < ½ NM (~3 to 4 hr in 3 days)	5% of time < ½ NM (~3 to 4 hr in 3 days)
Ceiling height (ft) (fixed wing ops)	3% of time ceiling ht. < 1500 ft with visibility < 1 NM	3% of time ceiling ht. < 1500 ft with visibility < 1 NM	3% of time ceiling ht. < 1500 ft with visibility < 1 NM
Atmospheric icing (helo ops)	3% of the time (~2 hr in 3 days)	3% of the time (~2 hr in 3 days)	3% of the time (~2 hr in 3 days)

TABLE 2

Typical Environmental Parameters for Pt. McIntyre during Break-up

Ice Parameter	Ice Concentration (tenths)		
	3	5	7
Local variability in concentration	0.2 to 0.3	0.4 to 0.5	0.6 to 0.8
Date (from-to)	7/10 through 7/12	7/7 through 7/9	7/4 through 7/6
Daylight hours (incl. twilight)	24	24	24
Floe ice thickness (ft)	3 to 4	3 to 4	3 to 4
Floe size (ft)	50 to 500	50 to 500	50 to 500
Melt ponds (% of surface area of ice)	40 to 50%	40 to 50%	40 to 50%
Ice drift speed (kt)	0.3 to 0.4, up to 0.8	0.2 to 0.3, up to 0.7	0.3 to 0.5, up to 1.0
Ice direction (to)	E	SE	NE
Wind speed (kts)	10 to 12	8 to 10	15 to 20
Wind direction (from)	W	NW	SW
Air temp. (day) - °F	45	45	44
Air temp. (night) - °F	35	34	33
Precipitation (snow) (inches)	0	0	0
Sea state height (ft)/period (s)	95% of time < 3 ft and periods of 6 to 10 s	N/A	N/A
Visibility (NM) (helo ops)	22% of time < ½ NM (~15 to 16 hr in 3 days)	22% of time < ½ NM (~15 to 16 hr in 3 days)	22% of time < ½ NM (~15 to 16 hr in 3 days)
Ceiling height (ft) (fixed wing ops)	11% of time ceiling ht. < 1500 ft with visibility < 1 NM	11% of time ceiling ht. < 1500 ft with visibility < 1 NM	11% of time ceiling ht. < 1500 ft with visibility < 1 NM
Atmospheric icing (helo ops)	N/A	N/A	N/A

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### 3. General Behavior of Offshore Blowouts and Oil Spills in Ice

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#### 3.1 Introduction

In subsequent sections of this report six hypothetical oil-well blowouts are selected for study and described tersely in terms of blowout behavior and oil spill behavior. The purpose of this chapter is to provide background information that will assist the reader in understanding the specifics of later discussions of these subjects. The next chapter has a similar purpose with respect to spill countermeasures.

There are two basic kinds of offshore oil-well blowouts. The first is a subsea blowout in which the drilling platform moves off site or is destroyed during the blowout. In this case the discharging oil emanates from a point on the sea bed and rises through the water column to the water surface. An example of this kind of oil-well blowout was the 1979 *Ixtoc 1* blowout in the Bay of Campeche, Mexico (Ross et al. 1979). The other possibility is a platform blowout or above-surface blowout in which the platform maintains its position during the accident (because it is undamaged or bottom-founded) and the oil discharges into the atmosphere from some point on the platform above the water surface, and subsequently falls on the water surface some distance downwind. Examples of this kind of blowout include the 160,000-barrel *Ekofisk* blowout in the North Sea in 1977 (Audunson 1980) and the 1500-barrel *Uniacke* blowout of condensate off Nova Scotia in 1984 (Gill et al. 1985). Oil-well blowouts that might occur at either the Northstar or Pt. McIntyre locations could only be of the above-surface kind, and further discussion is restricted to this kind.

#### 3.2 Behavior of Above-Surface Blowouts

As demonstrated in the *Ekofisk* and *Uniacke* blowouts noted above, the gas and oil released from an above-surface blowout will exit at a high velocity from the well-head and the oil will be fragmented into a cloud of fine droplets. The height that this cloud rises above the release point will vary depending on the gas velocity and the prevailing wind velocity. The fate of the oil and gas at this

point is determined by atmospheric dispersion and the settling velocity of the oil particles. Atmospheric dispersion potential can be characterized by using an atmospheric stability classification system developed by Turner (1970). Stability classes are determined by the turbulent structure of the atmosphere and by wind speed. Stability is quantified using a six-part scale with categories being labeled A through F. A is the most turbulent class and F is the most stable. Class D is typical for offshore conditions (Turner 1970) and it is this class that is selected for drilling locations in the Alaskan southern Beaufort Sea.

The oil particles discharged into the air will eventually "rain" down, with the larger droplets falling close to the release point and the smaller droplets falling further downwind. The width and thickness of resulting slicks of oil can be calculated using a step-by step procedure developed by Belore et al.(1998). The procedure, presented in Appendix C, is used in Chapter 7 to describe the behavior of the blowouts and the initial characteristics of the resulting slicks for the six scenarios considered. It should be noted that there is a large uncertainty associated the modeling results because of certain, key assumptions used in the model. The main assumption is that the average diameter of the droplets discharged in the blowouts is 0.75 mm. The rationale for using this number is explained in Appendix C or in Belore et al. 1998.

### **3.3 General Behavior of Oil Spilled on Open Water**

Once the oil from a blowout reaches the ocean surface it is swept away by winds and currents and undergoes a number of so-called "weathering" processes. This section provides an overview of the processes that have a major influence on the potential cleanup and impact of the oil. In broken ice conditions the oil will fall on both oil and ice. The behavior of the oil on open water is discussed in this section. The behavior of oil on ice and among ice floes is discussed in Section 3.6.

The most important phenomena that influence spill impact and control are movement, evaporation, natural dispersion, and emulsification. Each of these processes is discussed briefly below.

**Oil Movement.** Surface slicks may be transported away from the site of a spill by water currents. These currents usually combine residual movement and wind-induced surface movement. Mackay

(1984) reports that the rate of oil slick movement may be increased by a factor of 3 percent of the wind speed measured 10 m above the water surface. However, the final vector of oil movement depends on the combined influences of residual currents and wind-induced surface currents. Over relatively long distances, Coriolis forces (due to the earth's rotation) cause the direction of wind-induced slick motion to deviate some 10 to 15° to the right of the wind direction (in the Northern Hemisphere). In nearshore marine waters, the movement of oil slicks is also affected by tidal currents, river outflows and longshore currents.

**Oil Spreading.** Numerous models of oil spreading behavior have been developed over the past 25 years. All relate the properties of the oil (density, viscosity and interfacial tension) to its spreading on calm water. Most models today use the model developed by Mackay et al. (1980) which includes the assumption that as the slick spreads, it forms thick patches that contain most of the oil volume in a small portion of the area. These patches are surrounded by thin sheens (in the 0.001 mm range) containing a small portion of the total oil volume over a wide area. The feature is consistent with observed spill behavior.

Some oils do not spread on water as described above. This category includes oils that have a pour point (i e., the temperature below which the oil does not flow) that exceeds the ambient temperature. The pour point of an oil can be naturally high or may be high as a result of evaporative losses of hydrocarbons during exposure to the environment.

**Evaporation.** Evaporation is the most predictable oil spill process (Mackay 1984). The evaporation rate of an oil slick is controlled or affected by: 1) the temperature of the oil and the air; 2) the surface area of the oil in contact with air; 3) the thickness of the oil; 4) wind speeds; and perhaps most important 5) the concentration and vapor pressure of the individual components of the oil. The most useful studies of oil slick evaporation rates were conducted by researchers at the University of Toronto in the late 1970s and early 1980s (e.g., Nadeau and Mackay 1978, Stiver and Mackay 1983). In these studies, the volume or mass fraction of oil evaporated is related to an exposure coefficient (combining time, oil volume and area, and the "mass transfer coefficient" to the atmosphere) and to the vapor pressure-concentration relationship for the oil. The unique aspect of this approach is that

it permits the results from a variety of laboratory evaporation experiments to be easily extrapolated to actual environmental conditions with a high degree of confidence.

With an above-surface blowout, evaporation also occurs as the oil droplets from the blowout rain down onto the surface. The amount of oil that evaporates in this situation is controlled by the size of the droplets, the volatility of the oil, the length of time they are in the air, and the air temperature. Rather than use the model to estimate an initial evaporative loss for the droplets in the air, a fixed value of 20 % initial volume loss to evaporation was used in the study, as requested in the terms of reference for the study. This leads to an under-estimate of evaporative loss for one of the oils used in the study ( Milne Point as surrogate for Northstar) and an over-estimate for the other (Pt. McIntyre).

**Emulsification.** When most crude oils are spilled at sea, they tend to form water-in-oil emulsions. Emulsification occurs in the presence of mixing energy such as that provided by wave action. During emulsification, seawater is incorporated into the oil in the form of microscopic droplets. This water intake results in two undesirable changes to the oil. First, there is a significant increase in the bulk volume of the oil (usually up to a 4-fold increase), greatly expanding the amount of oily material that must be dealt with. Secondly, there is a marked increase in fluid viscosity (up to 100-fold). The much higher viscosities greatly inhibit the natural dispersion of oil and make the application of chemical dispersants useless.

Mackay (1983) and Mackay and Zagorski (1982) developed preliminary models for the emulsification process, and these are often used to describe the phenomena in quantitative terms.

**Natural Dispersion.** In conjunction with evaporation, the process of natural dispersion reduces the volume of oil on the water surface, thereby influencing the potential extent of surface and shoreline contamination. Dispersion rates are determined by oil/water interfacial tension, oil viscosity, oil buoyancy and slick thickness. Environmentally, sea state is the most important factor controlling the rate and amount of dispersion. Even the heaviest, emulsified oils can disperse over a period of time in heavy seas with frequent breaking waves



### **3.4 SL Ross Oil Spill Model**

The computerized oil spill behavior model that is used in this study – the SL Ross Oil Spill Model – has been used extensively in various studies of offshore oil spill behavior. The model incorporates and integrates all the processes noted above to arrive at an estimate of an oil's likely behavior. SL Ross has drawn upon the work of a number of researchers in developing its models for these processes and has added enhancements to deal with pour point, viscosity changes and waxy oil behavior. The model only applies to the behavior of oil spills on open water; it does not handle the effects of ice.

The model is able to provide the following spill data as a function of time: slick areas, thicknesses and volumes, for both the thin and thick slick portions; viscosity, density, pour point and water content of any emulsions that may form; the volumes and percentages of the thick and thin slick portions that evaporate and disperse; and the maximum possible in-water oil concentration as a result of natural or chemically aided dispersion.

### **3.5 Modeling of Pt. McIntyre and Northstar Crude Oils**

Because the behavior of a spill is significantly affected by the oil's initial properties, a spill model's particular utility lies in its ability to predict the spill behavior of specific oils. This cannot be done without testing the oil in the laboratory. At SL Ross a number of laboratory analyses are performed on crude oil and oil products to generate the parameters necessary for the modeling exercise. A distillation is completed on the fresh oil, and an oil sample is weathered for a prolonged period in a wind tunnel. The distillation and wind tunnel data provide the information necessary to predict the fraction of oil that will evaporate in a given time under a specific wind history or evaporative exposure. The wind tunnel weathering procedure also provides aged oil samples for property analysis. Oil density, viscosity, pour point, interfacial tension, flash point, and emulsification factors are determined at two temperatures for both the fresh and weathered oil samples. These analyses provide the coefficients needed to estimate oil properties and behavior at different temperatures and weathered states. The expressions used to estimate property changes with time and temperature are those given by Mackay et al. 1983.

Both oils considered in the modeling of the six scenarios were tested and modeled as described above and are now part of the SL Ross library of crude oils, available for use in the model. The two oils are (1) Pt. McIntyre Crude oil, for the Pt. McIntyre site, obviously, and (2) Milne Point crude oil for the Northstar site. Reports on these tests are available in SL Ross 1994 and SL Ross 1996, respectively, and tabular summaries of these are available in Appendix D. Milne Pt. crude oil was used to represent Northstar oil because at the time of testing not enough Northstar crude was available for a full program of testing, so Milne Pt. crude, which comes from a nearby oil field, was studied instead. A small sample (100mL) of Northstar crude was analyzed in order to compare selected properties with those of the Milne Pt. crude. The Northstar oil was found to be less dense, less viscous, and more volatile. This means that the oil spill scenarios at the Northstar site, described in Chapter 7, present a conservative picture of the persistence of spills that might occur at that location.

The following are brief summaries of the properties of each of the selected oils. Milne Point crude oil is a light oil (density of 0.849 g/mL @ 1°C, viscosity of 8.0 cP @ 15°C) with a high concentration of volatile components. It will not form emulsions until the oil is highly weathered (evaporated more than 20 %) and the emulsions that do form are likely unstable; that is, they break naturally when mixing energy is removed and also respond well to emulsion breaking chemicals. Pt. McIntyre crude oil is a medium crude oil (density of 0.911 g/mL @ 1°C and viscosity of 756 cP @ 1°C). It has a very high tendency to form stable emulsions, even when fresh.

### **3.6 Behavior of Oil Spilled on Ice and in Broken Ice**

Many studies on the behavior of oil spilled in ice infested waters have been performed over the past 20 years. 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. Another review of the subject that is more focused on the Alaskan situation is found in Dickins and Glover 1996, and it is this reference that we draw on now to summarize our current knowledge on the subject. Please note that a large portion of the Dickins and Glover review deals with the problem of oil spilled under ice, a case that could occur, for example, if an oil well blowout were to occur on the sea bed during winter and rose to the

underside of the ice cover. Such scenarios are not possible in the present study, so this aspect of oil/ice interaction is not dealt with here.

### **3.6.1 The Effect of Ice on the Four Main Oil Spill Processes**

The effect of broken ice on the four main spill processes of spreading, evaporation, dispersion and emulsification is briefly discussed first.

**Oil spill spreading** can be dramatically curtailed because of the presence of broken ice and brash ice. 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 (SL Ross and DF Dickins 1987)

**Oil spill evaporation** is not greatly affected by the presence of ice unless the oil is trapped under or within the ice. Evaporation of volatile components occurs whether the oil rests on water or on ice. 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 (SL Ross 1994)

**Oil spill dispersion and emulsification** rates for oil spills on water depend on the mixing energy available at the sea surface, and since the presence of ice tends to dampen the effects of wind on sea state, both dispersion and emulsification rates in broken ice conditions would be expected to be less than the case in open water conditions, all other factors remaining the same.

### **3.6.2 Oil Spilled Within Broken Ice, Spring through Fall**

During the primary period of spring break-up, oil spilled in broken ice conditions would be contained in the openings between floes and would coat the surrounding ice surfaces. As spring melt proceeds the area of contamination would correspondingly 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. The fate of oil trapped between floes will depend largely on the ice concentration and time of year.

During freeze-up, 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 through November.

At spring break-up, 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 openings 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.

### **3.6.3 Oil Spilled on Top of the Ice**

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. A number of process equations are available to predict the spreading and evaporation 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):

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

## **4. Overview of Spill Countermeasures**

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As with the previous chapter the purpose of this chapter is to provide background information on oil spill countermeasures that should help readers better understand the terse, scenario-based descriptions of countermeasures that are presented in Chapter 7.

Before starting the detailed review, some discussion of the differences between spills from blowouts and spills from tankers is warranted. Alaskans are painfully aware of the difficulties of cleaning up large tanker spills, so it is natural for them to believe that similar difficulties would exist in dealing with large spills from blowouts. This may not always be the case, as discussed below.

### **4.1 Differences between Fighting Blowout Spills and Tanker Spills**

**Tanker Spills.** Although hundreds of millions of dollars have been spent developing containment and recovery equipment (i.e., booms and skimmers) for dealing with tanker spills, the problem remains extremely difficult. The cleanup equipment itself is not the issue because offshore boom-and-skimmer systems are generally effective in containing and removing large amounts of oil on open water if the sea states and currents are not too high, and if the spill is small in area and large in thickness. Rather, the usual problem in recovering major oil spills in the open ocean is that spills tend to spread to large and unmanageable areas before cleanup systems can arrive on site. A 100,000 barrel spill, for example, can spread to a total, patchy area of about 8 square miles or 5000 acres within just 12 hours. Another problem is that recovery systems must move through slicks slowly (less than one knot) to avoid major surface oil losses due to entrainment, so recovery itself is a relatively slow process. Because response and cleanup times can be long, another problem arises: water-in-oil emulsification. Most crude oils will begin to emulsify within a short time – within minutes or hours for some – and this process can increase the amount of oily substance on the surface by a factor of four or so. This makes the spill recovery process that much slower because up to four times the amount of product must be picked up and disposed of.

It is often difficult for cleanup systems to reach tanker spills quickly because such spills can occur virtually anywhere along the world's marine transportation corridors. Although cleanup equipment can be stockpiled and made ready in particularly high risk areas, such as ports and other high traffic areas, this does not guarantee that spills will conveniently occur within easy striking distance. An effective response with mechanical systems must involve several ocean-going vessels working in tandem, some to manage the equipment and others to accept and store recovered oil, so the time to reach a spill and begin operations is limited to the time needed for all systems to arrive on site. This can take many hours depending on the spill location.

These problems explain traditionally why mechanical systems have done poorly on most historical spills, aside from any lack of preparation on the part of the responders. The number mentioned often by experts is that mechanical systems responding to historical spills have recovered at sea about 5 to 10 percent of the oil spilled. This number applies to the situation generally, but perhaps not to the Prince William Sound area today, because of the build-up of mechanical recovery capability that has taken place following the *Exxon Valdez* tanker spill in 1989.

**Blowout Spills.** The general capability for dealing with oil spills from offshore oil well blowouts is believed to be much better than for tanker spills. In these situations the contingency planner knows beforehand the exact location of the potential oil discharge and so is able to expend considerable effort in developing a site-specific preparedness to deal with the problem. Protection priorities, currents, wind patterns, spill movement predictions, etc. can all be studied before the event. Furthermore, although the total quantity of oil that can be released is large, the amount of oil discharged per day is relatively low and it can be recovered or treated with a modest amount of equipment or materials. Finally, the oil slick at the blowout site generally is in a concentrated, fresh and non-viscous state which benefits the main control techniques of skimming, burning and dispersing. All these factors put the contingency planner and oil spill responder in a relatively good position to deal with the problem.

For the specific case of an oil blowout from a gravel island in the Beaufort Sea, the situation is even better for several reasons. First, the oil is discharged at or above the island's surface where it can be easily removed by ignition and burning. Second, the island may be used as a base from which to

mount an oil spill control operation during open water conditions. And third, the presence of a solid ice cover for most of the year leads to the situation where an oil blowout from a gravel island is usually little different than a blowout on land. That is, most oil can be ignited and the remainder simply recovered by mechanical means from the landfast ice surface.

In summary, relative to other offshore oil spill situations, oil well blowouts and spills from gravel islands in the Alaskan Beaufort Sea are considered to be straightforward to clean up, particularly during the predominating periods of complete ice cover when the oil can be removed mechanically or burned, and open water when the oil on the water near the island can be dealt with by conventional containment and recovery devices.

Nevertheless, broken or unstable ice conditions exist for short periods during fall freeze-up and spring break-up in the Alaskan Beaufort Sea. The presence of the ice will inhibit spreading of the oil, however, with the blowout conditions considered in this study (i.e., open orifice blowouts with high gas-to-oil ratios), the initial slick thicknesses are too thin to allow for *in situ* burning without concentrating the oil in some manner. The other approach, using conventional booms and skimmers, also has serious problems because the oil is often too thin and widespread for cleanup systems to operate efficiently, if at all, among the ice floes.

In summary, spills from blowouts in open-water and complete-ice-cover situations are much more amenable to cleanup than instantaneous tanker spills. However, the capability in a broken-ice situation is generally not good regardless of spill type, as discussed below.

#### **4.2 Review of Cleanup Capabilities for Spills in Various Ice Concentrations**

The following sections are abstracted from Dickins and Glover 1996. These describe industry's proposed strategies and techniques for dealing with oil spilled in different combinations of ice and open water off the North Slope, drawing on experience with past spills (both accidental and experimental) and knowledge of the expected fate and behavior of oil in ice.

#### **4.2.1 Mid-winter Response (January to April)**

Current technology is considered capable of successfully cleaning up oil spilled on solid ice. By late December, the landfast ice is normally stable and, from this time until late May, cleanup operators can utilize the ice cover as a secure platform for support equipment, including trucks, bladders and portable trenching equipment. For oil trapped on or within the ice sheet in mid-winter, direct pumping would result in almost complete removal of the spilled oil. Ice roads and pads could be built to allow heavy equipment and vacuum trucks direct access to the oil pools. These trucks would recover oil directly into attached insulated tankers for transportation to waste disposal facilities. During extremely cold periods it might be necessary to use steam wands on the oil pools to facilitate recovery.

Cleanup could be accelerated by the use of *in situ* burning. Final cleanup in June, in particular, would benefit by the use of selective burning of oil on melt pools followed by manual recovery of any residue. The choice of burning on site or removal to shore would 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 could be placed on site or at shoreside positions to melt contaminated snow and ice. Recovered oil could then be trucked to designated disposal wells for re-injection or to a designated production facility for reprocessing. Burning on-site would become the preferred option late in winter when there might be insufficient time to transport the recovered oil to shore prior to break-up.

#### **4.2.2 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 freshly deposited on the surface, or oil remaining on the surface following a winter cleanup operation. However, this period also marks the beginning of 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 in Canada and Norway (Bech et al. 1993, Guenette et al 1995, SL Ross 1995 and 1998) has demonstrated that it is possible to effectively burn fresh crudes with up to 25 to 40 percent emulsification (water in oil), albeit at a reduced efficiency. 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. 1995 and 1997)

Work in Alaska and elsewhere has proved 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, 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 might increase the overall recovery effectiveness by up to 10 percent. Realistic estimates for the amount of residual oil remaining at the point of final ice break-up range from 10 to 20 percent. With appropriate safety precautions and a helicopter or amphibious vehicle in attendance, surface operations to collect residue could continue until within a few days of break-up. Once collected the residue could be 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 would depend on the ice concentrations. There will be a period of several weeks when response operations would 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 would become increasingly less restricted by ice and more able to rely on traditional open water mechanical containment and recovery techniques.

#### **4.2.3 Summer Response (August and September)**

Spills during the summer period, in open water or in water with some ice (say, concentrations up to 20 to 30%) would behave no differently than open-water spills elsewhere in the world. Response methods could include the usual combination of physical recovery, *in situ* burning and dispersant use. For platform blowouts as envisioned in this study the discharging oil could be contained and concentrated as it falls on the water downwind, and either physically recovered or burned as appropriate. Oil escaping this operation could be dispersed chemically, if this were deemed to be appropriate environmentally. All in all, the total operation could be highly efficient, mostly because of the reasons given earlier: the oil discharge rate would be relatively low, the spill location would be fixed, the oil discharged would always be fresh and unemulsified, and the slick swath or area would be relatively small

#### **4.2.4 Fall and Early Winter Response (October to December)**

This is the most difficult situation. 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. Rope-mop style skimmers could 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. There are dozens

of portable rope mop skimming systems within the North Slope response equipment inventories that 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 conventional skimming operations would likely be curtailed by thicker, more concentrated ice within one to two weeks of initial freeze-up.

In the beginning of the ice growing season many of the spill response vessels would remain operational. The jet powered vessels would 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 would 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 would have the longest sustainable operational period.

One possible strategy during freeze-up conditions might be to use *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, high removal efficiencies could be achievable.

Inevitably, as the ice continues to thicken, the oil would gradually become incorporated into the new ice formation. No cleanup measures could be effective at this point, so tracking the oiled ice would become a priority. This would be done with the use of satellite tracking beacons deployed at the spill source. The oiled ice may move only short distances (thousands of feet) in October before becoming landfast. At this point the coastline is protected from oiling by the fringe of new landfast ice that develops at the shoreline. For this oiled ice, conventional winter response procedures could be followed by transporting personnel and equipment to the site. Due to the low temperatures, remote locations and darkness involved in these type of operations, personnel safety considerations would require additional attention. Resources such as personnel shelters, portable lighting, portable heaters and restroom facilities would be required along with the initial response resources.

The contaminated area would 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. Handheld global-positioning-system (GPS) units would be used to record the exact locations of both surface and sub-surface pools.

Recovery operations on early-season, landfast ice would be similar to remote terrestrial spill response actions once the oil is brought to the surface. Logistics constraints may demand that *in situ* burning be utilized as the primary recovery option.

Despite all efforts, however, the oil recovery efficiencies for spills in the fall freeze-up period would be expected to be low.

## 5. Existing Spill Response Approaches and Systems

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In this section the systems that currently exist for dealing with spills in ice will be described. Included will be an overview of current cleanup approaches and plans, and a description of the key equipment available to implement these plans. The description of the equipment will include a discussion of their operational capacities and limitations and will set the stage for the subsequent evaluations for each of the blowout scenarios.

The chapter focuses on countermeasures for physically recovering spilled oil, but two short sections are written (in Sections 5.5 and 5.6) on the countermeasures of *in situ* burning and dispersant use.

### 5.1 Overview of Tactics

The tactics for dealing with the spills in the specified scenarios will depend on the degree of ice concentration, the ability to use containment boom to safely and effectively concentrate spilled oil for recovery or for *in situ* burning, and logistical considerations.

For spills in light ice conditions it will be feasible to use containment boom and skimmers to concentrate and recover oil. Short lengths of boom, up to 400 feet depending on ice concentrations, would be deployed in a J-configuration from a barge that would be used as a skimming platform and for storage of recovered fluids. High-strength boom would be required for this application to withstand contact with ice. Skimmers for this mode of operation could include either weir-type devices or oleophilic rope-mop skimmers. Overall effectiveness of this type of deployment would depend primarily on two factors: the rate at which oil is encountered and concentrated for recovery, and any inefficiencies resulting from encountering various ice forms.

The encounter rate, that is, the volumetric rate at which the boom/skimming system encounters the oil slick, is a function of the swath width of the booming system, the slick thickness, and the speed of advance of the system. The swath width of the booming system is a function of the length of boom deployed, which must be limited to a few hundred feet depending on ice concentrations. For the

purposes of this evaluation, the swath width will be assumed to be one-third the boom length. The slick thickness will vary with the distance from the spill source, and is provided by the scenario descriptions. The encounter speed may be as high as 0.7 knots, which is assumed to be the upper limit for containment effectiveness; at higher speeds oil will be lost past the boom due to entrainment failure. However, in responding to a blowout spill, the containment and recovery operation will generally be stationed at a fixed point at some safe distance from the source. In this case the encounter speed will simply be the speed at which the slick drifts into the containment configuration, estimated to be 0.3 to 0.7 knots in these scenarios.

In moderate to heavy ice conditions, it may not be practical to operate a barge/booming combination, in which case an oleophilic skimmer such as the *Foxtail* could be used to recover pockets of oil. Such an operation will be much less effective than one using containment booms due to the relatively thin slicks emanating from the blowout site. For evaluation purposes in these scenarios, a contain and recover approach is used throughout.

## **5.2 Booms and Skimmers and their Capacities**

**Containment Boom.** Containment of oil in ice infested waters will require the use of rugged, high-strength boom to withstand contact with ice. An ideal candidate for this task would be the *Ro-Boom* ocean model (36x43), of which ACS has a stockpile of 8000 ft, as well as an additional 2500 ft of other *Ro-boom* of similar size. This amount will be more than adequate for the blowout spills under consideration, in which the width of the thick portion of the slick is less than 300 feet, and the total slick widths are less than 2000 ft at a (safe operating) distance of 1 to 2 miles downstream of the source.

**Skimmers.** There are a number of different skimmers that could be employed in these scenarios, the selection of which will depend on the estimated encounter rate and the slick thickness. The following is a list of the key skimmers in the ACS inventory. The list includes each unit's derated recovery rate, which is meant to reflect a realistic estimate of the skimmer's recovery capacity. Note that in each of the subsequent scenarios, the calculated encounter rates will be compared to the derated recovery rates, and the lesser of the two will be used in determining recovery efficiencies.

**TABLE 5-1**  
**Summary of Key Skimmers**

<b>Skimmers held by ACS</b>	<b>Number available</b>	<b>Derated recovery rate, bbl/hr</b>
<b>Weir-type skimmers</b>		
TRANSREC 250	1	314
DESMI 250 Ocean	1	126
DESMI Harbor	3	88
Walosep W1	1	50
Walosep W4	1	113
DESTROIL	2	31
<b>Oleophilic skimmers</b>		
LORI side collector	1	217
Foxtail	1	66
T-54 disc	3	60

### **5.3 Operational and Safety Considerations**

In general, containment and recovery operations are most effective when carried out as close as possible to the source of the spill. There are two main reasons for this: 1) as the slick moves away from the source it will tend to spread laterally, perhaps to widths that cannot be contained with manageable lengths of boom; and 2) over time the oil may emulsify, making it more difficult to skim oil from the water and pump oil once recovered. With blowout spills this must be balanced with the safety considerations of operating within an area affected by the plume of oil droplets from the blowout. The criteria for a safety zone boundary, that is, the area in which continuous operations can be conducted, is an oil particulate concentration of 5 milligrams/m<sup>3</sup> which is the OSHA standard for an 8-hour exposure for response workers. This corresponds to a downstream distance of 4600 feet for the Point McIntyre scenario, and 5600 feet for Northstar.

When operating containment and recovery systems among broken ice there will be inefficiencies related to the avoidance of large ice floes and the accumulation of floes within the containment boom. There has been little experience or field studies to quantify this, although it is believed that conventional boom and skimmer operations would be effective at least in light ice concentrations (say, up to 3/10ths coverage), somewhat applicable in 5/10ths coverage with effectiveness declining rapidly as concentrations approach 7/10ths or greater. For the purposes of this evaluation it is necessary to quantify this in some manner. A proposed approach for this is detailed in Appendix C, and described briefly as follows.

Carrying out containment operations in a broken ice field could involve maneuvering around large floes, periodically reorienting the boom, and perhaps emptying the contained area of brash ice, slush, and smaller ice pieces. If the ice field could be idealized as being of equally spaced floes of equal sizes, one could develop a simple mathematical relation between the ice concentration and the average distance between floes. Given an average speed of advance, one could then calculate the amount of time that a containment system could advance through open water. This could then be combined with a given amount of time to reposition the system to calculate an estimated percentage of time that the containment system is able to advance and effectively contain and concentrate oil for recovery. Clearly an ice field is not made up of equally spaced floes of equal size, but doing this calculation for a range of floe sizes and averaging the results should provide a reasonable estimate of the effectiveness of containment operations in an ice field. Based on average floe sizes of up to 1000 feet in diameter, and an average speed of advance of 0.4 to 0.6 knots, an estimate of the containment efficiency in ice is 70% in 3/10ths ice concentrations, 40% in 5/10ths, and 20% in 7/10ths.

Additional factors that will be included in the evaluation relate to the storage aspects of the operation. These include the amount of free water that is recovered along with the oil, the amount of this water that is emulsified as it is pumped to storage, and the amount of free water that can be decanted from storage. The values used here are taken from the Guidance Document for Marine On-Water Response Strategy Plans developed by the North Slope Response Project Team (3/10/98).



Free water pickup is expressed as the oil recovery efficiency, defined as the percentage of water-free oil of the total volume of recovered fluid. This is particularly important for weir-type skimmers which are known to recover large volumes of water along with the recovered oil. Weir-type skimmers are defined as having a recovery efficiency of 20%. Oleophilic-type skimmers (e.g., the *LORI* brush skimmer and the *Foxtail* rope mop type device) recover relatively water-free oil.

As recovered fluid is pumped to storage it is assumed that some of the free water is mixed with the oil to form a water-in-oil emulsion. The assumed water content is 40%; thus the emulsion volume in storage is  $1 / (1 - 40\%) = 1.67$  times the recovered oil volume.

For planning purposes it can be assumed that 80% of the free water in storage can be decanted at the spill site. This water would be pumped from the bottom of the storage tank or barge, and would typically be discharged within the boomed area where containment and recovery equipment is operating.

#### **5.4 Logistical Constraints**

Compared with the response to spills during open water periods, the response during break-up and freeze-up will be limited to some extent by the availability of tugs and barges that are capable of operating in broken ice conditions. The following are summaries of the inventory and applicability of the response platforms and support vessels that are available and of the logistical restraints associated with these.

The presence of broken ice narrows the logistics options considerably, compared with either a solid ice or open water situation. Unlike the mid-winter or mid-summer periods, there is no one piece of equipment which can provide reliable access to and/or support at the spill site (e.g., ice roads and barges).

At freeze-up, the primary problem is rapidly forming new ice under freezing air temperatures. Although not severe when compared with conditions in January or February, the freezing potential and wind chill in October/November still represent considerable operational challenges, such as

helicopter blade icing, air cushion vehicle icing through freezing spray, internal ice build-up within barge tanks, and rapid consolidation of shipping channels broken through fast ice. At the same time, the air temperatures are low enough to rapidly generate large volumes of ice crystals and slush ice in any open areas and leads between the floes. This slush seriously affects small boat operations and may complicate oil recovery. Sea state is not usually a key operating issue with the presence of broken ice and, in October, the ice effectively dampens most swell and wind waves.

The rapidly diminishing daylight in October and frequent strong winds are also important operational constraints affecting flight operations, and reconnaissance effectiveness. Ice motion can carry the oiled ice away from the spill source at initial rates of over 10 miles per day, leading to a rapid increase in the contaminated area and in the logistics of coordinating the response over increasing distances. Safety of personnel and equipment offshore in October under worsening weather conditions will be one of the fundamental issues in selecting transport systems. Transport options will need to consider search-and-rescue and back-up equipment in the event of an emergency.

At break-up, the overall environmental setting is more moderate, with ice rapidly melting over time, 24 hours daylight, warmer temperatures and generally light winds. Major operational constraints are associated with maneuvering marine equipment through the floes in shallow water, and in some years with getting marine equipment away from West Dock through heavy ice in early July. Flight operations are more likely to be curtailed to some extent in July due to a lack of VFR conditions (low ceiling and visibility in fog)

Table 5-2 provides an overview of the logistics inventory on the North Slope and Table 5-3 Table 5-3 summarizes the general operating capabilities and limitations of each equipment group when operating within the environmental settings representative of the two main scenario groups of break-up nearshore and freeze-up offshore (refer to Tables 2-1 and 2-2 at the end of Chapter 2 for detailed climate and ice descriptions).

Specific pieces of equipment are further described in Appendix F in terms of their ability to provide transport and on-site support, as well as expected mobilization times. Additional information and the results of past experience are added where possible to appreciate how different vehicles can be

used in the subsequent scenarios. Attachments contain contact lists, specification sheets and resource material prepared by ACS for logistics planning

The focus here is on equipment currently in operation on the North Slope, together with additional equipment that could be made available within a few days of travel time (helicopters and air cushion vehicles). Other than small boats which can be brought in by road, there is no means of adding to the existing tug and barge fleet in the months of July or October due to heavy ice on the approaches to Prudhoe Bay.

The final analysis of each scenario considers the anticipated improvements which could result from using other forms of specialized logistics equipment not presently available or accessible at Prudhoe Bay. Possible examples would be additional air cushion vehicles, more capable ice strengthened tugs with icebreaking barges and larger IFR helicopters. Suggestions for either increasing or adding to the logistics resources available to support a broken ice response operation are provided in Appendix F.

**TABLE 5-2**  
**Summary of Logistics Inventory and Applicability**

Category	Equipment Number and Capacity	Applicability: Break-up, Freeze-up or Both
Fixed Wing: light	(1) ARCO Twin Otter	Both
Fixed Wing: heavy	(6+) Anchorage to Prudhoe or Seattle to Prudhoe - various operators, e.g., 24,400 lb (DC-6) or 46,000 lb (Herc)	Both
Helicopter: light	(1-2) 4-6 persons or 800 - 2,200 lb (e.g., Bell 206/BO105) Additional machines available out of Anchorage on short notice in October	Both
Helicopter: medium	(None Local) 12 persons or 3,000 lb (e.g., Bell 212) available out of Anchorage on short notice in October	Freeze-up
Helicopter: heavy	(2) 9 persons 7,900 lb sling (e.g., Bell 214ST out of Barrow)	Both
Marine Tugs	<u>Crowley Marine Services</u> (2) Ice capable offshore (Point Class)  (3) shallow draft inshore (River Class)  Note. one Point tug taken south for dry-docking summer 97 due to ice damage - due back 98  <u>Beaufort Marine (Lynden)</u> (1) shallow draft inshore (Arctic Tern)	Both Both           Break-up

**TABLE 5-2 (cont.)  
Summary of Logistics Inventory and Applicability**

Category	Equipment Number and Capacity	Applicability: Break-up, Freeze-up or Both
Marine Barges	<p><u>Crowley Marine Services</u> (2-3) deck barges non-ice strengthened</p> <p>(2-3) combination deck/tank barges with liquids capacity up to 5,500 bbl each</p> <p>(1) icebreaking barge capable of storing 21,700 bbl at 12.5 ft draft or 16,000 bbl for lightering to West Dock. Notes. Barge #213 does not have a current certification to carry oil cargoes. Crowley normally maintains 5 barges on the slope with one taken out each summer for dry-docking and inspection.</p> <p><u>Beaufort Marine (Lynden)</u> (1) ice strengthened deck barge (#23)</p> <p>(1) ice strengthened combination deck/tank barge (#20) with 12,200 bbl capacity</p> <p><u>ACS</u> (2) non ice strengthened deck barges (ex ARCO)</p> <p><u>Ice Services - TJ Borden</u> (2) 40 x 140 flexa float shallow draft 250 ton cap.</p>	<p align="center">Both</p> <p align="center">Both</p> <p align="center">Break-up</p> <p align="center">Break-up</p>
Support Boats	<p><u>ACS</u> (3) 30-40 ft inboard screw driven offshore workboats</p> <p>(5) 38-55 ft jet drive</p> <p>(about 45) 14-28 ft. assorted work boats</p> <p><u>MISC. (Oceanic &amp; BP)</u> (2) survey vessels 43-70 ft.</p>	<p align="center">Both</p> <p align="center">Break-up</p> <p align="center">Break-up</p> <p align="center">Break-up</p>
Air Cushion Vehicles	<p align="center"><u>Alaska Hovercraft</u> (1) LACV-30 (30 ton payload or 5,000 gallons)</p> <p>Note: additional craft available out of Anchorage</p>	<p align="center">Both</p>

**TABLE 5-3**  
**Summary of Key Logistics Constraints**

Logistics Category	Break-up (July)	Freeze-up (October)
<p><u>Air Support:</u> - helicopters</p> <ul style="list-style-type: none"> <li>• sling loads limited to 800 to 1,200 lb with equipment in Prudhoe (2 h), up to 7,900 lb with Bell 214 from Barrow (2.5 h), or up to 10,000 lb with equipment in Alaska (1 to 2 days)</li> </ul>	<ul style="list-style-type: none"> <li>• ice unsafe for shutdown and parking</li> <li>• limited visibility (22% &lt; 1/2 mile)</li> <li>• limited commercial availability in July (most commercial machines in Alaska are under long-term contract at this time of year)</li> </ul>	<ul style="list-style-type: none"> <li>• ice unsafe for shutdown and parking offshore</li> <li>• icing potential (3% of time)</li> <li>• daylight starting to become limited (may require IFR)</li> <li>• only one or 2 machines (BO105 and/or Bell 206L) in Prudhoe area on short notice (e.g., 2 hours)</li> <li>• high frequency of strong winds over 25 kt (10%)</li> </ul>
<p><u>Air Support:</u> - fixed wing (reconn)</p>	<ul style="list-style-type: none"> <li>• limited visibility (26% &lt; 1 mile) ARCO system not certified for IFR operation</li> </ul>	<ul style="list-style-type: none"> <li>• oil in slush/snow may give limited discrimination in IR or visual</li> </ul>
<p><u>Conventional Marine:</u> - tugs and barges</p> <p>Deck cargo 650 to 2,700 + tons depending on barge and water depth</p> <p>Liquid products (total capacity) 12,200 bbl ice strengthened (1) 16,000 bbl ice breaking (1) 12,000 bbl non ice str. (2)</p>	<ul style="list-style-type: none"> <li>• high ice concentrations limit speed &amp; maneuvering</li> <li>• draft limits (4 to 5 ft) may prevent vessels from reaching oiled ice driven into shallow water</li> <li>• ice packed into W. Dock early July may delay vessel operations</li> </ul>	<ul style="list-style-type: none"> <li>• limiting solid ice thickness of ~6 inches for conventional (blunt bow) barges, or up to 1.2 ft for icebreaking barge <i>Endeavor</i></li> <li>• fast ice between West Dock and offshore (will become the limiting factor by mid-October in determining barge access to an offshore site)</li> <li>• feasibility of breaking-out frozen-in equipment from West Dock unknown in ice over six to eight inches</li> <li>• freezing of oily water in tanks (separate first if possible)</li> <li>• risk of becoming trapped or beset offshore without additional marine support as back-up (shortage of tugs)</li> <li>• need minimum 48 hours to mobilize winterized vessels in October</li> </ul>

**TABLE 5-3 (cont.)  
Summary of Key Logistics Constraints**

<b>Logistics Category</b>	<b>Break-up (July)</b>	<b>Freeze-up (October)</b>
<p><u>Conventional Marine</u> - small work boats (&lt;50 ft)</p>	<ul style="list-style-type: none"> <li>• high ice concentrations, particularly under any pressure</li> <li>• limited oily water storage in any high volume discharge scenario</li> </ul>	<ul style="list-style-type: none"> <li>• slush ice clogging jet drives and/or outboards</li> <li>• limited or no icebreaking ability</li> </ul>
<p><u>Air Cushion Vehicles</u>  30 ton payload or up to 80 passengers  Note: mobilization time for more than one machine to arrive in Prudhoe Bay at any time of year could exceed five days</p>	<ul style="list-style-type: none"> <li>• no known limitations over rotting fast ice (potential problems offshore with rubble fields and/or ridging over four feet high)</li> </ul>	<ul style="list-style-type: none"> <li>• spray icing build-up on decks, intakes and props (manageable but need to allow for down-time and have back-up)</li> <li>• ice adfreezing to hull can add substantial deadweight and cut into payload (avoid prolonged shutdowns in the water in freezing temperatures)</li> <li>• potential downtime in October due to strong winds &gt;25 kt (avg 10% of the time)</li> </ul>

## **5.5 *In situ* Burning**

The main job in this study is to evaluate the countermeasures approach of mechanical recovery. The secondary job is to determine whether the cleanup approaches of *in situ* burning and dispersant use can be useful in supplementing the mechanical recovery capability. This and the following section provide summaries on these two alternative spill cleanup techniques

Research and actual spill experience have demonstrated that *in situ* burning (ISB) can be very effective when used on oil spills in ice conditions. This is because oil spilled in waters that are largely covered by ice will remain relatively thick and contained. The current interest in *in situ* burning for spills on open water started in the early 1980s with the development of fire-resistant oil containment boom. The petroleum companies operating in the southern Beaufort Sea in Alaska have been the leaders in supporting the various ISB technologies developed over the years.

There are many advantages of the ISB technique. The burning of thick, fresh slicks can be initiated very quickly by igniting the oil with devices as simple as an oil-soaked sorbent pad. *In situ* burning can remove oil from the water surface very efficiently and at very high rates. Removal efficiencies for thick slicks can easily exceed 90%. Removal rates of 1600 m<sup>3</sup>/hr (10,000 bbl/hr) can be achieved with a fire diameter of only about 100 m (300 ft). The use of towed fire containment boom to capture, thicken and isolate a portion of a spill, followed by ignition, is far less complex than the operations involved in mechanical recovery, transfer, storage, treatment and disposal. If the small quantities of residue from an efficient burn require collection, the viscous, taffy-like material can be collected and stored for further treatment and disposal.

There are two major concerns over the technique. First, there is the fear of causing secondary fires that threaten human life, property and natural resources, and, second, there are concerns over the potential environmental and human-health effects of the by-products of burning, primarily the smoke. Both concerns can be dealt with by good planning and operations.



Extensive experimentation on crude and fuel oils with a variety of igniters in a range of environmental conditions has confirmed the following rules-of-thumb for non-emulsified oil in relatively calm, quiescent conditions:

- the minimum ignitable thickness for fresh, volatile crude oil on water is about 1 mm;
- the minimum ignitable thickness for aged, unemulsified crude oil and diesel fuels is about 3 to 5 mm;
- the minimum ignitable thickness for residual fuel oils, such as Bunker "C" or No. 6 fuel oil, is about 10 mm; and,
- once 1 m<sup>2</sup> of burning slick has been established, ignition can be considered accomplished.

Aside from oil type, other factors that can affect the ignitability of oil slicks on water include: wind speed, emulsification of the oil and igniter strength. Secondary factors include ambient temperature and waves.

- The maximum wind speed for successful ignition of large burns has been determined to be 10 to 12 m/s.
- For weathered crude that has formed a stable water-in-oil emulsion, the upper limit for successful ignition is about 25% water. Some crude oils form meso-stable emulsions that can be easily ignited at much higher water contents. Paraffinic crude oils appear to fall into this category (Fingas et al. 1997).
- If the ambient temperature is above the oil's flash point, the slick will ignite rapidly and easily and the flames will spread quickly over the slick surface; flames spread more slowly over oil slicks at sub-flash temperatures.

Emulsification of an oil spill negatively affects slick ignition. This is because of the water in the emulsion, which can have a concentration of up to 90% for highly stable emulsions. The oil in the emulsion cannot reach a temperature higher than 100 °C until the water is either boiled off or removed. With emulsions, the heat from the igniter or from the adjacent burning oil must first boil the water before it heats the oil to its fire point.

The rate at which *in situ* burning consumes oil is generally reported in units of thickness per unit time (mm/min is the most commonly used unit). The 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 (> 3 m diameter) fires of unemulsified crude oil on water, the "rule-of-thumb" is that the burning rate is 3.5 mm/min. Automotive diesel and jet fuel fires on water burn at a slightly higher rate of about 4 mm/min.

Oil removal efficiency is a function of three main factors: the initial thickness of the slick; the thickness of the residue remaining after extinction; and, the coverage of the flame. The general rules-of-thumb for residue remaining after a successful burn are described below. Other, secondary factors include environmental effects such as wind and current herding of slicks against barriers and oil weathering.

The following rules-of-thumb apply for the residue thickness at burn extinction:

- for pools of unemulsified crude oil up to 10 to 20 mm in thickness the residue thickness is 1 mm;
- for thicker crude slicks the residue is thicker; for example, 3 to 5 mm for 50 mm thick oil,
- for emulsified slicks the residue thickness can be much greater; and,
- for light and middle-distillate fuels the residue thickness is 1 mm, regardless of slick thickness.

Wind and current can herd a slick against a barrier, such as a towed boom, thus thickening the oil for continued burning. As little as a 2 m/s wind is capable of herding oil to thicknesses that will sustain combustion. *Indeed, the phenomenon of "uncontained" in situ burning is based on the requirement of a self-induced wind (drawn in by the combustion process and the rising column of hot gases), to "herd" and keep an uncontained slick at burnable thicknesses.* Current can also dramatically increase burning efficiency (i.e., reduce the amount of burn residue) by herding burning oil against a barrier. The detrimental effects of current can include entrainment of residue beneath a floating barrier as the residue density and viscosity increase during the burn process, and overwashing of the burning slick, causing extinction of the flames. Excessive waves can also have a negative effect on the burning process.

The residue from a typical, efficient (>85%) *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, poorly sealed 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. The cooled residue from thick (>100 mm), efficient *in situ* burns of heavier crude oils can sink in fresh and salt water (SL Ross 1996).

A two-step process is likely involved in emulsion burning: "breaking" of the emulsion, or possibly boiling off the water, to form a layer of unemulsified oil floating on top of the emulsion slick; and subsequent combustion of this oil layer. High temperatures are known to break emulsions. Chemicals called "emulsion breakers", common in the oil industry, may also be used.

For stable emulsions the burn rate declines significantly with increasing water content. The decrease in burning rate with increasing water content is decreased further by evaporation of the oil. The effect of water content on the removal efficiency of stable weathered crude emulsions can be summarized by the following rules-of-thumb:

- little effect on oil removal efficiency (i.e., residue thickness) for low water contents up to about 12.5% by volume;

- a noticeable decrease in burn efficiency with water contents above 12.5%, the decrease being more pronounced with weathered oils; and
- zero burn efficiency for stable emulsion slicks having water contents of 25% or more. Some crudes, like Milne Pt. used as an analogue for Northstar crude in this report, form meso-stable emulsions that can be ignited and burn efficiently without emulsion breaker addition.

The primary objective of this study, as stated in the terms of reference for the study, is to evaluate the mechanical recovery capability that exists on the North Slope for dealing with blowout spills in broken ice conditions. *In situ* burning is to be considered a back-up method, that is, a method to deal with any oil that cannot be handled by existing mechanical systems. Although the following scenarios and analysis of ISB conform to this directive, it should be understood that ISB techniques could be used as a first option in a number of spill situations with good results.

## **5.6 Dispersant Use**

### **5.6.1 General Considerations**

When oil is spilled on water, it exhibits a cohesiveness or resistance to break up. This cohesive strength is due to the interfacial tension between the oil and water. A chemical dispersant acts at the oil-water interface to greatly reduce this interfacial tension. This action promotes the break-up of the oil film into droplets that disperse into the water phase. If the droplets are small enough they will have little buoyancy and will be carried away and diluted by normal ocean current and movement.

Despite the great decrease in interfacial tension, some mixing energy is still needed to promote movement and dispersion of the fine oil droplets into the water column. This energy can be supplied either by the natural motion and currents of the sea or by mechanical means such as work boats. The more energy that is available, the less dispersant that is required.

Dispersants will not be effective on highly viscous spills, either spills that are viscous to begin with such as Bunker C spills or spills that become viscous through water-in-oil emulsification. The exact cut-off point is not fully understood and it certainly varies with oil type. The general rule-of-thumb

has been that spills more viscous than 2000 cp to 10,000 cp are not dispersible. Recent research, using a relatively new dispersant product, Corexit 9500, indicates that the value could be up to 20,000 cp (see Lewis et al. 1998a or Lewis et al. 1998b). More research is needed in this area.

Dispersant will work only if the dispersant chemical, sprayed by aircraft or vessel, is thoroughly mixed into the oil. This is not a problem for thick slicks of oil, but is for very thin slicks. This is because the dispersant droplets in the spray, having to be fairly large to avoid being carried away by the wind (the recommended size is in the 0.5 mm range), cannot make good contact with slicks much thinner than the droplet diameter. The usual problem is that the dispersant droplets crash through the thin slicks and are quickly lost to the water before having a chance to blend with the oil.

The most controversial problem with dispersant use, aside from any issue related to effectiveness, is that dispersed oil can be toxic to animals in the water under the spill. When the small oil droplets enter the water they dilute quickly to concentrations in the range of 1 to 10 parts-per-million immediately under the treated slick. After spraying stops, concentrations decline rapidly towards background levels. The areas of elevated oil concentration in the water are temporary and restricted to the near surface waters. This oil will not be lethal to animals (except perhaps to extremely sensitive species directly under the treated slicks), but concentrations are theoretically high enough to cause tainting. Research has shown that if such contamination or tainting were to occur, the fish would purge the contamination within days or weeks. In the recent spill from the tanker, *Sea Empress*, off the coast of Wales, where large amounts of dispersant were used to treat the spill, no tainting was observed in fish caught in the vicinity of dispersant operations.

With specific regard to the use of dispersants on the blowout spills described in this study, the prospects are not promising (except for one scenario, Scenario 1) for reasons summarized below:

- Generally speaking, because the presence of ice tends to dampen surface mixing caused by wind, there is less opportunity for treated slicks to disperse easily. This is not to say that effective dispersion is not possible, but that it more difficult all things being equal.

- A few of the scenarios (Scenarios 4, 5 and 6) involve very viscous oil slicks. For these, dispersant use could be tried, but the results would likely not be good.
- Intelligent dispersant use involves environmental trade-off decision making, where the potential impacts of the untreated oil are compared to the potential impacts of the treated oil. Dispersants should not be used in the Alaskan Beaufort Sea until these trade-offs are sorted out. In 1985 a dispersant use decision making system was developed for the Canadian portion of the southern Beaufort Sea (Trudel et al. 1988), but this has yet to be done for the Alaskan portion. In the Canadian study it was found that dispersant use made good environmental sense in many scenarios, but it remains to be seen if that would be the case off the North Slope.

In any case, environmental impact issues are beyond the scope of this study. When dispersant use is discussed in the scenarios in Chapter 6, the discussion is limited to the issue of effectiveness.

#### **5.6.2 Platforms and Supplies in Alaska**

The State of Alaska has one of the best dispersant-use capabilities in the world. The spray systems and their specifications, and the amounts of dispersant available in Alaska, mostly owned by Alyeska Pipeline Services, are summarized in Table 5.4, Table 5.5 and Table 5.6. The total volume of dispersant is 100,000 gallons. Note that the product is Corexit 9527. There are dozens of dispersant products available globally, but only four products are approved for use in U.S. waters, by virtue of the fact that they are listed on the EPA NCP Product Schedule. These are: Corexit 9527, Neos AB 3000, Mare Clean 200, and Corexit 9500. In practical terms, however, only Corexit 9527 and the recently developed product, Corexit 9500, are stockpiled in North America in large quantities. Only Corexit 9527 is stockpiled in the PWS area and elsewhere in Alaska.

As noted in Table 5.4 there are three types of systems available in Alaska for applying dispersant to oil slicks: helicopter systems, vessel systems, and large fixed-wing aircraft. The aircraft system that currently has the largest delivery capacity is the C-130/ADDS pack which holds 5000 gallons of dispersant. Generally, helicopter systems are not considered appropriate for response to large offshore spills because of their limited range and payload. But when spills are close to land and good

**TABLE 5.4**  
**Dispersant Application Platforms in Alaska**

Type of System	Number	Payload	Location
Vessel spray system	2	1000 gallons	Valdez, AK
Vessel spray system	1	1000 gallons	Valdez, AK
Helicopter bucket	2	240 gallons	Valdez, AK
ADDS pack	2	5500 gallons	Anchorage, AK

**TABLE 5.5**  
**Specifications on Dispersant Application Vessels in Alaska**

	C-130/ADDS pack	Vessel	Helibucket
Payload	5000 gallons	min. 1000 gallons	240 gallons
Max. Speed	150 knots	10 knots	54 knots
Min. Speed	130 knots	3 knots	27 knots
Max. Pump Rate	800 gallons/min.	12 gallons/min.	120 gallons/min.
Min. Pump Rate	100 gallons/min.	12 gallons/min.	79 gallons/min.
Swath Width	150-200 feet	90 feet	100 feet
Reposition Time	4.25 min.	0 min.	2.25 min.

**TABLE 5.6**  
**Corexit 9527 Dispersant in Alaska Owned by or Available to Alyeska**

Volume (gallons)	Storage	Owned by	Location
60000	bulk	Alyeska	Anchorage, AK
4700	drums	Alyeska	Valdez, AK
11275	55-gal. drums	CISPRI	Anchorage, AK
9405	55-gal. drums	CISPRI	Nikiski, AK

maneuverability is required, they are very useful. This is exactly the situation that exists for the blowout spills at Northstar and Pt. McIntyre considered in this study. The fields are close to land and the spraying of dispersant product onto oil slicks scattered among broken ice will require maneuverable aircraft, such as helicopters, and skilled operators, both of which are found on the North Slope serving the petroleum industry on a regular basis.

The helicopter-based units are self-contained systems that are slung beneath the helicopter. They are made up of a dispersant reservoir, a pump-motor assembly and a spray-boom. The system has the advantage of not requiring any modification to the helicopter before use. Despite their higher cruising speeds (50 to 75 kt with external slung loads), the helicopter is limited by its limited operating range and very small payload, which ranges from 240 to 600 gallons for those systems available in the U.S. With a small payload, many sorties are required to deliver significant quantities of dispersant. Also, because of their high speed and low pumping rate, helicopter systems are limited to application rates of about 10 gallons per acre, and therefore require multiple passes to provide higher doses to the thick oil patches.

The general strategy for dispersant use for the blowout spills in this study would be to have two helicopter/spray bucket systems during daylight hours spray both the oil that is escaping mechanical operations at the time and the oil that escaped during the previous night. The details of this operation are described in Chapter 6 for the appropriate spills.



## 6. Detailed Scenarios

### 6.1 Introduction

This chapter uses the knowledge and information presented in the previous chapters to describe in succinct terms the likely behavior and cleanup potential of the six selected blowout scenarios. The general parameters for the scenarios are shown in Table 6-1.

**TABLE 6-1**  
**General Parameters for Blowout Scenarios at Northstar and Pt. McIntyre Sites**

Scenario Number	Description	Blowout Rate and Duration	Gas-to-Oil Ratio, SCF/barrel	Wind Speed, knots	Wind Direction (from)
1	North Star, 30% Ice, Freeze-Up	15,000 BOPD for 15 days minus 20% evaporation	2200	13.5	E
2	North Star, 50% Ice, Freeze-Up	same as above	2200	19	WSW
3	North Star, 70% Ice, Freeze-Up	same as above	2200	22.5	SW
4	Pt. McIntyre, 30% Ice, Breakup	12,000 BOPD for 15 days minus 20% for evaporation	750	11	W
5	Pt. McIntyre, 50% Ice, Breakup	same as above	750	9	SE
6	Pt. McIntyre, 70% Ice, Breakup	same as above	750	17.5	E

As explained in detail in Chapter 2 it is inconceivable that any of the above scenarios will truly involve a uniform distribution of ice floes at an unvarying concentration (either 30, 50 or 70%). Nonetheless, this simplifying assumption will be used to illustrate the potential effectiveness over

the range of possible conditions. The full approach for analyzing the scenarios for the purpose of determining spill response capability in broken ice conditions was explained in Chapter 2 (in Section 2.5.3) and is summarized below.

- First, detailed broken-ice scenarios will be developed in which ice floes cover 30%, 50% and 70% of the water surface uniformly. This, in fact, has already been done in Chapter 2 where each of the scenarios is described in detail, in terms of ice properties and environmental conditions, on the basis of certain simplifying assumptions, and these descriptions are summarized in Tables 2-1 and 2-2 at the end of that chapter.
- Next, the ice/environment scenarios will be used in modeling and delineating the distribution and movement of spilled oil onto the surrounding water and ice.
- Then, the ice and oil spill scenarios will be used to analyze countermeasures capability in fixed 30%, 50% and 70% ice concentrations, on a daily basis and over the 15-day blowout period.
- The broken ice capabilities will be quickly compared with the known countermeasures capabilities for spills that take place in open water and in a complete ice cover environment.

The major emphasis of the analysis is on the effectiveness of the mechanical recovery systems that now exist on the North Slope. However, because the spill scenarios are presented in detail in this chapter, it is also convenient in each scenario to discuss the use of additional mechanical equipment and other cleanup techniques (particularly *in situ* burning and dispersant use) and determine the extent to which these might improve cleanup effectiveness.

Before proceeding directly to the scenarios, please note the following. The first part of each scenario is a two-page description of the blowout behavior and the fate of the spill in ice. The behavior of the discharging oil from the blowouts is a very complicated affair involving drops of different size

falling at different rates and at different locations. This is explained in detail in Scenario 1, but is not repeated in the following scenarios. This extra technical discussion is presented in *Italic type* to allow uninterested readers to easily pass over it if desired. Similarly, in the countermeasures analysis, the first scenario in each of the broken ice regimes (freeze-up and break-up) is discussed in more detail than the ones that follow. This is done simply to avoid repetition.

## 6.2 Scenario 1. Northstar in 3/10ths Ice Cover During Freeze-up

### 6.2.1 Blowout and Spill Behavior (Scenario 1. Northstar, 3/10ths Ice, Freeze-up)

An uncontrolled blowout occurs in early October at the Northstar artificial island releasing 15,000 barrels of oil per day (BOPD) and  $33 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 2200 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 13 °F to a daytime high of 23 °F. The wind speed averages 13.5 knots from the east. The surrounding water is covered by 3/10ths new ice floes. The ice is 0.4 to 0.6 feet thick and covered by 1 to 2 inches of snow. The floes are hundreds to thousands of feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.4 knots to the west. Small waves (only a few inches in height, because of the reduced fetches in the ice) are present on the open water between the floes. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the ice).

As the oil and gas exit the 6.3-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. After this the volume median diameter<sup>2</sup> of the oil spray droplets is assumed to be 0.75 mm. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 120 feet above the release point. From this point the warm oil droplets begin to fall as they are carried downwind by the wind. Evaporation occurs during the droplets' descent, and it is assumed that, regardless of fall time or droplet diameter, the slick formed by the droplets has lost 20% of its volume to evaporation.

*The speed at which the droplets fall is governed primarily by their diameter: larger oil drops fall much faster than smaller droplets. For example, in still air, a 0.75 mm droplet falls at a speed of 7.5*

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<sup>2</sup> 50% of the volume of oil is contained in droplets larger than the volume median diameter and 50% is contained in droplets smaller than the volume median diameter.

ft/sec. If there were no turbulence in the wind, in the 16 seconds required for a 0.75 mm diameter droplet to fall 120 feet, it would be carried more than 360 feet downwind. In real wind conditions considerable amounts of turbulence exist and must be accounted for in determining the trajectory of the oil spray. If the oil spray generated by the blowout were imagined to be all one drop size (i.e., 0.75 mm diameter), the drops would still fall at different distances from the blowout because of the turbulence in the wind. As the spray of oil drops falls, it is being spread horizontally and vertically by air turbulence, or meandering of the wind. In the time required for 99.7% of the 0.75 mm droplets to fall to the surface the wind has carried the final few 0.75 mm droplets 920 feet from the blowout. The air turbulence also spreads out the droplets laterally as they fall, with the width of the "footprint" of the oil on the surface increasing with distance from the source in a parabola-like shape.

In reality, the spray of oil droplets is made up of many different droplet sizes. In determining the footprint of the oil spray on the surface, this must also be taken into account. This is accomplished by dividing the full range of oil drop sizes produced by the blowout into nine smaller ranges, each representing 10% of the total volume of all the oil droplets. Only nine drop-size ranges are used because 10% of the volume of oil released is assumed to be in droplets so small (much less than 50  $\mu\text{m}$ ) that they remain suspended in the atmosphere and never settle out. Each range is characterized by a droplet diameter that is representative of the droplets in the same range. For example the largest 10% of the volume of oil spray droplets is represented by a 1.55 mm diameter oil droplet; the smallest 10% that will settle is represented by a 0.05 mm diameter droplet. The dimensions of the oil spray footprint on the surface is calculated by determining the distance downwind and width for 99.7% of the representative droplets in each range to settle to the surface.

Table 6-2 shows the estimated width and thickness of the oil spray footprint as a function of the percentage of the volume of droplets that have fallen out of the plume and the distance downwind of the blowout in the 13.5 knot wind and 0.4 knot current of this scenario. The second column gives the size range of the droplets being modeled (i.e., the first row is calculated using a drop diameter representing the largest 10% of the oil drops, or 1.55 mm) and the third column gives the droplet diameter representing the size range. The distance downwind for 99.7% of these droplets to fall from

the 120 foot release height to the surface is shown in the fourth column. The largest droplets (i.e., the largest 10%) fall fastest and, on average, fall out of the plume nearest to the blowout; the smallest droplets (i.e., those with a diameter that 90% of the droplets are bigger than) fall very slowly and will drift downwind for long distances.

**TABLE 6-2**

***Predicted Near-source Dimensions of the Oil Spray Footprint from a Blowout  
During Freeze-up at Northstar in 3/10ths Ice Cover***

<i>Range</i>	<i>Size range of oil drops (by volume)</i>	<i>Droplet diameter used to represent size range (mm)</i>	<i>Distance downwind for 99.7% of the drops in the given size range to settle to the surface (ft)</i>	<i>Width of footprint for 99.7% of drops (ft)</i>	<i>Average oil thickness across width (mm)</i>
1	largest 10%	1.55	500	90	0.4
2	20%	1.35	530	100	0.7
3	30%	1.15	590	115	0.9
4	40%	0.95	660	130	1.1
5	VMD*	0.75	920	180	0.9
6	60%	0.55	1,200	230	0.9
7	70%	0.35	1,600	360	0.7
8	80%	0.15	6,600	1000	0.3
9	90%	0.05	33,700	6,600	0.05

\* Volume Median Diameter

The fifth column gives the width of the footprint at the given downwind distance created by the falling oil droplets. This number is strictly a function of atmospheric turbulence parameters. It is calculated by multiplying the standard deviation of atmospheric turbulence in the horizontal plane at the given distance downwind by 2.67 to account for 99.7 % of the drops falling out in that width. The final column gives the average thickness of the footprint created by the falling oil droplets if all the oil accumulated to the given downwind distance was spread evenly across the width of the

*footprint and was evaporated 20%. This value initially increases with distance from the blowout, reaches a maximum and then decreases as the spray gets farther from the blowout. This decrease is partly due to the large widths predicted for the large downwind distances for all of the smallest droplets to settle to the surface. For the purpose of further predictive modeling of the fate and behavior of the surface oil slick, the footprint thickness at the point where all (99.7%) of the droplets of a diameter representing 50% (by volume) have reached the surface is used. This thickness, and the corresponding width, are used to define the starting dimensions of the "thick" portion of the oil slick that is the focus of further modeling and the countermeasures assessments. In this case, the thick slick is 180 feet wide and 0.9 mm thick at the starting point of the surface slick modeling. This is at a distance of approximately 920 feet downwind of the blowout.*

For the purposes of these scenarios it was assumed that all of the oil landed past the perimeter of the island. This is a reasonable assumption for the prevailing westerly winds, but it is acknowledged that a small percentage of the oil could be deposited on the island particularly with wind from the east.

*Taking into account the fact that many of the drops in Range 6, about half of the drops in Range 7 and a few of the drops in Range 8 settle out in this (920 ft) distance the thick slick at this point contains about 60% of the oil that will eventually settle to the surface. As noted, at this point, the oil slick is assumed to be evaporated to 20% loss. About 40% of the oil that eventually settles to the surface falls beyond the 920 foot mark. Because most of these droplets are small (some of Range 7 and virtually all of Ranges 8 and 9) they travel far downwind and spread widely before settling out. These droplets form a very thin slick on either side of the thick oil. This very thin slick is a long, narrow triangular area with an average thickness that can be shown to be on the order of 35  $\mu\text{m}$ .*

*The approximate mass balance for the oil released from the blowout is: 20% evaporates from the drops in the air; the smallest 10% of the volume of the weathered droplets are so small that they remain suspended in the atmosphere; about 60% of the remaining oil (or about 40% of the total - 0.6 x 0.7, composed of mostly the larger droplets) settles to the surface within 920 feet and, if it lands on water, forms a slick 0.9 mm thick and 180 feet wide; and, 40% of the remaining oil (or*

*about 30% of the total - 0.4 x 0.7, composed of mostly small droplets) settles out farther downwind and forms a thin (35  $\mu$ m) slick bordering each side of the thick slick.*

For the purposes of this scenario, it is estimated that 70% of the oil spray lands on water and 30% lands on the surface of ice floes. The spray that lands on ice floes coats the surface and is absorbed by the snow. *The thickness of this oil coating is estimated by summing the amounts of oil of the various size ranges that settle onto the floes as they drift under the plume from the lee side of the island to the point at which oil droplets finish settling. Directly in the lee of the island, over the distance required for 97.7% of the VMD droplets to settle out (920 feet - see Table 6-2 above), it is assumed that the ice floes are coated evenly over a width equal to the plume width (in this case 180 feet). Further down drift, the oil coating is incremental.* The average oil thicknesses on the floe surface ranges from 1.2 mm near the center-line of the oiled strip to 0.005 mm out near the edges. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 33% after 72 hours.

Table 6-3 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 15 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 300 feet and a thickness of 0.5 mm. After 15 hours, the oil has evaporated to a point (28%) where its Pour Point (30 °F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water. For the duration of the scenario (72 hours) the thick slick generally moves with the oiled ice floes and does not spread further, although it may meander among the widely-separated floes in the ice field due to oceanic eddies or large-scale turbulence.

The presence of ice dampens the wave action that would normally exist with a 13.5 knot wind and reduces natural dispersion of the oil slick compared with open water conditions. The thick slick is predicted to begin to form a water-in-oil emulsion some 18 hours after the oil had been deposited on the water surface. If emulsification rates are the same in loose ice as in open water under identical winds, the slick would be fully emulsified (75% water content by volume) after 27 hours on the



water. By this time the thickness of the thick portion of the slick has increased proportionately to the volume of water in the emulsion, reaching about 1.5 mm for the 75% water emulsion.

The thick oil slick continues to evaporate and naturally disperse slowly throughout the 72 hour scenario. It loses 29% of its volume to evaporation and an additional 7% to dispersion after 24 hours; 32% to evaporation and 9 % to dispersion after 48 hours; and, 33% to evaporation and 11% to natural dispersion after 72 hours. The viscosity of the unemulsified oil increases to 180 cP after 12 hours; when the thick slick emulsifies, the slick viscosities are 7000 cP at 24 hours, 8700 cP at 48 hours and 9300 cP at 72 hours. The Pour Point of the thick oil after 72 hours has increased to 44 °F. At the end of the 72 hour scenario period, 18% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 18% ( $0.9 \times 0.3 \times [1 - 0.33]$ ) remains on the surface of ice floes. The remainder of the oil discharged has evaporated or naturally dispersed, never settles, or is in very thin slicks surrounding the thick slick. The oiled water area is a long (29 nautical miles), narrow (300 feet) strip that contains relatively thick (1.5 mm) emulsion slicks on the water surrounded by thin oil. The ice floes that were sprayed with oil as they passed under the blowout plume are coated with 0.005 mm to 1.2 mm of oil on the snow on their surface. The thicker coatings are on the floes near the center-line of the oiled strip.

Over time, the oil remaining on water will be incorporated into the surface layer of the growing ice and the oil remaining on floes will be covered by snow. A portion of the oiled ice will likely be formed into ridges and rubble fields during November and December as the thin ice deforms under pressures from wind and heavier pack ice to the north. Any oiled ice which escapes being incorporated into the fast ice will gradually drift west, and in many years could end up in the Chukchi Sea by spring. During the spring (late May to early June) any oil still remaining near the surface of level ice will rise to lie in melt pools; the oil incorporated into ridges and rubble fields will be released more slowly. Ultimately, rotting ice will release any oil still remaining at breakup in the form of thin sheens trailing the drifting floes.

**TABLE 6-3**  
**Summary of Slick Characteristics from a Blowout During Freeze-up**  
**at Northstar in 3/10ths Ice Cover over 72 Hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	26%	0	120	0.9	180
3	25	0	145	0.7	240
6	24	0	160	0.6	250
12	22	0	180	0.5	280
24	21	75	7000	1.6*	300
48	19	75	8700*	1.6*	300
72	18	75	9300*	1.5*	300

\*takes emulsification into account

### 6.2.2 Existing Mechanical Methods (Scenario 1. Northstar, 3/10ths Ice, Freeze-up)

This section evaluates the likely effectiveness of a containment and recovery operation in response to the scenario. The ice conditions at West Dock, more than the ice concentrations at the spill site, will govern the marine equipment that can be used for the operation and the speed of the response. The primary issue becomes one of breaking out the frozen-in vessels and moving them offshore through a band of newly forming fast ice which could easily extend a mile or more to the north of West Dock. Early in the freeze-up scenario, when 3/10ths ice concentration is assumed, up to four tugs and two ice-strengthened barges could be mobilized and used for offshore support of containment and recovery. Smaller boats could be used for boom handling on site; however, these vessels are not ice-strengthened and would need to be transported to the site as deck cargo on a barge. It is estimated that mobilization time for this marine support would be a minimum of 48 hours, and 60 to 72 hours until it arrived on-site. (It is noted that since the draft report was prepared, a decision was made to locate response equipment on Northstar Island. This change in capability was not addressed in this analysis.)

Given that the majority of the oil in these blowout scenarios is concentrated in a relatively narrow slick, a large number of systems would not be required to encounter all of the thick portions of oil. In fact, two containment systems, each involving 360 feet of boom deployed in a J-configuration, could encounter the entire 240-ft thick slick width (using a gap ratio of 1:3). For the moment, the effectiveness of two such systems will be evaluated, although the possible effectiveness of additional systems will be estimated later in the analysis. Oil recovery would be carried out using a skimmer operated from the barge and deployed at the apex of the 'J'. There are several weir-type skimmers stockpiled by ACS that would meet the estimated encounter rates in these scenarios, which will be in the range of 50 to 100 bbl/hour. (Alternatively, oleophilic skimmers such as the LORI brush skimmer or the Foxtail could be used, but weir-type skimmers are used in the evaluation to illustrate the greater fluid handling concerns of weir-type devices. The resulting estimate of system effectiveness would be the same in either case.) Table 6-4 summarizes the key equipment that would be used for the initial containment and recovery response for this scenario.

**TABLE 6-4**  
**Key Equipment for the Initial Containment and Recovery Response for Scenario 1**

Equipment Type	Examples	Function
Barges	<i>Endeavor</i> <i>Beaufort 20</i>	working platform and storage for skimming operation
Tugs	<i>Pt. Barrow</i> <i>Pt. Thompson</i> <i>Arctic Tern</i> <i>Sag River</i> <i>Toolik River</i> <i>Kavik River</i>	tow equipment to site and position on-scene
Containment boom	Ro-Boom 36x43	concentrate oil for recovery
Skimmers	Transrec 250 Desmi Ocean Desmi Harbor	oil recovery

The slick conditions of interest are those estimated for 3 hours down drift of the blowout. This corresponds to a distance of about 7000 feet, which is judged to be a safe operating distance based on hydrocarbon-in-air concentrations. At this point the thick slick is 240 feet wide and has an average thickness of 0.7 mm. For a containment system positioned downstream of a blowout, the encounter rate is calculated by multiplying the encounter width of the system by the slick thickness and the slick drift rate of 0.4 knots. In addition to this, one must account for the fact that, on average, 30% of the slick width would be covered by ice. Thus the encounter rate for oil on water and available for recovery would be reduced by 30%. So, for each containment system employing 360 feet of boom, the encounter rate is:

$$\begin{aligned} \text{encounter rate} &= (360 \text{ feet} \times 0.33 \text{ gap ratio}) \times 0.7 \text{ mm} \times 0.4 \text{ knots} \times (1 - 30\% \text{ ice}) \\ &= 83 \text{ bbl/hour} \end{aligned}$$

As noted above, this is within the derated recovery rate of several of the offshore skimmers that could be used; therefore, the encounter rate will be the limiting factor and will be used in subsequent calculations. Using this as the recovery rate, and using the guidelines of 20% oil recovery efficiency and 40% water-in-oil emulsion in storage, the total fluid recovery rate can be estimated as shown in the following table.

**TABLE 6-5**  
**Fluid Recovery Rates for Scenario 1**

Fluid	Calculation	Recovery rate
oil	lesser of system encounter rate and derated recovery rate	83 bbl/hr
total water	oil content in recovered fluid (recovery efficiency) = 20%	332 bbl/hr
emulsified water	emulsified water content in recovered fluid = 40%	55 bbl/hr
free water	total water less emulsified water	277 bbl/hr
total fluids	oil + emulsified water + free water	415 bbl/hr

Obviously, there will be inefficiencies when operating containment and recovery equipment among broken ice. These inefficiencies will be due to having to reposition containment boom to avoid large ice features and to rid the contained area of accumulations of small floes. As described previously, this containment efficiency is estimated to be 70% for this scenario; that is, due to interruptions related to the broken ice the containment operation is effective for 70% of the time.

Using these figures one can then estimate the total oil, emulsion, and free water that could be recovered per unit time period. Assuming that operations are restricted to daylight hours, the total fluid volumes per day are calculated by combining the hourly rates, the 70% encounter efficiency, and the 12 hours of daylight available at this time of year (see Table 6-6).

**TABLE 6-6**  
**Estimate of Recovered Fluids per 12-hr Time Period**

Item	Calculation	Volume
total fluids per 12 hours	415 bbl/hr x 12 hours x 70%	3486 bbl
total free water	277 bbl/hr x 12 hours x 70%	2327 bbl
volume that can be decanted	total free water x 80%	1861 bbl
total fluids stored per 12 hours	total fluids less decant	1625 bbl
oil	83 bbl/hr x 12 hours x 70%	697 bbl
emulsified water	55 bbl/hr x 12 hours x 70%	462 bbl
free water	total free water x 20%	466 bbl

The above calculations were for one system operating for only the 12 daylight hours. There is adequate equipment and marine support to provide for two systems, so the above estimates per system can be multiplied by two, resulting in the following estimates of oil and fluid recovery per 12-hr time period.

Estimate of Fluid Recovered by Two Systems per Day	
total oil recovered	1394 bbl
total fluid recovered	3250 bbl

A possible limitation in operating the described systems over a period of time is that of storage space. Given that there are a limited number of tugs/barges applicable to the freeze-up season, it would be a serious loss of effectiveness if a barge system were to have to shut down recovery operations in order to shuttle fluids back to storage at West Dock. Based on the above fluid recovery rates this would have to occur about every 8 days, translating into a loss in overall effectiveness of roughly 13% (1 day in 8 spent shuttling fluids). An alternative would be to consider the use of hovercraft to transport fluids from the spill scene in order to extend the use of the barge storage space. As described in detail in Appendix F, two hovercraft could be on scene within the same response time as the tug/barge combinations. The two machines, operating in tandem, could provide a shuttle throughput of up to 2600 bbl/day, which would extend the use of barge storage almost indefinitely:  $(14,000 + 12,200 \text{ bbl}) \div (3250 - 2600 \text{ bbl/day}) = 40 \text{ days available storage}$ .

#### **Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

This final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of visibility, VFR flying conditions, and wave heights. The response time for the freeze-up scenarios is estimated to be 60 hours, so for the 15-day period the effect is to reduce effectiveness by 17%  $((15 - 2.5) \div 15 = 0.83)$ . As discussed in Chapter 5, the combination of the three environmental factors is such that mechanical containment and recovery will be effective, on average, 77% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 1394 \text{ bbl/day} \times 0.83 \times 0.77 + 15,000 \text{ bbl/day} \\ &= 5.9 \% \end{aligned}$$

### **6.2.3 Additional Recovery Systems (Scenario 1. Northstar, 3/10ths Ice, Freeze-up)**

It is interesting to note the possible effectiveness of an additional system for this scenario. Given that the two identified systems can encounter the entire width of the thick slick, a third system would be limited to chasing relatively thin sheens. The thickness of oil outside of the thick portion is estimated to be 35  $\mu\text{m}$ , or 0.035 mm. This is only 1/20th (or 5%) of the thick slick thickness. This would correspond to an encounter rate of only 6 bbl/hr, and based on the above calculation procedure, a daily recovery volume of only 70 bbl (i.e., less than 1% of the daily blowout volume).

Consideration could also be given to deploying a third system to attempt to recover oil from the thick slick that is missed by the first two systems: although the two systems encounter all of the thick slick, they lose an estimated 30% of it due to inefficiencies associated with the ice conditions. More serious consideration will be given to this possibility in the break-up scenarios, and a calculation procedure is described for estimating the potential effectiveness of additional systems. However, in the freeze-up scenarios, given the other limiting factors (percentage of oil on ice, encounter efficiency, limited daylight hours), the effectiveness of each of the first two systems is only about 3%. Additional systems would recover only a portion of this, in this scenario, perhaps an additional 1%. Finally it is noted that there would be a limited time period with which to use additional systems: the freezing temperatures mean that the oil will be mixed with slush ice and soon incorporated into ice forming on the water surface.

### **6.2.4 Dispersant-Use (Scenario 1. Northstar, 3/10ths Ice, Freeze-up)**

In this scenario the amount of oil that falls on water to form relatively thick slicks ( $> 0.5$  mm) – after unavoidable losses due to evaporation, tiny-particle drift, and oil falling on ice – is 3900 barrels per day (15,000 BOPD  $\times$  0.26 – see Table 6-3). According to the above analysis of mechanical recovery capability the amount that can be physically recovered is 1394 barrels of oil per day. This leaves 2506 barrels of oil per day as a target for a dispersant program. This is the oil that has been lost because of inefficiencies of the recovery operation, mainly due to ice intrusions, and losses because

operations are assumed not to take place at night. The following analysis assumes that there are environmental incentives for using dispersant and that government approvals are in place.

The analysis focuses first on the logistics of the operation, that is, determining how much of the oil can be treated with dispersant using the proper dispersant-to-oil ratio (DOR). Once this is done an attempt will be made to assess how effective the dispersant might be in actually dispersing the oil from the water's surface. The program will use helicopter/spray-bucket systems for the operation. These are ideally suited for this kind of operation because spills are close to land, high maneuverability is required of the spray platforms, and there already is much helicopter experience in the area. The specifications of the helicopter/spray bucket systems were provided earlier in Table 5.5 in Chapter 5. These are summarized below.

Item	Capacity
Payload	240 gallons
Max. Speed	54 knots
Min. Speed	27 knots
Max. Pump Rate	120 gallons/min.
Min. Pump Rate	79 gallons/min.
Swath Width	100 feet
Reposition Time (360°)	2.25 min.

The slicks that are the target for dispersant spaying in this scenario, as noted in Table 6-3, are in the range of 0.5 to 0.7 mm. In order to treat slicks of this thickness using a dispersant-to-oil ratio (DOR) of 1:20, an application rate of about 30 gallons per acre would be required. The helicopter system specified in the above table has the capability of spraying about 10 gallons per acre, on average. So, each targeted slick would have to be sprayed about three times to achieve the proper dosage. Current expert opinion is that a DOR of only about 1:50 or even 1:60 may be sufficient for effective



treatment. In that case, only one pass might be required. However, to be conservative we will assume that a DOR of 1:20 will be used.

The oil available each day for dispersing (about 2500 barrels after evaporation) would therefore require about 5300 gallons of dispersant per day ( $2500 \times 42 / 20$ ). The two helicopter/bucket systems would therefore need to carry out about 10 sorties each per day (that is, during the 12 hours of daylight). Logistically, this would be accomplished as follows

The dispersant bucket system requires a helicopter with a sling capacity of at least 2,700 lb allowing for the payload and bucket weight. Bell 212s are readily available for charter out of Anchorage and could arrive at Deadhorse within 12 hours from a call-out (6 hours flight time plus mobilization and crewing). At the same time dispersant and the helibuckets would be loaded on Northern Air Cargo DC-6 aircraft for delivery to the Slope. The existing agreement with Alaska Clean Seas is to have the aircraft available for loading within two hours. It is assumed that all systems could be in place and ready to start operation within 12 hours of the accident. This is sooner than the mechanical recovery systems can be in place picking up oil (60 hours after the accident). Therefore, theoretically, the dispersant response could deal with all the oil discharged and on the surface in the first 12 hours of the spill and also the oil discharged over the next 48 hours before the mechanical systems arrive.

Thereafter it would only have to deal with the oil that was not recovered by the mechanical systems.

Based on the twelve hours of daylight available, the following conservative logistics plan is proposed for using two machines to treat the offshore slicks falling within one to two miles of the Northstar production facility.

Assumptions: (Bell 212 - operating limits supplied by ERA)

- endurance with 2,700 lb on the hook - 80 minutes
- transit and search speed with sling load - 65 knots
- refueling time - 10 minutes (5 min min. hot refuel)
- average pump rate - 100 gallons/min

- average speed while pumping - 40 knots (68 ft/sec)
- average open water (assume, slick) area between typical floes of 400 ft. dia in 3/10 ice = 288,900 ft<sup>2</sup> corresponding to an average lateral slick dimension of about 600 ft (for illustrative purposes only)
- loading and refueling at WDSP staging area at foot of West Dock causeway (8 nautical miles from Seal Island)

Results: (one machine - multiply by number available)

- transit time to and from the site - 15 minutes
- time to traverse typical slick - 8.8 seconds (600/68)
- repositioning time to empty bucket  
=  $(([240/100] \times 60)/8.8) \times 2.25 = 36.8$  minutes
- total time on site = repositioning time + bucket dump time = 36.8 min + 2.4 min = 39.2 min
- total sortie time = time on site + transit = 39.2 + 15 = 54 min. Need to refuel after each sortie - add 10 min making total net sortie time = 64 min.
- total number sorties per day =  $(12 \times 60)/64 = 11.25$
- allowing for crew change and reorientation half way through the day, a realistic scenario can call for 10 sorties/day

The above value of 10 sorties per 12-hr day is conservative in the sense that the helicopter repositioning time (360°) is taken to be 2.25 minutes. This could be cut in half easily by using 180° turns. In any case, it appears feasible to plan on twenty sorties with two machines flying 12 hours per day. The most sensitive parameter controlling the productivity of the operation is the average slick dimension, which is controlled in part by the floe size and other factors such as wind speed, distance downwind etc. Many more small slicks will greatly increase the repositioning time. On the other hand, larger floes may lead to fewer large slicks, with a corresponding reduction in the number of repositionings between individual applications.

The above analysis shows that the 2500 barrels of escaped oil can be treated with dispersant in a dispersant-to-oil ratio of 1:20. Now the question is: How effective will the treatment be in actually dispersing the oil? If the ice were not present and dampening the waves, one could estimate that the dispersant effective could be in the 50 to 80 % range, the range estimated for spills of Alaskan North Slope crude treated with Corexit 9527 (SL Ross 1997) No one can say with any certainty what the value would be in this case; there is simply no reliable knowledge on the subject of dispersant use in an ice situation like this. To be conservative, we will estimate that only 25% of the treated oil in this scenario will be dispersed. Continuing the conservative thinking, we will further assume in the next two scenarios involving 50% and 70% ice, that dispersant effectiveness will be essentially zero.

In summary, for this scenario it is assumed that the dispersant operation will disperse 25% of the 2500 barrels of oil that escaped the mechanical recovery operation.

#### **6.2.5 *In situ* Burning (Scenario 1. Northstar, 3/10ths Ice, Freeze-up)**

It is recognized that insufficient vessels exist to conduct an *in situ* burning (ISB) operation in addition to the containment and recovery operation described above. However, a description and assessment of such an operation is given below for assessment purposes.

The *in situ* burning unit that would make sense for this scenario consists of 360 feet of fire boom and two tugs. A helicopter carrying a Heli-torch would support the burn operation. The ISB unit, as with the containment and recovery system, would be deployed to encounter as much as possible of the thick slick. The encounter rate of each burn unit for this scenario is thus the same as for the recovery unit at:

$$\begin{aligned} \text{ISB encounter rate (max)} &= (360 \text{ feet} \times 0.33 \text{ gap}) \times 0.7 \text{ mm} \times 0.4 \text{ knots} \times (1 - 30\% \text{ ice}) \\ &= 83 \text{ bbl/hr} \end{aligned}$$

Unlike the containment and recovery system, the ISB system is envisioned as being used in a "batch" mode. Oil is collected in the back of the boom for a certain period of time, then the system is moved away from the heavy concentrations of oil and the accumulated oil is burned off. For the sake of

simplicity, it is assumed that the thick slick is encountered and collected for 50% of the time, and the remainder of the time is spent burning off the accumulated oil and maneuvering the unit back into the thick oil slick. This equates, over a 12-hour day, to collecting oil for 6 hours and burning and maneuvering for 6 hours. Each individual burn would take about 1.2 hours from ignition to extinction. After each day's operations, the section of fire boom would have to be replaced. It is potentially twice as efficient to collect and burn simultaneously; however, because the oil slick thicknesses emanating from the source could be close to the minimum ignitable for weathered crude (about 2 mm) there would be a danger of the fire burning back to the spill source. (The thickness is only 0.7 mm at 3 hours down current and this is the average thickness across the width of the thick slick.)

The estimated daily removal rate for one ISB unit is thus:

$$\text{ISB unit estimated daily removal rate} = (83 \text{ bbl/hr} \times 12 \text{ hr}) \times 0.5 = 498 \text{ bbl}$$

If all the vessels capable of operating in this scenario were used for ISB operations, a total of two ISB units could be deployed, removing an estimated 996 bbl of oil from the water surface per day. If more vessels were available, four ISB units could be operated to remove 1992 bbl per 12-hour day.

In this scenario the weathered oil on the ice floes is too thin to ignite.

A similar overall reduction in *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (80%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil volume removed by ISB} &= 996 \text{ bbl/day} \times 0.83 \times 0.77 \times 0.80 \div 15,000 \text{ bbl/day} \\ &= 3.4 \% \end{aligned}$$

## **6.3 Scenario 2. Northstar in 5/10ths Ice Cover During Freeze-up**

### **6.3.1 Blowout and Spill Behavior (Scenario 2. Northstar, 5/10ths Ice, Freeze-up)**

An uncontrolled blowout occurs in mid October at the Northstar artificial island releasing 15,000 barrels of oil per day (BOPD) and  $33 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 2200 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 8 °F to a daytime high of 18 °F. The wind speed averages 19 knots from the WSW. The surrounding water is covered by 5/10ths new ice floes. The ice is 0.6 to 0.8 feet thick and covered by 2 to 4 inches of snow. The floes are hundreds to thousands of feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.6 knots to the ENE. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the pack). The water will be covered with newly growing ice crystals and slush.

As the oil and gas exits the 6.3-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 90 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind.

In this scenario, the slick is 180 feet wide and 0.7 mm thick at the starting point of the surface slick modeling. This is at a distance of some 920 feet downwind of the blowout. At this point, the oil slick is assumed to be evaporated to 20% loss.

For the purposes of this scenario, it is estimated that 50% of the oil spray lands on water and 50% lands on the ice surface. The spray that lands on ice floes coats the surface and is absorbed by the snow. The range of oil thicknesses on the floe surface ranges from 0.9 mm near the center-line of

the oiled strip to 0.004 mm at the edges. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 34% after 72 hours.

Table 6-7 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 12 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 250 feet and a thickness of 0.4 mm. After 12 hours, the oil has evaporated to a point (28%) where its Pour Point (30 °F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water. For the duration of the scenario (72 hours) the slick moves with the oiled ice floes and does not spread further, although the thick slick may meander somewhat in the pack ice field due to oceanic eddies or large-scale turbulence.

The presence of ice inhibits the wave action that would normally exist with a 19 knot wind and suppresses natural dispersion of the oil slick. The ice also suppresses the formation of a water-in-oil emulsion.

The thick oil slick continues to evaporate slowly throughout the 72 hour scenario. It loses 31% of its volume to evaporation after 24 hours; 33% after 48 hours; and, 34% after 72 hours. The viscosity of the unemulsified oil increases to 210 cP after 24 hours; 240 cP after 48 hours; and, 250 cP at 72 hours. The Pour Point of the oil after 72 hours has increased to 47 °F.

At the end of the 72 hour scenario period, 17% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 30% remains on the surface of ice floes. The oiled water area is a long (41 nautical miles), narrow (250 feet) strip that contains 0.4 mm thick unemulsified oil slicks between floes. The ice floes that were sprayed with oil as they passed under the blowout plume are coated with 0.004 mm to 0.9 mm of oil covering the snow on their surface. The thicker coatings are on the floes near the center-line of the oiled strip.

Over time, the oil remaining on water will be incorporated into the surface layer of the growing ice and the oil remaining on floes will be covered by snow. A portion of the oiled ice will likely be formed into ridges and rubble fields during November and December as the thin ice deforms under pressures from wind and heavier pack ice to the north. Any oiled ice which escapes being incorporated into the fast ice will gradually drift west, and in many years could end up in the Chukchi Sea by spring. During the spring (late May to early June) any oil still remaining near the surface of level ice will rise to lie in melt pools; the oil incorporated into ridges and rubble fields will be released more slowly. Ultimately, rotting ice will release any oil still remaining at breakup in the form of thin sheens trailing the drifting floes.

**TABLE 6-7**  
**Summary of Slick Characteristics from a Blowout During Freeze-up**  
**at Northstar in 5/10ths Ice Cover over 72 Hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	21%	0	120	0.7	180
3	20	0	155	0.5	230
6	20	0	170	0.5	240
12	19	0	190	0.4	250
24	18	0	210	0.4	250
48	18	0	240	0.4	250
72	17	0	250	0.4	250

### 6.3.2 Existing Mechanical Methods (Scenario 2. Northstar, 5/10ths Ice, Freeze-up)

As in the first scenario, the ice conditions at West Dock as well as those at the spill site will limit the marine equipment that can be used for the response. In this scenario, midway through the freeze-up period with 5/10ths ice concentration, up to four tugs and two ice-strengthened barges could be

mobilized and used for offshore support containment and recovery. As in the first scenario it is estimated that 60 to 72 hours would elapse before these arrived on-site.

The slick conditions are similar to those in the first scenario, with heavy concentrations of oil in a relatively narrow slick, surrounded by a thin sheen. As in the first scenario, two containment systems could encounter the entire 230-foot slick width. Overall, a similar set of equipment -- tugs, barges, booms, and skimmers -- would be employed. The main difference in this scenario is the increased amount of ice, which lowers the effective encounter rate of the system (the system cannot access the oil that is distributed on the ice) and the lower containment efficiency associated with operating in the increased ice concentration.

In this scenario, the slick conditions at a point 3 hours down drift of the blowout are a thick slick of 230-foot width and 0.5 mm thickness. Combining this with the slick drift rate of 0.6 knots and the 50% ice concentration results in an encounter rate per system of:

$$\begin{aligned} \text{encounter rate} &= (345 \text{ feet} \times 0.33 \text{ gap ratio}) \times 0.5 \text{ mm} \times 0.6 \text{ knots} \times (1 - 50\% \text{ ice}) \\ &= 61 \text{ bbl/hour} \end{aligned}$$

This is less than the derated recovery rate of several of the offshore skimmers that could be used, so again the encounter rate is the limiting factor and is used in subsequent calculations. Following a similar calculation process as in the first scenario, the following table shows the calculations for total fluid recovery rates.



**TABLE 6-8  
Fluid Recovery Rates for Scenario 2**

Fluid	Calculation	Recovery rate
oil	lesser of system encounter rate and derated recovery rate	61 bbl/hr
total water	oil content in recovered fluid (recovery efficiency) = 20%	244 bbl/hr
emulsified water	emulsified water content in recovered fluid = 40%	41 bbl/hr
free water	total water less emulsified water	203 bbl/hr
total fluids	oil + emulsified water + free water	305 bbl/hr

Compared with the first scenario, the main difference here is the greater ice concentration and its effect on containment efficiency. For the 50% ice condition, the containment efficiency is assumed to be 40%, that is, the containment operation is effective for 40% of the time accounting for interruptions related to clearing ice from the containment and repositioning the system when avoiding large floes.

Assuming that operations are restricted to daylight hours, the total fluid volumes per day are calculated by combining the hourly rates, the 40% encounter efficiency, and the 10-½ hours of daylight available at this time of year.

**TABLE 6-9**  
**Estimate of Recovered Fluids per 10½-hr Time Period For Scenario 2**

Item	Calculation	Volume
total fluids per 10½ hours	305 bbl/hr x 10½ hours x 40%	1281 bbl
total free water	203 bbl/hr x 10½ hours x 40%	853 bbl
volume that can be decanted	total free water x 80%	682 bbl
total fluids stored per 10½ hours	total fluids less decant	599 bbl
oil	61 bbl/hr x 10½ hours x 40%	256 bbl
emulsified water	41 bbl/hr x 10½ hours x 40%	172 bbl
free water	total free water x 20%	171 bbl

The above calculations were for one system so the above numbers can be doubled to account for the two systems that would be deployed at the site:

Estimate of Fluids Recovered by Two Systems per Day	
total oil recovered	512 bbl
total fluid recovered	1198 bbl

As in the first scenario, hovercraft could be considered to shuttle fluids and make most effective use of the available storage within the barges on-site. In this instance, the maximum hovercraft throughput of up to 2600 bbl/day exceeds the daily recovery of fluids and would extend the use of barge storage indefinitely.

**Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

This final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of

visibility, VFR flying conditions, and wave heights. For all the freeze-up scenarios, the response time is estimated to be 60 hours, so for the 15-day period the effect is to reduce effectiveness by 17%  $((15 - 2.5) \div 15 = 0.83)$ . Also for all freeze-up scenarios, the combination of the three environmental factors are such that, on average, mechanical containment and recovery will be effective 77% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 512 \text{ bbl/day} \times 0.83 \times 0.77 \div 15,000 \text{ bbl/day} \\ &= 2.2 \% \end{aligned}$$

### **6.3.3 Additional Recovery Systems (Scenario 2. Northstar, 5/10ths Ice, Freeze-up)**

As in the previous scenario (section 6.2.3), the entire width of the thick slick can be encountered by two containment and recovery systems. Any additional systems would be limited to chasing thin sheens and would add little to the overall effectiveness of the response. Additional systems could be considered to attempt to deal with oil outside the thick slick, as well as portions of the thick slick missed by the first two systems due to ice-related inefficiencies; however, any additional systems would be even less effective than is described above.

### **6.3.4 Dispersant-Use (Scenario 2. Northstar, 5/10ths Ice, Freeze-up)**

In this scenario the amount of oil that falls on water to form relatively thick slicks ( $> 0.4$  mm) – after unavoidable losses due to evaporation, tiny-particle drift, and oil falling on ice – is 3150 barrels per day  $(15,000 \text{ BOPD} \times 0.21)$  – see Table 6-7). According to the above analysis of mechanical recovery capability the amount that can be physically recovered is 512 barrels of oil per day. This leaves 2638 barrels of oil per day as a target for a dispersant program.

The oil available each day for dispersing would therefore require about 5500 gallons of dispersant per day  $(2638 \times 42/20)$ . The two helicopter/bucket systems would therefore need to carry out about 10 sorties each per day (during the 12 hours of daylight), that is, about the same as the first scenario

involving 3/10ths ice. The logistical set-up would be identical to that described in the previous scenario.

The major question about dispersant use in this scenario is whether there would be enough oceanic mixing energy to effect good dispersion. This is difficult to say. To be conservative, we will assume that dispersant effectiveness in this situation will be close to zero, and will not "remove" any oil from the surface. However, in the real event it seems that it would make reasonable sense to try to disperse the escaping oil slicks. This may prove to be effective under the circumstances.

### **6.3.5 *In situ* Burning (Scenario 2. Northstar, 5/10ths Ice, Freeze-up)**

As in the first scenario it is recognized that insufficient vessels exist to conduct an *in situ* burning operation in conjunction with the containment and recovery operation described above, but if there were, the *in situ* burning unit would consist of 345 feet of fire boom and two tugs. A helicopter/Heli-torch system would support the burn operation.

The encounter rate of each burn unit for this scenario would be the same as for the recovery unit at:

$$\begin{aligned} \text{ISB encounter rate (max)} &= (345 \text{ feet} \times 0.33 \text{ gap}) \times 0.5 \text{ mm} \times 0.6 \text{ knots} \times (1 - 50\% \text{ ice}) \\ &= 61 \text{ bbl/hr} \end{aligned}$$

As in the first scenario the ISB system is envisioned as being used in a "batch" mode. Oil is collected in the back of the boom for a certain period of time, then the system is moved away from the heavy concentrations of oil and the accumulated oil is burned off. For the sake of simplicity, it is assumed that the thick slick is encountered and collected for 50% of the time, and the remainder of the time is spent burning off the accumulated oil and maneuvering the unit back into the thick oil slick. This equates, over a 10.5-hour day, to collecting oil for 5.25 hours and burning and maneuvering for 5.25 hours. Each individual burn would take about 1.2 hours from ignition to extinction. After each day's operations, the section of fire boom would have to be replaced. It is potentially twice as efficient to collect and burn simultaneously; however, because the oil slick thicknesses emanating from the

source could be close (0.5 mm at 3 hours is the average thickness across the width of the thick slick) to the minimum ignitable for weathered crude (ca. 2 mm) there would be a danger of the fire burning back to the spill source.

The estimated daily removal rate for one ISB unit is thus:

$$\begin{aligned} \text{ISB unit estimated daily removal rate} &= (61 \text{ bbl/hr} \times 10.5 \text{ hr}) \times 0.5 \\ &= 320 \text{ bbl} \end{aligned}$$

If all the vessels capable of operating in this scenario were used for ISB operations, a total of two ISB units could be deployed, removing an estimated 640 bbl of oil from the water surface per day. If more vessels were available, four ISB units could be operated to remove 1280 bbl per 10.5-hour day. This is slightly higher than the case of containment and recovery because it is envisioned that burning, then maneuvering the ISB unit back into the thick oil will take less time than for the conventional boom and skimmer system.

A similar overall reduction in *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (80%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow is:

$$\begin{aligned} \text{Oil volume removed by ISB} &= 640 \text{ bbl/day} \times 0.83 \times 0.77 \times 0.80 + 15,000 \text{ bbl/day} \\ &= 2.2 \% \end{aligned}$$

## **6.4 Scenario 3. Northstar in 7/10ths Ice Cover During Freeze-up**

### **6.4.1 Blowout and Spill Behavior (Scenario 3. Northstar, 7/10ths Ice, Freeze-up)**

An uncontrolled blowout occurs in late October at the Northstar artificial island releasing 15,000 barrels of oil per day (BOPD) and  $33 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 2200 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 3 °F to a daytime high of 13 °F. The wind speed averages 22.5 knots from the SW. The surrounding water is covered by 7/10ths new ice floes. The ice is 1 to 1.2 feet thick and covered by 5 to 6 inches of snow. The floes are hundreds to thousands of feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.7 knots to the NE. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the pack), except for the presence of an ice-free wake in the lee of the island. Small waves (only a few inches in height due to the restricted fetch) will exist in this wake area. The water in the wake area will be covered with newly growing ice crystals and slush. The pack ice drifts back in to fill the wake area within 1000 feet downwind of the island.

As the oil and gas exits the 6.3-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 75 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind.

In this scenario, the slick is 180 feet wide and 0.6 mm thick at the starting point of the surface slick modeling. This is at a distance of some 920 feet downwind of the blowout. At this point, the oil slick is assumed to be evaporated to 20% loss.

It has been noted that, in the lee of the artificial island, an open water area, or wake, will exist, stretching up to 1000 feet downwind. It is in this area that 60% of the oil will fall to the surface of the water. For the purposes of this scenario, it is estimated that 72% of the oil spray lands on water (60% falls out in the wake and 30% of the other 40% that settles out past the wake lands on water between floes and forms a very thin - 35 $\mu$  m - slick) and 28% lands on the surface of ice floes past the wake zone. The spray that lands on ice floes coats the surface and is absorbed by the snow. The range of oil thicknesses on the floe surface ranges from 0.2 mm near the center-line of the oiled strip to 0.003 at the edges. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 35% after 72 hours.

Table 6-10 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 9 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 240 feet and a thickness of 0.4 mm. After 9 hours, the oil has evaporated to a point (28%) where it's Pour Point (30 °F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water. For the duration of the scenario (72 hours) the slick moves with the oiled ice floes and does not spread further, although the thick slick may meander somewhat in the pack ice field due to oceanic eddies or large-scale turbulence.

The presence of ice inhibits the wave action that would normally exist with a 22.5 knot wind and suppresses natural dispersion of the oil slick. The ice also suppresses the formation of a water-in-oil emulsion.

The thick oil slick continues to evaporate slowly throughout the 72 hour scenario. It loses 32% of its volume to evaporation after 24 hours; 34% after 48 hours; and, 35% after 72 hours. The viscosity of the unemulsified oil increases to 220 cP after 24 hours; 250 cP after 48 hours; and, 260 cP at 72 hours. The Pour Point of the oil after 72 hours has increased to 48 °F.

At the end of the 72 hour scenario period, 33% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 23% remains on the surface of ice floes. The oiled area is a long (68 nautical miles), narrow (240 feet) strip that contains 0.4 mm thick unemulsified oil slicks on the water between floes. The ice floes that were sprayed with oil as they passed under the blowout plume are coated with 0.003 mm to 0.2 mm of oil covering the snow on their surface. The thicker coatings are on the floes near the center-line of the oiled strip.

Over time, the oil remaining on water will be incorporated into the surface layer of the growing ice and the oil remaining on floes will be covered by snow. A portion of the oiled ice will likely be formed into ridges and rubble fields during November and December as the thin ice deforms under pressures from wind and heavier pack ice to the north. Any oiled ice which escapes being incorporated into the fast ice will gradually drift west, and in many years could end up in the Chukchi Sea by spring. During the spring (late May to early June) any oil still remaining near the surface of level ice will rise to lie in melt pools; the oil incorporated into ridges and rubble fields will be released more slowly. Ultimately, rotting ice will release any oil still remaining at breakup in the form of thin sheens trailing the drifting floes.

**TABLE 6-10**  
**Summary of Slick Characteristics from a Blowout During Freeze-up**  
**at Northstar in 7/10ths Ice Cover over 72 Hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	41	0	120	0.6	180
3	38	0	160	0.5	230
6	37	0	180	0.4	240
12	36	0	200	0.4	240
24	35	0	220	0.4	240
48	34	0	250	0.4	240
72	33	0	260	0.4	240



#### 6.4.2 Existing Mechanical Methods (Scenario 3. Northstar, 7/10ths Ice, Freeze-up)

Compared with the previous two scenarios during freeze-up the greater ice concentration in this scenario limits the amount of oil on the water and available for containment and recovery, as well as severely limiting the applicability of containment and recovery countermeasures. The slick conditions are roughly the same as the other two freeze-up scenarios - a slick of 230-foot width and 0.5 mm thickness - allowing the same general approach and equipment for containment and recovery. However, the encounter rate, when reduced to account for the 70% ice concentration, will be much less than the available skimming capacity. Given the slick conditions and using the same approach as in the previous scenarios results in an encounter rate of only 43 bbl/hour.

As well, the greater ice concentration drastically affects the containment efficiency. For the 70% ice condition, the containment efficiency is estimated to be only 20%, that is, the containment operation is effective for only 20% of the time accounting for interruptions related to clearing ice from the containment and repositioning the system when avoiding large floes.

In all, using the same calculation procedure as in the first two freeze-up scenarios, only a small fraction of the blowout volume could be expected to be recovered given the 70% ice concentrations. The following is an estimate of the fluids recovered for two systems per 8-hour period (hours of daylight at the latter end of freeze-up):

Estimate of Fluids Recovered by Two Systems per Day	
	8-hr period
total oil recovered	138 bbl
total fluid recovered	322 bbl

### **Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

This final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of visibility, VFR flying conditions, and wave heights. As for all the freeze-up scenarios, the response time is estimated to be 60 hours, so for the 15-day period the effect is to reduce effectiveness by 17%  $((15 - 2.5) \div 15 = 0.83)$ . Also for all freeze-up scenarios, the combination of the three environmental factors are such that, on average, mechanical containment and recovery will be effective 77% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 138 \text{ bbl/day} \times 0.83 \times 0.77 \div 15,000 \text{ bbl/day} \\ &= 0.6 \% \end{aligned}$$

#### **6.4.3 Additional Recovery Systems (Scenario 3. Northstar, 7/10ths Ice, Freeze-up)**

As in the previous two freeze-up scenarios, the entire width of the thick slick can be encountered by two containment and recovery systems. Any additional systems would be limited to chasing thin sheens, or oil lost from the first two systems due to ice-related inefficiencies, and would add little to the overall effectiveness of the response.

#### **6.4.4 Dispersants and Burning (Scenario 3. Northstar, 7/10ths Ice, Freeze-up)**

Dispersant use does not make sense in this scenario, mostly because there is not enough mixing energy available to promote dispersion of the treated oil into the water.

Considering *in situ* burning, this scenario differs from the previous two in that a wake exists in the lee of the island, into which much of the oil spray is falling. At the end of the wake, just before the ice floes move back together, the thick slick is predicted to be 180 feet wide, 0.6 mm thick and

drifting at 0.7 knots. Although a containment and recovery system could not be deployed in the wake, due to the potential exposure to oil mist concentrations in the plume, an *in situ* burning operation could be mounted there that consists of 500 feet of fire boom held by two tugs using 350 feet of rope each. This would place the tugs 200 feet from the plume centerline (using a gap ratio of 1:3), a distance sufficient at this location to reduce airborne oil mist concentrations to below the target 5 mg/m<sup>3</sup>. A helicopter carrying a Heli-torch would support the burn operation.

The encounter rate of the ISB unit, deployed to encounter the entire width of the thick slick, is:

$$\text{ISB encounter rate (max)} = (180 \text{ feet}) \times (0.6 \text{ mm}) \times (0.7 \text{ knots}) = 267 \text{ bbl/hr}$$

Unlike the containment and recovery system, the ISB system is envisioned as being used in a "batch" mode. In the eight hours of daylight available in this scenario the system would collect oil continuously for 7 hours (capturing some 1869 bbl of oil, enough to cover only the back 1/3 of the pocket of the boom) then maneuver sideways and remove the oil with one burn at the end of the day. It is potentially slightly more efficient to collect and burn simultaneously. However, the oil slick thicknesses emanating from the source would be close to the minimum ignitable for weathered crude (ca. 2 mm) meaning there would be a risk of the fire burning back to the spill source.

The estimated daily recovery rate for this ISB operation is 1869 bbl.

The weathered oil on the ice floes is too thin to ignite.

A similar overall reduction in *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (80%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\text{Oil volume removed by ISB} = 1869 \text{ bbl/day} \times 0.83 \times 0.77 \times 0.80 \div 15,000 \text{ bbl/day} = 6.4 \%$$

## **6.5 Scenario 4. Pt. McIntyre in 3/10ths Ice Cover During Break-up**

### **6.5.1 Blowout/Spill Behavior (Scenario 4. Pt. McIntyre, 3/10ths Ice, Break-up)**

An uncontrolled blowout occurs in mid July at the Pt. McIntyre drill site releasing 12,000 barrels of oil per day (BOPD) and  $9 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 750 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 35 °F to a daytime high of 45 °F. The wind speed averages 11 knots from the west. The water to the east of the causeway is covered by 3/10ths melting ice floes. The ice is 3 to 4 feet thick and its surface is 40% to 50 % covered by melt ponds. The floes are fifty to five hundred feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.3 knots to the east. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the pack).

As the oil and gas exits the 4-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 70 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind.

In this scenario, the slick is 100 feet wide and 1.7 mm thick at the starting point of the surface slick modeling. This is at a distance of some 500 feet downwind of the blowout. At this point, the oil slick is assumed to be evaporated to 20% loss.

For the purposes of this scenario, it is estimated that 70% of the oil spray lands on water and 30% lands on the ice surface. The spray that lands on ice floes coats the surface and is slowly flushed by melt water into the melt pools on the floes. The range of oil thicknesses initially deposited on the floe surfaces ranges from 3 mm near the center-line of the oiled strip to 0.01 mm at the edges. The

flushing process results in wind-herded oil thicknesses on the melt pools of 10 mm. The oil covers up to 60% of the surface area of the melt pools; the largest slicks are on floes near the center-line of the oiled strip. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 22% after 72 hours.

Table 6-11 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 25,000 cP and a Pour Point of 68 °F at the point where the on-water modeling is started. As such, the oil slick does not spread on water. For the duration of the scenario (72 hours) the slick moves with the oiled ice floes and does not spread further, although the thick slick may meander among the widely-separated floes in the pack ice field due to oceanic eddies or large-scale turbulence.

The presence of ice dampens the wave action that would normally exist with an 11 knot wind and reduces natural dispersion of the oil slick compared with open water conditions. The slick is predicted to begin to form a water-in-oil emulsion immediately after the oil had been deposited on the water surface. If emulsification rates are the same in loose pack ice as in open water under identical winds, the slick would be fully emulsified (75% water content by volume) after 12 hours on the water. By this time the slick thickness has increased proportionately to the volume of water in the emulsion, reaching about 7 mm for the 75% water emulsion.

The oil slick continues to evaporate and naturally disperse slowly throughout the 72 hour scenario. It loses 21% of its volume to evaporation and an additional 0.01% to dispersion after 24 hours; 21% to evaporation and 0.06 % to dispersion after 48 hours; and, 22% to evaporation and 0.15% to natural dispersion after 72 hours. The viscosity of the emulsion increases to 1,000,000 cP after 24 hours; 1,100,000 cP at 48 hours and 1,200,000 cP at 72 hours. The Pour Point of the oil after 72 hours has increased to 71 °F.

At the end of the 72 hour scenario period, 30% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 21% on the surface of ice floes. The oiled area is a long (24 nautical miles), narrow (100 feet) strip that contains 7 mm thick

emulsified oil slicks on the water between floes. The ice floes that were sprayed with oil as they passed under the blowout plume contain melt pools with 10 mm thick slicks of oil covering up to 60% of the pool's surface. The larger pools of oil are on the floes near the center-line of the oiled strip. (Note that for the purposes of these scenarios, barriers to spill movement such as the Endicott causeway were ignored. The main objective of the scenarios was to address the countermeasures capability which is largely focused on near-source slick behavior and response.)

Ultimately, the rotting ice will release any oil still remaining in the form of thin sheens trailing the drifting floes.

**TABLE 6-11**  
**Summary of Slick Characteristics from a Blowout During Break-up at Pt. McIntyre in**  
**3/10ths Ice Cover over 72 Hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	31	0	25000	2.1	100
3	31	55	200000	4.2	100
6	31	69	600000	6.2	100
12	31	74	1000000	7.4	100
24	31	75	1000000	7.4	100
48	31	75	1100000	7.4	100
72	30	75	1200000	7.4	100

**6.5.2 Existing Methods (Scenario 4. Pt. McIntyre, 3/10ths Ice, Break-up)**

The response approach here is essentially the same as in the previous freeze-up scenarios: using one or two barge-based containment and recovery systems to encounter the entire thick portion of the slick. The key differences in the breakup scenarios are the following:

- Compared with the freeze-up scenarios there is a wider variety and greater number of marine systems that can be mobilized for the response. As well, initial mobilization should be much faster, with equipment on site within 12 hours as opposed to the 60 to 72 hours estimated for mobilization and transit for the freeze-up scenarios.
- At this time of year there are 24 hours of daylight, which should allow effective containment and recovery operations during "night-time".
- In the previous scenarios, although the systems could encounter all of the thick slick, a significant portion of the oil was lost due to inefficiencies associated with booming operations among broken ice. Some of these inefficiencies can still be expected in the break-up scenarios, but unlike the freeze-up scenarios, there may be significant benefits to using additional systems to attempt to contain and recover oil that is missed the first time. The prime difference here is the 24-hours of daylight and the resulting increase in per-system effectiveness.

As in the freeze-up scenarios, the relatively narrow slick of thick oil means it can be encountered in its entirety by two containment and recovery systems. For the moment the evaluation will consider two systems operating at a fixed location down drift of the blowout site, with the potential effectiveness of additional systems analyzed later. The following summarizes the major pieces of equipment that could be mobilized in response to this scenario.

**TABLE 6-12**  
**Key Equipment for Containment and Recovery in Scenario 4**

Equipment Type	Examples	Function
Barges	<i>Endeavor</i> <i>Beaufort 20</i> <i>BG 210/211/213</i>	working platform and storage for skimming operation
Tugs	<i>Pt. Barrow</i> <i>Pt. Thompson</i> <i>Arctic Tern</i> <i>Sag River</i> <i>Toolik River</i> <i>Kavik River</i>	tow equipment to site and position on-scene
Other boats	42' work boats (2#) <i>Northstar</i> 38-55' work boats - jet drive (5#)	boom handling and deployment
Containment boom	Ro-Boom 36x43	concentrate oil for recovery
Skimmers	Transrec 250 LORI Desmi Ocean Desmi Harbor	oil recovery

The slick conditions of interest are those estimated for 3 hours down drift of the blowout. This corresponds to a distance of about 5500 feet, which is judged to be a safe operating distance based on hydrocarbon-in-air concentrations. At this point the thick slick is 100 feet wide and averages 4.2 mm thick. Unlike the previous scenarios and because of the different oil, it is predicted that the oil will be somewhat emulsified at this point and contain 55% water. This emulsified water, therefore, will have to be taken into account in the calculations. For a containment system positioned downstream of a blowout, the encounter rate is calculated by multiplying the encounter width of the system by the slick thickness and the slick drift rate of 0.3 knots. In addition to this one must account for the fact that, on average, 30% of the slick width would be covered by ice. Thus the encounter rate for oil on water and available for recovery would be reduced by 30%. So, for each containment system employing 150 feet of boom, the encounter rate is:



$$\begin{aligned}
 \text{encounter rate} &= (150 \text{ feet} \times 0.33 \text{ gap ratio}) \times 4.2 \text{ mm} \times 0.3 \text{ knots} \times (1 - 30\% \text{ ice}) \\
 &= 156 \text{ bbl/hour} \quad (\text{emulsion}) \\
 &= 70 \text{ bbl/hour} \quad (\text{oil only})
 \end{aligned}$$

Both the emulsion encounter rate and the "oil only" encounter rate must be considered: the first is of concern when taking into account the derated recovery rate of the skimmer and when calculating the total fluid volumes; the latter is of concern when calculating the actual amount of oil recovered.

The emulsion encounter rate is within the derated recovery rate of several of the offshore skimmers that could be used; therefore, the encounter rate will be the limiting factor and will be used in subsequent calculations. Using this as the recovery rate, and using the guideline of 20% oil recovery efficiency (the actual emulsification of 55% water-in-oil emulsion in storage is used instead of the 40% guideline used in other scenarios), the total fluid recovery rate can be estimated as shown in the table below:

**TABLE 6-13**  
**Fluid Recovery Rates for Scenario 4**

Fluid	Calculation	Recovery rate
emulsion	lesser of system encounter rate and derated recovery rate	156 bbl/hr
oil	oil content in emulsion = 45%	70 bbl/hr
free water	oil content in recovered fluid (recovery efficiency) = 20%	624 bbl/hr
emulsified water	emulsified water content in recovered fluid = 55%	86 bbl/hr
total fluids	emulsion + free water	780 bbl/hr

As in the previous scenarios, there will be inefficiencies when operating containment and recovery equipment among broken ice. These inefficiencies will be due to having to reposition containment boom to avoid large ice features and to rid the contained area of accumulations of small floes. As described previously, this containment efficiency is estimated to be 70% for the 30% ice

concentration; that is, due to interruptions related to the broken ice the containment operation is effective for 70% of the time.

The total oil, emulsion, and free water that could be recovered per unit time period are then estimated based on the above figures. The table below shows the estimated fluid volumes per day, which are calculated by combining the hourly rates, the 70% encounter efficiency, and the 24 hours of daylight available at this time of year.

**TABLE 6-14**  
**Estimate of Recovered Fluids per 24-hr Time Period for Scenario 4**

Item	Calculation	Volume
total fluids per 24 hours	780 bbl x 24 hours x 70%	13,104 bbl
total free water	624 bbl/hr x 24 hours x 70%	10,483 bbl
volume that can be decanted	total free water x 80%	8387 bbl
total fluids stored per 24 hours	total fluids less decant	4717 bbl
oil	70 bbl/hr x 24 hours x 70%	1176 bbl
emulsified water	86 bbl/hr x 24 hours x 70%	1442 bbl
free water	total free water x 20%	2096 bbl

The above calculations were for one system. As there is adequate equipment and marine support to provide for two systems, the above estimates per system can be multiplied by two, resulting in the following estimates of oil and fluid recovery per 24-hours period.

Estimate of Fluids Recovered by Two Systems per 24-hr Period	
total oil recovered	2352 bbl
total fluid recovered	9434 bbl

The potential effectiveness of an additional system is now evaluated for this scenario. Attempting to recover oil outside the "thick slick" would be relatively ineffective. As discussed previously, the oil thickness outside the thick slick is estimated to be 35  $\mu\text{m}$ , or 0.035 mm, corresponding to an encounter rate of only 6 bbl/hr. Additional systems could be considered to attempt to recover oil from the thick slick that is missed by the first two systems: although the two systems encounter all of the thick slick, they lose an estimated 30% of it due to inefficiencies associated with the ice conditions.

The amount of oil remaining on the water is estimated by subtracting the amount recovered by the first two systems from the original slick.

original slick volume/hour (on water)	4.2 mm x 100 feet x 0.3 knots x (1 - 30%)	313 bbl/hr
emulsion recovered/hour	2352 bbl (oil) + 45% emulsion $\div$ 24 hours	218 bbl/hr
equiv. thickness of remaining emulsion slick	95 bbl/hr $\div$ (100 feet x (1 - 30%)) $\div$ 0.3 knots	1.27 mm

It is acknowledged that the remaining emulsion would not be a continuous slick of constant thickness, but for the purpose here of estimating the average encounter rate of a containment system over a 24-hour period, the discontinuities will tend to average out over time. Following the same calculation procedure as for the first two systems, but using a wider swath width of 100 feet to compensate for the thinner slick, a third system could recover an additional 739 bbl of oil, and 2933 bbl of total fluids. Similarly, reducing the slick by the amount recovered and applying a fourth system, an additional 218 bbl of oil and 877 bbl of total fluid can be recovered. After this, effectiveness drops rapidly, with daily recovered volumes of about 1% of the spill rate. In all, applying four systems to fight the spill in this scenario, the following are the estimated volumes of recovered oil and total fluids.

Estimate of Fluids Recovered By Four Systems per 24-hr Period	
total oil recovered	3309 bbl
total fluid recovered	13,244 bbl

### **Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

This final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of visibility, VFR flying conditions, and wave heights. The response time for the break-up scenarios is estimated to be 12 hours, so for the 15-day period the effect is to reduce effectiveness by 3% ( $(15 - \frac{1}{2}) \div 15 = 0.97$ ). As discussed in Chapter 5, the combination of the three environmental factors are such that, on average, mechanical containment and recovery will be effective 66% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 3309 \text{ bbl/day} \times 0.97 \times 0.66 \div 12,000 \text{ bbl/day} \\ &= 18 \% \end{aligned}$$

### **6.5.3 Additional Systems (Scenario 4. Pt. McIntyre, 3/10ths Ice, Break-up)**

The above analysis described the potential effectiveness for two containment and recovery systems that could encounter the entire width of the thick slick, as well as two additional systems to sequentially recover oil missed due to inefficiencies associated with ice conditions. Any additional systems would be limited to chasing thin sheens outside the area of thick oil, or attempting to recover oil missed by the first four systems. In either case, the encounter rate for these additional systems would be less than 10 bbl/hour, and the daily recovery volume would be less than 1% of the daily blowout volume.

#### 6.5.4 Dispersant-Use and Burning (Scenario 4. Pt. McIntyre, 3/10ths Ice, Break-up)

**Dispersant Use.** The strategies and good opportunities for using dispersants on this spill in 3/10ths ice would be similar to those discussed for the 3/10th ice freeze-up situation at Northstar (Scenario 1) except for one problem – the very high viscosity of the oil. After just a few hours on the water the oil is predicted to have a viscosity of over 100,000 cP. This is well beyond the viscosity limitations of even the most effective dispersant products today. If another production area involving a less viscous oil had been chosen for this spring break-up scenario, the dispersant results would have been similar and even better than to those calculated in Scenario 1. A springtime dispersant operation would likely be far more successful than an operation during freeze-up because the oil is not contaminated with slush ice, the air temperatures are higher, and, of greatest importance, there are 24 hours of daylight in which to conduct operations.

**In situ Burning.** At the safe distance for operations downwind of this blowout, the thick slick has emulsified to 55% water content. This prevents ignition. The use of "emulsion breaking" chemicals to promote ignition will not work with Pt. McIntyre crude oil that is weathered to this extent.

Ignition of the thick slick among the floes before it emulsifies is not recommended; the average slick thickness is greater than the minimum ignitable thickness for weathered oil on water and the fire could spread, uncontrolled, over the entire thick slick and back to the spill source.

The oil that falls on the ice floes in this scenario is ideal for *in situ* burning operations. After allowing the surface oil to concentrate in melt pools, about 60% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80% and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (90% of the total) would be ignited by Heli-torch operations results in an overall oil removal by burning of :

daily oil removed from floes by burning = (12,000 bbl) x (21% on ice) x 80% x 90% = 1815 bbl

A similar overall reduction in on-water *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (95%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil removed from water by ISB} &= 0 \text{ bbl/day} \times 0.97 \times 0.66 \times 0.95 \div 12,000 \text{ bbl/day} \\ &= 0 \% \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of on-ice ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow reduced to account for evaporative losses is:

$$\begin{aligned} \text{Oil volume removed from ice by ISB} &= 1815 \text{ bbl/day} \div 12,000 \text{ bbl/day} \\ &= 15 \% \end{aligned}$$

The total oil removed by ISB operations both on water and ice is:

$$\begin{aligned} \text{Total oil removed by ISB operations} &= 0\% + 15 \% \\ &= 15 \% \end{aligned}$$

## **6.6 Scenario 5. Pt. McIntyre in 5/10ths Ice Cover During Break-up**

### **6.6.1 Blowout/Spill Behavior (Scenario 5. Pt. McIntyre, 5/10ths Ice, Break-up)**

An uncontrolled blowout occurs in early July at the Pt. McIntyre drill site releasing 12,000 barrels of oil per day (BOPD) and  $9 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 750 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 34 °F to a daytime high of 45 °F. The wind speed averages 9 knots from the NW. The water to the east of the causeway is covered by 5/10ths melting ice floes. The ice is 3 to 4 feet thick and its surface is 40% to 50 % covered by melt ponds. The floes are fifty to five hundred feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.3 knots to the SE. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the pack).

As the oil and gas exits the 4-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 80 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind.

In this scenario, the slick is 100 feet wide and 2.1 mm thick at the starting point of the surface slick modeling. This is at a distance of some 500 feet downwind of the blowout. At this point, the oil slick is assumed to be evaporated to 20% loss.

For the purposes of this scenario, it is estimated that 50% of the oil spray lands on water and 50% lands on the ice surface. The spray that lands on ice floes coats the surface and is slowly flushed by melt water into the melt pools on the floes. The range of oil thicknesses initially deposited on the floe surfaces ranges from 3.7 mm near the center-line of the oiled strip to 0.01 mm at the edges. The

flushing process results in wind-herded oil thicknesses on the melt pools of 10 mm. The oil covers up to 75% of the surface area of the melt pools; the largest slicks are on floes near the center-line of the oiled strip. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 22% after 72 hours.

Table 6-14 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 25,000 cP and a Pour Point of 68 °F at the point where the on-water modeling is started. As such, the oil slick does not spread on water. For the duration of the scenario (72 hours) the slick moves with the oiled ice floes and does not spread further, although the thick slick may meander somewhat in the pack ice field due to oceanic eddies or large-scale turbulence.

The presence of ice inhibits the wave action that would normally exist with a 9 knot wind and suppresses natural dispersion of the oil slick. The ice also suppresses the formation of a water-in-oil emulsion.

The thick oil slick continues to evaporate slowly throughout the 72 hour scenario. It loses 20% of its volume to evaporation after 24 hours; 21% after 48 hours; and, 21% after 72 hours. The viscosity of the unemulsified oil increases to 27,000 cP after 24 hours; 28,000 cP after 48 hours; and, 30,000 cP at 72 hours. The Pour Point of the oil after 72 hours has increased to 70 °F.

At the end of the 72 hour scenario period 22% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 35% on the surface of ice floes. The oiled area is a long (19 nautical miles), narrow (100 feet) strip that contains 2.1 mm thick unemulsified oil slicks on the water between floes. The ice floes that were sprayed with oil as they passed under the blowout plume contain melt pools with 10 mm thick slicks of oil covering up to 75% of the pool's surface. The larger pools of oil are on the floes near the center-line of the oiled strip.



Ultimately, the rotting ice will release any oil still remaining in the form of thin sheens trailing the drifting floes.

**TABLE 6-14**  
**Summary of slick characteristics from a blowout during break-up at Pt. McIntyre in**  
**5/10ths ice cover over 72 hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	22	0	25000	2.1	100
3	22	0	26000	2.1	100
6	22	0	26000	2.1	100
12	22	0	26000	2.1	100
24	22	0	27000	2.1	100
48	22	0	28000	2.1	100
72	22	0	30000	2.1	100

#### 6.6.2 Existing Methods (Scenario 5. Pt. McIntyre, 5/10ths Ice, Break-up)

As in the previous break-up scenario, the relatively narrow slick of thick oil means it can be encountered in its entirety by one or two containment and recovery systems. For the moment the evaluation will consider one system operating at a fixed location down drift of the blowout site, with the potential effectiveness of additional systems analyzed later.

The slick conditions of interest are similar to the previous break-up scenario except that the oil does not emulsify due to the dampening effect on the wave energy of the higher ice concentration. At a point 3 hours down drift of the blowout, the thick slick is 100 feet wide and averages 2.1 mm thick. Combining this with the drift rate of 0.3 knots, and accounting for the ice concentration of 50%, the encounter rate for oil on water and available for recovery is estimated as:

$$\begin{aligned} \text{encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap ratio}) \times 2.1 \text{ mm} \times 0.3 \text{ knots} \times (1 - 50\% \text{ ice}) \\ &= 112 \text{ bbl/hour} \end{aligned}$$

This encounter rate is less than the derated recovery rate of several of the offshore skimmers that could be used, so the encounter rate is the limiting factor and is used in the calculations of recovery effectiveness. Following the same calculation procedure and guidelines for oil recovery efficiency, the total fluid recovery rate can be estimated as shown below:

**TABLE 6-15**  
**Fluid Recovery Rates for Scenario 5**

Fluid	Calculation	Recovery rate
oil	lesser of system encounter rate and derated recovery rate	112 bbl/hr
total water	oil content in recovered fluid (recovery efficiency) = 20%	448 bbl/hr
emulsified water	emulsified water content in recovered fluid = 40%	75 bbl/hr
free water	total water less emulsified water	373 bbl/hr
total fluids	oil + emulsified water + free water	560 bbl/hr

Compared with the previous break-up scenario, the main difference here is the greater ice concentration and its effect on containment efficiency. For the 50% ice condition, the containment efficiency is assumed to be 40%; that is, the containment operation is effective for 40% of the time accounting for interruptions related to clearing ice from the containment and repositioning the system when avoiding large floes. Given the 24-hours of daylight at this time of year, the total fluid volumes per day are calculated in the following table, combining the hourly rates and the 40% encounter efficiency.

**TABLE 6-16**  
**Estimate of Recovered Fluids per 24-hr Time Period**

Item	Calculation	Volume
total fluids per 24 hours	560 bbl/hr x 24 hours x 40%	5376 bbl
total free water	373 bbl/hr x 24 hours x 40%	3581 bbl
volume that can be decanted	total free water x 80%	2865 bbl
total fluids stored per 24 hours	total fluids less decant	2511 bbl
oil	112 bbl/hr x 24 hours x 40%	1075 bbl
emulsified water	75 bbl/hr x 24 hours x 40%	720 bbl
free water	total free water x 20%	716 bbl

The above calculations were for one system which could encounter the entire width of the thick slick. As in the previous break-up scenario, additional systems could be used to attempt to recover oil from the thick slick that is missed by the first system. The target for the additional systems is the oil that escapes containment due to inefficiencies associated with the ice conditions, assumed to be 60% for the 50% ice condition. Using the same calculation procedure as in the previous break-up scenario, a total of three additional systems are considered in sequence. For each system, the encounter rate is estimated by subtracting the oil recovered by the previous system and estimating an equivalent average oil thickness. The following table summarizes those calculations.

Estimate of Slick Conditions and Fluid Recovery for Four Systems Operated Sequentially				
System	Encounter thickness	Encounter rate	Oil recovered per 24 hours	Total fluid per 24 hours
#1	2.1 mm	112 bbl/hr	1075 bbl	2511 bbl
#2	1.26 mm	67 bbl/hr	643 bbl	1503 bbl
#3	0.76 mm	40 bbl/hr	384 bbl	899 bbl
#4	0.46 mm	24 bbl/hr	230 bbl	538 bbl
total	-	-	2332 bbl	5451 bbl

## **Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

The final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of visibility, VFR flying conditions, and wave heights. As for all the break-up scenarios, the response time is estimated to be 12 hours, so for the 15-day period the effect is to reduce effectiveness by 3%  $((15 - \frac{1}{2}) \div 15 = 0.97)$ . Also for all break-up scenarios, the combination of the three environmental factors are such that, on average, mechanical containment and recovery will be effective 66% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 2332 \text{ bbl/day} \times 0.97 \times 0.66 \div 12,000 \text{ bbl/day} \\ &= 12 \% \end{aligned}$$

### **6.6.3 Additional Systems (Scenario 5. Pt. McIntyre, 5/10ths Ice, Break-up)**

The above analysis described the potential effectiveness for four containment and recovery systems. Although one system can encounter the entire width of the thick slick, it is assumed that a substantial amount of oil is lost due to having to maneuver around ice floes and clear smaller ice from the containment configuration. Three additional systems were then analyzed for their ability to sequentially recover oil missed due to these inefficiencies. Any additional systems would be limited to chasing thin sheens outside the area of thick oil, or attempting to recover oil missed by the first four systems. In either case, the daily recovery volume would be less than 1% or less of the daily blowout volume.

#### 6.6.4 Dispersant-Use and Burning (Scenario 5. Pt. McIntyre, 5/10ths Ice, Break-up)

**Dispersant Use.** As mentioned in Scenario 4 this spill becomes too viscous too soon to consider using chemical dispersants.

**In situ Burning.** As discussed in the mechanical recovery analysis above, most of the thick slick emanating from the blowout can be dealt with by the containment and recovery operation. However, a description and assessment of an on-water *in situ* burning operation is given below for illustrative purposes. Burning of the oil that lands on ice floes is also discussed.

The requirements for *in situ* burning in this scenario would be 300 feet of fire boom and two tugs. A helicopter carrying a Heli-torch would support the burn operation. The encounter rate of each burn unit for this scenario is the same as for the recovery unit at:

$$\begin{aligned} \text{ISB encounter rate (max)} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 2.1 \text{ mm} \times 0.3 \text{ knots} \times (1 - 50\% \text{ ice}) \\ &= 112 \text{ bbl/hr} \end{aligned}$$

Again, the ISB system would be used in a "batch" mode. Oil is collected in the back of the boom for a certain period of time, then the system is moved away from the heavy concentrations of oil and the accumulated oil is burned off. It is assumed that the thick slick is encountered and collected for 50% of the time, and the remainder of the time is spent burning off the accumulated oil and maneuvering the unit back into the thick oil slick. This equates, over a 24-hour day, to collecting oil for 12 hours and burning and maneuvering for 12 hours. Each individual burn would take about 1.2 hours from ignition to extinction. Twice each day, the section of fire boom would have to be replaced. It is potentially twice as efficient to collect and burn simultaneously; however, because the average oil slick thickness emanating from the source equals the minimum ignitable for weathered crude (ca. 2 mm) there would be a danger of the fire burning back to the spill source.

The estimated daily removal rate for one ISB unit is thus:

$$\text{ISB unit daily removal rate from the water surface} = (112 \text{ bbl/hr} \times 24 \text{ hr}) \times 0.5 = 1344 \text{ bbl}$$

If two units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 2688 bbl. This is slightly higher than the case of containment and recovery because it is envisioned that burning, then maneuvering the ISB unit back into the thick oil will take less time than for the conventional boom and skimmer system.

The oil that falls on the ice floes in this scenario is ideal for *in situ* burning operations. After allowing the surface oil to concentrate in melt pools, about 75% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80% and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (90% of the total) would be ignited by Heli-torch operations results in an overall oil removal by burning of:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 12,000 \text{ bbl} \times 35\% \text{ on ice} \times 80\% \times 90\% \\ &= 3024 \text{ bbl} \end{aligned}$$

A similar overall reduction in on-water *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (95%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil removed from water by ISB} &= 2688 \text{ bbl/day} \times 0.97 \times 0.66 \times 0.95 \div 12,000 \text{ bbl/day} \\ &= 14\% \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of on-ice ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil volume removed from ice by ISB} &= 3024 \text{ bbl/day} \div 12,000 \text{ bbl/day} \\ &= 25 \% \end{aligned}$$

The total oil removed by ISB operations both on water and ice is:

$$\begin{aligned} \text{Total oil removed by ISB operations} &= 14 \% + 25 \% \\ &= 39 \% \end{aligned}$$

## **6.7 Scenario 6. Pt. McIntyre in 7/10ths Ice Cover During Break-up**

### **6.7.1 Blowout/Spill Behavior (Scenario 6. Pt. McIntyre, 7/10ths Ice, Break-up)**

An uncontrolled blowout occurs in early July at the Pt. McIntyre drill site releasing 12,000 barrels of oil per day (BOPD) and  $9 \times 10^6$  standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 750 scf/bbl). Over the first 72 hours of the incident, the air temperature ranges from a nighttime low of 34 °F to a daytime high of 44 °F. The wind speed averages 17.5 knots from the SW. The water to the east of the causeway is covered by 7/10ths melting ice floes. The ice is 3 to 4 feet thick and its surface is 40% to 50 % covered by melt ponds. The floes are fifty to five hundred feet in size. The ice is drifting at the same speed as the water (both wind-driven at 3% of the wind speed) at 0.5 knots to the NE. These conditions do not change over the time period of the scenario; as well, the ice concentrations do not change as it drifts away from the spill site (i.e., no convergence or divergence of the pack).

As the oil and gas exits the 4-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and agglomerate. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 40 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind.

In this scenario, the thick slick is 100 feet wide and 1.1 mm thick at the starting point of the surface slick modeling. This is at a distance of some 500 feet downwind of the blowout. At this point, the oil slick is assumed to be evaporated to 20% loss.

For the purposes of this scenario, it is estimated that 30% of the oil spray lands on water and 70% lands on the ice surface. The spray that lands on ice floes coats the surface and is slowly flushed by melt water into the melt pools on the floes. The range of oil thicknesses initially deposited on the floe surfaces ranges from 1.9 mm near the center-line of the oiled strip to 0.006 mm at the edges. The



flushing process results in wind-herded oil thicknesses on the melt pools of 10 mm. The oil covers up to 40% of the surface area of the melt pools; the largest slicks are on floes near the center-line of the oiled strip. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 22% after 72 hours.

Table 6-17 summarizes the predicted characteristics of the thick slick over a time period of 72 hours. The oil that forms the thick slick on the water has a viscosity of 25,000 cP and a Pour Point of 68 °F at the point where the on-water modeling is started. As such, the oil slick does not spread on water. For the duration of the scenario (72 hours) the slick moves with the oiled ice floes and does not spread further, although the thick slick may meander somewhat in the pack ice field due to oceanic eddies or large-scale turbulence.

The presence of ice inhibits the wave action that would normally exist with a 17.5 knot wind and suppresses natural dispersion of the oil slick. The ice also suppresses the formation of a water-in-oil emulsion.

The thick oil slick continues to evaporate slowly throughout the 72 hour scenario. It loses 21% of its volume to evaporation after 24 hours; 22% after 48 hours; and, 22% after 72 hours. The viscosity of the unemulsified oil increases to 29,000 cP after 24 hours; 33,000 cP after 48 hours; and, 36,000 cP at 72 hours. The Pour Point of the oil after 72 hours has increased to 73 °F.

At the end of the 72 hour scenario period, 12% of the oil released at the beginning of the scenario still remains in thick slicks on the water surface between floes and 49% remains on the surface of ice floes. The oiled area is a long (38 nautical miles), narrow (100 feet) strip that contains 1 mm thick unemulsified oil slicks on the water between floes. The ice floes that were sprayed with oil as they passed under the blowout plume contain melt pools with 10 mm thick slicks of oil covering up to 40% of the pool's surface. The larger pools of oil are on the floes near the center-line of the oiled strip.

Ultimately, the rotting ice will release any oil still remaining in the form of thin sheens trailing the drifting floes.

**TABLE 6-17**  
**Summary of Slick Characteristics from a Blowout During Break-up**  
**at Pt. McIntyre in 7/10ths Ice Cover over 72 Hours**

Time (h)	Thick oil left on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	12	0	25000	1.1	100
3	12	0	26000	1.1	100
6	12	0	26000	1.1	100
12	12	0	27000	1.1	100
24	12	0	29000	1.1	100
48	12	0	33000	1.1	100
72	12	0	36000	1.1	100

**6.7.2 Existing Methods (Scenario 6. Pt. McIntyre, 7/10ths Ice, Break-up)**

Compared with the previous two scenarios during break-up, the greater ice concentration in this scenario limits the amount of oil on the water and available for containment and recovery, as well as severely limiting the applicability of containment and recovery countermeasures. The slick conditions are roughly the same as the other two break-up scenarios allowing the same general approach and equipment for containment and recovery. However, the encounter rate, when reduced to account for the 70% ice concentration, will be much less than the available skimming capacity. Given the 100-foot slick width, 1.1 mm slick thickness, and the 0.5 knot drift results in an encounter rate of only 59 bbl/hour.

As well, the greater ice concentration drastically affects the containment efficiency. For the 70% ice condition, the containment efficiency is estimated to be only 20%, that is, the containment operation is effective for only 20% of the time due to interruptions related to clearing ice from the containment and repositioning the system when avoiding large floes.

In all, using the same calculation procedure as in the first two break-up scenarios, only a small fraction of the blowout volume could be expected to be recovered given the 70% ice concentrations. The following is an estimate of the fluids recovered by a single containment and recovery system in a 24-hour period.

Estimate of Fluids Recovered by One System per 24-hour Time Period	
	24-hr period
total oil recovered	283 bbl
total fluid recovered	660 bbl

As in the two other break-up scenarios, additional systems could be used to contain and recover portions of the thick slick that escape containment. As noted above, the containment system is estimated to be effective only 20% of the time, so although all the slick can be encountered theoretically, an estimated 80% is lost due to inefficiencies associated with the ice conditions. Following the same calculation procedure as in the other two break-up scenarios, a total of three additional systems are considered in sequence. For each system, the encounter rate is estimated by subtracting the oil recovered by the previous system and estimating an equivalent average oil thickness. The following table summarizes those calculations.

**TABLE 6-18****Slick Conditions and Fluid Recovery for Four Systems Operated Sequentially in Scenario 6**

System	Encounter thickness	Encounter rate	Oil recovered per 24 hours	Total fluid per 24 hours
#1	1.1 mm	59 bbl/hr	283 bbl	660 bbl
#2	0.88 mm	55 bbl/hr	226 bbl	525 bbl
#3	0.70 mm	52 bbl/hr	178 bbl	416 bbl
#4	0.56 mm	48 bbl/hr	144 bbl	336 bbl
total	-	-	831 bbl	1937 bbl

Unlike the previous two breakup scenarios, the oil recovered per system does not decline substantially. This is related to the very low effectiveness of each system due to inefficiencies associated with the 70% ice concentration. Because each of the systems recovers only a fraction of the available thick slick, the slick is essentially unchanged by each successive system. One might be tempted to suggest adding even more systems, but it should be noted that the last of the four noted above recovers only about 1% of the blowout volume, and subsequent systems would accomplish even less.

#### **Predicted Effectiveness of Existing Mechanical Systems in Recovering 15-Day Discharge**

This final step in this section is to use the above calculations to assess the effectiveness of existing systems to deal with the total volume of oil discharged over the 15-day blowout period. The assessment includes the effects of response-time delays, and the environmental derating factors of visibility, VFR flying conditions, and wave heights. As for all the break-up scenarios, the response time is estimated to be 12 hours, so for the 15-day period the effect is to reduce effectiveness by 3% ( $(15 - \frac{1}{2}) \div 15 = 0.97$ ). Also for all break-up scenarios, the combination of the three environmental factors are such that, on average, mechanical containment and recovery will be effective 66% of the time. The following is the estimate of effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= 831 \text{ bbl/day} \times 0.97 \times 0.66 \div 12,000 \text{ bbl/day} \\ &= 4.4 \% \end{aligned}$$

### 6.7.3 Additional Systems (Scenario 6. Pt. McIntyre, 7/10ths Ice, Break-up)

The above analysis described the potential effectiveness for four containment and recovery systems. Although one system can encounter the entire width of the thick slick, it is assumed that a substantial amount of oil is lost due to having to maneuver around ice floes and clear smaller ice from the containment configuration. Three additional systems were then analyzed for their ability to sequentially recover oil missed due to these inefficiencies. As noted above, any additional systems would have a daily recovery volume of less than 1% or less of the daily blowout volume.

### 6.7.4 Dispersants and Burning (Scenario 6. Pt. McIntyre, 7/10ths Ice, Break-up)

The viscosity of the oil and the ice conditions are too formidable in this scenario to consider the use of dispersants.

If it were necessary to implement *in situ* burning in this scenario 300 feet of fire boom and two workboats would again be needed. A helicopter carrying a Heli-torch would support both the on-water and ice floe burn operations. The encounter rate of each burn unit would be:

$$\begin{aligned} \text{ISB encounter rate (max)} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 1.1 \text{ mm} \times 0.5 \text{ knots} \times (1 - 70\% \text{ ice}) \\ &= 59 \text{ bbl/hr} \end{aligned}$$

The ISB system, used in a "batch" mode, would encounter thick slick 50% of the time; the remainder of the time would be spend burning off the accumulated oil and maneuvering the unit back into the thick oil. This equates, over a 24-hour day, to collecting oil for 12 hours and burning and maneuvering for 12 hours. Each individual burn would take about 1.2 hours from ignition to extinction. Twice each day, the section of fire boom would have to be replaced. It is potentially twice as efficient to collect and burn simultaneously; however, because the average oil slick thickness

emanating from the source is only one-half the minimum ignitable for weathered crude (ca. 2 mm) there would be a danger of the fire burning back to the spill source.

The estimated daily removal rate for one ISB unit is thus:

$$\begin{aligned} \text{ISB unit est. daily removal rate from the water surface} &= 59 \text{ bbl/hr} \times 24 \text{ hr} \times 0.5 \\ &= 708 \text{ bbl} \end{aligned}$$

If two units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 1416 bbl. This is slightly higher than the case of containment and recovery because it is envisioned that burning, then maneuvering the ISB unit back into the thick oil will take less time than for the conventional boom and skimmer system.

The oil that falls on the ice floes in this scenario is ideal for *in situ* burning operations. After allowing the surface oil to concentrate in melt pools, about 40% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80% and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (85% of the total) would be ignited by Heli-torch operations results in an overall oil removal by burning of:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 12,000 \text{ bbl} \times 49\% \text{ on ice} \times 80\% \times 85\% \\ &= 4000 \text{ bbl} \end{aligned}$$

A similar overall reduction in on-water *in situ* burning effectiveness to that determined above for mechanical containment and recovery, can be estimated using the same response time and environmental factors as for mechanical containment and recovery. For ISB operations the additional factor of the percentage of time that winds are less than 20 knots (95%) is also taken into account. The estimate of ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil removed from water by ISB} &= 1416 \text{ bbl/day} \times 0.97 \times 0.66 \times 0.95 \div 12,000 \text{ bbl/day} \\ &= 7.1\% \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of on-ice ISB effectiveness for the 15-day period, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Oil volume removed from ice by ISB} &= 4000 \text{ bbl/day} \div 12,000 \text{ bbl/day} \\ &= 33 \% \end{aligned}$$

The total oil removed by ISB operations both on water and ice is:

$$\begin{aligned} \text{Total oil removed by ISB operations} &= 7.1 \% + 33 \% \\ &= 40 \% \end{aligned}$$

## 6.8 Potential Benefits of Well Ignition

One option available to reduce or prevent oil entering the water is to intentionally ignite the well and consume as much as possible of the oil spray in the ensuing gas fire. The decision to ignite a well blowout is not one that should be taken lightly or made quickly. Checklists of questions and guidelines to assist with the decision are available (SL Ross and Energetex 1986). Based on equations in that report used to estimate the oil droplet combustion efficiency in such situations, 99% of the volume of oil droplets from the hypothetical blowout at Northstar would be consumed and 75% of the volume of oil droplets from the Pt. McIntyre blowout would be burned. The main difference between the two efficiencies is the greater flow-rate of gas with the Northstar well,  $33 \times 10^6$  standard cubic feet (scf) of natural gas per day as opposed to  $9 \times 10^6$  scf/day.

Based on measurements of the soot produced by burning oil and gas blowouts during the Gulf War, about 2 to 3% of the mass of oil burned in the blowout fire would be emitted as particulate matter (Laursen et al. 1992). This is much less than the expected soot yield of large *in situ* oil fires, which is on the order of 15% by mass (Fraser et al. 1997).

## 6.9 Potential Benefits of Deflecting the Blowout Plume

It has been suggested that perhaps the plume of gas and oil droplets emanating from the wellhead could be mechanically deflected horizontally to reduce the initial rise height of the oil spray. This could cause the droplets to fall to the surface sooner and allow removal operations to take place closer to the source. Considering the momentum of the gas jets (for the Northstar blowout the gas is exiting at sonic velocity - 1160 mph and for the Pt. McIntyre scenario the gas is exiting at 810 mph) the positioning of a deflector in the jet would be a considerable engineering challenge. As well, the deflection of the gas jet towards horizontal would change the dispersion of the gas and quite likely considerably extend the ground-level hazard zone associated with explosive concentrations of gas. The assessment of the feasibility of this concept is beyond the scope of this study.



It has also been suggested that a device could be inserted into the gas jet to agglomerate the oil spray droplets, increase their size and cause them to fall to the surface in shorter distances. Many such devices exist in the realm of air pollution control technology. The simplest, and perhaps most applicable to the envisioned use, are called demisters. These devices involve passing a gas stream laden with small droplets through a section of duct loosely packed with fine mesh. The droplets collide with and collect on the strands of mesh. As the strands become saturated with liquid, larger droplets are torn off by the passing gas. This process causes the droplet size distribution to be shifted upwards significantly. For a given liquid, there is a droplet diameter below which demisters are not effective, because these small droplets do not have sufficient mass to cross gas flow streamlines and collide with the strands, but are carried around the strands by the gas. As with the placement of a deflector in a blowout plume, the positioning of a demister in the jet would be a considerable engineering challenge. The assessment of the feasibility of this concept is beyond the scope of this study.

## 6.10 Summary of Countermeasures Effectiveness

### 6.10.1 Existing Countermeasures

In this chapter, six blowout scenarios were examined to determine the potential effectiveness of existing countermeasures, that is, excluding any possible use of dispersants or in-situ burning; the results are summarized in the table below. Effectiveness is defined here as the percentage of the blowout flow over the 15-day period that could be recovered by existing response systems. A second effectiveness number is also shown: it takes into account the reduction in blowout volume due to evaporative losses – fixed at 20 % for all scenarios – and losses due to tiny-particle drift – estimated to be 10 % of the total blowout flow. This second effectiveness number is therefore the percentage recovery of the oil that is estimated to land in the marine environment, that is, 70 % of the total blowout flow.

**TABLE 6-19**  
**Summary of Recovery Effectiveness for Six Scenarios**

Scenario Parameters	Freeze-up			Break-up		
	Ice Coverage			Ice Coverage		
	30%	50%	70%	30%	50%	70%
Estimated 15-day recovery, percentage of total blowout	5.9	2.2	0.6	18	12	4.4
Estimated 15-day recovery, percentage of total blowout that reaches ice/water surface	8.5	3.1	0.8	25	18	6.3

The results are discussed below according to the major variables in the analysis.

**Effects of Ice.** The ice concentrations in the six scenarios varied from 30% to 70% coverage. For spills in ice resulting from a blowout, the presence of ice floes has two negative implications. The first is simply that a certain percentage of the blowout lands on ice and is thus unavailable for containment and recovery based countermeasures. The second is that as the ice coverage increases, it will become more and more difficult to operate containment boom to concentrate oil for recovery. While broken ice is sometimes said to have a positive effect on spill behavior by reducing the normal effects of spreading, this is of little benefit for blowout spills where the initial slick thicknesses, even in the thick portion of the slick, are often less than 1 mm.

Particularly for the spills in 70% ice coverage, the effect of ice is to make a containment and recovery response essentially pointless. The combination of only 30% of the blowout flow actually landing on water and thus being available for recovery and the low efficiency of containment operations means that less than one percent, at best, of the total blowout flow could be recovered.

The situation for the 30% ice scenarios is somewhat better, with more of the oil landing on the water between floes, and more efficient containment operations.

**Initial Slick Conditions.** As described in each of the scenarios, the blowout plume comprises a range of sizes of oil droplets that rain down on the ice/water surface at some distance from the spill source. The result is a thick, relatively narrow band of oil directly down drift of the blowout source, with a much wider, relatively thin area on each side of the thick slick. It is estimated that about 60% of the oil that eventually reaches the surface will land in the thick portion of the slick.

It was also assumed that 20% of the total blowout flow would evaporate from the droplets in the air, and it was estimated that 10% of the droplets would be so small that they would remain suspended in the atmosphere. In total, an estimated 70% of the blowout flow will eventually reach the ice/water surface.

Combining the above numbers means that only about 40% of the total blowout flow (0.6 x 0.7) will reach the surface and form a thick slick. About 30% of the total blowout flow (0.4 x 0.7) will reach

the surface, but in a relatively thin slick for which a containment and recovery response would be relatively ineffective, even in open water conditions. The slick thickness in these thin portions is estimated to be 0.035 mm, meaning encounter rates would be on the order of 5 to 10 bbl/hour, and daily recovery volumes would be less than 1% of the blowout flow.

**Daylight Hours.** It was assumed that containment and recovery operations would be conducted only during daylight hours, for reasons of worker safety and due to difficulties in positioning containment equipment relative to the thick portions of the slick. For the freeze-up scenarios, with daylight hours ranging from 8 to 12 hours, this causes a decrease in effectiveness to only one-third to one-half what it otherwise could be. There is no reduction in effectiveness in the break-up scenarios given the 24-hours of daylight at that time of year.

**Other Problems During Freeze-up.** In addition to the limited number of daylight hours, there are two additional concerns during the freeze-up period that cause a reduction in effectiveness for the first three scenarios. The first is that the ice conditions at West Dock, where the primary equipment and marine logistics are located, will limit the speed of the initial response. In the freeze-up scenarios, it was estimated that the response time for containment and recovery would be 60 hours as opposed to the 12 hours used in the break-up scenarios. Over the 15-day period, this translates into a loss in effectiveness of 17%  $((15 \text{ days} - 60 \text{ hours}) \div 15 = 83\%)$ .

**Weather Limitations.** In the calculations of effectiveness, the first step was to estimate a daily recovery volume for the specified number of systems. This number was then used to calculate a 15-day recovery percentage, incorporating the effects of response time and the effects of weather limitations. For the freeze-up scenarios this latter factor was estimated to be 77%; that is, operations would be effective 77% of the time, combining suitable conditions of waves less than 3 feet (84%), visibility greater than ½-mile (95%), and ceiling height greater than 1500 ft (97%). Similarly, for the break-up scenarios, operations would be effective 66% of the time, combining waves less than 3 feet (95%), visibility greater than ½-mile (78%), and ceiling height greater than 1500 ft (89%).

**Equipment and Logistical Limitations.** As discussed above, the relatively narrow thick slick does allow for reasonable encounter rates using a limited number of containment and recovery systems and relatively short lengths of boom. In fact, in each of the six scenarios, the entire width of the thick slick could be encountered using one or two systems with a total boom length of no greater than 720 feet. Similarly, there are a number of skimmers with (derated) recovery rates that exceed the rate at which oil would be encountered in the thick slick, so the capability of recovery equipment should not limit the operation. Finally, there are adequate logistical systems to support the containment and recovery operation, including the storage and transfer of recovered fluids.

In each of the scenarios, consideration was given to the possible effectiveness of additional containment and recovery systems. In each case it was found that any such equipment would be limited to chasing relatively thin slicks of oil - either that which originally landed outside the thick portion of the slick or that which was lost past containment due to ice problems - and would contribute little to the overall effectiveness.

#### **6.10.2 Alternative Countermeasures**

For each of the six blowout scenarios the potential effectiveness of alternative countermeasures was also examined. This includes the use of dispersants, in-situ burning, and igniting the well to burn off the oil as it is emitted from the well. The results are summarized in the table below. In each case, effectiveness is defined as the percentage of the blowout flow over the 15-day period that could be dealt with by the particular technique.

**TABLE 6-20**

**Summary of Recovery Effectiveness<sup>1</sup> for Alternative Countermeasures**

Scenario Parameters	Freeze-up			Break-up		
	Ice Coverage			Ice Coverage		
	30%	50%	70%	30%	50%	70%
Existing Countermeasures	5.9	2.2	0.6	18	12	4.4
Dispersant-Use	4.2	0	0	0	0	0
In-Situ Burning <sup>2</sup> - on-water	3.4	2.2	6.4	0	14	7.1
- on-ice	0	0	0	15	25	33
Well Ignition	99			74		

1. All figures expressed as a percentage of total blowout flow.  
 2. Note that ISB on-water effectiveness is for comparison with existing containment and recovery effectiveness; ISB on-ice effectiveness would be in addition to either containment and recovery or ISB on-water effectiveness.

**Dispersant Use.** The use of dispersants is an attractive option for dealing with blowout-type spills, particularly those that are relatively close to centers of logistic support, as are the spills in these scenarios. The modest daily spill rate combined with the ability to deliver the required quantities of dispersant while the oil is relatively thick mean that there are good opportunities for application. However, the fact that there is broken ice has two major impediments to the overall effectiveness of a dispersant operation. First, the presence of ice tends to dampen any wave action which is required to allow dispersants to be fully effective. In this evaluation, it is assumed that dispersants would be ineffective in the 50% and 70% ice scenarios due to the limited wave energy, although dispersant application might be attempted. The second limitation is that, with the blowout spills in these scenarios, a fixed percentage of oil lands not on the water surface but on the ice as it drifts past the spill source (a percentage that matches the average ice concentration) and this oil would not be

"available" for dispersing into the water. This latter point applies equally to containment and recovery.

An additional negative, not related to the ice coverage, is the properties of the oil chosen for the break-up scenarios. Although the 24-hours of daylight would have otherwise made these scenarios attractive to a serious dispersant effort, the oil is of a viscosity that is currently thought to be resistant to dispersant effectiveness. It should be noted that the Pt. McIntyre oil used in the break-up scenarios has a viscosity that is atypical of North Slope crudes, and that most other oils could be much more amenable to dispersion.

On the positive side, a dispersant operation as described here could be mounted relatively quickly, within 12 hours as opposed to the 60 hours estimated for containment and recovery in the freeze-up scenarios.

**In-situ Burning.** For the freeze-up scenarios at low and medium ice concentration, in-situ burning offers little advantage over containment and recovery techniques. Because the slicks emanating from the blowout are below burnable concentrations, containment is required to concentrate and thicken the oil before it is burned. As in the evaluations of booming and skimming, in-situ burning is limited in these scenarios by both the inability to effectively contain oil among broken ice and the fact that there is only 10-1/2 to 12 hours of daylight. It should be noted that in these scenarios, although burning offers little theoretical improvement in effectiveness compared with containment and recovery, the lesser logistical requirements may lead to greater effectiveness in an actual spill incident.

For the freeze-up scenario in 7/10ths ice, there is a potential to contain and burn oil using the area of open water -- or wake -- that is likely to be present down drift of the production island. In this situation, a batch-type contain-and-burn operation is estimated to burn off up to 6.4% of the total blowout flow, well in excess of the predicted effectiveness of a containment and recovery operation.

For the break-up scenarios, burning on water using fire containment boom provides an effectiveness that is approximately equal to that afforded by containment and recovery. Because of the above-freezing temperatures, oil that lands on ice will tend to be herded into concentrations that may allow burning using only the natural containment provided by the ice. In this situation, burning the oil that lands on floes and concentrates in melt pools offers an oil removal capability that would supplement either the on-water burning operation or containment and recovery.

**Well Ignition.** The possibility and potential effectiveness of intentionally igniting the blowing well was briefly examined. Based on previous studies on this subject, it is estimated that up to 74% for the Pt. McIntyre scenarios (break-up) and up to 99% of the Northstar scenarios (freeze-up) would be consumed in such a fire. The main differences between the two wells is the much higher gas flow rate at Northstar.



## 7. Conclusions

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Six hypothetical oil well blowout scenarios were examined to determine the potential effectiveness of spill countermeasures in broken ice situations. The evaluation first analyzed the existing countermeasures capability, and then looked at the potential for improvements to effectiveness using alternative techniques such as dispersant use and *in situ* burning.

The spills that result from the blowouts will result in a relatively narrow slick of thick oil surrounded by a much wider, relatively thin slick. Near the spill source, the thick portion of the slick will have a width of 100 to 240 feet, a thickness of 0.5 to 2.1 mm, and will contain approximately 40% of the total blowout flow. The thin portion of the slick will have a slick thickness of only 0.035 mm, and will contain an estimated 30% of the total blowout volume. (The remaining 30% is predicted to either evaporate from airborne droplets or remain suspended in the air due to their very small size.)

The analysis of existing countermeasures predicts a range of spill recovery effectiveness values depending on the amount of ice coverage and season (break-up vs. freeze-up). Expressed as a percentage of the total blowout volume, estimated effectiveness varies from about 1% for the 7/10ths ice cover at freeze-up to as high as 18% for the 3/10ths ice cover during break-up.

As discussed in detail at the conclusion of the previous chapter these seemingly low percentages are caused by a combination of factors inherent to the scenarios:

- Only about 40% of the total blowout volume lands on the ice/water surface in a slick that is thick enough to allow effective use of containment and recovery equipment.
- Of the oil that lands on the ice/water surface, a fixed percentage (i.e., the assumed ice concentration) lands on ice floes and cannot be efficiently recovered mechanically.
- In the 50% and 70% ice scenarios, a containment and recovery operation would be severely limited by the need to regularly reposition containment booms and/or clear ice from the

containment area. It may be possible to use skimmers, without containment boom, to recover isolated pockets of oil; however, this approach would also severely limit the encounter rates owing to the relatively thin initial slick conditions resulting from blowout spills.

- In the freeze-up scenarios, the limited number of daylight hours restricts the possible effectiveness. It is assumed that operations will only be conducted during daylight hours due to the difficulties in positioning the containment and recovery equipment relative to the thick portions of the slick.

Employing additional containment and recovery equipment is unlikely to improve significantly on the above estimates of effectiveness. In each of the scenarios, the entire swath of thick oil can be encountered by one or two containment and recovery systems using modest lengths of boom. Any additional equipment would be limited to chasing relatively thin slicks of oil and would contribute little to the overall effectiveness.

Dispersants should be useful for responding to blowout spills in light ice conditions. Dispersant-use is likely to be more effective than mechanical systems in removing oil from the surface because the method, involving application of dispersant from helicopters, avoids the usual inefficiencies of vessels and spill equipment operating in an ice-infested environment. The major problem with dispersants, however, is that wave energy is required to mix the treated oil into the water. Because of this, it was assumed in the 50% and 70% ice scenarios that dispersant-use would be ineffective due to the dampening effect on wave energy in these higher ice concentrations. Another factor that strongly influences dispersant effectiveness is the viscosity of the oil being treated. In the break-up scenarios, the viscosity of the Pt. McIntyre crude oil was judged to be too high to allow for the effective use of dispersants. Oils less viscous than Pt. McIntyre crude oil will be more amenable to chemical dispersion.

*In-situ* burning could add to the overall effectiveness, particularly in the break-up scenarios. In those scenarios, with above-freezing temperatures, oil that lands on ice floes will tend to be herded into pools on the ice that may be subsequently burned. This burning of oil on ice would be an oil removal capability that would supplement an on-water burning operation or containment and recovery effort.

Consideration could be given to intentionally igniting the well such that the oil is consumed in the burning plume of gas (The feasibility or advisability of this option was not examined, only the possible effectiveness.) Well ignition would have the potential to significantly reduce the volume of oil entering the marine environment, consuming between 74% and 99% of the assumed oil volumes.

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## Appendix A

### Background on Petroleum Activities in the Alaskan North Slope

The following was abstracted from MMS 1998 and ADNR 1998.

The North Slope of Alaska contains the largest petroleum field discovered in North America, namely, Prudhoe Bay. It also contains many satellite fields with over 100 million barrels in reserves (see Figure A-1). Production from North Slope fields, including both onshore and offshore fields, peaked in 1988 at just over 2.0 million barrels per day. Present production is 1.4 million barrels per day.

Exploration began on the North Slope in the 1920s. The first lease sale was held in 1964, and the next few years saw a series of major discoveries: Prudhoe Bay (1968), Kuparuk (1969), and Milne Point (1970). Estimated reserves from these discoveries totaled 12 billion barrels. Oil production began in 1977 after the trans-Alaska oil pipeline was constructed.

Eight of the post-Prudhoe Bay discoveries are currently producing oil because of the Prudhoe Bay infrastructure and their relatively close location to the Trans-Alaska Pipeline. Six of these, Lisburne, Kuparuk, Milne Point, Endicott, Niakuk, and Point McIntyre are major fields (Table A-1). While initial production on the North Slope was from onshore areas, four fields produce at least some of their reserves from offshore areas, these fields are Endicott, Point McIntyre, Milne Point and Niakuk.

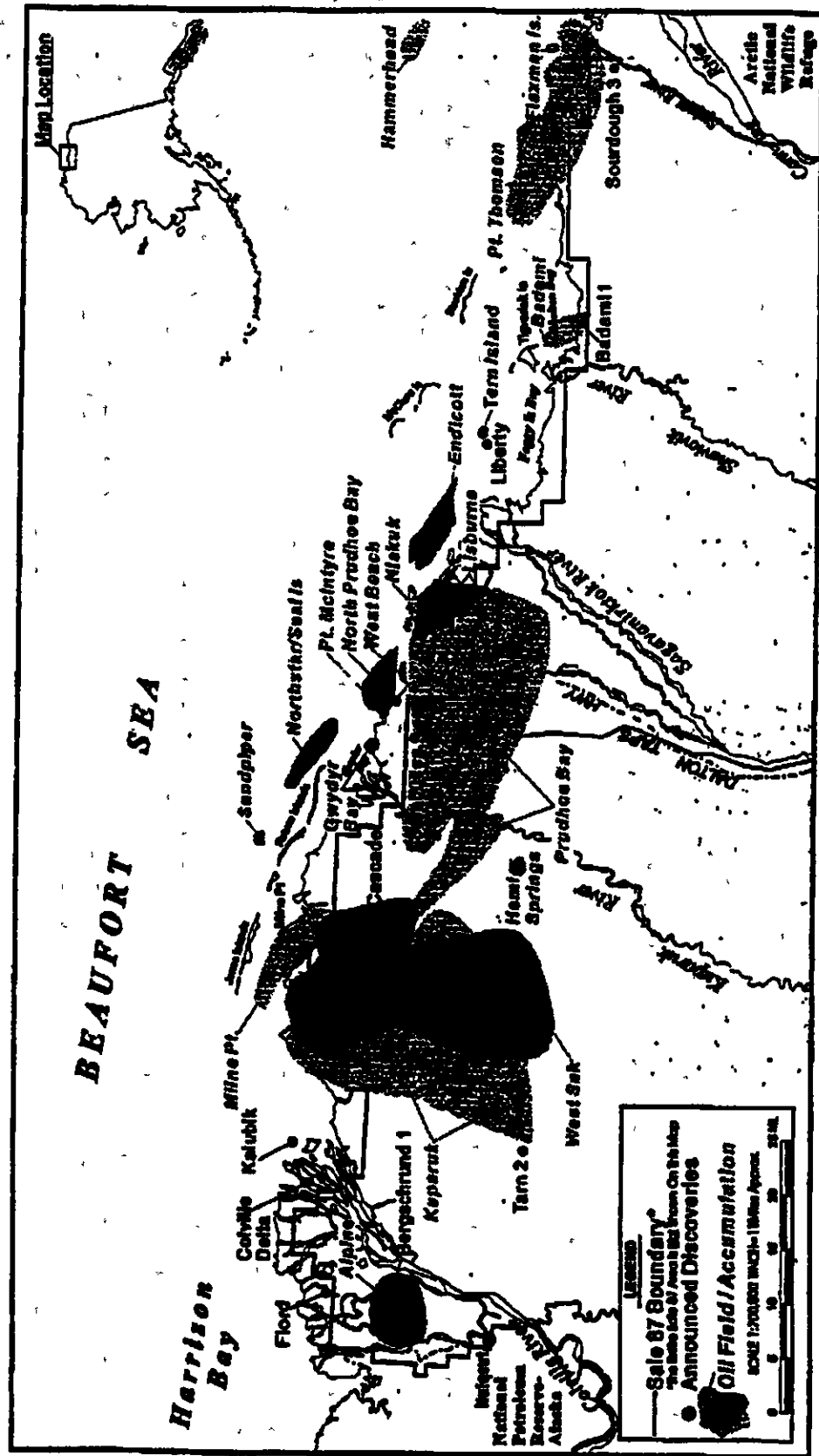
Table A-1: Major Producing Fields on the North Slope and in the Beaufort Sea

Field Name	Discovery Date	Production Began	Estimated Original Economically Recoverable Oil (MMBBL)	Estimated Original Economically Recoverable Gas (BCF)
Prudhoe Bay	1967	1977	12,219	28,203
Lisburne	1967	1981	145	362
Kuparuk	1969	1981	2,627	998
Milne Point	1969	1985	395	23
Endicott	1978	1987	622	987
Niakuk	1985	1994	66	34
Pt McIntyre	1988	1993	358	329

Source: ADNR 1998



FIGURE A-1 North Slope Fields and Announced Discoveries



Source: ADNR 1998

Offshore lands in the Beaufort Sea were first offered in 1979 in a sale that included State lands (within 3 miles of shore) and Federal lands (beyond 3 miles). Since then, several large, offshore oil fields have been discovered, including: Endicott/Duck Island, Point McIntyre, Seal Island/Northstar, Niakuk, and Tern/Liberty (in appraisal phase as of early 1998). These fields lie close to shore, beneath State lands or on the boundary between State and Federal lands. So far, only one offshore field, Endicott/Duck Island, has been developed, and it began producing in 1987. Northstar is the second offshore field scheduled for development; production is proposed to start in 1999.

The first Federal-only offshore lease sale in the Beaufort Sea was held in 1982. Since then, four more Federal sales have been held. A total of 28 exploration wells have been drilled. Nine wells are considered capable of producing oil in paying quantities. All these discoveries, however, remain undeveloped. Three presently non-commercial fields (Sandpiper, Hammerhead, and Kuvlum) have been unitized for possible future development.

In addition to Northstar, several fields have been proposed for development, including Badami, Alpine, Liberty, Tarn, and West Sak. The onshore Badami field, discovered in 1991, is estimated to contain 145 million barrels of economically recoverable oil, and is expected to come on-line in the fall of 1998.

The Liberty field is located on federal leases approximately five miles offshore in the Beaufort Sea, northwest of the Badami field. It is estimated to contain 120 million barrels of recoverable oil. Production is proposed to begin in 2000. The Tarn prospect is located southwest of Kuparuk and contains estimated proven and potential reserves of 50 million barrels. Production is expected to begin by late 1998 or early 1999.

The Sourdough field discovered in 1997 could contain 100 million barrels of recoverable oil. Further exploration is needed before determining whether to develop the field. The Sourdough project would require up to 35 miles of pipeline to link up with the Badami field to the west.

Finally, in February 1998, two new oil accumulations, Sambucca and Midnight Sun, were discovered during the drilling of a Prudhoe Bay "satellite" prospect. Test production from the discovery is planned for the first half of 1998.

## Appendix B

### Supplemental Data on Ice and Climate

To assess the potential variation from the established scenarios described in Tables 1 and 2 in the main text and the resulting effects on the oil spill response, Exceedance or cumulative probabilities for selected parameters are discussed below and presented in following tables.

- **Ice Drift Speed.** The cumulative frequency distributions of ice drift speed for freeze-up and break-up are presented in Table B-1, based on daily ice movement rates computed from ARGOS buoy records collected in the eastern Beaufort Sea during 1979-1987 and from three site-specific ARGOS buoys deployed between Northstar and West Dock during the 1996 break-up season. For example, the table can be read to show that on average, ice drift can be expected to exceed one knot at freeze-up for 1.9% of the time. It should be noted that ice drift can exceed the values shown for short periods in response to local winds and currents.
- **Wind Speed.** The cumulative frequency distribution of monthly wind speed is presented in Table B-2, along with a plot of monthly wind speed exceedance for four wind speeds (10, 15, 20, and 25 knots) in Figure A-1. During freeze-up, November is the windiest month, but October runs a close second with winds blowing harder than 15 knots 37% of the time. The winds tend to subside throughout the spring and early summer. July is the calmest month when winds are greater than 15 knots only 19% of the time.
- **Wind Direction:** The cumulative frequency distribution of monthly wind speed is presented in Table B-2, along with a plot of monthly wind speed exceedance for four wind speeds (10, 15, 20, and 25 knots) in Figure B-1. During freeze-up, November is the windiest month, but October runs a close second. For example, the table can be read to show that winds in October will be less than 15 knots 63% of the time. The winds tend to subside throughout the spring and early summer. For instance, in July, the calmest month, winds are less than 15 knots for 81% of the time. The seasonal trend in wind strength is shown clearly in Figure B-1 with the troughs in the curves corresponding to the summer period (July to August) and the peaks corresponding to the fall and early winter (October to January).
- **Air Temperature.** The cumulative frequency distribution of monthly air temperatures is given in Table B-4 for the entire year. Air temperature data are based on approximately 29 years (1957-85) of data recorded at Oliktok and 37 years (1949-85) of data recorded at Barter Island, respectively located approximately 40 nautical miles west and 90 nautical miles east of Northstar and West Dock. Except for a 1% chance that the air temperatures in October will be below  $-20^{\circ}\text{F}$ , it is unlikely that air temperatures will play any significant role in the development of oil spill response scenarios.
- **Visibility.** Visibilities from less than 0.25 nautical miles to greater than 10 nautical miles are presented in Table B-5 as cumulative probabilities of occurrence for each month. It can be seen that the break-up season during July has the most fog, with visibilities less than 0.5 miles occurring about 22% of the time. By contrast, the freeze-up season during October experience the least fog, with visibilities less than 0.5 miles occurring only 5% of the time.

**TABLE B-1**

**Exceedence Probability Distribution Of Ice Drift Speeds at Northstar and Pt. McIntyre**

<i>Season</i>	<i>Per Cent &gt; Net Daily Ice Movement Rate (knots)</i>							<i>Average Speed (knots)</i>
	<i>&gt;0.2</i>	<i>&gt;0.4</i>	<i>&gt;0.6</i>	<i>&gt;0.8</i>	<i>&gt;1.0</i>	<i>&gt;1.5</i>	<i>&gt;2.0</i>	
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

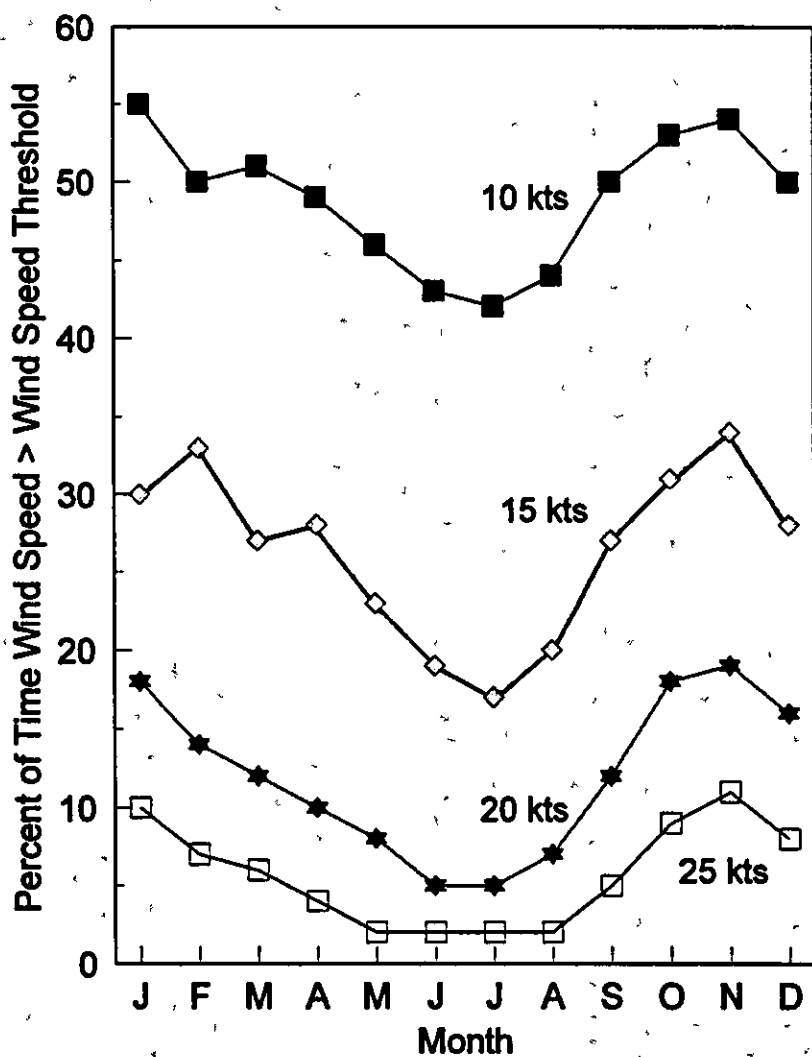
**TABLE B-2**

**Cumulative Frequency Distribution Of Monthly Wind Speeds  
at the Northstar and Pt. McIntyre Developments**

<i>Wind Speed (kts)</i>	<i>Cumulative Per Cent of Wind Speeds &lt; Listed Wind Speed</i>											
	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>July</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
5	18	20	20	21	21	21	21	18	17	15	14	18
10	46	49	48	50	50	51	52	46	42	41	38	47
15	68	71	72	72	77	77	81	76	69	63	59	72
20	82	84	88	91	92	94	95	93	84	80	76	84
25	90	93	96	97	98	98	98	98	93	90	87	92
30	96	97	99	99	100	100	100	100	98	95	94	96
35	98	99	100	100	100	100	100	100	99	98	98	99
40	99	100	100	100	100	100	100	100	100	99	99	100

FIGURE B-1

**Monthly Wind Speed Exceedence  
at the Northstar and Pt. McIntyre Developments**



**TABLE B-3**

**Wind Direction Occurrence at Northstar and Pt. McIntyre**

	<i>Per Cent Occurrence of Wind Directions</i>											
	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
<i>N</i>	3	4	3	5	6	7	7	6	7	5	3	3
<i>NE</i>	21	23	24	28	16	22	22	18	16	20	22	20
<i>E</i>	18	19	21	22	34	38	28	32	31	24	26	18
<i>SE</i>	6	4	5	4	6	3	5	6	8	8	6	5
<i>S</i>	5	4	3	5	3	2	4	4	5	7	5	5
<i>SW</i>	22	20	19	11	7	4	7	6	9	13	14	21
<i>W</i>	15	18	16	12	12	10	12	13	10	11	12	15
<i>NW</i>	4	4	3	4	6	8	11	10	8	5	3	4
<i>Calm</i>	6	4	6	9	10	6	4	5	6	7	9	9

**TABLE A-4**

**Cumulative Frequency Distribution of Monthly Air Temperatures  
at Northstar and Pt. McIntyre**

<b>Air Temp (°F)</b>	<i>Cumulative Per Cent of Air Temperatures (Listed Air Temperature)</i>											
	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
70	100	100	100	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	99	100	100	100	100	100
50	100	100	100	100	10	99	90	93	99	100	100	100
40	100	100	100	100	98	86	54	57	91	100	100	100
30	100	100	100	98	90	20	2	7	45	97	100	100
20	98	98	99	92	35	1	0	0	3	53	93	98
10	92	96	96	82	15	0	0	0	**	30	80	95
0	82	88	90	56	3	0	0	0	0	12	52	80
-10	67	74	72	33	**	0	0	0	0	4	28	57
-20	41	57	44	9	0	0	0	0	0	1	8	37
-30	22	37	16	1	0	0	0	0	0	0	1	16
-40	7	11	5	**	0	0	0	0	0	0	**	4
-50	**	2	**	0	0	0	0	0	0	0	0	0
<b>Avg. (°F)</b>	-15	-21	-17	-2	21	34	40	39	32	16	-1	-13

Note: The notation \*\* indicates less than 0.5 per cent but greater than zero.

**TABLE B-5****Cumulative Probability of Visibility by Month at Northstar and Pt. McIntyre**

<i>Month</i>	<i>Cumulative Probability of Visibility (NM)</i>					
	<i>&lt; 1/4</i>	<i>&lt; 1/2</i>	<i>&lt; 1</i>	<i>&lt; 2</i>	<i>&lt; 5</i>	<i>&lt; 10</i>
January	5.8	11.3	16.6	20.6	29.5	72.2
February	4.7	8.9	13.6	17.7	26.2	69.6
March	3.1	7.0	11.8	16.2	24.0	67.0
April	3.0	5.7	9.6	14.2	22.8	65.1
May	4.2	7.7	13.7	19.8	30.4	71.2
June	5.2	9.2	14.3	18.0	24.6	65.8
July	11.5	21.6	26.0	28.8	34.5	69.1
August	10.6	17.8	23.1	27.1	31.6	66.9
September	6.7	11.6	17.8	23.3	33.6	79.3
October	2.8	5.4	11.5	17.3	30.1	78.2
November	4.0	7.2	12.5	17.0	28.6	72.3
December	4.1	6.7	11.1	15.8	25.0	70.8

**Appendix C**

Paper on the subject of

**Oil Deposition Modeling for Surface Oil Well Blowouts**

delivered at the 21<sup>st</sup> Arctic and Marine Oil Spill Program  
Technical Seminar in Edmonton, June 1998



## **Oil Deposition Modeling For Surface Oil Well Blowouts**

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### **Abstract**

A surface oil and gas well blowout can send a plume of oil droplets into the atmosphere near the discharge site. The location that the oil falls to the surrounding ground or water and the rate of deposition at this point depends upon the height to which the oil is propelled, the size of the oil drops and the prevailing wind speed. A simple method is presented for estimating the fallout width and rate as a function of distance from the source, for the range of oil and gas flows likely to occur in the Alaska North Slope operations. This paper summarizes the results of a project completed for Alaska Clean Seas.

### **Project Objective**

The objective of the project was to estimate the likely fallout zone from a surface well blowout, under specific environmental conditions and blowout characteristics, for spill response planning purposes. The work was not intended to be a detailed scientific evaluation of the best modeling approach to the problem, but rather to use an existing method to meet the project's practical objective.

### **Model Description**

A computer model was developed based on the workbook method for atmospheric dispersion estimation by Turner (1970). The blowout and oil deposition model functions as follows. Input parameters of oil flow, gas flow, discharge pipe diameter, oil density, average wind speed, oil drop diameter, release height, and atmospheric stability class are read into the model. The gas exit velocity is estimated using a simple "gas flow divided by discharge area" relationship. The jet rise is calculated using a cold jet rise equation (Beychok, 1979). The oil drop settling velocity is calculated using an iterative terminal velocity equation. The distance that the drop will travel prior to hitting the 'ground' is determined using the rise height, settling velocity and wind speed. The plume spread in both the vertical

and horizontal is assumed to follow a Gaussian form as described by Turner (1970). A factor of 2.67 is applied to the final travel distance to account for vertical spread (this adds three standard deviations to the mean distance travelled). This results in 99% of the droplets, of the diameter being considered, falling by the distance calculated. The width that the plume will spread to, at the point of ground contact, is determined using Turner's (1970) atmospheric dispersion relationships. The 2.67 factor also is applied to the plume width to account for 99% of the droplets.

### Oil Drop Size Distribution

The oil drop size distribution from a surface oil and gas blowout is the one parameter about which little is known. Measured oil drop-size distributions for such events could not be found in a search of the libraries of S L.Ross, Environment Canada and Canadian Institute of Scientific and Technical Information. The following steps were taken to provide an estimate of the size distribution of these drops.

Observational data from the Uniacke (Martec, 1984) and Ekofisk (Audunson, 1979) blowouts were used to approximate the volume median drop diameter from surface blowouts. The spill model was run using the blowout conditions reported in the literature for these two incidents and various volume median oil drop diameters. The reported slick conditions for these spills were adequately predicted when a 500  $\mu\text{m}$  volume median diameter was used in the Uniacke discharge and a 750  $\mu\text{m}$  volume median diameter (VMD) was used for the Ekofisk spill. The comparisons between reported and modeled values can be seen in Table 1. This provides an average drop size but does not reveal the drop-size distribution.

Table 1 : Comparison of Reported and Modeled Slick Characteristics

Oil	Percent Evaporated		Slick Width (m)		Thickness (mm)	
	Reported	Modeled	Reported	Modeled	Reported	Modeled
Ekofisk <sup>1</sup>	35-40	39.5	100-200	200	1	1.14
Uniacke <sup>2</sup>	70	67.5	200	700	0.003	0.0046

<sup>1</sup> 8.5 m/s wind, 0.5 m/s water current, 5°C air and water temp, 750  $\mu\text{m}$  drop diameter

<sup>2</sup> 12.3 m/s wind, 0.26 m/s water current, 1°C air and water temp, 500  $\mu\text{m}$  drop diameter

The only oil drop-size distribution data that could be found from an oil and gas discharge were from measurements taken during an experimental subsea release under an ice cover (Buist and Dickins, 1980) In this study oil drop-size distributions were measured from ice core samples taken at various distances from the release point. These distributions have been combined in an area-weighted scheme to identify the likely drop-size distribution of the oil as it was discharged. The result of this analysis can be seen in Figure 1. The resulting distribution is linear rather than the log-linear relationship exhibited by most gas-atomization

systems. The reason for this is unknown, but, since this is the only data available, it is used in the final modeling with one modification. The volume median drop diameter of the subsea release was around 1050  $\mu\text{m}$ . This is somewhat higher than the 750  $\mu\text{m}$  diameter identified for above sea oil blowouts. This would seem reasonable since the gas flow would be reduced somewhat due to the over-pressure provided by the water above the submerged discharge point. This will reduce the gas exit velocity and result in reduced droplet shearing and larger drop diameters. To account for this, the measured drop size distribution in Figure 1 has been shifted so that the volume median diameter of the new curve is 750  $\mu\text{m}$ , but the slope of the curve has been preserved. The resulting drop-size distribution has been used in our modeling to identify the oil fallout rate as a function of distance from the release location. Due to the lack of supporting data we were unable to identify different drop size distributions as a function of the gas and oil flow rates and discharge pipe diameter.

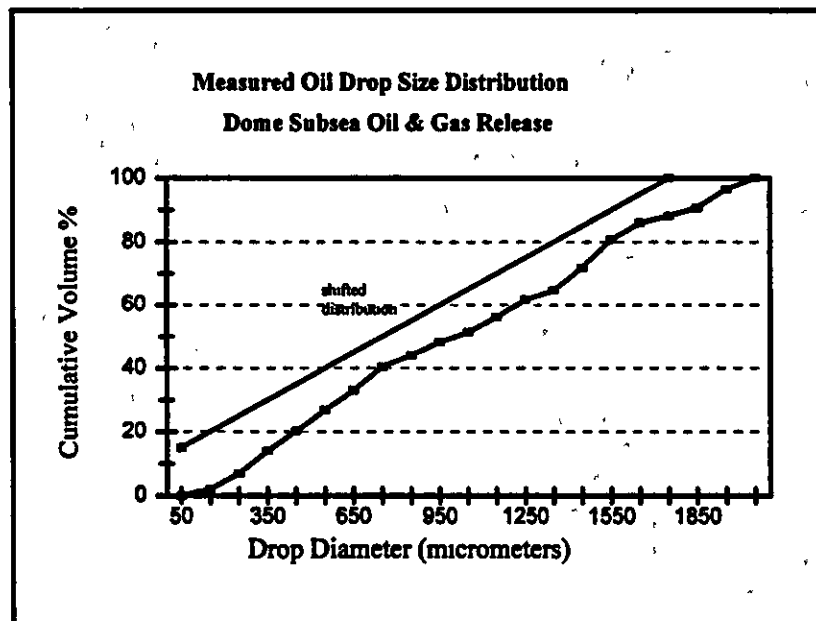


Figure 1 : Oil Drop Size Distribution from Subsea Oil & Gas Release

Pneumatic atomization equations, for predicting the VMD as a function of blowout parameters, have not given results that match the information available from field observations so they have not been used in this study.

#### Modeling Results

The input conditions considered in the modeling were as follows:

Oil Flow: Barrels of Oil per Day(BOPD)	5,500 8,000 12,000 15,000
Gas-to-Oil Ratio (GOR)(ft <sup>3</sup> gas/barrel oil)	400 750 2,200
Wind Speed (knots)	5 10 15 20
Discharge Pipe Internal Diameter (in)	4 & 6.3
Atmospheric Stability Class	D

The model was run for the drop diameters that correspond to the 10, 20, 30 ... 90 % cumulative volume cutoffs in Figure 1. Early modeling results identified that the wind speed has no effect on the deposition pattern due to two counteracting effects: the wind speed affects the rise height of the plume as well as the distance a drop will travel downwind prior to falling to the ground. A high wind reduces the rise height by bending the rising plume. Drops will fall to the ground sooner due to the reduced height but will travel just as far from the source due to the increased wind speed. The wind speed variable was therefore dropped from the test matrix. The results presented apply for most wind speeds but not for extreme cases (i.e., zero winds or very high winds will result in plume behavior different than that presented in this report).

It should also be noted that the horizontal dispersion relationship adapted from Turner (1970) is strictly valid only for distances greater than 100 meters from the source. We have applied Turner's relationships to points closer to the source and these results should be used with caution.

The gas flow exiting from the rupture controls the plume height and subsequent fallout characteristics. The plume fallout dimensions are therefore reported as a function of gas flow rather than oil flow and GOR. Figure 2 has been provided to permit a quick estimate of the gas flow from an oil flow (in barrels of oil per day) and a GOR (in scf/barrel). This figure also shows the maximum gas flow possible through the two pipe diameters considered (4 and 6.3 inch inner diameter pipes). Gas flows at the limits shown represent sonic exit velocities.

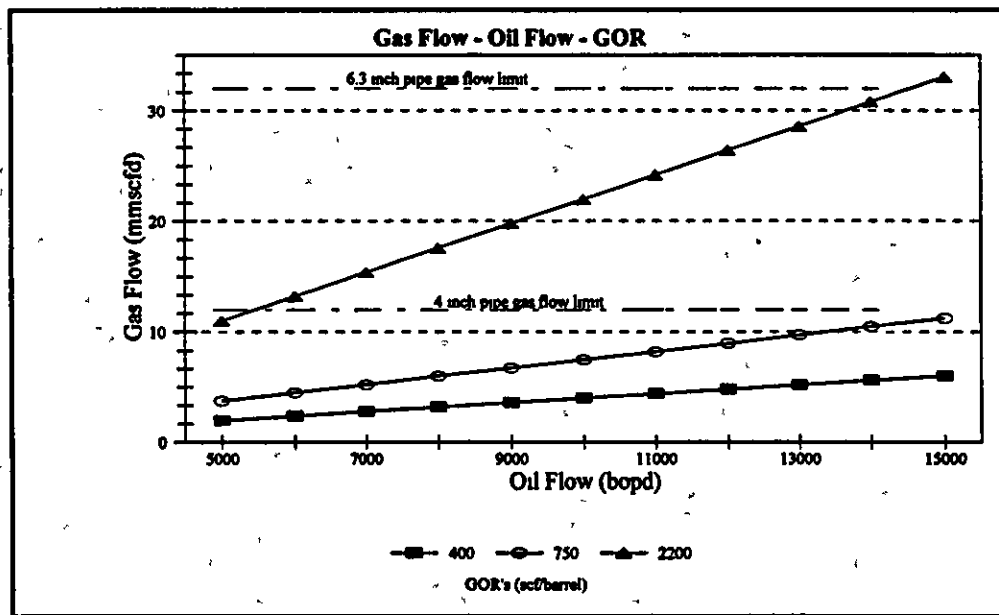


Figure 2 : Gas Flow - Oil Flow - GOR Relationship

Figures 3 and 4 can be used to determine the percentage of the total oil flow that will fall to the ground or water within a given distance downwind of the source for the 4 and 6.3 inch pipe diameters, respectively. The oil flow rate and the duration of the release can be applied to this number to determine the oil deposition rate and "average" oil thickness that would exist at the location.

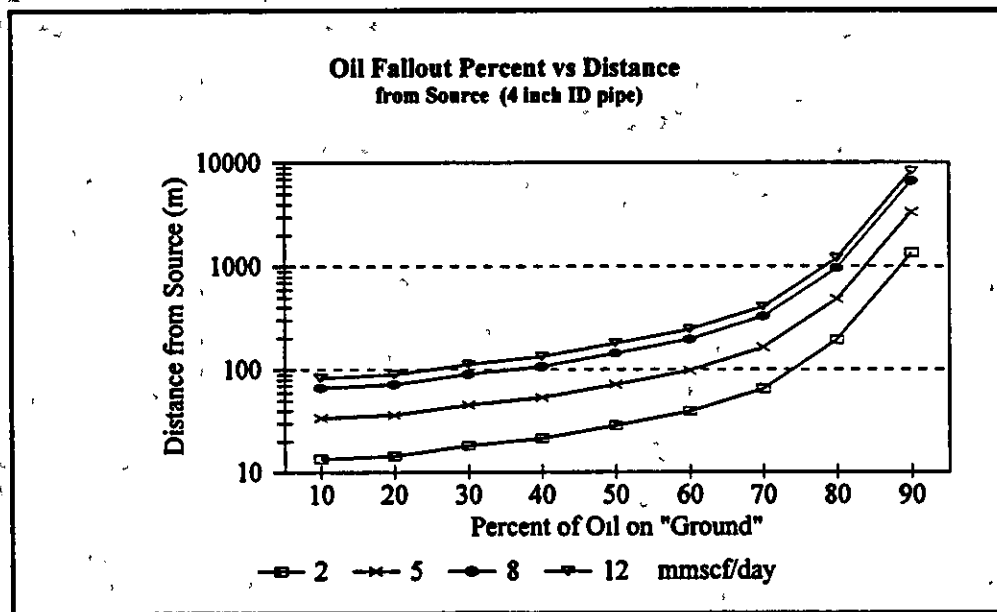


Figure 3 : Oil Fallout Percent vs Distance from Source (4 inch ID pipe)

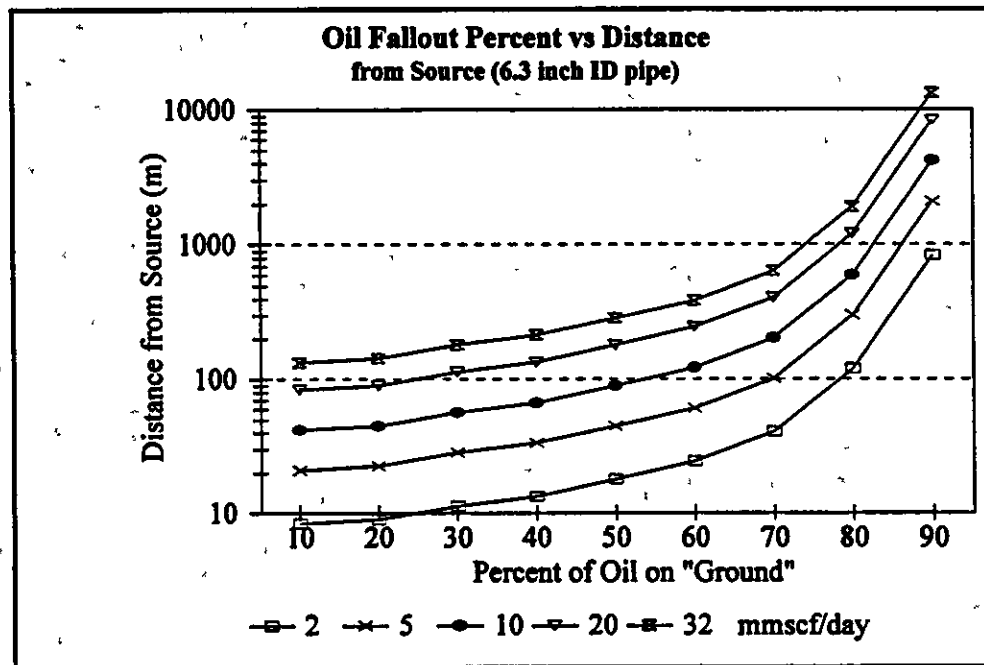


Figure 4 : Oil Fallout Percent vs Distance from Source (6.3 inch ID pipe)

Figures 5 and 6 can be used to determine the width of the plume at the location downwind.

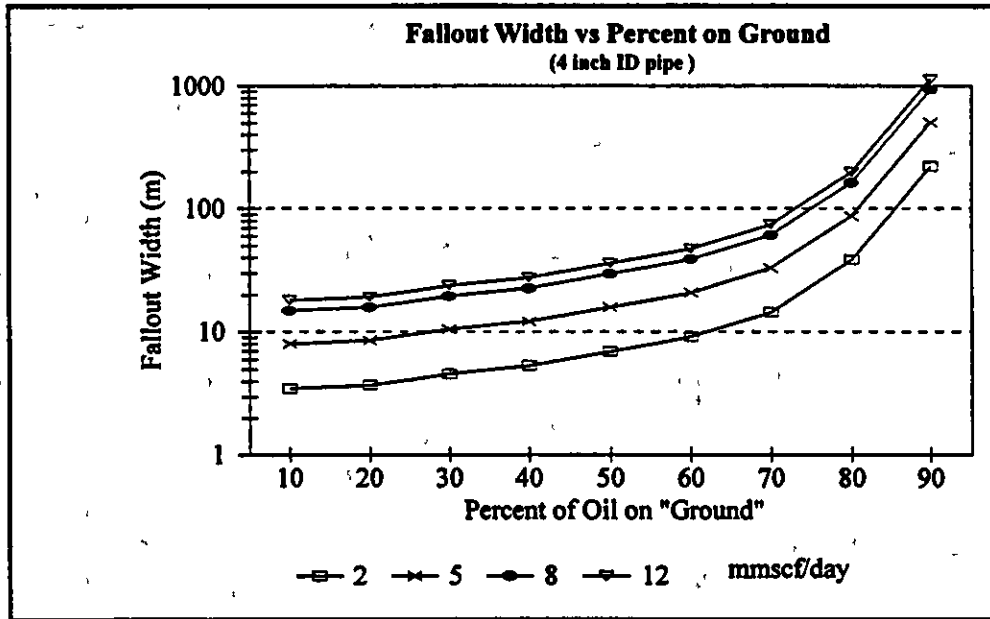


Figure 5 : Fallout Width vs Percent on Ground (4 inch ID pipe)

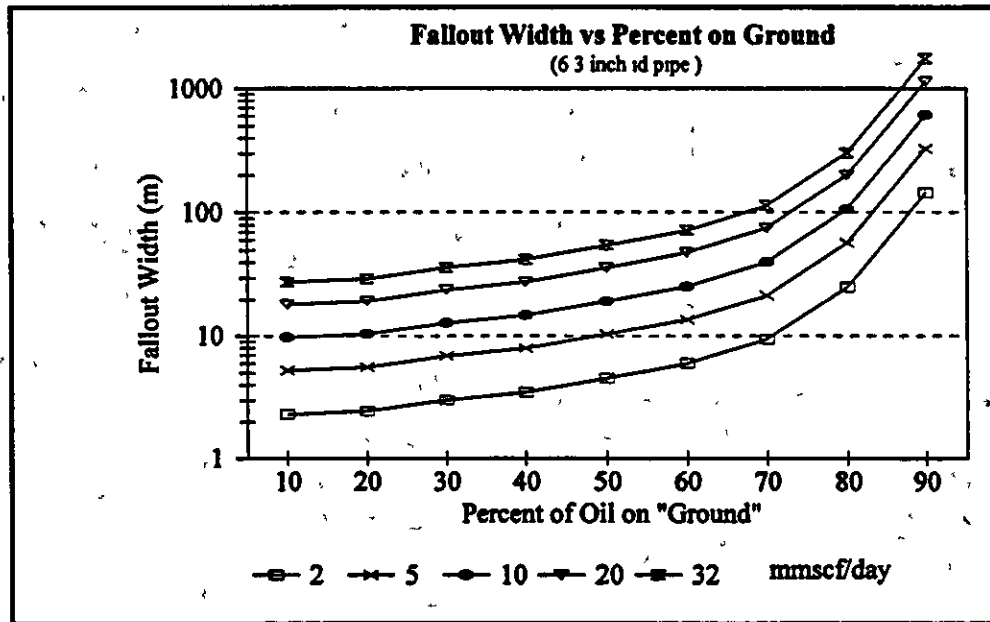


Figure 6 : Fallout Width vs Percent on Ground (6.3 inch ID pipe)

The following example is provided to illustrate how to use these figures. A well is assumed to be discharging oil and gas at a rate of 12000 BOPD with a GOR of 750 scf/barrel through a 6.3 inch diameter (7 inch outer diameter) pipe. To determine the amount of oil that falls within 200 meters from the source one would complete the following steps. From Figure 2 determine the gas flow to be about 8.75 mmscf/d. On Figure 4 interpolate between the 5 and 10 mmscf/d curves to approximate the required 8.75 mmscf/d curve. From this interpolated curve get the percent of oil falling within 200 meters of the source (about 72%). The total volume of oil falling within 200 meters of the source will be the total oil flow of 12000 BOPD times 0.72 times the duration of the blowout period. To determine the width of the fallout at 200 meters, use Figure 6 in the same way, and determine the fallout width at 72% of oil on "ground" (about 35 meters). This is the width that would be oiled if the wind came from the same direction during the entire release. If the wind is shifting the plume will deposit oil over a much wider area. If the wind's directional persistence throughout the release period is known these values can be applied to determine the percentage of oil falling and the resulting oil thicknesses in the various sectors around the spill source.

#### References

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Buist, I.A., D.F. Dickins, *Oil and Gas Under Sea Ice Volume 1*, Dome Petroleum Ltd., 1980.

Martec Limited, *Report on the Environmental Program associated with the blowout at Shell et al Uniacke G-72*, report for Shell Canada Resources Limited, 1984.

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**Appendix D**

**Properties of Point McIntyre and Milne Point Crude Oils**

**and**

**Comparison of Properties between Milne Point and Northstar Crude Oils**



# OIL NAME: Point McIntyre

## 1 0 TYPE Crude

	WEATHERING (Volume %)		
	0	9 8	17 9
2 0 DENSITY (g/mL)			
1°C	0 911	0 920	0 932
15°C	0 895	0 911	0 920
3 0 VISCOSITY			
3 1 DYNAMIC VISCOSITY (mPa s)			
1°C	756 3	1900 0	11912 5
15°C	44 2	125 1	441 3
3 2 KINEMATIC VISCOSITY (mm <sup>2</sup> /sec)			
1°C	830 2	2065 2	12781 7
15°C	49 4	137 3	479 7
4 0 INTERFACIAL TENSIONS @ 15°C (mN/m)			
4 1 AIR-OIL	33 5	35 0	34 7
4 2 OIL-SEAWATER	21 9	28 7	29 2
5 0 POUR POINT (°C)	-4	3	11
6 0 FLASH POINT (°C)	6	12	36
7 0 EMULSION FORMATION TENDENCY AND STABILITY			
7.1 TENDENCY			
15°C	1 00	1 00	1 00
7.2 STABILITY			
15°C	0 93	1 00	1 00

## 8 0 DISTILLATION DATA (°C)

VOLUME % EVAPORATED	LIQUID TEMPERATURE	VAPOR TEMPERATURE
IBP	88 8°C	59 6°C
5	109 6	92 7
10	167 2	92 1
15	244 8	106 0
20	284 3	129 3
30	335 8	192 0
40	379 8	236 6
45	398 1	207 3

## 9 0 WEATHERING

$$F_v = \frac{\ln(1 + 7401 \emptyset \exp(6.3 - 3910/T_k)/T_k)}{(7401/T_k)}$$

where  $F_v$  is fraction of oil weathered by volume  
 $\ln$  is natural log  
 $\emptyset$  is evaporative exposure  
 $\exp$  is exponential base  $e$   
 $T_k$  is environmental temperature (Kelvin)

# OIL NAME: Milne Point

## 1.0 TYPE Crude

	WEATHERING (Volume %)		
	0	34.5	41.6
<b>2.0 DENSITY (g/mL)</b>			
1°C	0.844	0.894	0.898
15°C	0.834	0.883	0.888
30°C	0.823	0.871	0.879
<b>3.0 VISCOSITY</b>			
<b>3.1 DYNAMIC VISCOSITY (mPa s)</b>			
15°C	8.0	77.1	94.6
30°C	5.2	16.8	30.7
<b>3.2 KINEMATIC VISCOSITY (mm<sup>2</sup>/sec)</b>			
15°C	9.6	87.3	106.5
30°C	6.3	19.3	34.9
<b>4.0 INTERFACIAL TENSIONS @ 20°C (mN/m)</b>			
4.1 AIR-OIL:	25.2	29.3	32.9
4.2 OIL-SEAWATER	17.1	23.4	24.9
5.0 POUR POINT (°C)	< -9	0	12
6.0 FLASH POINT (°C)	< -4	85	92
<b>7.0 EMULSION FORMATION TENDENCY AND STABILITY</b>			
<b>7.1 TENDENCY</b>			
15°C	0.12	0.90	0.91
<b>7.2 STABILITY</b>			
15°C	0.00	0.30	0.30

## 8.0 DISTILLATION DATA (°C)

	VOLUME % EVAPORATED	LIQUID TEMPERATURE	VAPOR TEMPERATURE
IBP		87.1°C	43.3°C
5		121.6	72.8
10		140.5	82.2
15		195.7	103.2
20		213.1	109.8
30		257.9	130.2
40		304.6	144.2
50		350.9	201.5

## 9.0 WEATHERING

$$F_v = \frac{\ln(1 + 6534 \cdot \emptyset \cdot \exp(9.6 - 4866/T_k)/T_k)}{(6534/T_k)}$$

where  $F_v$  is fraction of oil weathered by volume  
 $\ln$  is natural log  
 $\emptyset$  is evaporative exposure  
 $\exp$  is exponential base  $e$   
 $T_k$  is environmental temperature (Kelvin)

## North Star and Milne Pt. Comparison

### 10 TYPE Crude

	Fresh North Star	Fresh Milne Pt	47.9% North Star	41.6% Milne Pt.
20 DENSITY (g/mL) 25°C	0.818	0.829	0.876	0.885
30 VISCOSITY				
31 DYNAMIC VISCOSITY (mPa s) 25°C	29	62	114.0	73.3
32 KINEMATIC VISCOSITY (mm <sup>2</sup> /sec) 25°C	35	75	130.1	82.8
40 INTERFACIAL TENSIONS @ 20°C (mN/m)				
41 AIR-OIL:	29.9	25.2		32.9
42 OIL-SEAWATER	2.5	17.1		24.9
50 POUR POINT (°C)	< -9	< -9	21	12

## Appendix E

### Estimate of Containment Efficiency in Broken Ice

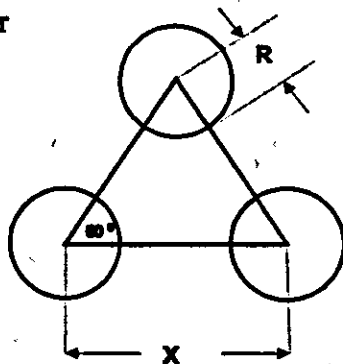
When operating containment and recovery systems among broken ice there will be inefficiencies related to the avoidance of large ice floes and the accumulation of floes within the containment boom. There has been little experience or field studies to quantify this, although it is believed that conventional boom and skimmer operations would be effective at least in light ice concentrations (say, up to 3/10ths coverage), somewhat applicable in 5/10ths coverage with effectiveness declining rapidly as concentrations approach 7/10ths or greater. For the purposes of this evaluation it is necessary to quantify this in some manner. The following is a proposed approach for this.

Carrying out containment operations in a broken ice field could involve maneuvering around large floes, periodically reorienting the boom, and perhaps emptying the contained area of brash ice, slush, and smaller ice pieces. For the purposes of this evaluation scheme, the ice field can be idealized as being of equally spaced floes of equal sizes. This can be then used to calculate the average distance between floes for a given ice concentration and floe size. This average distance would be the amount of open water between floes, within which one could operate containment equipment without obstruction. For a given average speed of advance, one could then calculate the amount of time that a containment system could advance through open water. Finally, this could then be combined with a given amount of time to reposition the system to calculate an estimated percentage of time that the containment system is able to advance and effectively contain and concentrate oil for recovery.

It is acknowledged that an ice field is not made up of equally spaced floes of equal size, and that a containment and recovery system operating in a broken ice field would likely encounter "longer-than-average" periods of open water, just as it would also encounter "longer-than-average" periods of ice in concentrations greater than the 30, 50, or 70% assumed. Since the objective of this exercise is to produce an overall efficiency number that would apply over a period of time, it should be reasonable to assume that these effects average out over time.

For example, floes of an average diameter of 1000 feet would have an average separation of 740 feet given a 30 % average ice concentration, calculated as follows:

- R = floe radius
- X = floe separation, center to center



$$\begin{aligned} \text{ice area} &= 3\# \times (60^\circ - 360^\circ) \times \pi R^2 \\ &= \pi R^2 / 2 \end{aligned}$$

$$\begin{aligned} \text{total area} &= \frac{1}{2} \times (X) \times (X \sin 60^\circ) \\ &= (\sin 60^\circ / 2) \times (X^2) \end{aligned}$$

$$\text{Ice area} - \text{total area} = 30\% = (\pi R^2) - (X^2 \sin 60^\circ)$$

$$X = R \times \sqrt{\pi \times 0.3 \times \sin 60^\circ}$$

for diameter = 1000 feet, R = 500 feet, X = 1740 feet

$$\begin{aligned} \text{separation distance} &= X - 2R \\ &= 740 \text{ feet} \end{aligned}$$

At an average speed of advance of 0.4 knots, the open water separation would be traversed in:

$$\begin{aligned} \text{time} &= 740 \text{ feet} \div 0.4 \text{ knots} \\ &= 18 \text{ minutes} \end{aligned}$$

In light ice concentrations such as 3/10ths, assume 5 minutes downtime to release contained ice or reposition equipment, thus the operating efficiency is estimated to be:

$$\begin{aligned} \text{efficiency} &= 18 \text{ minutes} \div (18 + 5) \\ &= 79\% \end{aligned}$$

Similar calculations can be performed for floe sizes ranging from 100 to 5000 feet in diameter, but increasing the "repositioning time" to 10 minutes for 50% ice and 15 minutes for 70% ice, as follows:

Average Floe Diameter, feet	Average Floe Separation, feet of open water			Estimated Efficiency		
	30%	50%	70%	30%	50%	70%
Ice Coverage						
100	74	35	14	27	7.9	2.2
500	370	174	69	65	30	10
1000	739	347	139	79	46	19
2000	1479	694	277	88	63	31
5000	3696	1736	693	95	81	53

Clearly the efficiency is sensitive to both ice concentration and the average floe size that is assumed. Recognizing that the broken ice field will contain a mix of floe sizes, the results of the above table can be averaged to provide an estimate of containment efficiency of 70% in 3/10ths ice, 40% in 5/10ths ice, and 20% in 7/10ths ice.

## Appendix F

### Background Information and Details on Logistics

This section provides background information and details on the different types of aviation and marine support equipment available at Prudhoe Bay and in Alaska to support an oil spill response in broken ice during the months of July or October.

#### Acknowledgments

The authors wish to express their appreciation to all of the individuals and companies who provided information and took the time to answer difficult questions needed to complete this section. (see Contact List at end of Appendix)

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- Aircraft and Helicopters
- Marine Equipment
- Air Cushion Vehicles
- Summary of Logistics Effectiveness
- Options to Improve Logistics Capabilities
- Contacts
- References

#### Aircraft and Helicopters

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This heading is subdivided into:

- Helicopters (Light Lift): 800 to 1,200 lb sling load, 4 to 6 passengers  
Examples: Bell 206B/L, BO-105
- Helicopters (Light to Medium): 2,200 to 10,000 lb sling load, 12 to 21 pass.  
Examples: Bell 212/214, Vertol 107, Super Puma, Astar
- Fixed Wing (Reconnaissance): Example: ARCO Twin Otter
- Fixed Wing (Freight): Examples: Northern Air Cargo (NAC) DC-6 (24,400 lb); Lynden Airfreight Electra and L382 Hercules (up to 46,000 lb)

The focus here is twofold: (1) obtaining immediate mobility in terms of transport from the Prudhoe Bay support base to the spill site and/or barges on location; and (2) reserving the heavy lift capacity to move additional response equipment from southern staging points as needed.

Two to three light helicopters (BO105 or Bell 206L) are normally available in the Prudhoe area within 2 to 3 hours. These will likely be used in the first stages of the response for low level visual reconnaissance, helitorch operations, and deployment of oil spill tracking beacons.

A major consideration with helicopter support of an offshore blowout will be securing a safe landing site offshore during break-up or freeze-up, when the sea ice itself cannot provide a safe bearing surface. Helicopters on young or rotting ice are limited to temporary set downs on the larger ice floes (e.g., to collect samples and check oil film thickness), usually with the rotors turning (at the pilot's discretion). There are no hard and fast rules for these types of operations; any decision will depend on a safety evaluation by the pilot considering the local conditions (e.g., evidence of local cracking and proximity to any substantial areas of open water). Longer set downs and short term parking with light helicopters may be possible in late October once the ice thickness exceeds one foot. One barge on location needs to be established as a helicopter landing base with emergency fuel and provisions for overnight tie downs.

Although there are no legal requirements preventing single engine VFR helicopters from operating offshore with popout floats, the safety of an extended operation would be greatly enhanced by insisting on twin engine IFR capability and full pontoon floats. There is no guarantee that such equipment would be available on short notice.

The availability of medium to heavy lift helicopters is limited, particularly in July when most, if not all, of the equipment in Alaska is on full-time contract (ERA - pers. comm.) ERA estimates that a minimum of three days would be required to bring in additional machines from their Louisiana base. In October, an Astar (2,200 lb sling) and a Bell 212 (3,000 lb) are often available for spot charter in Anchorage and could be on-site at Deadhorse within 6 hours, weather permitting. The closest source for a medium to heavy lift machine at any time of year is the North Slope Borough Search and Rescue (SAR) unit at Barrow with two Bell 214ST's (7,900 lb sling load or 9 people). Response time from Barrow would likely be less than three hours; a memorandum of understanding exists between ACS and the Borough to ensure that the equipment will be available in an emergency. Neither helicopter would be available in the case of any pre-existing or new life threatening situation which developed during the spill.

There are no heavy lift helicopters permanently based in Alaska outside of the military. Columbia Helicopters may be able to release a Boeing-Vertol 107 (10,000 lb) from ongoing logging operations in southeast Alaska, but this would need to be negotiated at the time. Travel estimates from Ketchikan to Deadhorse are ~15 hours in July and 2 days in October. The same company has a number of Chinooks with up to 14 tons external sling capacity, but the only two machines in North America are on long-term contracts and neither can be considered available. The 107 or Chinook are essentially flying shells with a hook and are not certified for passengers or internal loads (Patterson, pers. comm.)

Fixed wing aircraft are primarily useful as an airborne command post and for regular mapping of contaminated area and oil movement; the ARCO Twin Otter based at Kuparuk is well equipped in this regard, with FLIR (Infrared) and high resolution (low light) video linked to onboard GPS and compatible with Geographic Information System (GIS) mapping systems like MapInfo. The system can be installed and ready to go in 25 minutes and with an endurance of 4 -5 hours, the Twin Otter could serve as an airborne command post to coordinate offshore activities. A typical altitude for the



initial mapping pass over an incident is 2,000 ft. Swath widths are variable with 10:1 zoom. For example, from 1,000 ft, coverage would range from 150 to 1,500 feet.

The most favorable conditions for IR detection tend to be thin oil films on water at night. Surface temperature discrimination has been tested to 0.2 °C. Airborne video will see discoloration of oil on snow but there could be confused targets with dirt on the ice in July. Fine oil mist mixed with snow and/or slush ice (expected to be a common condition in most broken ice spills) is probably the most difficult situation for detection (Parrish pers. comm.)

With the reconnaissance package onboard, the Twin Otter is certified VFR, which sets the operating limits as three miles and/or 500 ft ceiling at Deadhorse and anywhere in the Prudhoe Bay Unit (PBU) at night. During daylight hours, ARCO has FAA clearance to file VFR with forward visibility down to one mile

There is no shortage of medium fixed wing utility aircraft in Alaska (e.g., Caravan, King Air, Navaho etc.). A wide variety of machines could be in Prudhoe within four hours of a call out. Heavy lift freighters are available through operators in Anchorage, principally Northern Air Cargo (NAC) and Lynden, with payloads ranging from 12 to 23 tons (e.g., DC-6, Electras, L382 Hercules). Given the time needed to order and assemble any heavy loads for supplemental spill response gear, the availability of aircraft in this category is not expected to be the critical path. ACS has an existing MOU with NAC which calls for a dedicated DC-6 aircraft to be ready to load in Anchorage for example within 2 hours.

Aviation Attachments: refer to selected spec sheets, ACS Aviation Support Guide, company/agency contact lists.

### Marine Equipment

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All vessels presently known to be at Prudhoe Bay and having some potential to support a response operation in broken ice are described below.

Tugs and barges are the most important pieces of offshore marine equipment, with demonstrated capabilities in a wide range of broken ice conditions; barges provide a stable, safe working platform as well as the necessary storage volume to support skimming operations. A wide mix of smaller vessels are also available from various sources to support a spring break-up operation; only a few of these have any significant application during freeze-up.

Ice strengthening is a definite advantage, but not essential in the spring or in the early stages of freeze-up. Non ice strengthened equipment can operate effectively in high concentrations of broken ice with careful handling, as demonstrated by the oil industry and sealift operators in the US and Canadian Beaufort offshore areas over the past 30 years or more.

The most serious operating concerns relating to the freeze-up scenarios are: (1) breaking out from West Dock and reaching the Northstar spill site; and (2) maintaining a channel through the new fast ice along shore to allow lightering of recovered product to shore; and (3) managing a number of barges offshore in moving ice with only one or two powerful tugs (Note: from 1998 on, it is expected that two Point Class tugs will be available again). An additional concern involves the

possibility that any oil water left in the tanks for an extended period in October could start to freeze solid, at which point pumping out may be impossible until the following summer. This problem can be prevented by careful decanting of recovered fluids before filling barge tanks in a freeze-up situation.

The shortage of tugs may become a limiting factor, particularly in the higher ice concentrations when anchoring in moving ice may not be possible. In 3/10 and 5/10 ice, the shallow draft River class tugs may be able to manage at one or possibly two additional barges on site, while the more capable Point tugs are dedicated to the Endeavor to fully utilize her icebreaking capability. In 7/10 of ice it may not be feasible to lighter with the Endeavor while leaving other barges and systems offshore at the same time (assuming that any marine equipment could be broken out from West Dock and moved offshore through over a foot of fast ice).

From discussions with the operators, the following ice limits are suggested for barge operations after freeze-up. Note: these limits should be treated as a rough guide; there are no hard and fast rules which will apply in every ice situation. Depending on unpredictable factors such as air temperature, snow on the ice, and winds compacting and deforming the new ice, a tug and barge which may be making steady progress one day can be stopped twenty four hours later in conditions which appear visually to be the same.

#### **Suggested Guide to Barge Operating Limits in Solid Ice**

***Endeavor***  
(icebreaking bow)

14 to 15 inches of solid unbroken (fast) ice with two Point Class tugs, up to 12 inches with one Point Class tug, and up to 24 inches partially consolidated ice in a previously broken channel. The *Endeavor* can operate in thicker ridged or rafted ice (over two feet in places) by taking advantage of cracks and leads to maintain forward progress, not necessarily in the direction desired (Sawin, pers. comm.)

**Crowley 200 series**  
(non ice strengthened)

4 to 6 inches of solid unbroken ice or up to 9 inches of broken ice in a fresh channel through fast ice (ie., in a convoy situation behind the Endeavor)

**Lynden 20 and 23**  
(ice class barges)

4 to 6 inches of solid unbroken ice or up to about 12 inches of broken ice in a fresh channel (estimated as possible with sufficient tug power)

Note: The above guidelines refer to very close pack ice or compact ice (9 to 10/10). It is assumed that all of the barges presently on the slope could operate in closely packed broken ice offshore at slow speed during October and November up to about 7/10 concentration.

The estimated minimum time to mobilize tugs and barges from a cold start in October is two days (Roth, pers. comm), following which some additional time may be needed to install response equipment, accommodation modules etc. Hopefully, much of this could be ongoing while the equipment itself is being mobilized. Mobilization in July becomes a matter of hours as the Point tugs are usually operating by July 4-5 out of W. Dock.

The greatest uncertainty surrounds the question of whether or not marine equipment could be broken free at West Dock and moved offshore through solid ice over about 8 to 9 inches ie., two of the freeze-up scenarios considered here (Sawin pers comm.).

Only the *Endeavor* and *Challenger* (presently in Seattle) have true icebreaking bow forms and a flared hull to clear ice while under way. The *Endeavor* demonstrated her ability to break well over a foot of new ice during sea trials in the fall of 1982 and she has operated in much thicker ice for short periods. Other barges will break some solid ice but rapidly become limited by the power available to overcome the resistance of the blunt bow which tends to plough ice and snow ahead of the vessel. Slush ice build-up can quickly become the limiting condition, even in very thin ice (less than 4 inches). Hatfield and Dickins (1981) estimated that a conventional barge shape would have great difficulty breaking over 6 inches of new ice in freshly broken channel. Multiple passes along a single channel may increase this limit to about 9 inches temporarily, but the enhanced ice growth from overturning cold ice blocks will begin to seriously affect vessels progress after a relatively small number of passes. It may be necessary to transit with the *Endeavor* back and forth to West Dock every 48 hours just to maintain the broken ice channel in a partially consolidated state.

Shallow draft tugs such as the *Sag River* also have a barge like bow shape and tend to stop moving forward as they ride up on the ice. This problem can be overcome by mobilizing the less capable tugs and barges as a convoy behind the *Endeavor*. Once offshore among broken floes, the River Class tugs could still operate effectively for part of October. These smaller tugs would be most useful in a July broken ice condition when they could push barges in shallow water through rotting floes (see below).

Broken ice at break-up usually presents a much easier case for conventional marine equipment. The exception would be if the ice becomes pressured through wind packing. Regular tugs and barges can push their way (slowly) over long distances through rotting floes in high concentrations (up to 9/10), as demonstrated in past operations and trials. The industry Task Group carefully documented the July 1983 trips with the barge *Endeavor* and two *Point* class tugs from Barter Island to Prudhoe Bay, and with the barge *Satco 10* and tugs *Fox* and *Bear* from Flaxman Island to Prudhoe. Even without an icebreaking bow, the *Satco* barge was able to cover 55 nautical miles at an average speed of over 2 knots in over 7/10 ice. In a return convoy from Barter Island, some 15 conventional (non ice strengthened) barges and ten tugs made it back to Prudhoe without mishap though 106 miles of heavy ice.

It was concluded from these experiences that non-ice-breaking tugs and barges can operate effectively in close pack ice (7 to 9/10) when the ice is an advanced stage of melt, and is not under significant pressure. In their "Evaluation of Industry's Oil Spill Countermeasures Capability in Broken Ice", SL Ross (1983) concluded that an ice strengthened barge with two tugs could negotiate substantial stretches of broken ice in concentrations of 8 to 9/10 in the spring. High power is not essential under these conditions, and a much wider variety of smaller work boats under 1,000 hp can still provide useful support for spill response (including moving the large 200 series (60 X 200 ft) barges short distances).

**Primary Inventory:** covering mostly heavy equipment with substantial capabilities in most broken ice scenarios

Crowley Marine Services

*Endeavor* (ABS Class A1)  
90 X 205 ft  
Icebreaking barge \*

16,000 bbl at 9 ft draft (W. Dock limit)  
21,700 bbl at 12.5 ft draft (offshore storage)  
liquids + dry deck cargo  
Typical Ice Limit: 1.2 ft continuous in October, 2 ft rafted in spots with 2 Point Class tugs (up to one foot solid ice with a single Point Class tug)

BG 210/211/213  
60 X 200 ft  
non - ice strengthened

5,500 bbl liquids, stern ramp + dry deck cargo  
Notes: 211 & 213 \* in Seattle at time of writing (due back at Prudhoe, summer 1998); 211 has a 16 person camp; 213 lacks current inspection certificate as a tank barge (assume waiver for temporary storage in an emergency)

Typical Ice Limit: 4 to 6 inches at freeze-up or thicker floes at break-up

BG 215/216/218  
60 X 200 ft

Deck barges, non ice strengthened  
Typical Ice Limit: 4 to 6 inches at freeze-up

*Point Barrow/Point Thompson*  
2,110 hp

Twin screw nozzles, ~ 47,000 lb  
bollard thrust, 8 - 9 ft draft  
Most useful offshore for Northstar scenarios at freeze-up

*Sag River/Toolik River/Kavik R.*  
1,100 hp

Triple screw, open props  
~ 22,000 lb bollard (est.), 3.5 ft draft  
Most useful inshore for Pt. McIntyre scenarios at break-up (still able to operate in broken ice for part of October - move offshore in convoy)

\* *Endeavor* is scheduled to leave the Beaufort for USCG inspection late 1998 or 1999. No decision has been made on whether this barge will be positioned back into the Beaufort (Tornga, pers. comm). The *Endeavor* is the most ice capable vessel in the US Beaufort and the only barge able to operate offshore in most years up to the end of October. Crowley maintains a much larger and heavier icebreaking barge in storage in Seattle, the *Arctic Challenger*. This vessel has dimensions of 90 X 205 ft with capacities up to 22,000 bbl at a 9 ft draft or 50,000 bbl at 16.7 ft draft. *Challenger* is designed to be pushed through thicker ice with over three times the horsepower of the *Endeavor*. With two 6,000 hp tugs, this barge could operate routinely in level ice up to about 18 inches (early to mid-November). No decision has been made to keep the *Arctic Challenger* in the long-term. Refer to discussion on future possibilities at the end of this section.

Note at the end of September, Crowley winterizes all of its vessels, leaving the 200 series barges pushed bow into the beach near West Dock, with the Point Class tugs moored in deeper water at the stern of the barges and the shallow draft tugs lifted out of the water onto the barge decks. *Endeavor* is moored bow in to the causeway alongside West Dock.

**Lynden Incorporated (Beaufort Marine J.V.)**

***Beaufort 23***

34 X 147 ft  
Chartered to ACS - 1997  
for use with the Trans Rec

Deck cargo: West Docks 2 and 3  
(600 tons) at draft of ~5.9 ft.  
(light draft 1.8 ft)  
Ice Class ABS 1A (second highest)  
Probable ice limit in October: 5 to 6 inches in a  
previously unbroken sheet or up to 9 in broken  
channel

***Beaufort 20/21***\*

60 X 202 ft

Deck cargo: West Dock 3 (1,500 tons)  
at draft of 7 ft (light draft = 2.8 ft)  
Fuel: 12,200 bbl in 8 tanks at 7.8 ft  
Ice Class ABS 1AA (highest)  
Probable ice limit in October: 5 to 6 inches in a  
previously unbroken sheet

***Arctic Bear***\*

1,700 hp

51,000 lb bollard, twin screws in nozzles  
Min draft 6 ft (8 ft icebreaking)  
Ice strengthened, est. icebreaking capability similar to  
Point Class Crowley tugs (~6-8 inches).

***Arctic Tern***

20,000 lb bollard, twin screw shallow 730 hp draft  
(3.5 ft). Most useful for break-up scenarios  
(no significant icebreaking capability)

\* presently in Seattle with the Beaufort 21 - possible tow to  
Prudhoe summer 1998 - no decision has been made on over-  
wintering this equipment at the present time (Lynden, pers  
comm)

**Secondary Inventory (lighter equipment limited mostly to break-up operations)**

There are numerous smaller work boats and barges available in the Prudhoe Bay area (see general list below and attachments). Most of this equipment could be used locally in Prudhoe Bay during break-up but, few if any of these vessels have sufficient power to break more than a few inches of solid ice nearshore after freeze-up.

As described above, the main problem in October is being able to make passage through the band of thin fast ice separating West Dock from the broken ice offshore. Jet drives and outboards are not considered useful in a freezing environment with slush in the water (ACS pers. comm.).

Work boats with screws (e.g., *North Star* and new 42 ft. vessels being delivered to ACS in 1998), could potentially operate offshore for part of October by being transported out to the spill site as deck cargo on one of the barges. Previous demonstrations have used a heavy lift

Skycrane to sling the *North Star* offshore. Once on location in broken thin ice, these smaller boats could work locally to support the skimming systems.

#### Alaska Clean Seas (ACS)

New 42 ft (1998) X 2  
870 hp

2.5 ft draft, with push knees to handle  
200 series barges. Unknown potential in ice but  
expect good utility in 3 to 6/10 at break-up and  
some applications offshore  
in early October

Northstar - 32 ft

Usually last boat out of the water in mid-October.  
Straight shaft, twin screw. Could be used offshore  
for part of October.

38 - 55 ft (5 in total)

All jet drive (assume no capability under freezing  
conditions)

14 to 28 ft (~45 in total)

mix of jet drives and outboards skiffs, inflatables,  
V hull, flat bottom, and landing craft (see ACS  
listing)

*Caribou and Lemming* (2)  
60 X 160 ft

Deck barges (non ice strengthened)  
One at East Dock, one at West Dock. These  
barges are ex-ARCO with no current USCG  
certificates. Useful to support spring operations in  
shallow water - not recommended for offshore use  
at freeze-up.

#### Ice Services - TJ Borden

flexa float barge (2)  
40 X 140 ft

Shallow draft, 250 ton capacity  
Self propelled hinged out drive  
Expect limited capability in ice over 3/10.  
Most applicable to shallow water response and in  
support of shoreline clean-up in July.

#### Beaufort Marine J.V. (Lynden)

Mop King (Landing Craft)

Twin screw w/5 ton crane

#### Oceanic Research Services

*Annika Marie*  
14 X 43 ft

3.5-ft draft research/work boat, fibreglass hull  
Expect limited ice capability up to about 5/10  
(summer only)

## BP Exploration

Catamaran  
69 ft

Seismic vessel, sleeps 12, good working deck area  
Unknown ice capability - possible use in July only

## Out-of-Region Marine Equipment

There is no practical means of gaining access out of region marine equipment beyond those resources which are on hand at Prudhoe Bay in July or October. Exceptions would be small work boats which could be brought up the haul road or shipped by air.

The inventory of available marine equipment in the Beaufort Sea region has become much more limited since offshore exploration and development ended in Canada in the late 1980's. All of the ice capable barges, supply ships, and icebreakers once operated by Amoco and Gulf have now left the Beaufort Sea. Northern Transportation Company (NTCL) operates an extensive fleet of powerful tugs and barges (non ice strengthened) along the Beaufort Sea coast between late July and September 30. They recently acquired two ex-Canmar ice class barges (thought to be US bottoms - Jones Act exempt), but the company has no plans in the future to winter-over these or any other ice capable equipment within reach of Prudhoe after the end of September (Briggs, pers. comm.). Similarly, the Canadian Coast Guard is no longer committed to maintaining icebreakers in the Western Arctic.

At present the most capable icebreaker operating along the Alaskan coast in any given year is likely to be the 22,000 shp *Kapitan Khlebnikov* on tourist cruises. This class of vessel could operate in the vicinity of Northstar for much of the winter, but would be restricted by draft from approaching any closer to shore. At 9.4 m draft, the USCG icebreakers which occasionally appear in the Beaufort Sea area on research voyages have the same problem.

Marine Attachments: refer to selected spec sheets, ACS Marine Vessel Support Guide, company/agency contact lists, photographs of barge operations in broken ice from the Tier II demonstrations.

## Air Cushion Vehicles

Hovercraft (often referred to as ACV's), offer a number of unique advantages over other forms of transportation, especially in shallow water areas with a mix of ice and water.

To make up for the relative lack of direct experience (compared with conventional marine equipment), this section provides background on hovercraft capabilities, with an outline of their history and operating record in different ice environments in Canada and Europe.

ACV's are completely amphibious and can travel just as well over a mix of broken floes as they can over solid ice or open water. At the same time they can come up on the beach to be loaded or unloaded on dry land before returning to the spill location. Major limitations

are strong winds (>25 kt) and the possibility of skirt damage in very rough ice. As to be expected with a hybrid vehicle combining marine and aeronautical technologies, the older designs of ACV's (represented by the LACV-30 presently on the Slope) tend to require a high level of maintenance. One machine cannot be expected to operate continually without blocks of time each day set aside for maintenance. This is taken into account in estimating a conservative lighter rate for ACV's used as part of the logistics solution.

Air cushion vehicles have a long history of arctic trials and operations dating back to 1966. Dickins (1989) provides details of many of these experiences in Canada the United States and Scandinavia. Examples include: a pioneering 4,000 mile trip from the UK to Sweden in 1972 by the BH.7 (including 1,100 miles over a mix of solid and broken ice); a year-round freight operation with two SR.N6 machines over ice and open water in the Mackenzie Delta from 1974 to 1977, and trials with the Jeff(A) at Prudhoe Bay from November 1983 to July 1984 (including a test run from East Dock to Challenge Island and back in mid-July over rough rotting ice with a 75 ton load). A review of air cushion vehicle applications for spill response on the North Slope for the Alaska Oil and Gas Association (AOGA) concluded that, for a large part of the year, ACV's offer the only reliable means of carrying heavy loads safely to offshore sites in the Beaufort Sea (Dickins, 1979).

The Canadian Coast Guard used a Bell Voyager (less powerful prototype to the LACV-30 presently available in Alaska) on routine icebreaking operations, spill response, and aids to navigation maintenance on the St. Lawrence River from 1974 to 1988. Every spring, this craft prevented millions of dollars in flooding by breaking up the river ice and preventing ice jams; typical ice thickness' broken at about 10 knots ranged from 19 to 20 inches. At a slower speed (2 to 4 knots), the Voyager broke about 10 inches of ice by introducing an air cavity under the sheet. The AP.1-88 replacement for the Voyager (a cargo version of the craft in Lynden's fleet in Anchorage) has performed similar duties, including icebreaking, for the past ten years (1988 to 1998). A newer more powerful AP.1-88 derivative is about to enter service with the Montreal Coast Guard hovercraft unit (1998).

From 1984 to the early 1990's Scandinavian Airlines System contracted for up to three AP.1-88 passenger hovercraft (100 seats) to operate between Denmark and Sweden over a variety of ice conditions, often encountering rough broken floes and ice rubble. Even in the most severe winters (temperatures down to -8 °F) these craft still managed a reliability of 80 to 85%. Over 27 months between 1984 and 1986, two craft carried 310,000 passengers.

At present, Lynden Incorporated (Alaska Hovercraft) maintains the only fleet of air cushion vehicles in Alaska. Of primary interest for the oil spill response role are the LACV-30 (ex US Army ship to shore lighters) with a 30 ton payload capacity and a large open working deck (32 X51 ft). This vehicle can carry bladders or the standard intermodal 5,000 gallon (20 ft long) fuel tanks on deck. One of these craft is stationed at Prudhoe Bay on cold stand-by, with an estimated 24 hours required to mobilize with a crew out of Anchorage.

A further 6 machines are kept in Anchorage in different states of readiness. With special road clearances for a 30 ft width, it would be possible to transport one of these hovercraft by trailer to Prudhoe over a 2 to 3 day period. Expected total mobilization times from first call



to arrival at Deadhorse from Anchorage are: 5 days for the first, 10 days for the second, and one month for the third and fourth machines

In addition to the LACV-30, Lynden has two AP.1-88's certified for 88 passengers or up to 8 tons internal small package type loads. One of these craft is in Anchorage and could also be moved by road to the North Slope in an emergency within one week. Although not optimized for freight, Lynden's AP.1-88 would be the safest and most effective way of moving large numbers of people to and from the Northstar spill location in October.

Both of these designs have proven themselves with extensive over-ice experience under ice conditions often more severe than expected off Prudhoe Bay in October. When icebreaking is not the primary mission, the LACV-30 can cruise at over 40 knots over young ice while causing only superficial cracking. While the load center must be kept within prescribed c.g. limits while on cushion, the craft can also act as a stable self propelled barge in the displacement mode with skimmers and equipment over the side (taking care to lift up on cushion periodically to break the ice around the skirts and underneath).

Although ice needs to be cleared periodically from exposed surfaces under freezing conditions, hovercraft have not experienced any significant problems with propeller icing even over thin breaking ice. SAS avoided operating at low speed on cushion over open water in freezing conditions to limit ice build-up on the superstructure (another alternative is to drop into the water and move forward on partial cushion with the skirt in the water to trap spray). Other procedures included hot water/glycol spray at base (similar to aircraft deicing rigs at airports), and operating at lower cushion settings to reduce air flow and associated spray in freezing conditions. As ice concentration increases the severity of superstructure icing rapidly decreases. The worst areas tend to be close to the ice margin where there is a greater opportunity of wind waves and spray. Dickins (1983) provides a detailed summary of all known ACV cold climate operating experiences, along with operational measures taken to deal with specific conditions.

During October, strong winds over 25 knots persist for 10% of the time on average (Ref. Table A-2 in Appendix A). These winds are close to the operating limits for the LACV-30, especially in conditions of freezing spray. There are no known limitations in operating over broken ice in the spring. Winds are much more moderate at that time of year, with situations over 25 knots occurring less than 3% of the time.

**Example ACV Lightering Scenario:** The LACV-30 operated by Lynden (Alaska Hovercraft) was designed as a ship to shore lighter. This machine could transport 5,000 gallon (119 barrel) loads from a spill site at Northstar to West Dock in less than 18 minutes travel time regardless of ice conditions (assuming a conservative 25 knot block speed). With two machines operating in parallel during daylight/twilight hours averaging 10 hours in October (allowing sufficient time for repairs and maintenance at night) the LACV-30's could lighter a minimum of 1,800 barrels per day based on one return trip every 70 minutes (36 minutes travel, and 34 minutes transfer), and allowing for at least two craft refueling.

With high volume transfer pumps at each end and a typical cruise speed of 30 knots, it would be possible to achieve a return time of less than one hour. For the first half of

October, with 12 hours of natural light for operating, a daily throughput of 2,600 barrels is considered achievable (amounting to 17% of the blowout flow rate). It should be noted that with searchlights and GPS navigation, hovercraft are capable of operating safely in conditions of darkness and poor visibility which would ground all but the most sophisticated IFR helicopters.

Depending on the encounter rate and throughput efficiency of the skimming systems, it appears that the air cushion vehicle is an effective means of lightering recovered product while allowing the tug and barge systems to stay on location for as many hours as possible. Given the shortage of capable tugs to manage barges offshore, the air cushion vehicle option offers significant advantages, particularly in the 5/10 and 7/10 ice concentrations.

ACV Attachments: LACV-30 and AP.1-88 spec sheets, photographs of hovercraft over broken ice (SAS, Canadian Coast Guard, British Hovercraft Corp.)

### Summary of Logistics Effectiveness

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Logistics options can be divided according to three broad effectiveness factors: transport from a shore-based staging area to and from the spill site, on site support for the response operation, and mobilization times.

1. Transport: payload (weight and volumetric constraints), transit time, ability to deal with the ice, and weather limits (expected worst-case downtime).
2. On-site support: deck area, internal or deck tank storage for recovered product, weather and ice limits, maneuverability in ice, and accommodation.
3. Mobilization: factors include a combination of crew travel time and time needed for equipment preparation and warm-up. Personnel may have to flown-up to the slope, and equipment may have to be taken out of storage and/or de-winterized. These factors are particularly acute in October as the heavy marine equipment is normally prepared for winter lay-up by the end of September. Crowley estimates about 48 hours for a cold start-up depending on weather and ice conditions at the time.

Table F-1 summarizes these effectiveness factors for each equipment category.

**TABLE F-1**  
**Logistics Effectiveness Summary**

<b>Category</b>	<b>Transport</b>	<b>On-site Support</b>	<b>Mobilization Time (hours)</b>
<b>Fixed Wing: light</b>	N/A	ARCO Twin Otter for remote sensing	one hour from call
<b>Fixed Wing: heavy</b>	Anchorage to Prudhoe Seattle to Prudhoe 24,400 lb (DC-6) to 46,000 lb (Hercules)	N/A	2 hours to loading 9 hours to loading
<b>Helicopter: light</b>  Bell 206/BO105/Astar	4-6 persons or  800 - 2,200 lb	helitorch, surface samples, reconn, ice tracking beacons	July - 2/3 machines in 2 hours Oct - 1/2 machine in 2 hours additional machines from Anchorage in 6 hours
<b>Helicopter: medium</b>  Bell 212	12 persons or 3,000 lb	reconn + freight transfer	July - non available Oct - 2+ in 6 hours
<b>Helicopter: heavy</b>  214ST, BV107, Super Puma	9 - 22 persons 7,900 - 10,000 lb sling  Note. 107 not cert. for passengers	freight transfer	July (107) 1 in 15 h July (214) 2 in 2 5 h Oct (107) 1+ in 24 h Oct (214) 2+ in 2 5 h
<b>Marine Tugs/Barges</b>	600 to 2,700 tons + capacity on deck cargo barges  Total Barges 4-5 tank/deck combination barges, and 3-4 deck cargo only (# in any given year depend on dry-docking schedules)  Total Tugs 5-6	marine base for helicopter operations, accomm barge, spill response barge, recovered liquids storage  Offshore storage as Ice Str. Barges - 1 @ 12,200 bbl Non ice str. barges - 2-3 @ 5,500 bbl Icebreaking Barge - 1 @ 16,000 bbl	Oct - 48 h to start-up, estimate 60-72 h to arrival on-site  July - 2-4 h or less notice after July 5 (typ) expect 12 to 16 h to on-site with equip loaded
<b>Support Boats</b>  - ACS fleet + other Prudhoe Contractors & BP	light freight + personnel (July)  no significant ice capability in Oct	<u>Spring break-up</u> - skimmer platforms - boom tending - temporary storage	July - 6 to 8 hours on-site depending on ice  October - limited utility except <i>Northstar</i> & 2 new ACS boats (1998)

Category	Transport	On-site Support	Mobilization Time (hours)
<b>Air Cushion Vehicles</b> - AP.1-88 (80 pass) - LACV-30 (30 tons)	- personnel rotation - recovered oil lighter - fast freight  Note est. lighter capacity between Northstar and West Dock - 1,800 to 2,600 bbl/day with (2) machines	- skimmer platform with deck tanks (transfer to main barges)	July or Oct  1 LACV30 in 24 h, 2nd LACV30 or one AP.1-88 from Anchorage in 5 days

### Options to Improve Logistics Capabilities

Future logistics options involve asking a number of what if questions. For example, what if there were dedicated heavy-lift helicopters on the Slope? what if there were more capable icebreaking barges and tugs etc.?

In reducing what could be an endless list of possibilities, it helps initially to identify possible solutions to deal with the particular deficiencies in the existing logistics resources currently available in the Prudhoe Bay area. The significance of these deficiencies must be weighted against the needs of specific scenarios. For example, the lack of heavy lift helicopters may not be significant if it turns out that there is no great need to sling heavy loads offshore.

Based on the equipment overview presented above, a number of potential logistics shortcomings stand out during periods of broken ice in July, October and early November.

- Shortage of helicopters with any significant load carrying capacity or IFR capability (particularly in July when almost all commercial machines are fully committed). Offshore scenarios in October or November may need twin engine IFR to establish an acceptable level of safety and reliability. The only short-notice source of medium/heavy lift equipment is the SAR unit at Point Barrow.

Given the difficulty in operating small support boats under freezing conditions in October, there are only two possible avenues to move and support large number of personnel offshore: air cushion vehicles and helicopters.

Possible solution: (1) rely on military support for a long term response beyond 72 hours; (2) contract for a medium/heavy lift helicopter(s) (e.g., Puma, Bell 212 or 214) to be available within a specified number of hours out of Anchorage; (3) plan on using air cushion vehicles as fast offshore work "boats" at freeze-up.

- Shortage of ice capable barges and tugs. This deficiency is most critical for the October scenarios; in most years there are only two tugs (*Point Barrow* and *Thompson*) with sufficient power to move conventional barges through more than a few inches of ice, and maintain a channel between West Dock and an offshore location such as Northstar (only one of these tugs was on the Slope through the winter of 97/98). Lynden's ice strengthened tug the *Arctic Bear* may be operating out of Prudhoe Bay from 1998 on. There is only one barge, the *Endeavor*, capable of transporting deck cargo and recovered liquids through more than about 6 inches of ice, a condition which is often reached by October 10. Other barges are capable of operating in broken ice offshore until later; the limiting condition becomes one of gaining access to and from West Dock through the new fast ice beginning to extend out from shore. Regardless of the type of barge or tug, marine operations will eventually have to cease as the ice builds up in late October or possibly early November in a favorable year.

Possible solution(s): (1) contract for an additional powerful tug capable of supporting and moving barges in broken ice; (2) contract for an additional icebreaking barge capable of maintaining offshore logistics resupply with heavy loads and recovered liquids through October and into early November (ideally capable of routine operations in 1.2 to 1.5 ft of solid ice); (3) utilize hovercraft as the primary method of transportation to and from shore, leaving the barges primarily as offshore storage, response platforms and accommodation support. Two LACV-30's are capable of lightering over 1,800 bbl of recovered fluids in a ten hour day over the 8 mile run between West Dock and Seal Island (Northstar).

- Mobilization times for heavy marine equipment, particularly in October when tugs and barges presently on the slope are already in a state of winter lay-up. Minimum time from first call to arrival on-site (e.g., Northstar) of a fully equipped response barge would be between 48 and 72 hours. Minimum time to obtain a single operating air cushion vehicle would be 24 hours.

Possible solution(s): (1) contract to maintain critical equipment such as the *Endeavor*, both Point Class tugs and an LACV-30 hovercraft in a state of "hot standby" in October - that is delay the winterization; (2) conduct regular icebreaking around West Dock and along a channel leading to open water and broken ice further offshore for as long as possible through October; (3) maintain a dedicated ice breaking, or ice strengthened oil response barge with the most appropriate equipment to deal with a broken ice condition onboard in a state of operational readiness for as long as the ice allows.

A sustained offshore operation may depend on having the icebreaking barge available as a shuttle to and from West Dock. In that case it would be logical to use the ex - SATCO ice strengthened barges with conventional bows (operated by Lynden), as a dedicated oil spill response platform(s), and the non-ice strengthened series 200 barges as back-up on site storage for as long as they are able to operate. The *Endeavor* would be left as the primary means of lightering

large volumes of recovered liquids to a shore tank farm. The only practical alternative to this approach is to rely on hovercraft as lighters.

- Lack of any means of accessing an offshore spill location with conventional marine equipment (existing) from early to mid-November. As discussed above, even icebreaking barges reach their realistic operating limit in about 1.2 ft of level ice in late October or early November. By the third week in November there is a very low probability of experiencing broken ice in the vicinity of Seal Island (Northstar). In early December, ice road construction can usually begin and offshore response can start to use the ice surface as a reliable working platform. This leaves ten to 20 days in late October and November when the available marine equipment may no longer be able to access the offshore area from West Dock. Air cushion vehicles could provide the only possible form of surface access to the spill site at this time.

Possible solution(s): (1) contract for a LACV-30 hovercraft through the critical period from early October to early December; (2) utilize a more capable ice breaking barge such as the Arctic Challenger to expand the marine operating season (this would require substantially more powerful tugs than those currently available at Prudhoe Bay)

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Names with telephone numbers indicate individuals contacted during the course of this project.

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Northern Air Cargo                                      see ACS agreements

Air Logistics, Fairbanks                                      owner Alyeska BO-105 (helitorch)

Evergreen Helicopters, Anchorage                                      misc. light machines

North Slope Borough SAR Unit,  
Barrow                                              emergency call out with Bell 214ST

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## Appendix G

### Probability of Very Large Blowouts During Broken Ice Periods

It must be recognized that the oil well blowouts in this study, involving up to 225,000 barrels of oil spilled, are extremely rare events. That they would occur during the brief periods of broken ice adds to their extreme improbability. The purpose here is to work through some calculations to demonstrate how truly remote the possibilities are.

A study for BP Exploration (Alaska) Inc. was recently completed on the probability of blowouts and oil spills from the planned Northstar and Liberty oil development projects in the Beaufort Sea (SL Ross 1998). The following analysis was drawn from that study. We restrict ourselves to blowout probabilities associated with the Northstar venture. The situation for Point McIntyre would be similar. We also restrict ourselves to what we call "very large" oil spills, defined as being larger than 10,000 barrels and "extremely large" oil spills, defined as being larger than 150,000 barrels, a size that corresponds to the ones considered in this broken ice study. The following analysis is based on the assumption that drilling and production operations are equivalent in safety terms to offshore drilling elsewhere. The analysis can be considered conservative given that the drilling is actually taking place on land (artificial, gravel islands), which is known to be safer than drilling offshore.

#### Historical Statistics

In the U.S. only two moderate-size oil-well blowouts involving oil spills greater in size than 50,000 barrels have occurred since offshore drilling began in the mid-fifties. One must look beyond the U.S. to find a reasonable database on very large and extremely large offshore oil-well blowouts. Table G-1 lists all worldwide blowouts involving the spillage of more than 10,000 barrels each. For our definition of "extremely large" spills, that is, oil spills 150,000 barrels in size or greater, it is seen that there have been five such spills in the history of offshore drilling, two of which occurred during development drilling and two of which occurred during production or workover activities. The fifth was from exploration drilling.

**Blowouts during Drilling.** Spill frequencies are best expressed in terms of a risk exposure factor such as number of wells drilled. On a worldwide basis approximately 36,633 offshore wells were drilled from 1955 to 1980 of which 24,896 were development wells (Gulf 1981). The total number of development wells drilled up to 1988 has been estimated to be 51,000 (Sharples et al. 1989). Thus the frequency of extremely large spills from oil-well blowouts during development drilling up to 1988 becomes  $3.9 \times 10^{-5}$  spills per well drilled ( $2/51,000$ ) or one such spill for every 25,500 wells drilled. A similar analysis can be done for so-called "very large" spills, that is those larger than 10,000 barrels. Referring to Table G-1 it is seen that, up to 1988, four development drilling blowouts have produced spills in this category, so the spill frequencies for these become  $7.8 \times 10^{-5}$  spills per well drilled ( $4/51,000$ )

The number of wells drilled worldwide since 1988 is not readily available, but the literature indicates that only one large oil well blowout larger than 10,000 barrels occurred since that time (this was the Timbalier Bay production-well blowout occurring in state waters of the U.S. Gulf of Mexico in September, 1992). This means that estimates based on more current statistics would be even lower than those noted above because no drilling-related blowouts have occurred since 1988.



**Table G-1**  
**Historical Large Oil Spills from Offshore Oil-well Blowouts**

Area	Reported Spill Size (bbl)	Date	Operation Underway
Mexico (Ixtoc 1)	3,000,000	1979	Exploratory Drilling
Dubai	2,000,000	1973	Development Drilling
Iran <sup>1</sup>	?	1983	Production
Mexico	247,000	1986	Workover
Nigeria	200,000	1980	Development Drilling
North Sea/Norway	158,000	1977	Workover
Iran	100,000	1980	Development Drilling
U.S.A., Santa Barbara	77,000	1969	Production
Saudi Arabia	60,000	1980	Exploratory Drilling
Mexico	56,000	1987	Exploratory Drilling
U.S.A., S. Timbalier 26	53,000	1970	?
U.S.A., Main Pass 41	30,000	1970	Production
U.S.A., Timbalier Bay/Greenhill	11,500	1992	Production
Trinidad	10,000	1973	Development Drilling

1. The Iranian Norwuz oil-well blowouts in the Gulf of Arabia, which started in February 1983, were not caused by exploration or drilling accidents but were a result of military actions during the Iraq/Iran war.

**Blowouts during Production and Workovers.** Table G-1 shows the occurrence of two extremely large (>150,000 bbl) and five very large (>10,000 bbl) oil spills from blowouts during production and workovers. Developing an exact risk exposure for these events is not easy because of lack of data, but it is estimated that the total oil produced offshore on a worldwide basis up to the end of 1995 is about 100 billion barrels, and that the total producing oil well-years is 200,000 well-years (SL Ross 1998). Generally, in analysing accidents in the oil and gas industry the exposure variable of "well-years" is used to normalize data for the continuous operation of production. This exposure is also convenient to use for workovers inasmuch as these maintenance activities, although not being continuous operations, usually occur with regularity, say, every five to seven years or so during the lifetime of a well.

On this basis the worldwide frequency of extremely large oil spills (>150,000 bbl) from oil-well blowouts that occurred during production or workovers is  $2/200,000 = 1.0 \times 10^{-5}$  blowouts/well-year. For very large spills (>10,000 bbl) the number is  $2.5 \times 10^{-5}$  blowouts/well-year.

Finally, it is emphasized that the spill frequencies derived above for extremely large spills, however low, are based on spills in countries (except Norway) that do not generally have regulatory standards as stringent as those existing in the USA. For example, the largest oil spill in history, the Ixtoc I oil-well blowout in the Bay of Campeche, Mexico, that occurred in 1979, was caused by drilling

procedures (used by PEMEX, Mexico's national oil company) that are not practiced in U.S. waters and which are contrary to U.S. regulations and to the accepted practices within the international oil and gas industry.

### Calculated Frequencies for the Northstar Project

The exposure numbers for Northstar (wells to be drilled, well-years of operations, etc) are shown in Table G-2.

**Table G-2  
Drilling and Production Plans for Northstar**

Years of Production	20
Oil Producer Well-years	266
Total Oil Production (Million barrels)	145
<b>Well Statistics</b>	
- Development Oil Producers	14
- Development Gas Injectors	7
- Drilling Time Frame	2 years

Using the above worldwide spill frequency statistics as a basis for prediction, the spill frequencies estimated for the projects would be:

- Predicted frequency of extremely large oil spills (>150,000 bbl) from blowouts during a drilling operation, based on an exposure of wells drilled:  $21 \times 3.9 \times 10^{-5} = 8.2 \times 10^{-4}$ . This represents a 0.082% chance over the two-year drilling period, or an average annual probability of one in 2400.
- Predicted frequency of very large oil spills (>10,000 bbl) from drilling blowouts based on an exposure of wells drilled:  $(14+7) \times 7.8 \times 10^{-5} = 1.6 \times 10^{-3}$  or a 0.16% chance over the drilling period. On average, the annual probability is one in 1300.
- Predicted frequency of extremely large oil spills (>150,000 bbl) from production/workover blowouts, based on an exposure of well-years:  $266 \times 1.0 \times 10^{-5} = 2.7 \times 10^{-3}$  or a 0.27% change over the project's lifetime (20 years) or a one-in-7400 chance per year. This means that if the project continued forever at the same, fixed conditions, one could expect an oil spill larger than 150,000 barrels once every 7400 years.
- Predicted frequency of very large oil spills (>10,000 bbl) from production/workover blowouts, based on an exposure of well-years:  $266 \times 2.5 \times 10^{-5} = 6.7 \times 10^{-3}$  or a 0.67% chance over the project's lifetime (20 years) or a one-in-3000 chance per year.

Now, considering the period of broken ice only, assuming that the total period as a worst case is approximately eight weeks (3 in break-up and 5 in freeze-up), the above blowout probability numbers should be divided by 6.5 that is, 52 weeks / 8 weeks). The final numbers are shown in Table G-3 below.

It is seen that for the first two years of the project, while virtually continuous drilling is occurring, the probability per year is one in 16,000 that an extremely large blowout oil spill (>150,000 bbl) would occur during either the freeze-up or the break-up periods. Once development drilling is completed, the equivalent annual probability drops to one in 48,000. This means that if the production operation were to continue forever at the given rates, one could expect an extremely large spill during broken ice conditions once every 48,000 years.

One final note: In the scenarios it was assumed that the blowouts flowed unabated for a period of 15 days. One of the main reasons that oil spills from historical blowouts have been relatively small is that most have been brought under control quickly either through mechanical procedures or because of the tendency of a blowing well to "self-bridge" and stop naturally. As discussed in SL Ross 1998, for 145 blowouts in the U.S. Gulf of Mexico from 1956 to 1986, 60% were controlled in less than one day, 81% were controlled in less than a week, and 91% within one month.

**Table G-3**  
**Predicted Number of Very Large and Extremely Large Spills from Blowouts**  
**for the Northstar Project over its 20-year Lifetime**

<b>Event</b>	<b>Historical Frequency</b>	<b>Northstar Exposure</b>	<b>No. of Events</b>	<b>Annual Probability</b>	<b>Annual Probability during Broken Ice (8 weeks)</b>
Development drilling blowout with oil spill > 10,000 bbl	$7.8 \times 10^{-5}$ /wells drilled	21 wells drilled over 2 yrs	$1.6 \times 10^{-3}$	one in 1300	one in 8,500
Development drilling blowout with oil spill > 150,000 bbl	$3.9 \times 10^{-5}$ /wells drilled	21 wells drilled over 2yrs	$8.2 \times 10^{-4}$	one in 2400	one in 16,000
Production/workover blowout with oil spill > 10,000 bbl	$2.5 \times 10^{-5}$ /well-year	266 well-years	$6.7 \times 10^{-3}$	one in 3000	one in 20,000
Production/workover blowout with oil spill > 150,000 bbl	$1.0 \times 10^{-5}$ /well-year	266 well-years	$2.7 \times 10^{-3}$	one in 7400	one in 48,000

**Appendix H**

**Addendum to Report:  
Realistic Scenario for the Spring Break-up Period**

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## Appendix H

### Addendum to Report: Realistic Scenario for the Spring Break-up Period

#### 1. Introduction

Following a review of the initial draft report, a subsequent analysis was undertaken to address one of the key limitations of the study. In the initial work, as reported in the main text of this report, the weather and ice conditions were assumed to be unvarying throughout each of the six scenarios. This is not a realistic situation. As described in detail in Chapter 2, the break-up and freeze-up periods are likely to include a range of ice concentrations. This addendum to the original work considers the response capability under a more realistic set of conditions for the break-up period only. The freeze-up situation has been analyzed separately and is reported elsewhere. To avoid unnecessary repetition, it is assumed that the reader is familiar with the approach and methodology of the analysis used in the main text of the report, and where possible, reference is made to those analyses.

#### 2. Description of Environmental Conditions

##### 2.1 Assumptions and Background

The patterns and behavior of ice in the study area during the June and July ice melt and break-up period were studied in detail for a five-year period (Vaudrey 1981 to 1985). This experience was incorporated in the design basis ice criteria for the Northstar Development (Vaudrey 1996). Results indicated that break-up typically commenced in the vicinity of Seal Island around July 4 with year-to-year variations from an early break-up in the last week of June to a late break-up in the second week of July. The decrease in ice concentrations from 10/10 fast ice immediately prior to break-up is usually rapid with close to open water conditions (less than 1/10 ice) being achieved by July 26 on average (std. deviation of 11 days).

A typical progression of ice concentrations in the vicinity of Seal Island would follow the pattern below:

Onset of break-up: Day 1	9/10 ice with leads and fractures
Days 2 - 3	7 to 8/10
Days 4 - 5	5 to 6/10
Days 6 - 15	3 to 5/10
Days 15 - 22	1 to 3/10
Day 22 - summer	0 to 1/10

The table below lists the other environmental conditions that will apply throughout the scenario:

Air temperature (day)	45°F
Air temperature (night)	35°F
Floe ice thickness	3 to 5 feet, Days 1 to 3 1.5 to 4 feet, Days 4 to 15
Daylight	24 hours
Floe Size	500 to 1,000 feet, Days 1 to 3 50 to 500 feet, Days 4 to 15
Melt Ponds	40 to 50%, Days 1 to 3 60 to 70%, Days 4 to 15
Ice Drift Rates*	use 3% of the wind for average (may be double this average for periods of hours)
Ice Drift Direction	use 30° to the right of the wind typ.
Sea State	N/A for Days 1 to 3 98% < 3 feet for Days 4 to 15
Visibility	22% < ½ nm
Ceiling	11% < 1,500 feet with vis , nm

\*Note: only apply speed rule from Day 3 on. Ice is still too confined to move freely Days 1 and 2.

## 2.2 Descriptive Oil in Ice Scenario: Suggested Pattern of Wind Events

The following description attempts to paint a temporal picture of what might happen to the ice cover around Northstar during a typical break-up sequence. It should be noted that there are literally hundreds of credible combinations of ice, winds and temperatures that could lead to different outcomes.

The table below summarizes the weather patterns and anticipated ice conditions around the island. The sequence is not intended to represent any particular year, but was created as a composite of observed patterns of ice deterioration in the vicinity of Seal Island between 1981 and 1985 (Ref. Vaudrey individual reports).



**Table H-1:  
Sequence of Wind Events Corresponding to a 15 day Break-up Scenario at Northstar**

<b>Dates</b>	<b>Wind Direction °T</b>	<b>Wind Speed kts</b>	<b>Anticipated Ice Conditions Vicinity of Northstar (Seal Island)</b>
July 4 Day 1	SW	20	deteriorated fast ice, 4 to 5 feet thick, starts to shift and fracture - concentrations remain at 9 to 9.5/10 all day but leads and cracks open up and large floes (>1,000 feet) start to become visible. Movements at this stage limited to 100's of feet.
July 5 Day 2	E	15	ice starts to open up around the island with movements of up to 1,000's of feet. Concentrations 8 to 9/10 fairly homogeneous.
July 6 Day 3	E	10	concentrations in the 7 to 8/10 range move steadily past the island at about 0.3 kt.
July 7 to 9 Days 4 to 6	SE (variable)	calm to 10 kt	5 to 6/10 concentrations wallow around the island with no consistent drift pattern.
July 10 to 14 Days 7 to 11	N (variable)	5	3 to 5/10 (highly in homogeneous) concentration drift slowly in the vicinity of the island with no particular pattern and speeds less than 0.1 kt. Large (1,000's of feet of open water interspersed with belts and patches of ice up to 5/10) Floe sizes more likely in the 100- to 500-foot range.
July 15 Day 12	E	15	3 to 5/10 move to the NW past the island at rates up to 0.5 kt.
July 16 to 18 Days 13 to 15	E	20	concentrations in the 1 to 3/10 range move sporadically in patches past the island with stretches of open water for up to ½ mile.

### 3. Spill Behavior

An uncontrolled blowout occurs in early July at the Northstar artificial island releasing 15,000 barrels of oil per day (BOPD) and 33 x 10<sup>6</sup> standard cubic feet (scf) of natural gas per day (a Gas-to-Oil Ratio [GOR] of 2200 scf/bbl). Over the 15-day period of the incident, the air temperature ranges from a nighttime low of 35 °F to a daytime high of 45 °F. Daylight exists for 24 hours. The surrounding water is initially covered by 9+/10ths deteriorating fast ice that is 3 to 5 feet thick. At the beginning of Day 3 the ice sheet breaks up and begins to move under the influence of the wind. Ice concentrations decline continuously after this and reach 1/10th to 3/10ths by Day 15. Table H-1 shows the wind and ice conditions assumed for this scenario. The ice floes are initially 500 to 1000 feet in size; however, as breakup progresses the floes fracture and reduce to 50 to 500 feet in size for Days 4 through 15. The ice is drifting at the same speed as the water (both wind-driven at 3% of

the wind speed). Small waves (only a few inches in height, because of the reduced fetches in the ice) are present on the open water between the floes on Days 7 through 15.

As the oil and gas exit the 6.3-inch inside diameter tubing at the wellhead the high velocity of the gas atomizes the liquid oil. The gas and oil droplets pass through the derrick or machinery spaces and the droplets agglomerate. After this the volume median diameter<sup>1</sup> of the oil spray droplets is assumed to be 0.75 mm. The kinetic energy of the gas jet from the wellhead carries the droplets to a height of 120 feet above the release point. From this point the oil droplets begin to fall as they are carried downwind by the wind. The speed at which the droplets fall is governed primarily by their diameter: larger oil drops fall much faster than smaller droplets. For example, in still air, a 0.75 mm droplet falls at a speed of 7.5 ft/sec. If there were no turbulence in the wind, in the 16 seconds required for a 0.75 mm diameter droplet to fall 120 feet, it would be carried more than 360 feet downwind. In real wind conditions considerable amounts of turbulence exist and must be accounted for in determining the trajectory of the oil spray. If the oil spray generated by the blowout were imagined to be all one drop size (i.e., 0.75 mm diameter), the drops would still fall at different distances from the blowout because of the turbulence in the wind. As the spray of oil drops falls, it is being spread horizontally and vertically by air turbulence, or meandering of the wind. In the time required for 99.7% of the 0.75 mm droplets to fall to the surface the wind has carried the final few 0.75 mm droplets 920 feet from the blowout. The air turbulence also spreads out the droplets laterally as they fall, with the width of the "footprint" of the oil on the surface increasing with distance from the source in a parabola-like shape.

In reality, the spray of oil droplets is made up of many different droplet sizes. In determining the footprint of the oil spray on the surface, this must also be taken into account. This is accomplished by dividing the full range of oil drop sizes produced by the blowout into nine smaller ranges, each representing 10% of the total volume of all the oil droplets. Only nine drop-size ranges are used because 10% of the volume of oil released is assumed to be in droplets so small (much less than 50  $\mu$ m) that they remain suspended in the atmosphere and never settle out. Each range is characterized by a droplet diameter that is representative of the droplets in the same range. For example the largest 10% of the volume of oil spray droplets is represented by a 1.55 mm diameter oil droplet; the smallest 10% that will settle is represented by a 0.05 mm diameter droplet. The dimensions of the oil spray footprint on the surface of fast ice adjacent to the island were calculated by determining the deposition rate as a function of distance downwind (from the product of the mean concentration of a given droplet size in the air and that droplets terminal settling velocity) and the width of the oiled area for 99.7% of the representative droplets in each range to settle to the surface.

As the warm oil droplets fall in the air they evaporate. It is assumed that, regardless of fall time or droplet diameter, the slick formed by the droplets has lost 20% of its volume to evaporation

### 3.1 Day 1

As the oil rains down on the surface of the fast ice it begins to accumulate in depressions and pools on the surface of the adjacent ice. Close to the source, starting about 50 m downwind of the

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<sup>1</sup> 50% of the volume of oil is contained in droplets larger than the volume median diameter and 50% is contained in droplets smaller than the volume median diameter

wellhead, the deposition rate, averaged over the width of the plume, is high enough to exceed the holding capacity (or equilibrium thickness, defined by McMinn 1972 as 38.1 mm for an assumed effective roughness height of 0.5 feet) and the oil spreads away from the initial deposition zone. Farther from the blowout the deposition rate declines and the width of the plume increases until the point is reached where the slick thickness generated over the scenario time period does not exceed the equilibrium thickness and the oil does not spread from where it was initially deposited.

Over the 24 hours of Day 1 of the scenario (see Table H-1) 10,800 bbls of oil are deposited on the ice: (15,000 bbl/day x 0.8 x 0.9). Figure H-1 shows the thickness of the slick on the ice downwind of the blowout after the first day, when it is assumed that the ice moves and carries this oiled area away to the NE. The first droplets of oil hit the ice surface some 50 m downwind of the blowout. A short distance downwind of this the oil is deposited in amounts sufficient to exceed the equilibrium thickness; this rate of deposition continues until a distance of 210 m from the blowout. In this area the oil spreads laterally away from the deposition zone. Figure H-2 shows the width of the oiled area as a function of distance downwind of the source after 24 hours deposition. The zone where additional spreading occurs is apparent. Figure H-3 shows a schematic "bird's eye" view of the oiled ice after 24 hours deposition. The total oiled area is 31 ha (0.12 sq. mi.).

Figure H-4 shows the cumulative percentage of the 10,800 bbls of oil deposited per day that falls to the ice as a function of distance downwind: 50% of the oil falls within 100 m; 75% falls within 220 m and 90% falls within 540 m.

### 3.2 Day 2

On Day 2 of the scenario two major ice movements occur: one at midnight and one at noon, dividing the oiled area into two equal portions. Figure H-5 shows the thickness of each of the two equal areas as a function of distance from the location of the source and Figure H-6 shows the corresponding width. Figure H-7 shows a pictorial view of one area; the total area oiled in each portion is 30 ha, for a total of 60 ha oiled on Day 2.

### 3.3 Day 3

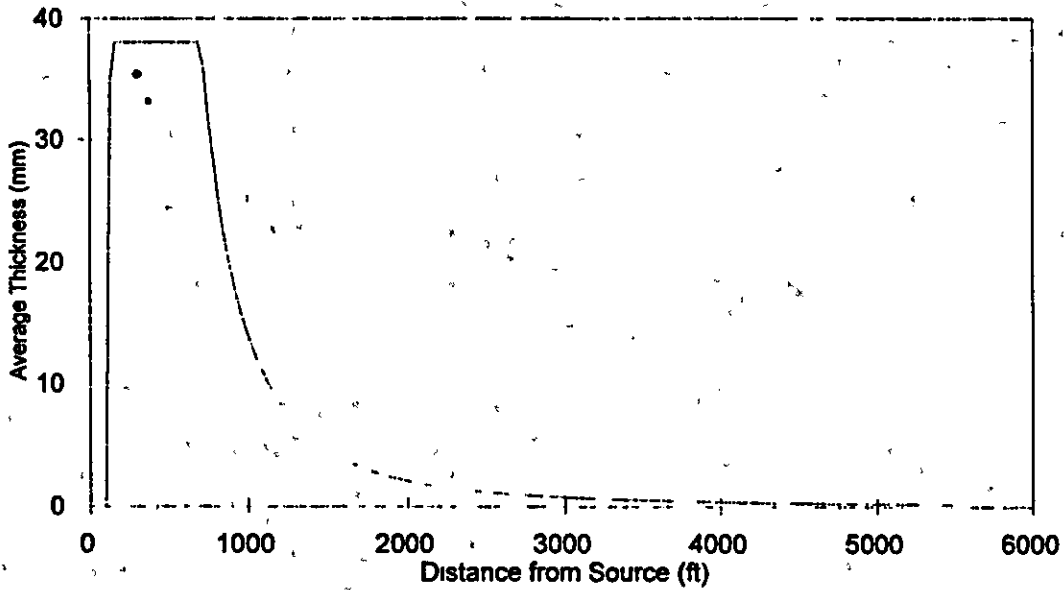
The dimensions of the slick on water or ice floes as they pass under the blowout plume on Days 3 through 15 were estimated as in the six "average" scenarios described in the text of the main report (width and distance defined as those for 99.7% of a given droplet size to settle - thickness a function of current speed). For the purpose of further predictive modeling of the fate and behavior of the surface oil slicks, we use the footprint thickness at the point where all (99.7%) of the droplets of a diameter representing 50% (by volume) have reached the surface. This thickness, and the corresponding width, are used to define the starting dimensions of the "thick" portion of the oil slick.

On Day 3 the wind is 10 kt from the east and the current is 0.3 knots to the west. As such, the thick slick is 180 feet wide and 1.3 mm thick at the starting point of the surface slick modeling. This is at a distance of approximately 920 feet downwind of the blowout. The thick slick at this point contains about 60% of the oil that will eventually settle to the surface. As noted, at this point the oil slick is assumed to be evaporated to 20% loss. About 40% of the oil that eventually settles to the surface falls beyond the 920 foot mark. Because most of these droplets are very small, they travel far

**Figure H-1**

**Distance from Source vs Avg. Thickness**

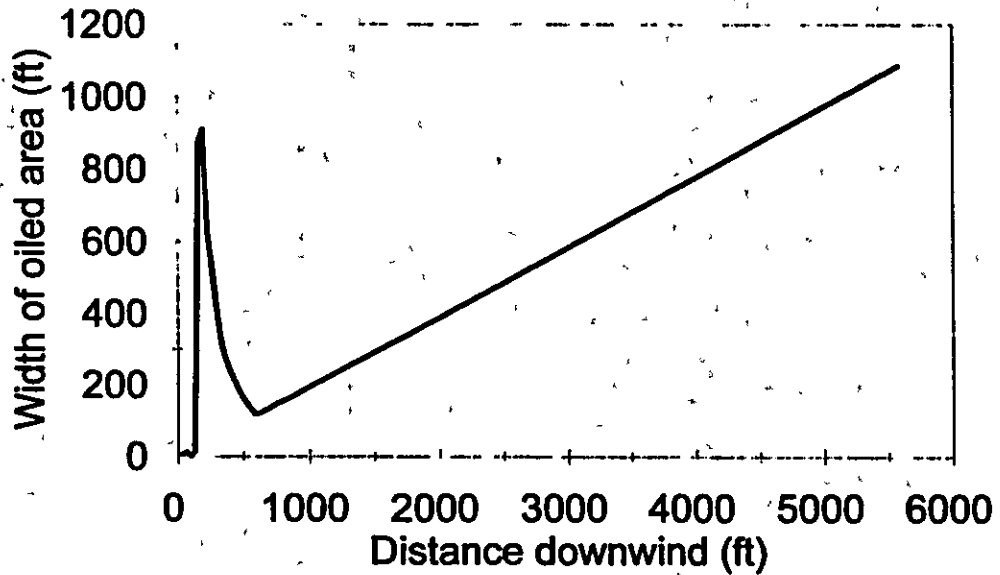
24-hour release



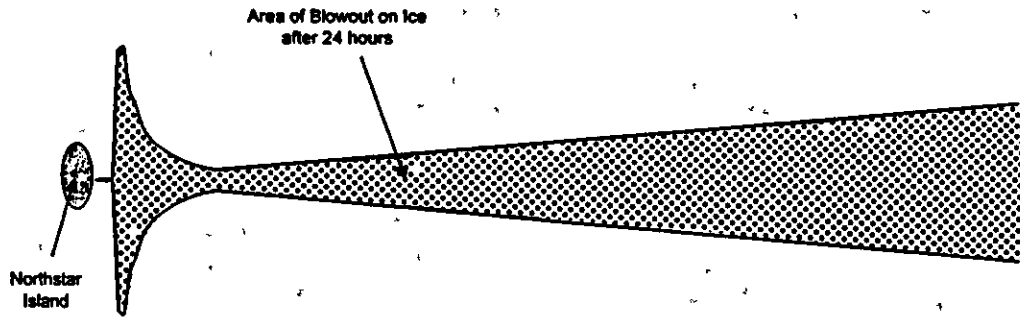
**Figure H-2**

**Width of oiled area downwind**

After 12 hours deposition



**Figure H-3**  
**Schematic view of the oiled ice on Day 1 after 24 hrs deposition**



**Figure H-4**  
**Cumulative Percentage on Ice Downwind**  
Percent of total deposited on ice

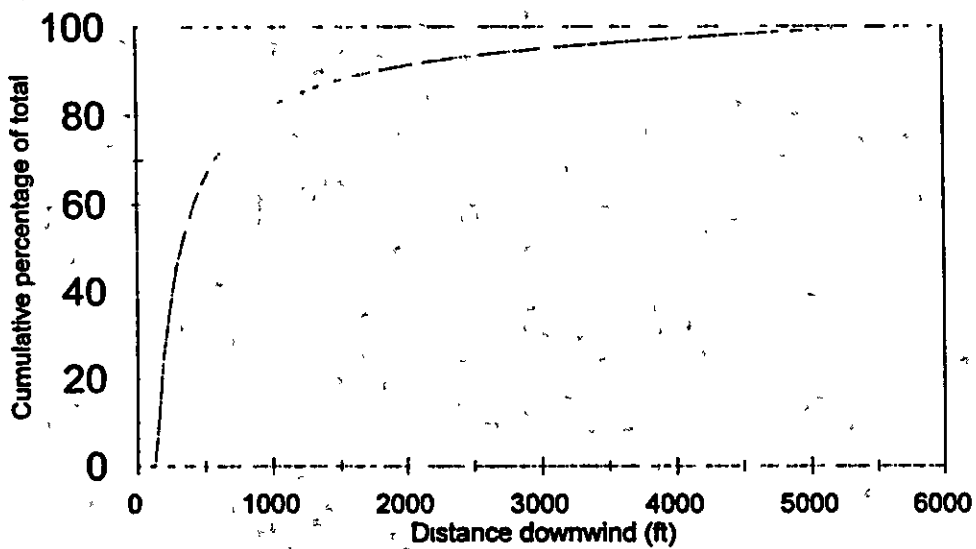


Figure H-5

Distance from Source vs Avg. Thickness  
12-hour release

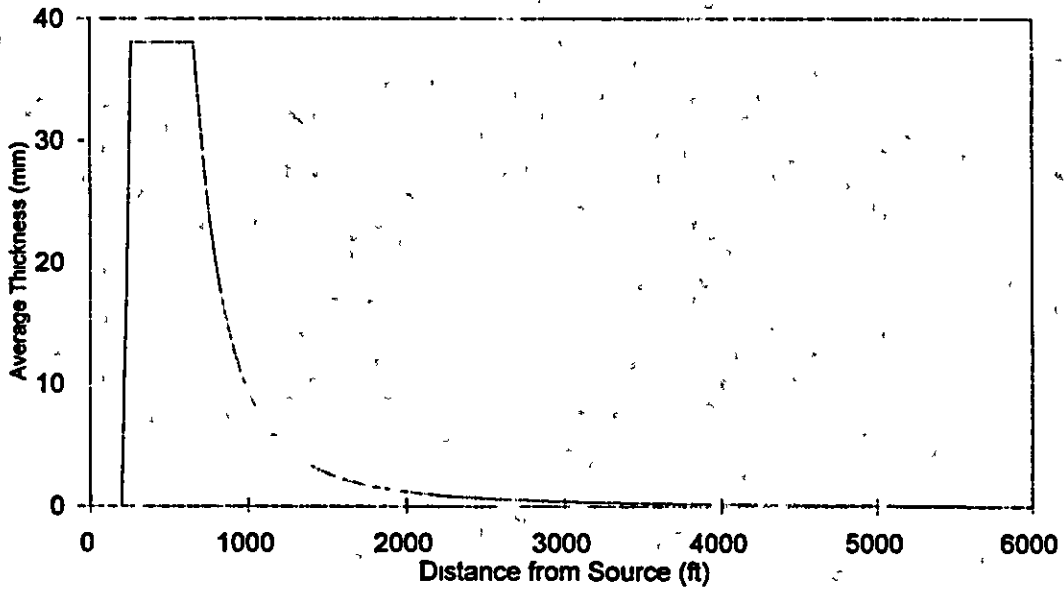
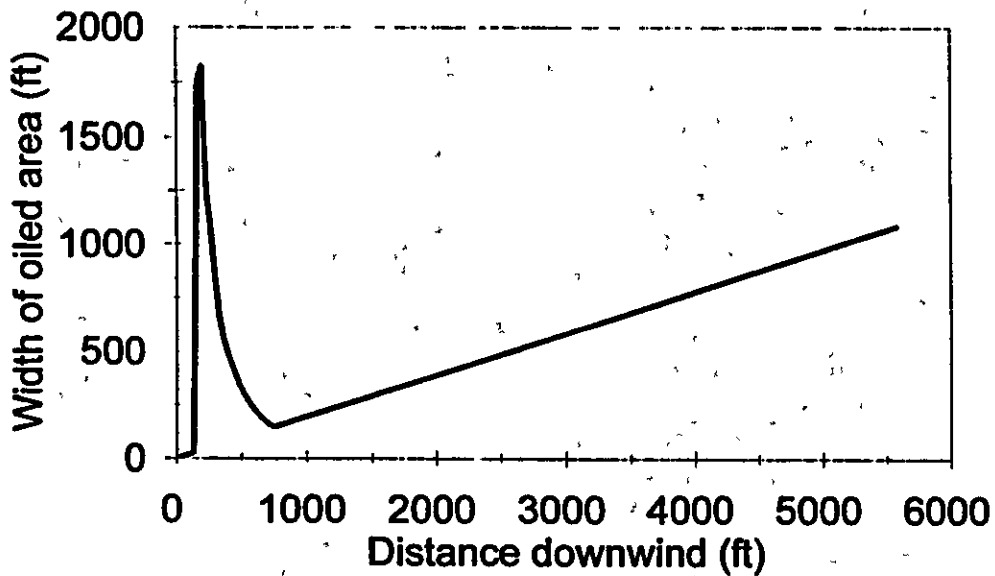
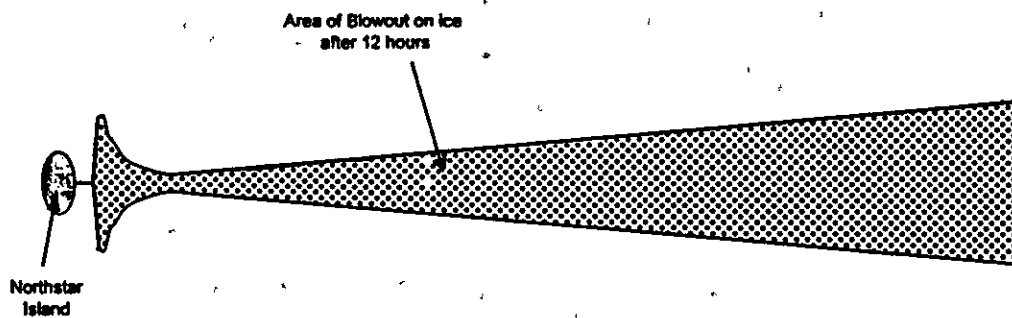


Figure H-6

Width of oiled area downwind  
After 24 hours deposition



**Figure H-7**  
**Schematic view of one of two areas of oiled ice on Day 2**



downwind and spread widely before settling out. These droplets form a very thin slick on either side of the thick oil. This very thin slick is a long, narrow triangular area with an average thickness that is on the order of 35  $\mu\text{m}$  (0.035 mm).

The approximate mass balance for the oil released from the blowout is: 20% evaporates from the drops in the air; the smallest 10% of the volume of the weathered droplets are so small that they remain suspended in the atmosphere; about 60% of the remaining oil (or about 40% of the total - 0.6 x 0.7, composed of mostly the larger droplets) settles to the surface within 920 feet and, if it lands on water, forms a slick 1.3 mm thick and 180 feet wide; and, 40% of the remaining oil (or about 30% of the total - 0.4 x 0.7, composed of mostly small droplets) settles out farther downwind and forms a thin (35  $\mu\text{m}$ ) slick bordering the thick slick on both sides.

For the purposes of this scenario, it is estimated that 30% of the oil spray lands on water and 70% lands on the surface of ice floes. The thickness of this oil coating ice floes is estimated by summing the amounts of oil of the various size ranges that settle onto the floes as they drift under the plume from the lee side of the island to the point at which oil droplets finish settling. Directly in the lee of the island, over the distance required for 97.7% of the average size drops to settle out (920 feet), it is assumed that the ice floes are coated evenly over a width equal to the plume width (in this case 180 feet). Further down drift, the oil coating is incremental. The average oil thicknesses on the floe surface ranges from 1.7 mm near the center-line of the oiled strip to 0.007 mm out near the edges. The spray that lands on ice floes is slowly flushed by melt water into the melt pools on the floes. The flushing process results in wind-herded oil thicknesses on the melt pools of 10 mm. The oil covers up to 60% of the surface area of the melt pools; the largest slicks are on floes near the center-line of the oiled strip. This oil will evaporate at a rate negligibly different from the oil that falls on the water, reaching a total evaporative loss of 29% after 24 hours.

Table H-2 summarizes the predicted characteristics of the thick slick over a time period of 24 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 18 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 410 feet and a thickness of 0.5 mm. After 21 hours, the oil has evaporated to a point (28%) where it's Pour Point (30°F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water.

The presence of ice eliminates the wave action that would normally exist with a 10 knot wind and suppresses natural dispersion and emulsification of the oil slick.

The thick oil slick continues to evaporate slowly throughout the 24 hour modeling period. It loses a total of 29% of its volume to evaporation after 24 hours. The viscosity of the unemulsified oil increases to 170 cP after 12 hours and reaches 190 cP at 24. The Pour Point of the thick oil after 24 hours has increased to 32 °F.



**Table H-2: Summary of Day 3 slick characteristics**

Time (h)	Thick oil remaining on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	13%	0	120	1.3	180
3	12	0	140	0.9	240
6	12	0	150	0.7	290
12	11	0	170	0.6	360
24	11	0	190	0.4	420

### 3.4 Days 4, 5 and 6

On Day 4 the wind drops to 3 knots from the south-east and the current is 0.1 knots to the north-west. As such, the thick slick is 180 feet wide and 4.2 mm thick at the starting point of the surface slick modeling

Table H-3 summarizes the predicted characteristics of the thick slick on Days 4, 5 and 6 over a time period of 24 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 24 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 1000 feet and a thickness of 0.7 mm.

The presence of ice eliminates the wave action that would normally exist with a 3 knot wind and suppresses natural dispersion and emulsification of the oil slick.

The thick oil slick continues to evaporate slowly throughout the 24 hour modeling period. It loses a total of 32% of its volume to evaporation after 24 hours. The viscosity of the unemulsified oil increases to 140 cP after 12 hours and reaches 160 cP at 24. The Pour Point of the thick oil after 24 hours has increased to 22 °F.

**Table H-3: Summary of slick characteristics over the first 24 hours of Days 4, 5 and 6**

Time (h)	Thick oil remaining on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	21	0	120	4.2	180
3	21	0	130	1.8	420
6	21	0	130	1.3	560
12	20	0	140	1	760
24	19	0	160	0.7	1000

### **3.5 Days 7 through 11**

On Days 7 through 11 the wind is 5 knots from the North and the current is 0.15 knots to the Northwest. As such, the thick slick is 180 feet wide and 2.5 mm thick at the starting point of the surface slick modeling

Table H-4 summarizes the predicted characteristics of the thick slick on Days 7 through 11 over a time period of 24 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. For the first 24 hours after its creation, the thick portion of the slick on water continues to spread laterally as it drifts with the ice, reaching a width of 720 feet and a thickness of 0.6 mm.

The presence of ice dampens the wave action that would normally exist with a 5 knot wind and reduces natural dispersion of the oil slick compared to open water conditions. The slick is predicted to begin to form a water-in-oil emulsion 42 hours after the oil had been deposited on the water surface. If emulsification rates are the same in loose pack ice as in open water under identical winds, the slick would be fully emulsified (75% water content by volume) after more than 72 hours on the water.

The thick oil slick continues to evaporate slowly throughout the 24 hour modeling period. It loses a total of 27% of its volume to evaporation after 24 hours. The viscosity of the unemulsified oil increases to 150 cP after 12 hours and reaches 170 cP at 24. The Pour Point of the thick oil after 24 hours has increased to 26 °F.

**Table H-4: Summary of slick characteristics over the first 24 hours of Days 7 through 11**

Time (h)	Thick oil remaining on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	25	0	120	2.5	180
3	25	0	130	1.4	320
6	24	0	140	1.1	410
12	23	0	150	0.8	540
24	22	0	170	0.6	720

### 3.6 Day 12

On Day 12 the wind increases to 15 knots from the east and the current is 0.45 knots to the west. As such, the thick slick is 180 feet wide and 0.8 mm thick at the starting point of the surface slick modeling.

Table H-5 summarizes the predicted characteristics of the thick slick on Day 12 over a time period of 24 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. After 12 hours, the oil has evaporated to a point (28%) where its Pour Point (30°F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water. At this point it is 290 feet wide.

The presence of ice dampens the wave action that would normally exist with a 15 knot wind and reduces natural dispersion of the oil slick compared to open water conditions. The slick is predicted to begin to form a water-in-oil emulsion 15 hours after the oil had been deposited on the water surface. If emulsification rates are the same in loose pack ice as in open water under identical winds, the slick would be fully emulsified (75% water content by volume) after 24 hours on the water.

The thick oil slick continues to evaporate slowly throughout the 24 hour modeling period. It loses a total of 30% of its volume to evaporation after 24 hours. The viscosity of the unemulsified oil increases to 180 cP after 12 hours and reaches 7900 cP at 24 (due to emulsification). The Pour Point of the thick oil after 24 hours has increased to 36 °F.

**Table H-5: Summary of Day 12 slick characteristics**

Time (h)	Thick oil remaining on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	25	0	120	0.8	180
3	24	0	150	0.6	220
6	23	0	160	0.5	240
12	21	0	180	0.4	290
24	20	75	7900*	1.6*	290

\* takes emulsification into account

### 3.7 Days 13, 14 and 15

On Days 13, 14 and 15 the wind increases further to 20 knots from the East and the current is 0.6 knots to the West. As such, the thick slick is 180 feet wide and 0.6 mm thick at the starting point of the surface slick modeling.

Table H-6 summarizes the predicted characteristics of the thick slick on Days 13, 14 and 15 over a time period of 24 hours. The oil that forms the thick slick on the water has a viscosity of 120 cP and a Pour Point of 10 °F at the point where the on-water modeling is started. After 9 hours, the oil has evaporated to a point (28%) where it's Pour Point (30°F) exceeds the ambient water temperature and the thick portions of the slick cease to spread on water. At this point it is 240 feet wide.

The presence of ice dampens the wave action that would normally exist with a 15 knot wind and reduces natural dispersion of the oil slick compared to open water conditions. The slick is predicted to begin to form a water-in-oil emulsion 12 hours after the oil had been deposited on the water surface. If emulsification rates are the same in loose pack ice as in open water under identical winds, the slick would be fully emulsified (75% water content by volume) after 18 hours on the water.

The thick oil slick continues to evaporate slowly throughout the 24 hour modeling period. It loses a total of 31% of its volume to evaporation after 24 hours. The viscosity of the unemulsified oil increases to 2900 cP after 12 hours and reaches 8500 cP at 24 (due to emulsification). The Pour Point of the thick oil after 24 hours has increased to 39 °F.

**Table H-6: Summary of slick characteristics over the first 24 hours of Days 13, 14 and 15**

Time (h)	Thick oil remaining on water (% of total released)	Emulsification (% water vol.)	Slick viscosity (cP @ 30 °F)	Thick slick thickness (mm)	Thick slick width (ft)
Initial	34	0	120	0.6	180
3	30	0	160	0.5	200
6	29	0	170	0.4	220
12	26	63	2900*	0.9*	240
24	25	75	8500*	1.6*	240

\* takes emulsification into account

## 4. Countermeasures

### 4.1 Overview

The selection of countermeasures will vary according to the ice concentrations. As described in the main text of this report, in a break-up scenario the two main tactics of *in situ* burning and containment and recovery are comparable in their effectiveness at dealing with oil amongst broken ice floes. This is because the slicks that result from blowout spills are not thick enough for effective skimming or burning unless the oil is first concentrated and thickened. *In situ* burning does have an advantage over skimming when it comes to burning oil that lands on ice. Given the above-freezing temperatures, oil that lands on ice will accumulate and thicken somewhat in melt pools on the surface of the ice. This thickening process allows for *in situ* burning of oil that would otherwise be present in only thin sheens and thus difficult to recover. As well, at the start of the break-up period the ice is relatively motionless for a few days, during which time the oil from the blowout will accumulate downwind of the source in burnable thicknesses. In this situation, *in situ* burning would be the primary response option, although for safety reasons, it would not take place until the oiled ice moved away from the blowout source.

### 4.2 Day 1

The oil that is deposited on the ice in the first two days of the blowout is ideally suited for removal by *in situ* burning. Approximately 75% of the oil that hits the ice is located within 700 feet of the blowout (some 8100 bbls), in very thick slicks (about 40 mm). Another 20% of the oil that hits the ice is located up to 3300 feet from the blowout (some 2160 bbl) in thinner slicks (as thin as 0.6 mm). When the ice containing the first day's oil deposits moves away from the island on Day 2, the oil would be burned. Igniting the thick oil near the source-end of the area would result in a burn of 95% removal efficiency (or 7700 bbls), leaving behind a residue of about 2 mm (or 400 bbls). The thinner oil, concentrated in melt pools, could be burned with an average removal efficiency of 80% (or 1730

bbls), leaving behind a 1 mm thick residue on the melt pools (or 430 bbls). In total, of the 10,800 bbls of oil deposited on the ice surface on Day 1, 9430 bbls, or 87%, could be removed by *in situ* burning. This corresponds to 63% of the total blowout flow of 15,000 barrels.

#### 4.3 Day 2

On Day 2 two ice movements occur creating two individual oiled ice areas, which for these purposes are assumed to be identical. Approximately 70% of the oil in each of the two areas that hits the ice is located within 560 feet of the blowout (some 7600 bbls in total), in very thick slicks (about 40 mm). Another 25% of the oil that hits the ice is located up to 3300 feet from the blowout (some 2700 bbl) in thinner slicks (as thin as 0.3 mm). When the ice containing the second day's oil deposits moves away from the island on Day 3, the oil would be burned. Igniting the thick oil near the source-end of both areas would result in a burn of 95% removal efficiency (or 7200 bbls), leaving behind a residue of about 2 mm (or 400 bbls). The thinner oil, concentrated in melt pools, could be burned with an average removal efficiency of 80% (or 2160 bbls), leaving behind a 1 mm thick residue on the melt pools (or 540 bbls). In total, of the 10,800 bbls of oil deposited on the ice surface on Day 2, 9360 bbls, or 87%, could be removed by *in situ* burning. This corresponds to 63% of the total blowout flow of 15,000 barrels.

#### 4.4 Day 3

In ice concentrations greater than 5/10ths, *in situ* burning would likely be the response tactic of choice. Although *in situ* burning offers little theoretical improvement in effectiveness compared with containment and recovery, the lesser logistical requirements will likely lead to greater effectiveness in an actual spill incident. As well, *in situ* burning offers the potential to burn oil contained in the melt pools that would form on ice floes.

The requirements for *in situ* burning in this scenario would be three burn systems, each using 300 feet of fire boom and two tugs. A helicopter carrying a Heli-torch would support the burn operation. The encounter rate of each burn unit for this scenario would be:

$$\begin{aligned} \text{ISB encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 0.7 \text{ mm} \times 0.3 \text{ knots} \times (1 - 70\% \text{ ice}) \\ &= 22 \text{ bbl/hr} \end{aligned}$$

The ISB system would be used in a "batch" mode. Oil would be collected in the back of the boom for a certain period of time, then the system would be moved away from the heavy concentrations of oil and the accumulated oil would be burned off. It is assumed that the thick slick is encountered and collected for 50% of the time, and the remainder of the time is spent burning off the accumulated oil and maneuvering the unit back into the thick oil slick. This equates, over a 24-hour day, to collecting oil for 12 hours and burning and maneuvering for 12 hours. Each individual burn would take about 1.2 hours from ignition to extinction. Twice each day, the section of fire boom would have to be replaced. It is potentially twice as efficient to collect and burn simultaneously; however, because the average oil slick thickness emanating from the source is close to the minimum ignitable thickness for weathered crude (ca. 2 mm) there would be a danger of the fire burning back to the spill source.

The estimated daily removal rate for one ISB unit is thus:

$$\text{ISB unit daily removal rate from the water surface} = (22 \text{ bbl/hr} \times 24 \text{ hr}) \times 0.5 = 264 \text{ bbl}$$

If three units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 792 bbl. This would be slightly higher than the potential effectiveness of three containment and recovery units because it is envisioned that burning, then maneuvering the ISB unit back into the thick oil will take less time than for the conventional boom and skimmer system.

The oil that falls on the ice floes in this scenario is ideal for *in situ* burning operations. After allowing the surface oil to concentrate in melt pools, about 75% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80%, and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (90% of the total) would be ignited by Heli-torch operations, the overall oil removal by burning becomes:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 15,000 \text{ bbl} \times 50\% \text{ on ice} \times 80\% \times 90\% \\ &= 5400 \text{ bbl} \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of ISB effectiveness expressed as a percentage of the total blowout flow and including operations on both water and ice for Day 3 of the scenario, is:

$$\begin{aligned} \text{Oil volume removed by ISB} &= (792 + 5400 \text{ bbl/day}) \div 15,000 \text{ bbl/day} \\ &= 41\% \end{aligned}$$

#### 4.5 Days 4, 5, and 6

Similar tactics would be employed for Days 4 through 6 as the ice concentration decreases to 5 to 6/10ths. At a distance corresponding to 12 hours downwind of the spill source, the thick slick width is 760 feet and the thickness is 1.0 mm. The ice and the slick are drifting at a rate of only 0.1 knots. Using this as an encounter speed would result in a very slow operation. Rather, it is likely that the operation would proceed at a greater speed, say 0.4 knots, in a downwind direction to maximize the encounter rate of oil. (Selecting 0.4 knots as the encounter speed allows two units, each with an encounter width of 100 feet, to effectively encounter the entire width of the thick slick: 2 units x 100 feet x 0.4 knots is approximately equal to 760 feet x 0.1 knots.) Using two *in situ* burn units, each comprising 300 feet of fire-resistant boom and two tugboats and supported by one Helitorch, the following estimates can be made for effectiveness of "on-water" burning. The encounter rate of each system would be:

$$\begin{aligned} \text{ISB encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 1.0 \text{ mm} \times 0.4 \text{ knots} \times (1 - 50\% \text{ ice}) \\ &= 71 \text{ bbl/hr} \end{aligned}$$

As for the Day 3 scenario the ISB systems would be used in a "batch" mode. The estimated daily removal rate for one ISB unit is thus:

$$\text{ISB unit daily removal rate from the water surface} = (71 \text{ bbl/hr} \times 24 \text{ hr}) \times 0.5 = 852 \text{ bbl}$$

If two units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 1704 bbl.

As in the Day 3 scenario, the oil that falls on the ice floes could also be dealt with by *in situ* burning. After allowing the surface oil to concentrate in melt pools, about 75% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80% and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (90% of the total) would be ignited by Heli-torch operations results in an overall oil removal by burning of:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 15,000 \text{ bbl} \times 35\% \text{ on ice} \times 80\% \times 90\% \\ &= 3780 \text{ bbl} \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of ISB effectiveness expressed as a percentage of the total blowout flow and including operations on both water and ice for each of Days 4, 5, and 6 of the scenario, is:

$$\begin{aligned} \text{Oil volume removed by ISB} &= (1704 + 3780 \text{ bbl/day}) \div 15,000 \text{ bbl/day} \\ &= 37\% \end{aligned}$$

#### 4.6 Days 7 through 11

In ice conditions of 3 to 5/10ths, either containment and recovery or *in situ* burning could be considered. As described in the main report, these two options would be similarly effective at dealing with oil on the water among ice floes. *In situ* burning does provide a major advantage in the break-up situation in that oil that is deposited onto the ice will form melt pools on the ice that can be subsequently burned. For this reason, it is assumed for the following that the response tactic would be *in situ* burning, using fire-resistant boom to concentrate oil from amongst ice floes, and using the Helitorch to ignite oil contained in melt pools on the ice.

The cleanup tactics would be the same as those employed for Days 4 through 6, but the effectiveness estimates will vary slightly as the ice concentration decreases to 3 to 5/10ths. At a distance corresponding to 12 hours downwind of the spill source, the thick slick width is 540 feet and the thickness is 0.8 mm. Again, the ice and the slick are drifting at a rate of only 0.15 knots which, if used as an encounter speed would result in a very slow operation. Rather, the calculation procedure here assumes that the operation would proceed at a speed of 0.4 knots, in a downwind direction to maximize the encounter rate of oil. (Selecting 0.4 knots as the encounter speed allows two units, each with an encounter width of 100 feet, to effectively encounter the entire width of the thick slick: 2 units x 100 feet x 0.4 knots is approximately equal to 540 feet x 0.15 knots.) Using two *in situ* burn units, each comprising 300 feet of fire-resistant boom and two tugboats and supported by one



Helitorch, the following estimates can be made for effectiveness of "on-water" burning. The encounter rate of each system would be:

$$\begin{aligned}\text{ISB encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 0.8 \text{ mm} \times 0.4 \text{ knots} \times (1 - 40\% \text{ ice}) \\ &= 68 \text{ bbl/hr}\end{aligned}$$

Using the same assumptions used previously regarding a batch-burn process effectively using 50% of a 24-hour day, the estimated daily removal rate for one ISB unit is:

$$\text{ISB unit daily removal rate from the water surface} = (68 \text{ bbl/hr} \times 24 \text{ hr}) \times 0.5 = 816 \text{ bbl}$$

If two units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 1632 bbl.

As in Days 3 through 6, the oil that falls on the ice floes could also be dealt with by *in situ* burning. After allowing the surface oil to concentrate in melt pools, about 75% of the surface area of the pools would be covered with 10 mm-thick oil. Taking into account an average oil-removal-by-burning efficiency of 80% and conservatively estimating that only oil in melt pools greater than 50 ft<sup>2</sup> (90% of the total) would be ignited by Heli-torch operations results in an overall oil removal by burning of:

$$\begin{aligned}\text{daily oil removed from floes by burning} &= 15,000 \text{ bbl} \times 28\% \text{ on ice} \times 80\% \times 90\% \\ &= 3024 \text{ bbl}\end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of ISB effectiveness expressed as a percentage of the total blowout flow and including operations on both water and ice for each of Days 7,8,9,10, and 11 of the scenario, is:

$$\begin{aligned}\text{Oil volume removed from ice by ISB} &= (1632 + 3024 \text{ bbl/day}) \div 15,000 \text{ bbl/day} \\ &= 31\%\end{aligned}$$

#### 4.7 Day 12

The cleanup tactics would be essentially the same as those employed for the previous eight days, except that a third *in situ* burning system would be required to encounter the entire thick slick width at the prevailing drift speed of 0.45 knots. At a distance corresponding to 12 hours downwind of the spill source, the thick slick width is 290 feet and the thickness is 0.4 mm. Using three *in situ* burn units, each comprising 300 feet of fire-resistant boom and two tugboats and supported by one Helitorch, the following estimates can be made for effectiveness of "on-water" burning. The encounter rate of each system would be:

$$\begin{aligned}\text{ISB encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap}) \times 0.4 \text{ mm} \times 0.45 \text{ knots} \times (1 - 30\% \text{ ice}) \\ &= 45 \text{ bbl/hr}\end{aligned}$$

Using the same assumptions used previously regarding a batch-burn process effectively using 50% of a 24-hour day, the estimated daily removal rate for one ISB unit is:

$$\text{ISB unit daily removal rate from the water surface} = (45 \text{ bbl/hr} \times 24 \text{ hr}) \times 0.5 = 540 \text{ bbl}$$

If three units were deployed to encounter the entire thick slick available the total daily ISB removal rate from water would be 1620 bbl.

The calculation of oil removal by burning from ice floes is similar to the previous Days 3 through 11, except that the percentage of oil in pools greater than 50 ft<sup>2</sup> diameter is reduced to 85% to account for the lighter coating of oil:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 15,000 \text{ bbl} \times 21\% \text{ on ice} \times 80\% \times 85\% \\ &= 2142 \text{ bbl} \end{aligned}$$

The ISB operations targeting the oil on ice floes would continue until all the available oil had been ignited. Delays in operations due to response time and environmental factors would not affect the overall removal effectiveness. The estimate of ISB effectiveness expressed as a percentage of the total blowout flow and including operations on both water and ice for each of Day 12 of the scenario, is:

$$\begin{aligned} \text{Oil volume removed from ice by ISB} &= (1620 + 2142 \text{ bbl/day}) \div 15,000 \text{ bbl/day} \\ &= 25\% \end{aligned}$$

#### 4.8 Days 13, 14, and 15

In ice conditions of 1 to 3/10ths, containment and recovery operations would be the preferred option applicable and could be fairly effective. Compared with the scenarios in higher ice concentrations, a greater percentage of the oil falls on water (rather than ice) and is thus available for recovery. Also, the lesser ice concentrations mean that containment operations can be carried out with little downtime due to ice incursions.

As in the scenarios previously described in the main report, the relatively narrow slick of thick oil means it can be encountered in its entirety by one or two containment and recovery systems. For the moment the evaluation will consider one system operating at a fixed location down drift of the blowout site, with the potential effectiveness of additional systems analyzed later.

The slick conditions of interest are those at a point 3 hours down drift of the blowout: the thick slick is 200 feet wide and averages 0.5 mm thick. Combining this with the drift rate of 0.6 knots, and accounting for the ice concentration of 10%, the encounter rate for oil on water and available for recovery is estimated as:

$$\begin{aligned} \text{encounter rate} &= (300 \text{ feet} \times 0.33 \text{ gap ratio}) \times 0.5 \text{ mm} \times 0.6 \text{ knots} \times (1 - 10\% \text{ ice}) \\ &= 96 \text{ bbl/hour} \end{aligned}$$

This encounter rate is less than the derated recovery rate of several of the offshore skimmers that could be used, so the encounter rate is the limiting factor and is used in the calculations of recovery effectiveness. Following the same calculation procedure and guidelines for oil recovery efficiency, the total fluid recovery rate can be estimated as shown below:

**Table H-7: Fluid Recovery Rates for Days 13 - 15**

Fluid	Calculation	Recovery rate
oil	lesser of system encounter rate and derated recovery rate	96 bbl/hr
total water	oil content in recovered fluid (recovery efficiency) = 20%	384 bbl/hr
emulsified water	emulsified water content in recovered fluid = 40%	64 bbl/hr
free water	total water less emulsified water	320 bbl/hr
total fluids	oil + emulsified water + free water	480 bbl/hr

Compared with the previous scenarios in the main report, the main difference here is the lesser ice concentration and its effect on containment efficiency. For the 10% ice condition, the containment efficiency is assumed to be 90%; that is, the containment operation is effective for 90% of the time accounting for interruptions related to clearing ice from the containment and repositioning the system when avoiding large floes. Given the 24-hours of daylight at this time of year, the total fluid volumes per day are calculated in the following table, combining the hourly rates and the 90% encounter efficiency.

**Table H-8: Estimate of Recovered Fluids per 24-hr Time Period**

Item	Calculation	Volume
total fluids per 24 hours	480 bbl/hr x 24 hours x 90%	10368 bbl
total free water	320 bbl/hr x 24 hours x 90%	6912 bbl
volume that can be decanted	total free water x 80%	5530 bbl
total fluids stored per 24 hours	total fluids less decant	4838 bbl
oil	96 bbl/hr x 24 hours x 90%	2074 bbl
emulsified water	64 bbl/hr x 24 hours x 40%	1382 bbl
free water	total free water x 20%	1382 bbl

The above calculations were for one system which could encounter half the width of the thick slick. A second system could be used, with identical recovered oil and fluid volumes. As in the previous break-up scenario, additional systems could be used to attempt to recover oil from the thick slick that is missed by the first system. The target for the additional systems is the oil that escapes containment due to inefficiencies associated with the ice conditions, assumed to be 10% for the 90% ice

condition. Using the same calculation procedure as detailed in the main report, two additional systems are considered. For each system, the encounter rate is estimated by subtracting the oil recovered by the previous system and estimating an equivalent average oil thickness. The following table summarizes those calculations.

Estimate of Slick Conditions and Fluid Recovery for Two Additional Systems				
System	Encounter thickness	Encounter rate	Oil recovered per 24 hours	Total fluid per 24 hours
#1	0.049 mm	9 bbl/hr	194 bbl	972 bbl
#2	0.049 mm	9 bbl/hr	194 bbl	972 bbl
total	-	-	388 bbl	1944 bbl

Note that the slick remaining after these two systems would be an average of only 0.007 mm thick, with an encounter rate of less than 1 bbl/hour and a daily recovery volume of much less than 1% of the daily blowout volume.

The following is the estimate of effectiveness for each of Days 13 through 15, expressed as a percentage of the total blowout flow:

$$\begin{aligned} \text{Recovered oil volume} &= (2 \times 2074 + 2 \times 194) \text{ bbl/day} - 15,000 \text{ bbl/day} \\ &= 30\% \end{aligned}$$

*In situ* burning could be considered as an option for dealing with the small fraction of the oil that lands on ice floes. In this instance, *in situ* burning would supplement the containment and recovery operation. Using the same calculation procedure as for the previous Days 3 through 11:

$$\begin{aligned} \text{daily oil removed from floes by burning} &= 15,000 \text{ bbl} \times 7\% \text{ on ice} \times 80\% \times 85\% \\ &= 714 \text{ bbl} \\ &= 4.8\% \text{ of } 15,000 \end{aligned}$$

The total oil removal for Days 13 - 15 is thus (30% + 4.8% = 35%).

#### 4.9 Summary of Effectiveness

Table H-9 summarizes the estimated effectiveness for each of the 15 days of the scenario. The highest effectiveness values are for Days 1 and 2 when oil that pools in a thick layer on the relatively stationary ice and can be removed through *in situ* burning. The lowest values is for Day 12 where the moving broken ice reduces the effectiveness of cleanup operations. The average effectiveness over the 15-day period is 38% of the total 15,000 barrel/day blowout flow, and 53% of the oil that lands on the ice and/or water surface.

**Table H-9: Summary of Response Tactics and Estimated Effectiveness**

Day	Main Response Tactics	Estimated Effectiveness	
		of total blowout flow	of oil that lands on ice/water surface
1	<i>in situ</i> burning of oil on ice	63%	87%
2	<i>in situ</i> burning of oil on ice	63%	87%
3	<i>in situ</i> burning of oil amongst and on ice	41%	57%
4 - 6	<i>in situ</i> burning of oil amongst and on ice	37%	51%
7 - 11	<i>in situ</i> burning of oil amongst and on ice	31%	43%
12	<i>in situ</i> burning of oil amongst and on ice	25%	35%
13 - 15	containment and recovery and <i>in situ</i> burning	35%	49%
Average		38%	52%

Note the estimated volume of oil that lands on the ice/water surface takes into account the assumed 20% evaporative loss and the further 10% of oil drops that are so small when discharged from the well that they remain in the air and never land

## 5. References

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