VOLUME 2

REPORT OF TASK GROUP ONE
Worst Case Scenario

FOR THE
BEAUFORT SEA STEERING COMMITTEE
April 1991

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REPORT

by

TASK GROUP NUMBER ONE

WORST CASE SCENARIO

for

BEAUFORT SEA STEERING COMMITTEE

APRIL, 1991

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et du gaz des terres du Canada

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Date: 6 June 1991

Mr. Robert Hornal
Chairman, Beaufort Sea Steering Committee
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V6J 4S5

Dear Mr. Hornal,

Attached please find a copy of the Task Group 1 report entitled "Assessing the Costs of a Major Oil Spill in the Canadian Beaufort Sea."

The directive for Task Group 1 was to create a generally acceptable procedure for developing and estimating the potential cost of a "worst case" oil well blowout scenario. The procedure was developed by estimating the costs of various component operations associated with the management of an oil well blowout in the Beaufort Sea - exclusive of the cost of remedial measures and wildlife compensation which is the subject of the Task Group 2 report. The cost for these operational components, such as well control, oil containment, recovery and disposal were then calculated according to four blowout examples.

This approach introduces the inevitable question "to what extent do the four examples in this report approximate the worst case scenario for a petroleum operator in the Beaufort Sea ?". On the one hand, the oil type, flow rates and duration result in pollution that is unlikely in the extreme (see the CPA companion report). On the other hand, this report did not define "how clean is clean" which is the end point in countermeasure expenditures.

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Instead, the Task Group preferred the use of the term "examples" as an alternate to "scenarios", emphasizing that the report offers a method of assessing the costs as opposed to providing the definitive answer to the question "how much will it cost ?".

As costs appreciate and changes take place within the Beaufort Sea area, new factors may be introduced into the analysis. However, it is unlikely the basic approach will alter, and for this the report offers a detailed procedure for estimating the cost of a worst case scenario.

Kind Regards,

Shawn Gill

S.D. Gill PhD.
Chairman, Task Group 1

ASSESSING THE COSTS OF A MAJOR OIL SPILL IN THE CANADIAN BEAUFORT SEA

for

TASK GROUP 1 OF THE BEAUFORT SEA STEERING COMMITTEE

by

S.L. ROSS ENVIRONMENTAL RESEARCH LIMITED
and
ENVIRONMENTAL PROTECTION BRANCH
CANADA OIL AND GAS LANDS ADMINISTRATION

APRIL 1991

EXECUTIVE SUMMARY

This report describes methods for calculating:

* the likely effectiveness of offshore oil spill cleanup operations in response to oil well blowouts in the Southern Beaufort Sea
* the numbers of ships, aircraft, equipment, personnel,etc. required to conduct:
  - offshore oil spill cleanup operations;
  - shoreline protection operations;
  - shoreline cleanup operations;
  - surveillance and monitoring;
  - disposal operations;
  - spring in-situ burning; and,
  - landfast ice cleanup.
* an estimated cost for each of the above operations broken down into direct operating costs, indirect support and administration costs and capital costs
* an estimated cost for relief well drilling operations

The methods are applied to four example blowout scenarios in order to illustrate the use of the techniques. the four scenarios used are:

1. a 10,000 BOPD subsea blowout in 30 m of water in summer, open-water conditions at 70°6'N, 134°W
2. a 10,000 BOPD subsea blowout in 30 m of water in fall, lasting through freeze-up, under transition zone ice at 70°6'N, 134°W
3. a 5000 BOPD above-sea or platform blowout from an artificial island near the Mackenzie Delta in summer open-water conditions at 69°39'N, 136°W
4. a 5000 BOPD above-sea blowout from an artificial island near the Mackenzie Delta in winter, landfast ice conditions at 69°39'N, 136°W

Table S1 shows the results of using the prescribed methods for the four scenarios (exclusive of control-of-well costs).

Table S1

Scenario Summary

SCENARIO		VOLUME OF OIL (bbl)						ESTIMATED COST ($ millions) FOR					
	Released	Removed	Dissipated Naturally	On Shore	Offshore Cleanup	Shoreline Protection	Shoreline Cleanup	Surveillance & Monitoring	Disposal	Spring In-situ Burning	Landfast Ice Cleanup	Total
10,000 BOPD sub-sea blowout in open water for 45 days	450,000	192,000	204,000	54,000	26	56	308	10	49	0	0	449
10,000 BOPD late-season blowout for 65 days	650,000	152,000	480,000	18,000	20	10	89	8	20	83/55**	0	230
5000 BOPD island blowout in open water for 30 days	150,000	74,000	57,020	18,500	9	31	183	7	23	0	0	253
5000 BOPD island blowout in landfast ice for 100 days	500,000	394,000	106,000	0*	0	0	0	0	0	0	11	11

* assumed

** coastal-based/icebreaker-based

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1. membership found in Volume 1.

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1. INTRODUCTION

1.1 BACKGROUND

"How much would an oil well blowout in the Beaufort Sea cost to cleanup?" This was the question asked during a liability and compensation workshop held in Inuvik in March 1990. The discussion involved matters related to an oil company's liability for oil spill damages and their financial capability to undertake what would be an expensive cleanup operation. The question was timely in view of the enormous expenditures made by Exxon Corporation in Alaska following the grounding of the Exxon Valdez some 12 months earlier.

With numerous oil spill cleanups documented in the literature since the grounding of the Torrey Canyon in 1967, it would seem that the answer to the question could be easily defined. Indeed, such a review had been conducted in 1985 by COGLA in an attempt to assess the financial liability of offshore drilling operations on frontier lands. That study (COGLA 1985) indicated that there was a correlation between the length of shoreline oiled (as opposed to the amount of oil coming ashore) and the cost of cleanup. In the 5-6 years since the study was completed new information on Beaufort Sea reservoirs and cleanup technology has emerged. The objective to more accurately assess these potentially sizeable costs, particularly in light of the Exxon Valdez experience, made it opportune to incorporate contemporary parameters specific to the Beaufort Sea.

At the outset it was recognized there were five generic components to costing out a Beaufort Sea oil well blowout:

- well control expenses
- marine recovery and disposal measures
- shoreline protection, cleanup, and disposal operations
- wildlife harvest loss compensation
- wildlife and habitat restoration measures

This study, conducted under the auspices of the Beaufort Sea Steering Committee's Task Group 1, examined the first three components. The remaining two factors, compensation and restoration measures, were assessed by Task Group 2, for which a separate report was prepared.

It was also acknowledged at the outset that the aggregate cost of an oil well blowout was influenced by a host of variables that included the type of well and drilling platform, seasonal constraints, type of oil, its distribution as a function of well location and season, level of effort, and extent of the cleanup operation. The goal, therefore, was to define these variables in sufficient detail to enable the reader to adapt the appropriate components to a specific pollution incident or scenario, thereby deriving the potential cost to be anticipated for that particular scenario.

The approach adopted for calculating the cost of oil spill containment, recovery and disposal operations was to assess the 1990 cleanup and logistical support capability within the Canadian Beaufort Sea area, assign the necessary priorities (i.e., well control, shoreline protection, cleanup, then disposal), and develop costs for these various components (to a limit of 13 floatels or base camps). This approach limits the level of effort to that which exists/can be supported by the Beaufort Sea infrastructure and at the same time avoids the socio-economic dislocation documented in the report prepared by the Inuvialuit Petroleum Corporation on the trip to the Valdez to investigate the matter of compensation (IPC, 1990).

This study makes no attempt to describe why an oil spill cleanup would be necessary. It merely develops costs for control and cleanup operations using logistical expenses typical for the Beaufort Sea area. Suffice to say, the cost of an oil spill cleanup is closely related to the value placed on the threatened or damaged resources. In the case of the 1974 Metula tanker spill in Chile (54,000 tons), cleanup expenses were negligible because the spill occurred in an unpopulated area and, accordingly, cleanup was viewed as being unnecessary. The Amoco Cadiz tanker (224,000 tons), on the other hand, broke up on a heavily populated section of French coastline where there is extensive tourist, fishing, shipping and recreational activities. The cleanup for that spill has been estimated at $240 million.

The Beaufort Sea communities have long expressed a concern for oil pollution as it represents a threat to the areas wildlife that is the foundation of subsistence livelihood. This, then, is the primary reason that cleanup would be undertaken instead of leaving it to nature's slow restorative powers.

Beyond this, pollution of the Arctic - Canada's last frontier - is repugnant to all peoples. The point at which cleanup ceases to benefit the environmental recovery process can only be determined after the fact, at the time of the spill

While assumptions have been made concerning the extent of contamination and the duration of the required cleanup in the four blowout examples, the measured approach to cleanup implies that shoreline restoration would continue beyond the first summer season. However, no allowances have been made for exposed shorelines being self-cleaned through erosion or sedimentation. In addition, it is not known to what extent cleanup would be required in subsequent years to protect wildlife and encourage its restoration. In the final analysis the extent of shoreline cleanup, a major component of the overall cost, will be determined by shoreline cleanup assessment teams on a beach-by-beach basis. Regardless, the character of the Beaufort Sea coastline, with its isolated communities and lack of roads, means that most operations will be staged out of base camps (floatels), the cost of which has been determined as accurately as possible.

1.2 STUDY OBJECTIVE

The objective of the study was to develop a methodology for estimating the costs of controlling and cleaning up major oil spills that result from oil-well blowouts in the Canadian Beaufort Sea. The approach taken was first to analyse in detail the spill behaviour and countermeasures associated with four hypothetical, well-defined blowout situations. Spills are described in detail using assumptions on spill size and oil properties based on the character of two known Beaufort Sea oils and reservoir fluids and historical weather and ice data. A sophisticated mathematical/computer model was used to describe the behaviour and fate of the four spills as a function of the various spill conditions such as blowout flowrate, oil type and weather conditions.

The above scenario-specific analysis was then used to develop formulae for estimating the countermeasures unit operational costs of any blowout situation in the Beaufort Sea as a function of blowout flowrates and duration, oil properties, time of spill, spill location, etc.

The formulae are based on the capability that currently exists within the Beaufort Sea area (1990). Operational costing formulae for the following countermeasures operations are presented.

i) well control operations
ii) offshore near-source oil spill countermeasures
   - containment and recovery
   - in-situ burning
iii) shoreline operations
   - protection
   - cleanup
iv) surveillance and monitoring
v) oily material disposal

These various formulae are then applied to each of the four selected examples to provide estimates of the costs associated with the individual countermeasures unit operations (e.g., containment and recovery, shoreline cleanup, etc.).

1.3 REPORT READERSHIP

This report was written for a readership familiar with the technology and terminology of oil spill behaviour and response. As such, justifications and detailed background information on recommended spill cleanup approaches are not provided in the interest of reducing the bulk of the report. Section 13 contains a short list of the less familiar terms and acronyms contained in this report.

2. OVERVIEW OF METHODS

2.1 METHODOLOGY AND DATA REQUIREMENTS

This section gives a general overview of the approach used to develop unit costs for various oil spill cleanup operations.

2.1.1 Oil Well Blowout Examples

Four oil well blowout examples are described (Section 11) that include the following parameters:

- the season, location, oil type, flowrates and duration of the blowout (Section 11.2)
- physical properties of the oil as a function of time/distance (Section 11.2)
- near-source dimensions of the blowout (Section 11.3);
- locations and amounts of shoreline oiling and physical state of the oil on shore;
- types and lengths of shoreline oiled; and,
- areas of ice that are oiled.

2.1.2 Offshore Oilspill Countermeasures

The marine (near source) countermeasures would be based upon the facilities available through the BSOSC (supplemented by hardware retained in the CCG Tuktoyaktuk inventory) - namely the oil pollution response barge, burners, boom, and fireproof boom for burning oil on water. The capabilities of these systems are then matched with the oil spill examples (scenarios) for which the following determinations are made:

- the rate at which containment boom or fire booms encounter oil or emulsion near-source;
- the rate at which oil is recovered near-source;

- the rate at which oil is burned in fire booms near-source;
- the need for additional containment and/or recovery systems over and above those available from inventory;
- the likely effectiveness of open-water countermeasures, taking into account response times, sea states and weather conditions;
- the likely effectiveness of aerially-mounted, in-situ burning operations for spills under moving ice; and,
- the likely effectiveness of ice-based cleanup operations for spills on or under landfast ice.

2.1.3 Approach for Costing Offshore Countermeasures (Section 4.0)

The method used to determine the cost of logistics to support the offshore cleanup involves determining the requirements for individual response techniques (i.e., the Co-op Response Barge recovery operations; in-situ burning with a combination conventional/fire/containment/fire proof boom etc.). These techniques are defined as near-source countermeasures modules. The daily cost of these modules is then estimated by summing the approximate daily costs of leasing the logistics equipment; salaries and overheads associated with personnel to operate both the oil spill equipment and the support systems (i.e., accommodation, food, transportation, base camp support, etc.). The overall near-source countermeasures cost for a particular blowout scenario in open water can then be estimated by summing the daily costs of the modules identified as needed in the scenario and then multiplying this by the number of days the blowout persists (Section 11).

2.1.4 Approach for Costing Shoreline Protection and Cleanup

The basic premise was to consider only shoreline protection and cleanup activities that are sustainable by the existing industry or contractor infrastructure in the Southern Beaufort Sea area (i.e., base camps or mobile camps - about 1800 persons in total). The influx of perhaps thousands of temporary workers into the area to clean shorelines is not viewed as desirable nor acceptable, and hence is not considered in the analysis.

Shoreline protection and cleanup effort levels are based upon the studies performed by Dr. Ed Owens of Woodward-Clyde Consultants for Amoco Canada Petroleum's Beaufort Sea drilling program (Woodward Clyde 1990). Much of this, in turn, is drawn from Dr. Owen's experience at many spills, including the Nestucca and Exxon Valdez incidents.

The approach to determining shoreline response logistics and costs (protection and cleanup) is somewhat different than that used for the offshore component. With the "available infrastructure" constraint, the approach was to use existing, available floating camps or barge vessels as "floatels" to support work teams along a section of shoreline remote from a shorebase. These "floatels" are self-sufficient in terms of manpower, fuel and equipment but require regular resupply by vessel for food, etc.

The average cost of a floatel was determined by summing the chargeout rate, manning costs, and associated vessel and helicopter support costs. It is assumed that one floatel per week is readied and deployed.

The estimated cost of shoreline cleanup operations involved first determining the rate at which the personnel and equipment on the average floatel could clean the 3 beach types (open coast beach, backshore beach and mainland lagoon coast). Since the number of floatels is known, it was simply a matter of dividing the length of oiled shoreline by the daily cleaning rate and multiplying this period by the daily cost of operating a floatel.

2.1.5 Approach for Determining Surveillance and Monitoring Costs

Surveillance and monitoring costs were calculated by establishing aircraft, sensor, personnel and support requirements for offshore open-water, offshore freeze-up and shoreline spill tracking activities; calculating a cost per unit time for each activity; and, multiplying each by the appropriate time span.

2.1.6 Approach for Estimating Disposal Costs

Disposal costs are split into three categories: fluids collected offshore, combustible material from manual shoreline cleanups, and oily sediment collected by earth moving equipment. Unit costs for each activity are determined by accounting for equipment, personnel and support requirements; these unit costs are then multiplied by appropriate values (i.e., m^3 of sediment, number of floatel days, etc.).

2.2 REPORT DEVELOPMENT

Section 3 of this report outlines the countermeasures for dealing with oil spilled at sea, under or on ice. This is followed by a more detailed appraisal of the costs associated with the open water operations (Chapter 4). Section 5 concentrates on the unit (floatel) costs that accompany shoreline protection and cleanup operations. In like manner, Chapters 6, 7, 8 and 9 describe how costs are developed for monitoring cleanup, disposal of oily debris, meltpool burning and cleanup on landfast ice.

Chapter 10 is devoted to estimating control of well costs.

Section 11 outlines the four oil spill examples and applies the cost formulae developed in Chapters 4 though 9.

3. COUNTERMEASURES FOR OIL AT SEA

3.1 INTRODUCTION

This chapter presents the various methods that are available to respond to and clean up spills in the Beaufort Sea and introduces the calculations to determine the at-site countermeasures efficiencies that may be expected using the various cleanup methods. This will be used in subsequent chapters as a basis for estimating the logistics and costs associated with the four specific oil well blowout examples presented in Chapter 11.

3.2 METHOD FOR EVALUATING COUNTERMEASURES EFFECTIVENESS FOR OPEN WATER SPILLS

There are two options for open-water oil spill countermeasures: i) containment followed by physical recovery, and ii) containment followed by burning. The potential effectiveness of each of these cleanup methods is calculated in this report using a highly quantitative method of analysis. The assumptions and formulae are described below for each cleanup method. This is followed by a list of the specific equipment, materials and vessels that are presently available in the Beaufort Sea to support operations involving the specific cleanup method under analysis. In Section 11, in the spill scenario descriptions themselves, indices of cleanup effectiveness or efficiency are calculated by inserting statistics on existing equipment (e.g., length of containment boom) into the general formulae or equations that have been constructed. The use of oil spill dispersants is not included in this report as this approach has not proven to be cost effective.

3.2.1 Factors Affecting Countermeasures Effectiveness for Open Water Spills

The effectiveness of a spill cleanup operation near an offshore oil well blowout will be influenced by the following factors:

A. Slick interception factor: This is the fraction of the slick that can be intercepted by the deployed offshore-rated containment boom (calculated as 1/3 the length of boom deployed divided by the near-source slick width). The lengths of deployed boom for the Co-op's Response Barge recovery system and the Co-op's in-situ burning boom are 1000 m and 1032 m respectively (see Figures 1 and 2 in Section 3.3 below). Multiplying the slick interception factor by the oil or emulsion flowrate produces an "encounter rate" for the containment system.

B. Skimmer recovery rates: The recovery rate capability of available skimmers is based on data from tests or actual offshore use and is the rate that oil (or emulsion) is recovered excluding free water. If emulsion is presented to the skimmer, the equivalent oil recovery rate is calculated by multiplying the applicable oil recovery rate by the fraction of oil contained in the emulsion (i.e., 100 m^3/hr of an emulsion containing 75% water = 25 m^3/hr of oil). If the encounter rate exceeds the applicable recovery rate, the recovery rate is the controlling factor; if the encounter rate is less than the recovery rate (as is generally the case with blowout slicks), then the encounter rate is the controlling factor.

C. Conditions favourable for in-situ burning: In addition to recovery systems, fire-proof (long-life) or fire-containment (24- hour life) boom can be utilized for offshore oil removal. In this instance the encounter rate of the boom system (1/3 of the length of boom deployed) is used to determine removal rates for slicks with less than 50% water content in emulsified oil. If the water content of the encountered slick exceeds 50% the slick is assumed to be unignitable. If fire containment boom is used, the size of the fire is calculated on the basis of a 2.5 mm/min burn regression rate and the length of fire containment boom in contact with the fire is assumed to require replacement every 24 hours.

D. Dispersant use: The aerial application of oil spill dispersants is not currently viewed as a cost effective countermeasure for the Beaufort Sea. However, the potential exists to increase the quantity of oil intercepted at sea by the application of dispersants from vessels. Since this capability does not presently exist within the BSOSC, it is not factored into the cost estimates. However, this capability can be implemented by air freighting the necessary hardware and chemicals to the Beaufort area.

E. Weather and sea conditions: It is assumed that offshore spill recovery would not be attempted during the following environmental conditions:

i) nighttime
ii) less than VFR flying conditions (incorporating fog, and other conditions limiting the ability to direct operations from the air)
iii) significant wave heights greater than 1.5 m (this prevents containment of the oil by booms)
iv) ice concentrations greater than 2/10ths coverage (interrupting containment operations and calming seas to the point where dispersants are no longer effective)
v) for the special case of chemical dispersant operations, calm, open-water sea conditions would render their application ineffective.

For each of the above constraints, the percentage of time that favourable weather and sea conditions exist at the scenario blowout sites has been determined. By multiplying the individual percentages, the overall percentage of the time that containment and recovery or burning operations and dispersant operations would be feasible is determined.

F. Response-time factor: The time required to get response equipment to the site and operating is factored in as: (1 minus the estimated response time/the total length of time the blowout lasts) or, in the case of a late-season blowout: (1 minus the estimated response time/the length of time the blowout persists in open-water conditions).

3.2.2 Equations for Calculating Efficiency of Recovery and Burning

The following are the equations that are used to calculate the volume of oil recovered and burned for any set of blowout spill and response conditions. The effectiveness or efficiency of the specific operation is determined by simply dividing the calculated volumes by either the volume of the oil discharged from the blowout or the amount of oil on the surface available for treatment (after initial evaporation losses).

A. Physical Recovery, where the containment boom(s) encounter rate is the limiting factor:

$$V_{OR} = Q_{BR}\,(1 - F_{EVAP,\,INIT})\ t\ F_{SIR}F_{TRP}F_{RT}$$

where

V_{OR}	= volume of oil recovered
Q_{BR}	= volumetric oil flowrate of the blowout
$F_{EVAP,\,INIT}$	= fraction of oil evaporated from the slick near-source (i.e., prior to the slick reaching the recovery systems)
t	= blowout duration (time)
F_{SIR}	= fraction of the predicted near-source width of the slick that is intercepted by the containment boom(s) associated with the recovery system
F_{TRP}	= fraction of time containment possible
F_{RT}	= fraction of time the equipment is on site, based on response time

B. Physical Recovery, where recovery rate is the limiting factor:

$$V_{OR} = Q_{RR}\,(1 - W_{NS})\ t\ F_{TRP}F_{RT}$$

where

Q_{RR}	= applicable skimmer recovery rate
W_{NS}	= emulsion water content fraction, near-source

C. In-Situ Burning

$$V_{OB} = Q_{BR} (1 - F_{EVAP,INIT}) \, t \, F_{SIB} F_{TRP} F_{RT}$$

where

V_{OB} = volume of oil burned in-situ

F_{SIB} = fraction of the predicted near-source width of the slick that is intercepted by the boom, or system of booms, associated with in-situ burning.

and the area of the burn is estimated by;

$$A_{IB} = Q_{BR} (1 - F_{EVAP, INIT}) F_{SIB}/R_R$$

where

A_{IB} = area of fire

R_R = burn regression rate = 2.5 mm/min

and the length of the boom in contact with the fire is

$$L_{IB} = \pi^{½} A^{½}_{IB}$$

where

L_{IB} = length of boom in contact with fire

π = 3.14159...

3.3 CO-OP OPEN-WATER EQUIPMENT SPECIFICATIONS

The Co-op equipment used to conduct the analysis is listed below. Only equipment applicable to open water spills are considered at this point.

3.3.1 Containment and Recovery

The primary components of the Beaufort Sea Oil Spill Cooperative (BSOSC) Response Barge (Figure 1) are as follows:

- 988 m (3260 ft) of Ro-Boom Ocean model (1.7 m overall height; 0.6 m freeboard);
- One Transrec 250 skimmer (nameplate capacity = 250 m^3/hr water and 100 m^3/hr emulsion of 30,000 cp viscosity; operational capacity = 70 m^3/hr (10,500 BOPD) for viscosity $<$30,000 cp; 50 m^3/hr (7500 BOPD) for viscosity $>$30,000 cp based on Norwegian field trials with the Transrec 350 model - Nordvik 1989);
- one Desmi 250 skimmer (nameplate capacity = 75 m^3/hr; operational capacity 50 m^3/hr (7500 BOPD) for viscosity $<$10,000 cp, 25 m^3/hr (3750 BOPD) for viscosity $>$10,000 cp based on tank tests with a nearly identical skimmer - Buist and Potter 1989);
- one Ro-Skim skimmer section for Ro-Boom (operational capacity unknown but possibly as per Desmi 250);
- emulsion treater (nameplate capacity = 29 m^3/hr (4400 BOPD) inlet, 10 m^3/hr (1500 BOPD) oil outflow);
- TOPS flare burner (nameplate capacity = 80 m^3/hr; operational capacity = 27 m^3/hr (4100 BOPD) based on available water pump on barge);
- 1106 m^3 (7000 bbl) of barge cargo tank capacity.

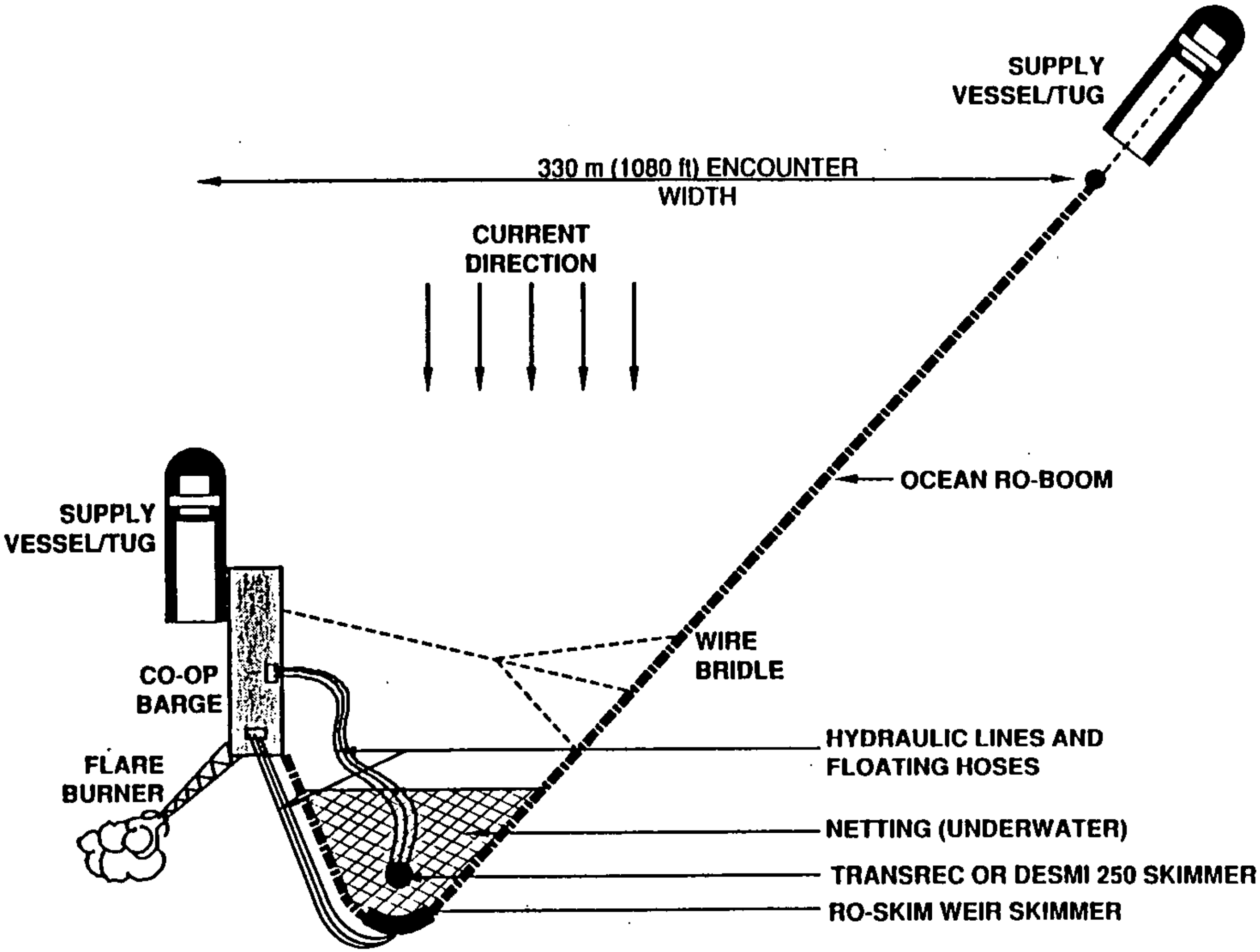
3.3.2 In-Situ Burning

The primary components of the BSOSC fireproof/fire containment/conventional boom system (Figure 2) are:

- 77 m of stainless steel fire proof boom placed in the centre of the pocket
- 455 m of 3M fire containment boom one half of which is connected to each end of the fire proof boom
- 500 m of conventional, 36" boom, one half of which is connected to each end of the fire containment boom.

FIGURE 1

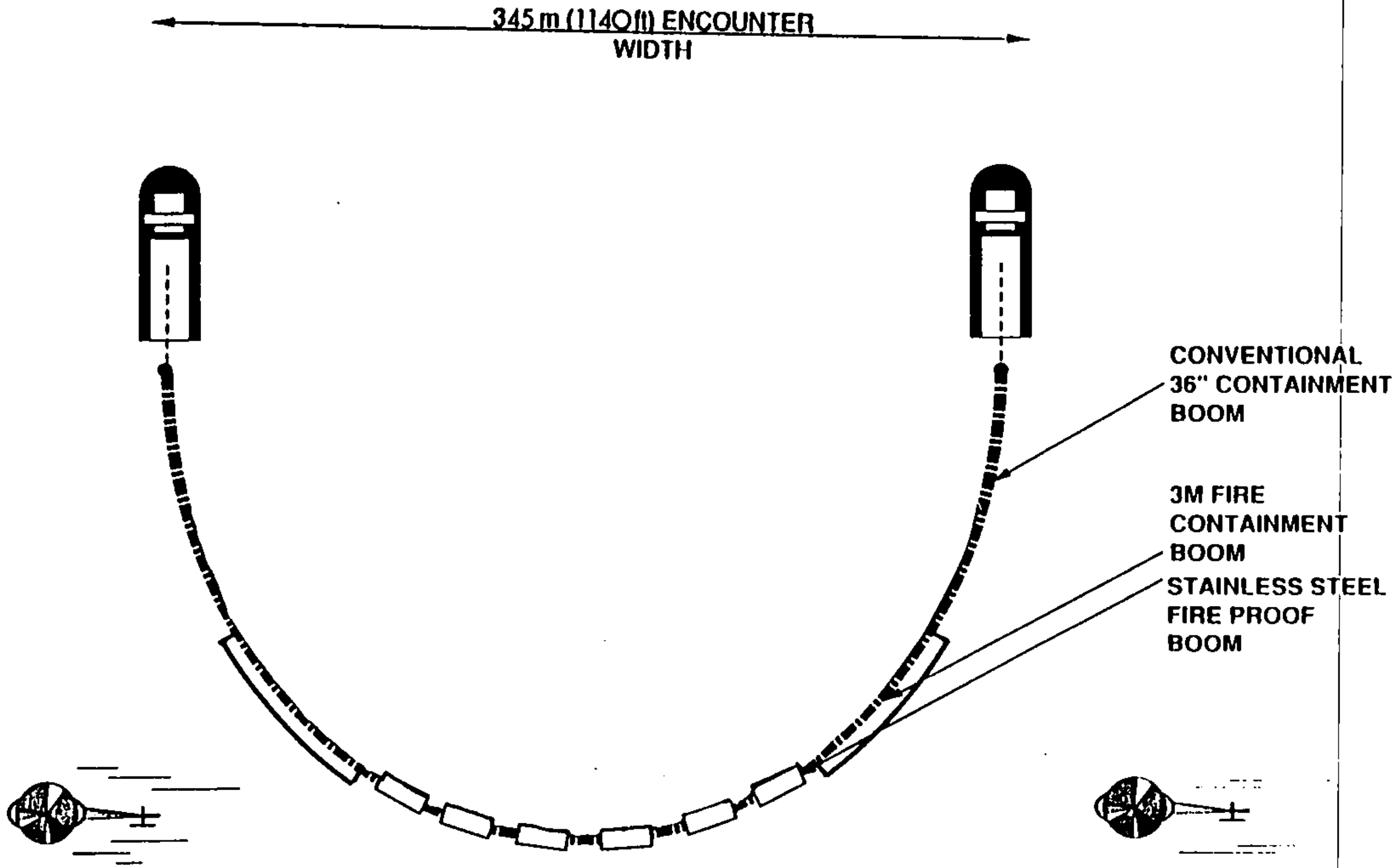
SCHEMATIC OF REDESIGNED RESPONSE BARGE DEPLOYMENT



adapted from Gulf 1990

FIGURE 2

SCHEMATIC OF FIRE PROOF AND FIRE CONTAINMENT BOOM DEPLOYMENT



adapted from Gulf 1990

3.3.3 Response Combining Physical Recovery and Burning

Figure 3 illustrates how the Co-op Response Barge system and the combination fire proof/fire containment/conventional boom system for in-situ burning could be deployed in response to a blowout that exceeded the capabilities of the Response Barge containment boom. The in-situ burning operation would be situated behind (i.e., downwind) of the recovery operations.

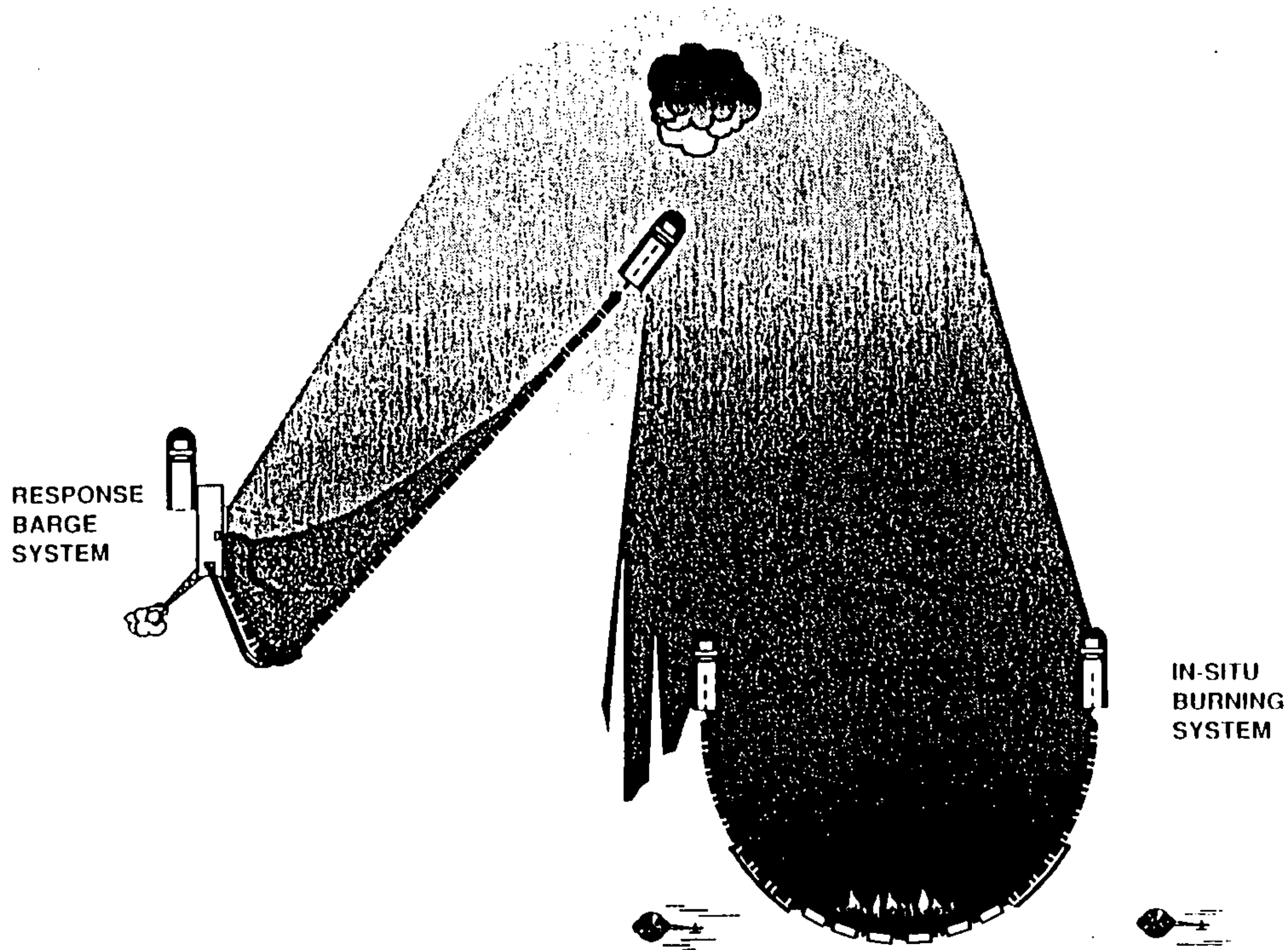
3.4 COUNTERMEASURES FOR OIL SPILLS IN ICE

Oil spill countermeasures for oil spilled on or under ice are analysed differently than for spills on water. Since the oil is contained by the ice, and does not spread appreciably, there is time to prepare and position cleanup equipment in readiness to accomplish maximum cleanup efficiency. For the spill scenarios considered, two different oiled ice responses were considered.

3.4.1 Spills under Moving Ice

The assumption is made that safety considerations would preclude any attempt to undertake cleanup operations during the winter months in the transition zone. The strategy, therefore, is to track the oiled ice and commence a burning operation where oil surfaced in melt pools and/or collects in open leads. The thickness of the oil layer originally discharged under the ice, the size of oil slicks on melt pools the following spring, the operational capabilities and limitations of the Co-op's Helitorch System, the operational capabilities and limitations of medium-lift helicopters (i.e., Bell 212, etc.) and weather constraints to flying and oil ignition in spring time are combined to calculate both the maximum achievable oil removal by in-situ burning of oil on melt pools and the number of Helitorches and helicopters required to accomplish this in the time available prior to break-up. Specific details on the calculations are given in the scenario description (Section 11.3).

FIGURE 3
COMBINED RESPONSE TO A BLOWOUT



adapted from Gulf 1990

3.4.2 Spills on Landfast Ice

For oil released onto landfast ice during winter, mechanized and manual scraping of the ice and subsequent burning of the collected oily snow are considered. In-situ burning of oil under and on ice during the subsequent melt season is also considered. Specific details are given in Chapter 9 and Section 11.4.2.

3.5 DETERMINATION OF AMOUNT OF SHORELINE OILING

The method for determining the amount of oil/emulsion that comes ashore (described in greater detail in Chapter 11) was estimated as follows:

- a computerized oil fate model was used to determine the time for an open water slick to dissipate under average, seasonal environmental conditions; this dissipation time was converted to a distance by multiplying by an average current (0.25 m/s for the Beaufort Sea)
- using the predicted dissipation distance (to achieve a 99% dissipation) as a radius, a circle was drawn on a map with the scenario well site at the centre;
- the circle was divided into 8 segments, corresponding to wind directions (i.e., N, NE, E....);
- for those segments where the circle encompasses a shoreline, the average distance from the shoreline section to the well site was estimated;
- this distance was converted to time (using the average surface current) and thus a percent of the oil remaining in the slick at that time could be determined from the dissipation time for the given oil type;
- the amount of oil that could come ashore in a particular section without considering near-source countermeasures was then calculated by:

$$V_{OSNC} = Q_{BR}F_RF_Wt$$

where

V_{OSNC}	= volumes of oil on shoreline section with no countermeasures
Q_{BR}	= blowout oil flowrate
F_R	= fraction of oil originally released that remains in the slick at the average distance to the shoreline section
F_W	= fraction of time that the wind blows from the direction that would move oil ashore on the particular shoreline section
t	= duration of blowout

The effect of offshore, near-source countermeasures can be estimated by multiplying V_{OSNC} by $(1 - ((V_{OR} + V_{OB} + V_{OD})/Q_{BR}t))$, or the fraction of the oil released that is not removed near-source.

The corresponding volumes of emulsion are four times the oil volumes.

4. LOGISTICS AND SUPPORT COSTS FOR MARINE COUNTERMEASURES (OPEN WATER)

In this section, the logistics, personnel and support required to conduct open-water oil spill countermeasures operations near blowout sites are estimated.

4.1 VESSEL, BARGE AND BASE CAMP UNIT SUPPORT REQUIREMENTS AND COSTS

Table 1 shows the numbers of personnel required to operate various classes of vessels that could be used to conduct near-source countermeasures at the site of a blowout. These data were developed at a 3-day meeting held in Calgary in the fall of 1990 with the Beaufort Sea marine, drilling and base managers of Gulf Canada Resources, Amoco Canada Petroleum, Esso Resources Canada and Chevron Canada (see Appendix 1). The costs shown in Table 1 are estimates only for emergency response operations and should not be taken as commercial rates for normal operations purposes.

4.2 CO-OP RESPONSE BARGE MODULE

In order to move the Co-op Response Barge from Tuktoyaktuk to the blowout site a vessel capable of accessing Tuktoyaktuk Harbour is required. It is assumed that the Response Barge is on site and operating in one day.

Once on site, a vessel with bow and stern thrusters and a variable pitch propeller capable of maintaining station at speeds of 0.5 knots and less (ideally joy-stick controlled) is required to tend the response barge. This vessel would also ideally serve as the command and control centre for offshore, near-source oil spill cleanup operations.

TABLE 1

Unit Costs, Personnel and Support
Required for Offshore Cleanup Vessels, Barges and Base Camps

VESSELS AND BARGES

Vessels	Personnel Crew	Personnel Others	Estimated Cost Per Day
Class 3 or 4 Icebreaker	20	12-15	$50,000
Class 2 Supply Vessel	13	0-15	$25,000
Other Home Trade II Tugs and Ships	7	0-6	$15,000
Barges			
10,000 ton	0	0	$10,000
8500 ton	0	0	$10,000
1500 ton	0	0	$3000
1000 ton	0	0	$3000
800 ton	0	0	$2000
600 ton	0	0	$2000
400 ton	0	0	$2000

PERSONNEL COSTS

Item	Estimated Cost Per Day
Salary, benefits, etc.	$500/day/person
Accommodation, food, etc.	$200/day/person

TABLE 1 (Cont.)

Unit Costs, Personnel and Support

Required for Offshore Cleanup Vessels, Barges and Base Camps

SUPPORT BASE COSTS

Item	Estimated Cost Per Day
1 person extra at shore base to support each 4 persons offshore (over and above normal complement for drilling)	\$700/day/person (salary (benefits, etc. & accommodation, food etc.)

AIRCRAFT SUPPORT
(wet, i.e., including fuel cost)

Item	Estimated Cost Per Day
737 flights from Calgary or Edmonton (3 per week to support offshore oil spill cleanup)	\$35,000/flight x 3 ÷ 7 = \$15,000/day
Hercules C-130 freight flights (to the Beaufort Sea from 8 hours flying distance away)	\$100,000/flight
Large Helicopter - S61, etc. (including 2 pilot and 1 engineer)	\$4000/hour x 8 hours = \$32,000/day
Medium Helicopter - Bell 212, 576 etc. (including 2 pilots and 1 engineer)	\$2000/hour x 8 hours = \$16,000/day
Small Helicopter - Bell 206, etc. (including 2 pilots and 1 engineer	\$1500/hour x 8 hours = \$12,000/day
Fixed Wing - Twin Otter, etc. (including 2 pilots)	\$1500/hour x 8 hours = \$12,000/day
Pilot/Engineer Support Costs	\$200/day/person

Operation of the boom, skimmer(s), oil/water separators and flare burner on the Response Barge would require 6 operators and 2 supervisors per shift; 24-hour operations would involve 16 personnel. Management of the overall near-source cleanup operations on a 24-hour basis would require 12 personnel. In addition, helicopter access to the Response Barge and its support vessel would be required.

As such, a Class 3 or 4 icebreaker is best suited to the task of tending the Response Barge. A Class 2 supply boat or Home Trade II vessel would also suffice but the command and control activities would have to be moved elsewhere.

Also, a low-speed manoeuvrable vessel is required to tend the other end of the Ro-Boom. Preferably a joy-stick controlled Class 2 supply vessel could be used; a smaller Home Trade II would suffice. This vessel would support 4 operators and one supervisor for 24-hour-a-day boom tending operations.

In total, the following are the logistics and support requirements and costs for the Co-op Response Barge operations.

Item		**Cost Per Day**
1 Class 3 or 4 icebreaker		$50,000
1 Class 2 supply vessel		25,000
32 extra personnel		16,000
support costs for 32 personnel		6400
	Total:	**$97,400**

In addition to the above logistics and personnel requirements, the following items would likely be purchased as backups (to eliminate any mechanical downtime by having redundant systems onboard the Barge) and/or replacements:

Item		Cost
1 Transrec 250 skimmer		$1,000,000
1000 m Ro-Boom		500,000
TOPS Flare Burner		100,000
	Total:	$1,600,000

4.3 FIRE BOOM IN-SITU BURNING MODULE

The combination conventional/fire containment/fire proof boom system for in-situ burning would be transferred from Tuktoyaktuk to the site on the Response Barge. Once on-site it would require two low-speed manoeuvrable vessels for deployment and tending. For costing purposes it is assumed that one of these ships is a Class 2 supply vessel and the other is a Home Trade II vessel or tug. For 24-hour-per-day operations each vessel would carry 4 boom operators and 1 supervisor.

Periodic ignition of the oil contained by the boom would be carried out from the helicopter stationed on the command/control ship at the Response Barge.

In total, the following are the logistics and support requirements and costs for in-situ burning operations:

Item		Cost Per Day
1 Class 2 vessel		$25,000
1 Home Trade II ship or tug		15,000
10 extra personnel		5000
support costs for 10 extra personnel		2000
	Total:	$47,000

In addition to these daily costs, the following would likely be purchased as backups or replacements:

Item		Cost
Fire containment boom		$500,000
Fire proof boom		500,000
	Total:	$1,000,000

4.4 ADDITIONAL CONTAINMENT AND RECOVERY SYSTEMS

It may be the case that additional vessels and offshore containment and recovery equipment, over and above the equipment available from the Co-op, will be needed to encounter the entire width of the slick generated by a blowout. If so, the following are the logistics requirements and support costs associated with the deployment of an offshore boom in a "V" configuration by two vessels and operation of a skimmer in the pocket of the "V" by a third vessel.

Item		Cost Per Day
2 Home Trade II vessels for boom tending		$30,000
1 Class 2 supply vessel for skimming		25,000
3 supervisors and 12 extra personnel for 24-hour-per-day operations		7500
support costs for 15 extra personnel		3000
	Total:	**$65,500**

In addition, the following would be purchased as backup or a replacement for the additional system:

Item		Cost
1 offshore skimmer		$1,000,000
1000 m offshore boom		500,000
Transfer pumps and hoses (for transfer of recovered oil from skimming vessel to temporary storage shuttle barge - see below)		1,000,000
	Total:	**$2,500,000**

4.5 TEMPORARY STORAGE

If the recovery rate of the Co-op Response Barge skimmer(s) exceed(s) the disposal rate of the TOPS flare burner mounted on the Barge, or an additional containment and recovery system is used, temporary storage for recovered oil will be required offshore.

This would take the form of one or two large (10,000 ton) barges moored near the site and a tug with a smaller (e.g., 600 ton) barge shuttling between recovery operations and the storage barges. The following would be required:

Item		Cost Per Day
2 x 10,000 ton barges		$20,000
1 x Home Trade II tug		15,000
1 x 600 ton barge		2000
1 supervisor and 4 pumpmen		2500
support costs for 5 personnel		1000
	Total:	**$40,500**

In addition, the following items would be purchased to transfer oil to and from the various barges:

Item		Cost
Transfer pumps and hoses		1,000,000
	Total:	**$1,000,000**

4.6 OTHER SUPPORT AND COSTS

In order to co-ordinate and support an offshore cleanup operation there are certain onshore support logistics and costs necessary. These include: 25 corporate emergency management staff located at the shore base; 1 medium helicopter with 2 pilots and one engineer; 3 x 737 flights per week; 5 freight flights; and, additional support staff at the base camp at the ratio of 1 for each 4 offshore (ships crew plus extra personnel).

The additional cost of this is:

Item	Cost Per Day
corporate emerg. mgmt. team (25)	$12,500
1 medium helicopter	16,000
3 x 737 flights (105,000/week ÷ 7)	15,000
support staff salaries at base camp (16 for Co-op Barge system, 8 for in-situ burning, 11 for additional containment/recovery system and/or 3 for temporary storage)	$500/person
living and accommodation costs:	
for emerg. mgmt team	$5000
for helicopter	$600
for base camp additional support staff	$200/person

In addition, \$500,000 would be needed for the 5 freight flights to move the required backup/additional equipment to the Beaufort Sea.

4.7 TOTAL OFFSHORE, NEAR-SOURCE CLEANUP COSTS

The estimated cost of the offshore operations near the source of the spill can be expressed as follows;

$$C_{op,off} = \text{Ndays} \ (\text{BARGESYS\$} + \text{BURNSYS\$} + \text{ADDNLSYS\$} + \text{TEMPSTOR\$} + \text{SUPPORT\$}) + \$500{,}000$$

$$C_{wrmp,off} = C_{op,off}(14 / N_{days})$$

$$C_{cap.off} = \text{BARGEEQUIP\$} + \text{BURNEQUIP\$} + \text{ADDNLEQUIP\$} + \text{TEMPSTOREQUIP\$}$$

$$C_{total,off} = C_{op.off} + C_{wrmp,off} + C_{cap,off}$$

where:

$C_{op,off}$; $C_{wrmp,off}$; $C_{cap,off}$; and, $C_{total,off}$: operating, warmup, capital and total costs for offshore cleanup

N_{days}: the number of days until the well stops flowing

BARGESYS\$, BURNSYS\$, ADDNLSYS\$, TEMPSTOR\$ and SUPPORT\$: estimated costs per day to operate the Co-op Response Barge, the Co-op In-situ Burning system, any additional systems, temporary storage and other support costs.

BARGEEQUIP$, BURNEQUIP$, ADDNLEQUIP$ and TEMPSTOREQUIP$: estimated equipment purchase costs for the Co-op Barge recovery system, the Co-op in-situ burning system, any additional systems and temporary storage equipment

The offshore near source cleanup costs are further developed using the four blowout examples in Section 11.5.

5. LOGISTICS AND SUPPORT COSTS FOR SHORELINE PROTECTION AND CLEANUP

5.1 INTRODUCTION AND BACKGROUND

In this section, the logistics and support costs for shoreline protection and cleanup are developed using facilities available in the Beaufort area, 1990.

5.2 SHORELINE PROTECTION

Three shoreline protection techniques are prescribed for use on the coastlines of the Southern Beaufort Sea: the use of lightweight boom to exclude or divert oil from sensitive areas; the construction of beach berms along low-lying barrier beaches to prevent oil overtopping the beach and impacting sensitive backshore areas; and, the construction of dikes across narrow, shallow inlets to prevent oil moving into sensitive backshore areas.

Shoreline protection operations would be instituted as soon as possible after a spill. Protection priorities would be based in part on shoreline surveillance and monitoring activities (see Section 6.0). The approach taken for shoreline protection (and cleanup) operations would be to outfit large camp barges or vessels with sufficient beds, equipment, small vessels, barges and landing craft and materials to support up to 220 persons at a remote location. These camp barges and vessels, called "floatels", would be located at a safe anchorage near their designated shoreline area. Protection (and cleanup) operations along the nearby coastline would be supported on a daily basis by small vessels with shallow-draft barges or landing craft.

In general, each "floatel" would be equipped with the following for shoreline protection operations:

- 7500 m of lightweight boom;
- numerous small anchors, chains, ropes and pennant buoys;

- pole anchors;
- ~~15 small workboats c/w 25 HP outboard motors;~~
- 4 front-end loaders;
- 2 small tractors; and
- 40-220 personnel

and supported by:

- 3 small tugs with shallow-draft barges, or 3 landing craft
- a fuel barge (400 ton)
- 1 large helicopters
- 1 medium helicopter

It is assumed that shoreline protection operations are only conducted while the well is still blowing. Shoreline protection operations would cease once the well has been killed and the last slick has come ashore; after this the available resources would be directed towards shoreline cleanup. It should be noted that the resources used for shoreline protection could, if necessary, be redirected to shoreline cleanup of high priority areas before the blowout was killed without significantly altering the overall total cost.

Table 2 lists the available barges, rigs and camps that could be used as floatels. The barges are the best suited to the task, having relatively shallow draft and large deck space for cargo.

For the scenarios under consideration it will be assumed that: the rig involved in the blowout is unavailable; that another is held as a standby for relief-well drilling; that only the Molikpaq is suitably located for use as a floatel (the SSDC is set down offshore Alaska); and, that the McKinley camp is needed for accommodations in McKinley Bay unrelated to shoreline protection. Therefore, referring to Table 2, a maximum of 7 floatels totalling 735 beds (170 support staff and 565 supervisors and workers) could be mobilized for shoreline protection efforts; the average sized floatel is 105 persons (735/7). These are: the Wurmlinger, Kiggiak and Constructor camp barges; the Arctic Breaker barge with Gruben's Camp placed on it; the Molikpaq and two floating drilling units. All the floatels have sufficient deck space to carry the necessary equipment and all can land and support a large helicopter.

The support costs for personnel based on these floatels, including the lease rate for the vessel or barge, is $200/day/person onboard a barge and $400/day/person onboard a rig. The average support cost is $285/day/person ((420 x $200 + 315 x $400)/735). Salaries and overheads are $500/person/day.

The shoreline protection response package for each floatel would cost:

7500 m of lightweight boom @ $50/m		$375,000
15 small workboats c/w 25HP outboards @ $5000		75,000
5 front-end loaders @ $140,000/year		700,000
5 small tractors @ $70,000/year		350,000
	Total (for each floatel):	$1,500,000

Daily costs for each floatel would be:

3 small tugs		$45,000
4 x 400 t barges (one for fuel)		6000
1 large helicopters		32,000
1 medium helicopter		16,000
personnel salaries & overheads (105 @ $500)		52,500
personnel support costs (105 + 4 pilots + 2 engineers) @ $285/person/day)		31,635
Onshore personnel (105 ÷ 4 @ $700/day)		18,900
	Total (for each floatel/day)	$202,000

In addition, for the shoreline protection operation as a whole three 737 flights per week ($15,000/day) would be required (less, proportionately, than for offshore operations since it is presumed that the local labour pool, with its intimate knowledge of the physical environment, will be heavily utilized for shoreline protection operations) and ten freight flights ($1,000,000) would be required for supplies. Two Class 2 supply vessels ($25,000 per day each) and two Twin Otters ($12,000 per day each) would resupply the floatels.

TABLE 2

Barges, Vessels and Camps for use as Floatels

Unit	Total Beds	Support Staff	Worker Beds	Draft (m)	Crane (Yes/No)
Camp Barges					
Wurmlinger	40	10	30	3	No
Kiggiak	70	15	55	4	Yes
Constructor	220	40	180	3	Yes
Other Barges					
Arctic Breaker with Grubens Camp	90	15	75	4	No
Arctic Tuk with McKinley Camp	125	25	100	4	No
Rigs					
Molikpaq*	105	30	75	8	Yes
Kulluk	105	30	75	10	Yes
Explorer 1	105	30	75	4	Yes
Explorer 2	105	30	75	4	Yes
Explorer 3	105	30	75	7	Yes
SSDC*	130	30	100	8	Yes
Base and Mobile Camps					
Canmar	290	75	215	--	--
Nalluk	184	50	134	--	--
NTCL	80	20	60	--	--
ATL	120	25	95	--	--
Gruben	50	5	45	--	--
McKinley	125	25	100	--	--
Others in Tuk (see Arctic Tuk)	3 x 50	--	150	--	--

* used where parked if location suitable (i.e., Herschel Island, McKinley Bay, Summers harbour, etc.)

5.3 SHORELINE CLEANUP

Shoreline cleanup costs are almost impossible to estimate with confidence because:

- the locations and levels of shoreline oiling are difficult to predict;
- the absence of predetermined cleanup priorities; and
- the impossibility of predicting the success rate of shoreline protection.

Nevertheless an attempt was made to estimate shoreline cleanup costs based on a level of effort approach. As with the shoreline protection operations, the approach taken is to keep shoreline cleanup operations within the accommodation capabilities of the existing oil company and contractor infrastructure in the area.

There are three generic types of shoreline cleanup proposed for the coastlines of the Southern Beaufort Sea (Woodward-Clyde 1990): open-coast beach cleanup, backshore beach cleanup and mainland lagoon coast cleanup. Each is described and analysed separately below. Costs are calculated on a per-kilometre basis and can be applied to a particular scenario by determining the number of kilometres of a particular beach type to be cleaned.

5.3.1 Open-Coast Beach Cleanup

This beach type consists of open-coast sand and gravel beaches and barrier spits that can be accessed by mechanized equipment from the sea. On the basis of a 5 m wide strip of beach oiled, it is estimated (Woodward-Clyde 1990) that a cleanup crew consisting of a supervisor, a front-end loader, a tractor with a small blade and 10 people can clean at least 0.5 km of beach per day (3.5 km/week). Each floatel would support about 5 of these mechanized beach cleanup teams (5 FEL's, 5 small tractors, 65 personnel) at an average cost of $202,000/day. Each floatel supporting 5 such cleanup crews could cover 2.5 km of open-coast beach per day (17.5 km per week) at an average cost of $81,000/km ($202,000/25). The fixed cost of items (front-end-loaders, tractors, etc.) are accrued to the shoreline protection operations for the first year; in subsequent years, if required, $700,000 for front-end-loaders and $350,000 for small tractors (from southern suppliers) per floatel would have to be added.

5.3.2 Backshore Beach Cleanup

This beach type consists of sheltered sand/gravel beaches not accessible by mechanized equipment. It is estimated that one manual cleanup crew consisting of 50 labourers and two supervisors can clean 0.35 km/day of backshore beach (2.5 km/week). On average, each floatel can support 1.5 manual cleanup crews; thus the cost per kilometre of back barrier beach cleaned is $385,000 ($202,000/(0.35 x 1.5)).

5.3.3 Mainland Lagoon Coast Cleanup

This type of coastline includes inundated tundra coast, delta, estuaries, backshore lagoons and marshes that require gentle manual cleaning using low-pressure flushing combined with skimming and/or manual recovery using sorbents from small boats. It is estimated that one crew consisting of 5 pump sets, 5 skimmers, 500 m of lightweight boom, 10 small flat-bottomed boats and 37 personnel could clean 0.2 km per day of mainland lagoon coast. With each floatel, on average, able to support two such crews, the average cost per kilometre is $505,000 ($202,000/(0.2 x 2)) plus $640,000 in additional equipment (10 pump sets @ $100,000, 10 skimmers @ $500,000 and 20 flat-bottomed boats @ $40,000) per floatel.

5.3.4 Additional Costs for Shoreline Cleanup

A team of 15 personnel would manage the shoreline cleanup operation from Tuktoyaktuk. Salaries, overheads and support costs for this effort would be $10,500 per day. Three 737 flights per week ($15,000/day) and ten freight flights would also be required in addition to those for moving shoreline protection equipment ($1,000,000). Two Class 2 supply vessels ($25,000/day each) and two Twin Otters ($12,000/day each) would be required to support of floatels.

5.3.5 Summary and Constraints

The following summarizes the cleaning rate per floatel and cost per kilometre for cleaning the various shorelines in the Southern Beaufort Sea:

Type	Rate per Floatel	Cost per Floatel
Open Coast	2.5 km/day	$81,000/km
Backshore Beach	0.5 km/day	$385,000/km
Mainland Lagoon	0.4 km/day	$505,000/km + $640,000 for equipment per floatel

These rates and costs are based on the average floatel with 105 beds (735 ÷ 7) and 20 support staff (140 ÷ 7) see Section 5.2. With the approach used in this study (i.e., maximum workforce limited by the number of existing available beds) the rate at which oiled shorelines can be cleaned is modest.

The lengths of various types of shoreline along the Southern Beaufort Sea coast are (Woodward-Clyde 1990):

Area	Type	Length
YUKON COAST[1]	open-coast beach	300 km
(Alaska/Yukon border	backshore beach	90 km
to Yukon/NWT border)	mainland lagoon	20 km
MACKENZIE DELTA[2]	open-coast beach	270 km
(Yukon/NWT border	backshore beach	25 km
to Kittigazuit Bay)	mainland lagoon	820 km

TUKTOYAKTUK PENINSULA[3]	open-coast beach	160 km
(Kittigazuit Bay to	backshore beach	110 km
Cape Dalhousie)	mainland lagoon	630 km
TOTALS	open-coast beach	730 km
(Alaska/Yukon border	backshore beach	225 km
to Cape Dalhousie)	mainland lagoon	1470 km

1. Obtained by doubling the estimate for Alaska/Yukon border to Kay Point.
2. Obtained by doubling the estimate for Middle Channel to Kittigazuit Bay.
3. Obtained by 1.6 times the estimate for Tuktoyaktuk to McKinley Bay.

Theoretically, to clean all the above beaches would take the 11 available floatels (all rigs utilized as floatels) and two floatel-sized crews based at Tuktoyaktuk and McKinley Bay (for a total of 13 x 105 = 1365 personnel) 340 days (730/(2.5 x 13) = 23 days for open-coast beach plus 225/(0.5 x 13) = 35 days for backshore beach plus 1470/(0.4 x 13) = 283 days for mainland lagoon coast) or 3½ years on the basis of a 100 day cleanup season. This is an estimate that does not take into account the potential for shoreline protection measures to reduce or eliminate backshore beach and mainland lagoon cleanup, the potential for sedimentation and erosion to "self-clean" exposed shorelines, and possible decisions to not clean certain low-priority backshore beach or mainland lagoon coasts.

It is, of course, impossible to predict the numerical value of these effects; however, for the purposes of this study, it will be assumed that for each of the applicable examples in Section 11:

- all the open coast beach in an impacted sector is oiled evenly;
- all the open coast beach oiled is cleaned;
- 50% of the backshore beach and mainland lagoon coast is oiled; 50% is not oiled;
- all the backshore beach that is oiled is cleaned;
- 50% of the mainland lagoon coast that is oiled is cleaned; 50% of the mainland lagoon coast that is oiled is not cleaned.

Under these assumptions, (i.e., only 50% of the backshore beach is cleaned and only 25% of the mainland lagoon coast is cleaned) the cleanup of the coastline from the Alaska/Yukon Border to Cape Dalhousie would require 112 days 730/(2.5 x 13) = 23 days for open coast beaches plus 225 x 0.5/(0.5 x 13) = 18 days for backshore beaches plus 1470 x 0.5 x 0.5/(0.4 x 13) = 71 days for mainland lagoon coast) with the maximum effort. This implies that the cleanup would require two summer seasons. The cost of this shoreline cleanup (as per the summer subsea blowout example Section 11.6.1) would be $308,000,000 (730 x $81,000 + 225 x 0.5 x $385,000 + 1470 x 0.5 x 0.5 x $505,000 + 13 x $640,000 + 112 x ($10,500 + $15,000) + $1,000,000 + 112 x ($50,000 + $24,000)). It should be noted, if it is assumed that shoreline protection efforts are 100% efficient, that the shoreline cleanup cost (for the oiling of the entire coast from the Alaska/Yukon Border to Cape Dalhousie) is the cost of cleaning just the open-coast beaches: $62,000,000 (730 x $81,000 + 23 x ($10,500 + $15,000) + 1,000,000 + 23 x ($50,000 + $24,000)).

5.4 COMBINED SHORELINE RESPONSE COSTS

The cost of shoreline protection and cleanup operations can be estimated using the following equations:

$$C_{op,shprot} = \$202{,}000((N_{days}-7) + (N_{days}-14) + (N_{days}-21) + \ldots) + (N_{days}/7 \times 14 \times \$202{,}000) + N_{days}/7 + \$1{,}000{,}000 + N_{days}(\$10{,}500 + \$15{,}000) + (2 \times (N_{days}-7) \times (\$25{,}000 + \$12{,}000))$$

$$C_{cap,shprot} = N_{floatels} \times 1{,}500{,}000$$

$$N_{days,ocb} = L_{ocb}/(2.5 \times N_{floatels})$$

$$N_{days,bsb} = L_{bsb} \times 0.5/(0.5 \times N_{floatels})$$

$$N_{days,mlc} = L_{mlc} \times 0.5 \times 0.5/(0.4 \times N_{floatels})$$

$$N_{days,shcln} = N_{days,ocb} + N_{days,bsb} + N_{days,mlc}$$

$$C_{op,shcln} = (L_{ocb} \times \$81,000) + (L_{bsb} \times 0.5 \times \$385,000) + (L_{mlc} \times 0.5 \times 0.5 \times \$505,000) + (N_{days,shcln} \times (\$10,500 + \$15,000)) + \$1,000,000 + (N_{days,shcln} \times 2 \times (\$25,000 + \$12,000))$$

$$C_{cap,shcln} = N_{floatels} \times \$640,000$$

where:

$C_{op,shprot}$ and $C_{op,shcln}$:	estimated operating costs for shoreline protection and cleanup
$C_{cap,shprot}$ and $C_{cap,shcln}$:	estimated capital costs for shoreline protection and cleanup
N_{days}:	the number of days until the well stops flowing
$N_{days,ocb}$; $N_{days,bsb}$ and $N_{days,mlc}$:	number of days to clean open coast beach; back shore beach and mainland lagoon coast
$N_{days,shcln}$:	number of days to clean shoreline
L_{ocb}; L_{bsb} and L_{mlc}:	lengths of open coast beach; back shore beach and mainland lagoon coast in area affected by scenario
$N_{floatels}$:	number of floatels available for shoreline protection and/or cleanup

6. UNIT COSTS FOR SURVEILLANCE AND MONITORING ACTIVITIES

6.1 OPEN WATER

The following is the estimate of the equipment required to carry out a major surveillance and monitoring operation for a blowout in the Southern Beaufort Sea.

6.1.1 Operational Support for Offshore Countermeasures

One medium helicopter would be used to direct the vessels attending the containment/in-situ burning boom for optimum recovery/removal efficiencies. This helicopter could also deploy a Helitorch for periodic ignition of oil for in-situ burning.

6.1.2 Area-wide Remote Sensing

The CCRS Falcon jet (or a platform of equivalent capability) would be based in Inuvik to provide large-area remote sensing coverage of the spill.

6.1.3 Near-source Remote Sensing

Two Twin Otters, each fitted with the Esso Simple Remote Sensing System, would be based out of Tuktoyaktuk and tasked to provide daily reconnaissance of the position of slicks moving towards shore.

6.1.4 Shoreline Surveillance and Assessment Teams

One small helicopter with a coastal geologist and a video tape operator would be assigned to continuously videotape the coastline of potentially affected areas. In addition two medium helicopters would be required to transport shoreline cleanup assessment teams.

A team of 5 people, based in Tuktoyaktuk, would assemble, correlate, archive and summarize the remote sensing and shoreline oiling data.

6.1.5 Estimated Costs

The following is the estimated cost per day for the surveillance and monitoring operations described above.

Item		Est. Cost Per Day
Offshore/Nearshore		
1 medium helicopter (including 2 pilots & 1 engineer)		$16,000
2 Twin Otters (including 4 pilots)		12,000
2 Esso Simple Remote Sensing Systems (including 2 operators)		3200
CCRS Falcon (including 2 pilots & 2 operators)		15,000
Support costs for pilots, etc. (13 x $200)		2600
Additional support staff at base (13/4 = 4 x $700)		2800
	Total:	**$51,600**

Shoreline

1 small helicopter (including 1 pilot & 1 engineer)		$12,000
2 medium helicopters (including 4 pilots & 2 engineers)		16,000
10 personnel (10 x $500)		5000
Support costs for 18 personnel (18 x $200)		3600
Staff at base (18/4 x $700)		3500
	Total:	**$40,100**

Administrative Support

5 personnel (5 x $700)		$3500
½ 737 flight per week		7500
	Total:	**$11,000**

6.2 FALL FREEZE-UP

In the event of a late-season blowout lasting into freeze-up a different type of surveillance and monitoring operation is required. In this case the movement of the ice is tracked; the oil is encapsulated in the ice.

6.2.1 Operational Support for Near-Source Countermeasures

One medium helicopter would remain on station with the oil spill cleanup vessels to monitor ice conditions and direct the deployment of the response equipment during periods of low ice concentrations.

6.2.2 Satellite-Tracked Buoy Deployment

During the period when the blowout releases oil under ice one ARGOS buoy would be placed on an oiled ice floe every other day, on average. Each of the buoys would be interrogated (i.e., its position determined by a satellite) on a daily basis over a period of 200 days.

6.2.3 SLAR Overflights

Also during the freeze-up period an extra month of SLAR overflights may be required (Oct. 15 - Nov. 15). In addition, if vessels are to be used during spring in-situ burning operations an additional one SLAR flight per week over the 6 week cleanup period would be required for vessel route determination.

6.2.4 Area-Wide Surveillance in Spring

The CCRS Falcon would be utilized for 10 weeks (2 weeks prior to melt, 6 weeks of melt and 2 weeks after breakup) to monitor oil appearance and distribution on ice and its distribution after breakup.

6.2.5 Operational Support for In-Situ Burning Operations in Spring

Four fixed-wing aircraft, outfitted with Inertial Navigation Systems and appropriate communications would act as spotter planes and direct individual helicopter ignition runs over the oiled sites. This would last for 6 weeks.

6.2.6 Unit Cost Estimates

The following are the estimated costs for surveillance and monitoring for a late-season blowout:

Item	Est. Cost Per Day
1 medium helicopter (including 2 pilots & 1 engineer)	$16,000/day
ARGOS buoy interrogation ($40/buoy/day x 25)	1000/day
SLAR overflights	50,000/week
CCRS Falcon	100,000/week
4 fixed-wing aircraft	48,000/day
Support Costs for pilots, etc. (8 persons total)	1600/day
Administrative costs (included in general response costs)	

In addition, the purchase of 25 ARGOS buoys would cost $100,000.

6.3 COMBINED SURVEILLANCE AND MONITORING COSTS

The following are the equations that can be used to estimate surveillance and monitoring costs:

$$C_{ow,sm} = (N_{days} \times \$51,600) + ((N_{days,shcln} + N_{days}) \times (\$40,100 + \$11,000))$$

$$\begin{aligned} C_{ls,sm} = & (N_{days,ow} \times \$51,600) + (N_{days,fr} \times \$16,000) + \$100,000 + (N_{days,tospr} \times \$1000) \\ & + (N_{weeks,slar} \times \$50,000) + (N_{weeks,ccrs} \times \$100,000) + (N_{days,melt} \times \$48,000) \\ & + (N_{days,metl} \times \$1600) + ((N_{days,ow} + N_{days,shcln}) \times (\$40,100 + \$11,000)) \end{aligned}$$

where:

$C_{ow,sm}$ and $C_{ls,s,}$: open water and late season surveillance and monitoring cost estimates

N_{days}: number of days blowout lasts

$N_{days,shcln}$: number of days estimated to clean shorelines

$N_{days,ow}$; $N_{days,fr}$; $N_{days,tospr}$; and $N_{days,melt}$: number of days of open water; freeze-up; until spring; and days of melt

$N_{weeks,slar}$ and $N_{weeks,ccrs}$: number of weeks that SLAR overflights and/or the CCRS Falcon are required

7. LOGISTICS AND COSTS ASSOCIATED WITH DISPOSAL OPERATIONS

7.1 OIL RECOVERED OFFSHORE

Unless the oil encountered/recovered by the Co-op's Response Barge system and any additional systems deployed exceeds 27 m^3/hr (4100 BOPD) no additional offshore disposal system or cost is required. If the oil recovered does exceed 4100 BOPD it would be temporarily stored offshore (see Section 4.5) and then flared using the Co-op Barge system after the blowout had ceased. Costs for this flaring operation are:

Item		Est. Cost Per Day
2 x 10,000 ton barges		$20,000
1 supervisor, 2 pumpmen		1500
2 flare operators		1000
support costs for 5 personnel		1000
	Total:	**$23,500/day**

The number of days required can be estimated by dividing the barrels of oil/emulsion recovered by 4100 then subtracting the number of days the Barge is operating on-site during the blowout.

7.2 OIL AND OILY MATERIAL COLLECTED FROM SHORELINES

7.2.1 Oily Sediment from Open Coast and Backshore Beach Cleanup

The oil content of material removed from beaches can vary considerably. As a first-order estimate it is assumed that 50% of the stranded oil is removed by mechanical and/or manual cleaning that results in an accumulation of oily sediment having 2% oil by volume (S.L. Ross 1988). The volume of oily sediment is therefore half of the volume of stranded oil divided by 0.02.

Based on the approach of temporary stockpiling of the recovered material at recommended sites (Dickins et al. 1987) then removal of the sediment the following winter over ice roads and landfilling in an engineered landfill, the estimated unit cost is $60/m^3. If the oily sediment is to be treated in a rotary kiln at a central location to burn out the oil prior to landfilling, the following additional costs are estimated:

Item		**Cost per Day per Kiln**
Rotary kiln - 10 m^3/hour		$2,000,000
Personnel (15 per kiln for 24 hour operation)		7500/day
Support costs for 15 personnel		3000/day
Additional base personnel (15/4 = 4 @ $700/day)		2800/day
	Total:	**$13,300/day**

In addition, one medium helicopter would support each 4-kiln operation.

7.2.2 Fluid Oil and Oily Debris from Backshore Beach and Mainland Lagoon Cleanup

Oily debris recovered from backshore beach manual cleanup and mainland lagoon manual sorbing would be burned on site in heli-portable debris incinerators. One per cleanup crew (2 per floatel) would be manned by two operators (4 per floatel). Fluid oil recovered by low-pressure flushing operations would be disposed of by flaring using heli-portable rotary-cup burners (one per crew = 2 per floatel) operated by two personnel (4 per floatel). Estimated costs are:

Item		**Cost Per Day Per Floatel**
a) **Backshore Beaches**		
4 operators		$2000/day
Support costs		800/day
Base support		700/day
	Total:	**$3500/day**

plus two heli-portable incinerators costing $30,000 each = $60,000 per floatel

b) **Mainland Lagoon**

8 operators		$4000/day
Support costs		1600/day
Base support		1400/day
	Total:	**$7000/day**

plus two heli-portable incinerators (2 x $30,000 = $60,000) and two rotary cup incinerators (2 x $100,000 = $200,000) for a total of $200,000 per floatel.

7.3 COMBINED COSTS FOR DISPOSAL OPERATIONS

The following equations are used to estimate disposal costs for a particular scenario:

$$N_{days,off,dispose} = (V_{OR}/((1 - F_{wc}) \times 4100)) - N_{days}$$

$$C_{dispose,off} = (N_{days,off,dispose} \times \$23{,}500)$$

$$V_{SED} = V_{OSC} \times 0.5 / 0.02$$

$$N_{days,kiln} = V_{SED} / (N_{kilns} \times 24 \times 10)$$

$$C_{dispose,shore} = (V_{SED} \times \$60) + (N_{kilns} \times \$2{,}000{,}000) + (N_{kilns} \times N_{days,kiln} \times \$13{,}300) + ((N_{kilns} / 4) \times N_{days,kiln} \times \$16{,}000) + (N_{floatels} \times N_{days,bsb} \times \$3500) + (N_{floatels} \times N_{days,mlc} \times \$7000) + (N_{floatels} \times (\$60{,}000 + \$260{,}000))$$

where:

$N_{days,off,dispose}$: the number of days of additional offshore disposal operations required

V_{OR}; V_{SED}; and V_{OSC}:	the volumes (m^3) of oil recovered; sediment requiring disposal; and, on shorelines, taking into account offshore countermeasures
$C_{dispose,off}$ and $C_{dispose,shore}$:	estimated costs for offshore and shoreline disposal operations
N_{days}; $N_{days,bsb}$; $N_{days,mlc}$:	the number of days the blowout lasts; the number of days required to clean back shore beaches; and the number of days required to clean mainland lagoon coasts
$N_{days,kiln}$:	the number of days of kiln operations required
N_{kilns} and $N_{floatels}$:	the number of kilns and floatels required
F_{wc}:	the water content of the emulsion at the specified time/location

8. LOGISTICS AND SUPPORT REQUIREMENTS AND COSTS FOR SPRING HELITORCH IN-SITU BURNING OPERATIONS

There are two possible approaches to mounting a springtime oil in ice burning operation using helicopters and Helitorch. One is to use coastal bases for refuelling and resupplying the helicopters and the other employs icebreakers to refuel and resupply the helicopters.

8.1 COASTAL-BASED OPERATIONS

In this approach, ice roads are constructed along the shore leading to temporary refuelling bases each 50 km or so along the coast where the oiled ice is anticipated to be during the spring melt. Small portable camps, fuel, bladders, mixing gear, Helitorches, etc. are then trucked to each base and readied for springtime operations. Once the melt begins medium helicopters would use the sites as bases for aerial ignition operations offshore. The unit costs associated with this approach are:

Item		Cost per Day per Base*
2 medium helicopters (including 4 pilots & 2 engineers)		$32,000
4 pumpmen		2000
Support personnel (9 x $500)		4500
Support costs (20 x $200)		4000
Base support (20/4 x $700)		3500
Gasoline & gel (27,120 L/day x $1/L + 324 kg/day @$25/kg)		35,220
Fuel bladders, portable berms		1000
	Total:	**$82,220**

* flying 24 sorties per day

In addition, two weeks mobilization and two weeks demobilization per base should be added (at full cost); $100,000 for ice road construction (50 km apart x $2000/km); and $40,000 for 4 Helitorches (2 spares per camp).

8.2 ICEBREAKER-BASED OPERATIONS

In this approach, helicopters fly daily out to an icebreaker located in the midst of the oiled ice area and fly sorties from this location rather than returning to the coast to refuel. It should be noted that the safety aspects of carrying gasoline on an icebreaker and mixing gelled gasoline on or near (i.e., on the ice) an icebreaker must be addressed. The potential advantage of this approach is the reduced numbers of helicopters required (having only to fly 15 km to an ignition site instead of 90 km reduces the time for one sortie to 1 hour from 2, effectively halving the number of helicopters required). The unit costs associated with this approach are:

Item		**Cost per Day per Icebreaker***
1 Class 3/4 icebreaker (incl. 20 crew)		$50,000
4 medium helicopters (including 8 pilots & 4 engineers)		64,000
8 pumpmen		4000
Support costs (20 x $200)		4000
Base support costs (40/4 x $700)		7000
Gasoline & gel (108,480 L/day @ $1/L + 1269 kg/day @$25/kg)		141,000
Fuel bladders, etc.		4000
	Total:	**$274,000**

* flying 96 sorties per day

Two weeks mobilization, 2 weeks steaming and two weeks demobilization at $50,000/day should be added to account for getting the icebreakers into position and returning. Eight Helitorches per ship would also be purchased ($80,000).

8.3 COMBINED COSTS FOR SPRING IN-SITU BURNING

The following are the equations to be used to estimate spring, in-situ burning costs:

$$N_{sorties} = A_{oiled\ ice} / 7.3$$

$$N_{helis} = N_{sorties} / 165$$

$$N_{bases} = N_{helis} / 2$$

$$C_{spburn,coastal} = (N_{bases} \times ((6 + 4) \times 7) \times \$82,220) + (N_{bases} \times (\$100,000 + \$40,000))$$

$$N_{helis,ship} = N_{sorties,ship} / 330$$

$$N_{icebreakers} = N_{helis,ship} / 4$$

$$C_{spburn,icebreak} = (N_{icebreakers} \times 6 \times 7 \times \$274,000) + (N_{icebreakers} \times 7 \times (2 + 2 + 2) \times \$50,000) + (N_{icebreakers} \times \$80,000)$$

where:

$N_{sorties}$ and $N_{sorties,ship}$: number of Helitorch sorties required from coastal bases or icebreakers

$A_{oiled\ ice}$: area of ice oiled by scenarios (ha)

N_{helis} and $N_{hetis,ship}$: number of helicopters required at coastal bases or at icebreakers over 6 week melt period

N_{bases} and $N_{icebreakers}$: number of coastal bases or icebreakers required

$C_{spborn,coastal}$ and $C_{spborn,icebreak}$: cost of spring in-situ burning operations using coastal bases or icebreakers

9. LOGISTICS AND SUPPORT REQUIREMENTS AND COSTS FOR CLEANUP ON LANDFAST ICE

The cleanup of oil on and under landfast ice can involve several stages or modules. These are described separately below.

9.1 ICE ROAD ACCESS AND SPILL MONITORING

The first priority is to access the site and make preparations for cleanup. Ice road construction is estimated to cost $2000/km. Ice coring to map oil distribution would involve one supervisor and two corers drilling 40 cores per day covering one hectare. The cost would be $2100/day. For cost estimating purposes twice the projected area of oil under ice should be used.

9.2 SCRAPING AND BURNING OF OILED SNOW ON SMOOTH ICE

The most efficient way to remove oil spilled on ice and mixed with snow is to use front-end loaders and/or manual scraping with snow scrapers to place the oiled snow in donut-shaped piles and burn the oil out of the snow.

Rubber-tired loaders fitted with 5 m^3 buckets and supported by one supervisor, one operator and 5 laborers with scrapers could scrape 2.5 ha of smooth ice in a 12-hour day. Estimated costs are:

Item	Est. Cost per Day
Front-end loader (for short term use)	$1000
Personnel (7 x $500 + 7 x $200)	4900
Base support (7/4 x $700)	1400
Total:	$7300

On the basis of a snow depth of 25 cm, each front-end loader crew would create ten donut-shaped piles (30 m in diameter containing 630 m^3 of oiled snow) per day. Each pile would require about 4 hours to burn. Thus a crew of 4 with one supervisor could ignite the 10 piles and oversee their burning in a 12-hour day. An additional crew of 5 would be required to cut trenches and drainholes for the water produced during the burning operation. Estimated costs are:

Item		Est. Cost Per Day
Personnel (10 x $500 + 10 x $200)		$7000
Base support (10/4 x $700)		2100
	Total:	**$9100**

9.3 BURNING OIL APPEARING ON ICE IN SPRING

The approach to dealing with large volumes of oil released under landfast ice or on rough ice is to slot fire-resistant boom into the ice around the affected area. Installation of 100 m of fire-containment boom would cost:

Item		Est. Cost Per 100 m
Fire-containment boom		$30,000
Installation (1 supervisor and 3 labourers for 4 days x $700)		11,200
	Total:	**$41,200/100 m**

Once the oil begins to appear on the ice surface and collect in melt pools, burning operations would commence. A helicopter with a Helitorch would be used to ignite the large numbers of meltpools. This would cost:

Item		Est. Cost per Day
1 medium helicopter (including 2 pilots & 1 engineer)		$16,000
Support costs (3 x $200)		600
	Total:	**$16,600/day**

In addition, 2 Helitorches would be purchased as replacements ($20,000) and each sortie (covering 2 ha) would involve 1130 L of gasoline ($1130) and 13.5 kg of gelling agent ($338) at a cost of $1500.

9.4 FINAL POLISHING

If the scenario involves only oil on ice or oil released under ice in late fall or early winter it may be possible to conduct a final polishing of the ice surface prior to breakup. This involves low-pressure flushing to concentrate oil films followed by manual ignition and/or sorbing of the concentrated oil. A team, consisting of a supervisor and 4 laborers equipped with a fire pump and hose could polish 0.5 ha/day at an estimated cost of:

Item		**Est. Cost per Day**
Personnel (5 x $500 + 5 x $200)		$3500
Base support (1 x $700)		700
Sorbents		500
	Total:	**$4700/day/team**

Included would be $5000 for the pump and hose.

Disposal of collected sorbents and burn residue would require two on-site heli-portable incinerators at a cost of:

Item		**Est. Cost per Day**
Personnel (5 x $500 + 5 x $200)		$3500
Base support (1 x $700)		700
	Total:	**$4200**

Included would be $60,000 for two incinerators.

9.5 ADMINISTRATIVE SUPPORT

A team of 25 personnel at the base camp would manage the emergency response with an estimated cost of \$39,100/day (see Section 4.6 with one 737 flight per week).

9.6 COMBINED COSTS FOR LANDFAST ICE CLEANUP

The following are the equations used to estimate the cost of cleanup on landfast ice:

$$C_{lndfst,melt} = (D \times \$2000) + (2 \times (A_{oil,underice} + A_{oil,rfice}) \times \$2100) + ((A_{oil,smice} / 2.5) \times (\$7300 + \$9100)) + ((CIR / 100) \times \$41,200) + (42 \times \$16,600) + \$20,000 + ((A_{oil,underice} + A_{oil,rfice}) \times \$1500 / 2) + (A_{oil,smice} \times \$4700 / 0.5) + \$5000 + (A_{oil,smice} \times \$4200 / 0.5) + \$60,000$$

$$C_{lndfst,brkup} = (N_{days,brkup} + 14) \times \$97,400$$

$$C_{lndfst,support} = (N_{days} + N_{days,melt} + N_{days,brkup}) \times \$39,000$$

where:

$C_{lndfst,melt}$; $C_{lndfst,brkup}$ and $C_{lndfst,support}$:	estimated costs for cleanup operations during the melt; after breakup; and support costs
D:	distance from population centre or existing ice road to scenario site
$A_{oil,underice}$; $A_{oil,rfice}$; and $A_{oil,smice}$:	areas of oil under ice; oil in/on rough ice; and, oil on smooth ice or island surfaces
CIR:	circumference of oiled areas

N_{days}; $N_{days,melt}$; and $N_{days,brkup}$: number of days that blowout lasts; number of days from end of blowout to end of melt; and, number of days after melt that open water cleanup is required

10. BEAUFORT SEA WELL CONTROL COSTS

10.1 INTRODUCTION

This section addresses the cost of well control operations as distinct from the other expenses that would accompany an oil well blowout in the Beaufort Sea. The approach adopted in determining the costs is quite different, and indeed less specific, than the method used in the balance of this report for determining cleanup costs. The process for estimating spill clean-up costs is based upon extensive environmental research in the Beaufort Sea area, assumptions concerning the fate and effects of spilled oil and considerable spill clean-up experience gained over the years from shipping-related incidents. Well control costs, on the other hand, vary markedly depending upon circumstances at the time of the blowout and the efficiency of well control operations, for which assumptions cannot be made with the same degree of confidence. Compounding the difficulties in the predictive process is the fact that no two well control operations are similar even though the root cause of the accident and the procedures to remedy the situation involve the same principles.

10.2 FACTORS AFFECTING OVERALL COSTS

In general terms, the cost of offshore well control operations is a function of the status of the well at the time of the accident, the extent of damage to equipment including the drilling unit and the various options available to regain control of the well. Obviously, if surface kill techniques can readily be exploited without a relief well, the cost of the operation will be a fraction of what it could otherwise be. Such an operation is exemplified by the 1984 Uniacke G-72 gas well blowout on the Scotian Shelf. That well was brought under control within 11½ hours of the well control crew re-boarding the rig 10 days after the blowout occurred.

Statistics (Manadrill 1985) based on worldwide experience indicate that relief wells were the mechanism for controlling 10% of all blowouts, - self-bridging and surface intervention (eg. Uniacke) accounting for the remaining 90%. Indeed, when the statistics are restricted to oil well blowouts, the subject of this report, relief wells were found to be instrumental in the control of only 1% of these blowouts.

The requirement to drill a relief well as a contingency, whether or not relief well drilling is the ultimate means of establishing well control, will obviously increase well control expenses. For example, the 1984 West Venture N-91 underground gas blowout involved two relief wells, neither of which were completed before the problem was successfully resolved by a snubbing operation (introduction of a drill string into the well through a specialized assemblage of high pressure valves). Nevertheless, for the purpose of this report, the cost of initiating a relief well operation (rig mobilization, chargeout rates and various support costs), as a contingency against the failure of surface kill techniques, is to be included in the overall cost of well control operations.

Well control costs do not necessarily increase with the release of hydrocarbons to the atmosphere. The West Venture N-91 incident was an underground blowout involving over pressure gas migrating from one geological formation to another, without a loss to the atmosphere (COGLA 1985). The estimated cost of this operation was $190 million, in large part due to difficulties in dealing with overpressure formation gas and the time consuming methodical snubbing operation. Costs for the two relief wells, an accommodation platform and the original jackup rig accumulated while the snubbing operation progressed.

Although the release of hydrocarbons to the atmosphere may influence total loss (cleanup, damage and evacuation costs) it may only affect well control costs indirectly. The world's largest oil spill occurred in 1979 from a step out well drilled in the Bay of Campéche. This blowout released some 500-600,000 tons of crude oil into the Gulf of Mexico over a 240 day period. The cause of this incident was attributed to an inexperienced drill crew that did not effect corrective measures in a timely manner. As a result, the well ignited and the derrick weakened and collapsed overboard, effectively eliminating the option of effecting surface kill. It has been estimated that it cost $120 million US (1979) to control this well using three relief well units (Lepine 1979, Gill 1979, Offshore 1979, Owen and Kerr 1982 & 1985). Although the loss of the original drilling rig aggravated the situation, much of the cost may be attributed to the fact that directional survey data did not exist for the original well. Since a well is not a vertical hole, but deviates considerably, relief well drillers did not know the exact bottom hole location. As a result they were obliged to penetrate the productive horizon in the general vicinity of the original well and attempt to establish communication. Since this is a very crude, imprecise procedure, it took the better part of a year before the Ixtoc-I finally stopped flowing.

10.3 COSTS AS A FUNCTION OF AFE

From the foregoing it is apparent that appropriate well control operations depend upon a number of variables at the time of the problem (including contingency preparations) that are not as readily costed as oil spill clean-up expenses. One approach to estimating the potential control of well expenses used by industry engineers, insurance adjusters, and loss control experts is the application of a multiple of the drilling AFE (authorization for expenditure) i.e. the cost of drilling the original well. This approach to estimating potential losses has certain advantages;

- the AFE reflects the estimated cost of drilling the original well, being based upon the well's characteristics, location, water depth, availability of support services, current market chargeout rates, tubulars and consumables.

- the AFE reflects differences in platform costs eg. ice island, artificial island, floating or bottom-founded MODU.

- the AFE is a sound indicator of well footage costs and rates that would apply to the drilling of a relief well.

- the AFE allows for inflation or fluctuations in chargeout rates that vary according to supply and demand.

The difficulty with this general approach to estimating potential losses from an actuarial standpoint is the absence of published well control insurance loss statistics. This results in a certain degree of subjective assessment when arranging insurance coverage for an offshore well. In general terms, allowances must be made for:

- cost of removing wreckage
- fire fighting
- surface kill procedures and relief well costs
- cost of making well safe
- damage costs/legal expenses
- seepage and pollution
- cost of redrilling the well.

For purposes of this discussion, only the cost of ultimately making the well safe will be considered, seepage and pollution being the subject of the remainder of this report.

While the practice of assessing potential well control costs by a multiple of the AFE is appealing because of its simplicity, there is considerable difference of opinion among experts as to what that multiple should be.

In the 1985 edition of Blowouts: Well Control Insurance and Risk Management, the authors suggest a multiple of 3.0 to 4.5, depending upon depth and pressure, with separate provisions for pollution from marine operations (Owen and Kerr 1985). While this multiple would appear upon inspection to be a reasonable assessment, there are scant data to provide a perspective on this range. The data that do exist in the public domain is for highly publicized protracted operations that were exceptional because of problems and poor planning from the outset. However, it is probably instructive to review several exceptional cases before considering the circumstances that attend a typical Beaufort Sea well.

10.4 SOME EXAMPLES OF CONTROL COSTS

The 1984 Uniacke gas well blowout, referred to earlier, is considered to be representative of the 90% of blowouts that do not require a relief well. Following the blowout and evacuation of the semisubmersible drilling unit, Vinland, the control efforts involved the mobilization of specialized high pressure high volume pumps, manifold equipment, support vessels for rig cooling/well control operations, and a well control team. The entire operation, including a scientific environmental monitoring program, amounted to approximately $6 million, which is a 0.1 multiple of the AFE ($59 million) (COGLA 1984, Waldner 1990, Gill et al. 1985). Because this incident was handled with a minimum of equivocation, negligible delays occurred that would otherwise compound the well control cost.

The 1979 Pemex Ixtoc-I oil well blowout, on the other hand, was estimated to have cost $US 120 million to control. Attempts to connect hydraulic control lines and high pressure-high volume flow lines to the subsea BOP for a surface kill operation proved to be prohibitively dangerous. Divers attempting to make underwater connections were defeated by negligible visibility, currents, and the debris left from the collapsed derrick. This necessitated a relief well drilling operation using three other MODU's. However, without knowing the bottom hole location, relief well drillers were required to guess the location of their target. Commenting on that incident, Red Adair was quoted as saying "Trying to stab around for a downhole pipe is costly and time consuming. Well drift can push a hole 300 meters off target. In the case of one mid-east well, the operator spent a whole year on a relief well trying to intercept a blowing well". In the case of the 1979 Pemex Ixtoc-I well the entire process including mistakes and setbacks required eight months before the well was finally killed. Using chargeout rates prevalent at the time the well control costs are estimated to have been 20-25 times the AFE.

In 1986 Pemex experienced a second major oil well blowout that cost $48 million to control. With an estimated AFE of $3-4 million, this would imply a multiplier of 10. Information on this incident, however, is sketchy at best (Abel 1990).

Prior to the occurrence of the West Venture N-91 underground gas blowout on the Scotian Shelf in 1984 there was little evidence to suggest that well control losses would ever exceed $150 million. However, well control costs amounted to $190 million which is 5 times the $38 million AFE. This well, of course, did not involve fire, loss of the rig, nor the completion of the relief wells. Accordingly, a multiple of 7 times the AFE has been recommended to COGLA as an indication of the financial resources required for worst case control costs for an offshore well (Gordon 1990).

The most expensive well control operation to date involved Saga Petroleum A.S. drilling in the Ekofisk area of the North Sea in 1989 (Abel 1990, Wright 1990). This too was an underground blowout involving a surface kill operation from the jackup Nedrill Trigon with a contingency relief well drilled from the semisubmersible Treasure Saga. The entire operation, including the semisubmersible Safe Britannia and service vessels providing accommodation and support, required 330 days to resolve. The entire operation cost $272 million, 23 times the cost of the original well. The delay is attributed to a management decision to conduct only one critical operation at a time. Although a relief well was spudded within 10 days of the blowout, priority was given to the surface kill operation that lasted 313 days before it was abandoned. During that period relief well drilling was suspended for 119 days. Well control experts agree that had a comprehensive approach been adopted at the outset the problem would have been resolved much more expeditiously and at a fraction of the cost (Abel 1990, Adams 1990).

While data on blowout losses are available from insurance underwriters, there is a lack of documentation concerning well control procedures, AFE, and other circumstances. The data are thus of little value in setting an AFE multiple for Beaufort Sea wells. Commenting on the AFE multiple approach to estimating potential well costs, one well control specialist (Adams 1990) agreed with the 3.0-5.0 range, suggesting a higher multiple be applied to low AFE wells (on land) and a lower multiple to high AFE wells (offshore).

The few cases outlined above would suggest that the duration of well control operations is a determining element in total cost. To the extent that precautionary measures (preparedness) can reduce this time frame, costs can also be minimized.

10.5 BEAUFORT SEA CIRCUMSTANCES

From what amounts to an inadequate data base, it is necessary to turn to the Beaufort Sea operating area and consider the circumstances that relate to well control operations in that special environment. Five general parameters are discussed:

- Corporate philosophy
- Operator experience
- Well control preparedness

- Canadian regulatory regime
- Community infrastructure

10.5.1 Corporate Philosophy

Although blowouts are a rare occurrence, and readily prevented by adherence to sound oil field practices, it is becoming increasingly apparent, that when they do occur, the difference between a difficulty of relative short duration and a financial disaster with enormous industry-wide consequences is often the full commitment of senior management to resolving the problem. Thus, the decisive factor during the early stages of crisis management is the prevailing corporate philosophy and sense of responsibility.

Beaufort Sea petroleum operators, like all oil companies active on frontier lands, are Canadian corporations employing Canadian citizens who are well acquainted with the priorities of safety, environmental protection and the regulatory regime that governs a company's right to petroleum exploration. Evidence of corporate responsibility is seen in the company policies that relate to operating practices, work force training and personnel management. Most of the safety practices in place today, although required by regulation, were initially adopted by the oil companies. It is recognized that a major oil spill in Arctic waters may have long-lasting environmental and socio-economic effects. With respect to offshore drilling, this could well delay or prevent further Beaufort Sea petroleum development. Petroleum operators appreciate that an uncontrolled oil well blowout of any duration would affect the fortunes of all companies, not just the principal company. While still conducting business on a competitive basis, area operators have entered into equipment sharing agreements, coordinated flight tracking and other cooperative arrangements as a contingency against a marine emergency. The Beaufort Sea Oil Spill Cooperative and joint ice reconnaissance programs are other examples of intercompany cooperation. Another is the understanding that in the event of a blowout, drilling and support equipment will be made available from competing companies at rates that equate to cost not profit.

The net effect is a corporate philosophy that is ready to implement the appropriate countermeasures with the support of the petroleum industry. In specific terms, this ensures that the enormous losses incurred as a result of equivocation, lack of commitment, or unpreparedness, as exemplified by the Saga incident, do not occur on frontier lands.

10.5.2 Experience

Beaufort Sea petroleum operators have accumulated a great deal of experience in drilling under Arctic conditions over the last 18 years of offshore exploration. Such innovations as long range ice reconnaissance, platform stability regimes, refrigerated drilling fluids for permafrost integrity and ice breaking techniques were developed in the Beaufort and are characteristic of area operations. The geology of the area is now well understood. This experience not only bodes well for routine operations but is an asset in the event a relief well becomes necessary. Beaufort Sea operators, unlike most exploration companies, own and operate the drilling platforms and support vessels used in their drilling programs. Furthermore, these facilities are shared among operators either through lease or joint venture arrangements eg. Esso's use of the Molikpaq to drill the Isserk well. The end result is a nucleus of expertise that is readily available within the area on a first name basis. For purposes of drilling a relief well, this translates into a thorough knowledge of the resources available for an operation and the techniques, precautions and procedures involved in drilling an alternate well - quite apart from relief well contingency plans that are prepared for each specific project. In terms of cost, this means a relief well could be successfully completed within weeks instead of months, without costly overruns that could exceed financial provisions.

10.5.3 Well Control Preparedness

In a general sense preparedness is an extension of corporate philosophy, much of which in turn is enforced by the current regulatory regime. However, quite apart from what the law requires, Beaufort Sea operators have long recognized that because of remoteness, if a problem develops they must be capable of handling it themselves without outside assistance. For example, it would be take some twelve hours before a government search and rescue operation could be mobilized in the Beaufort Sea. For its part, COGLA requires operators to be capable of drilling a relief well with readily available hardware without delays due to seasonal restraints. What the Beaufort Sea lacks in the abundance and diversity of petroleum services, compared to highly developed areas such as the North Sea or the Gulf of Mexico, it makes up for in specialized expertise and precautions. While the availability of alternate MODU's for a specific relief well is limited, the specialized requirements of a Beaufort Sea platform can nevertheless be met with redundancy by purpose built MODU's available in the Beaufort and Chuckhi Seas. As stated above, operators are quite familiar with the specifications, physical limitations, crewing and support requirements for each unit. Vital facilities such as icebreakers, accommodation platforms, tubulars, and communications facilities are not only available in the immediate area, but are owned and operated by the oil companies, who more often than not, are joint venture partners in the various projects.

From a management standpoint, company contingency plans identify a clear chain of command, with priorities and responsibilities for key personnel. This is complemented by communications facilities that include a headquarters crisis centre with direct links to supervisory personnel on the drilling platform, at the base camp or at other locations in the field.

Thus, while well control operations in the Beaufort Sea would appear quite problematic as a result or remoteness, it is argued that experience in Arctic drilling combined with extensive contingency planning should result in a problem being contained within the projected period of 45 to 70 days. This, in turn, would tend to argue in favour of a lower AFE multiple.

10.5.4 Canadian Regulatory Regime

The Oil and Gas Production and Conservation Act authorizes the Chief Conservation Office (who is appointed by the Ministers of EMR and DIAND) to ensure that in the event of a spill, appropriate action in taken, consistent with safety and the prevention of pollution, to reduce or mitigate any danger to life, health, property or the environment. Where it is apparent that such action is not being taken, the Chief Conservation Officer is empowered to assume the management and control of such operations, for which any cost shall be borne by the petroleum operator.

While this degree of regulatory control is accepted as normal by Canadians, it should be appreciated, that most blowouts have occurred in countries that did not have the same measure of regulatory control (nor environmental concern). In terms of well control operations, this degree of government involvement and public concern ensures that corrective measures will be implemented with regulatory approval and without undue delay.

Beaufort Sea operators are required to prepare a detailed relief well plan specific to their operation at the time application is made for drilling program approval. The plan must identify an alternate drilling platform that can be mobilized within two weeks, and be capable of drilling a relief well within seasonal constraints. In most cases, the candidate MODU is the property of a joint venture partner. However, if the alternate platform is under contract, evidence of its availability for emergency purposes is required. The plan must also confirm that major consumable (eg. casing, cement, mud, and fuel) are immediately available. Specialty equipment, not available within the area, such as high pressure pumps, large bore manifolds, heavy lift helicopters, electromagnetic proximity tools, directional drilling equipment and the related oil field services must be sourced. These precautions are intended to minimize the time lost in after-the fact planning and better prepare the operator for responding to a well control problem.

In order to mobilize regulatory expertise commensurate with an emergency in the petroleum sector, COGLA has defined a system of crisis management whereby specialists from the private sector, petroleum boards, and other government agencies convene to review the situation, and the various operational options in consultation with the petroleum operator (COGLA Emergency Response Plan). This ensures that the appropriate government agencies are fully appraised of a problem while at the same time providing a forum for reviewing the proposed course of action. This mechanism also provides the process whereby special government resources may be tasked to the well control operation (eg. inspection teams, icebreakers, heavy lift aircraft) should the gravity of the situation warrant government assistance.

The Canadian regulatory regime, therefore, embodies the authority, regulatory compliance procedures and provisions to ensure that the petroleum operator initiates an appropriate emergency response. While this system represents a significant overhead cost to the Canadian taxpayer, it provides assurance that should an oil well blowout occur in the Beaufort Sea, little time would be lost in mobilizing a response tailored to circumstances of the problem. It is highly unlikely, therefore, that the inordinate cost overruns that characterized the Pemex and Saga blowouts would occur in the Canadian Beaufort Sea.

10.5.5. Community Infrastructure

During the last 18 years of Beaufort Sea exploration, the infrastructure to support offshore operations has expanded markedly with improvements to air services, warehousing, marine facilities, resupply, accommodation, communications, construction capability and weather forecasting. These improvements are reflected in the rapid growth of the tourism industry. Thus, while the Beaufort Sea is indeed remote from centers of industrial development in terms of air miles, the community is nevertheless capable of supporting marine operations of major proportions.

10.6 A BEAUFORT SEA AFE MULTIPLE

From the perspective of northern operators, drilling costs in the Beaufort Sea reflect high equipment operating costs (chargeout rates) which exceed those of any other area in the world. This is because the cost of a dedicated platform or ice breaker must be recovered on the basis of limited seasonal usage, say, one well per year. However, by prior inter company agreement, these same chargeout rates, under emergency conditions, would equate to cost - not profit. Relief well costs involve sizeable multiples for emergency transport (air vs. surface) and specialized services that, in total, account for only a small proportion of the original AFE. Accordingly, the application of a simple multiple to the AFE, based on procedures established in other operating theatres, without adjustment, is probably not reflective of Beaufort Sea conditions.

In an attempt to accommodate these factors within the framework of an AFE multiple, that for purposes of this report could be applied to artificial islands, winter drilling etc., the following table was developed to illustrate the AFE cost components for a well drilled from a floating MODU.

TABLE 3

Control of Well Costs

Beaufort Sea Floating Platform

AFE Item	Cost $ Million	Relief Well Multiple	Cost	Surface Kill Cost**	2nd Relief Rig
Base camp 85 days	8	X2 for increased personnel	16	2	2
MODU rates including mobs/demobs	40	X1.5 for additional icebreakers	60*	25	12*
Transportation (air and surface)	2.5	X5 for emergency air lift	12.5	3	5
Consumables casing, cement & mud	4.5	X2 for wastage and & kill products	9.0	2.0	1
Drilling Services	4.5	X3 for specialized hardware & personnel	13.5	5	4.0
Site survey	0.5				
Drill stem testing	0.7				
Fuel	3.0	X1.5 for additional vessels	4.5	2.0	1.0
Mob/Demob	7	X.5	3.5	—	—
TOTALS	**70.7**		**119**	**39**	**25**

* chargeout rates for emergency conditions have not been reduced in this calculation.

** values assigned are believed to be quite conservative; 2nd relief well speculated to be largely mobilization costs.

The figures used are viewed to be very conservative (1991 rates) with further allowances for simultaneous surface kill operations of an unrealistically protracted duration (keep in mind this is an open hole and not an underground blowout). In addition, allowances have been made for the mobilization of a second relief well unit as a tertiary precaution.

From this analysis an aggregate cost of $183 million is obtained, a multiple of 2.6 times the original AFE. While different values can be invoked for an island-based operation (described elsewhere in this report) the multiple is nevertheless consistent with the views of those familiar with northern operations (Pidcock 1990, Schilling 1990) and the general conditions attending Beaufort Sea drilling. The higher multiples experienced elsewhere in the world were associated with underground blowouts and problematic reservoir conditions not found in the Beaufort Sea.

10.7 CONCLUSION

From the foregoing it can be concluded that a blowout in the Beaufort Sea would be followed by the immediate implementation of well control contingency measures. This would result in a minimum of delays and expense as conditions would not be allowed to deteriorate unnecessarily.

It is also anticipated that relief well preparations would be implemented immediately regardless of the prospects for a surface kill. Indeed, it is to be expected that preparations for both operations would proceed simultaneously.

In order to provide an appropriate measure of redundancy, mobilization of a second relief well MODU is anticipated.

At the same time, well control specialists, and kill equipment would be airlifted to the area from various source points in North America.

The necessary vessel and aircraft support to attend two relief wells and a surface kill operation would be engaged, whether or not any or all of these resources were instrumental in the kill operation.

These precautionary measures may exceed the cost of those measures that ultimately are responsible for resolution of the problem - including self-bridging. While the 2.6 multiple exceeds Beaufort Sea operator projections in the extreme, it affords ample margin for delays due to weather conditions, logistical problems, fire, and wreck removal, and is consistent with comments received on this report (Adams 1990, Schilling 1990).

On balance then, it is postulated that Beaufort Sea well control costs, for the purpose of this report, could be as high as 2.5 to 3.0 times the project AFE, exclusive of seepage and pollution and redrill costs.

11. CALCULATIONS FOR FOUR BLOWOUT EXAMPLES

11.1 INTRODUCTION

In this section four oil well blowout scenarios are developed and then used as examples to demonstrate the oil spill cleanup cost methodology.

11.2 BLOWOUT CONDITIONS AND OIL CHARACTERISTICS

Four oil well blowout scenarios are described based on two different well sites that represent a range of drilling situations in the Southern Beaufort Sea.

1. a subsea blowout in 30 m of water in summer, open-water conditions at 70°6'N, 134°W (Figure 6)
2. a subsea blowout in 30 m of water in fall, lasting through freeze-up, under transition zone ice at 70°6'N, 134°W
3. an above-sea or platform blowout from an artificial island near the Mackenzie Delta in summer open-water conditions at 69°39'N, 136°W (Figure 10)
4. an above-sea blowout from an artificial island near the Mackenzie Delta in winter, landfast ice conditions at 69°39'N, 136°W

The situation of an above-sea blowout in winter in moving ice is not specifically addressed because the countermeasures techniques available to clean up such a spill are identical to those for a subsea blowout under moving ice (i.e., tracking oiled ice through the winter, then in-situ burning of oil on melt pools the following spring).

11.2.1 Blowout Flowrates and Durations

In order to illustrate the procedure for assessing component costs, four blowout examples are described hereunder.

As indicated in the Introduction, the cost of an oil spill is a function of a host of variables, including amount others, seasonal conditions at the time of the spill, type of oil, flow rates, and duration of the blowout. With regard to flow rates and duration, which of course determine the size of the oil spill, the question arises as to how representative the examples would be of an oil well blowout in the Beaufort Sea. For a perspective on this matter the reader is referred to the comparison document entitled "Worst Case Scenario - A Report Prepared on Behalf of the Canadian Petroleum Association" for the Beaufort Sea Steering Committee prepared by Adams Pearson Associates Inc. This report suggests that 10,000 BOPD flow rates are possible, but will likely involve rates less than 2000 m^3/d total fluids (oil and water) and that the time to remedy the blowout will likely take less than a week. Accordingly, it is suggested that the following examples, in all probability, represent the upper limits to worst case scenarios, and should therefore be considered as case studies illustrative of procedures rather than examples of accidents that may be anticipated in this particular area.

Sub-sea blowout offshore	- 10,000 BOPD (Barrels of oil per day) - GOR = 356:1
Above-sea blowout near delta	- 5000 BOPD - GOR = 43:1

The sub-sea blowout is hypothesized to last for 45 days in the open-water season, until killed by a relief well; in the case of the late-season blowout this is assumed to take 65 days. The above-sea blowout during open-water conditions is assumed to last for 30 days; over winter the relief well and kill operation is hypothesized to take 100 days. These times while excessive in terms of effecting surface control measures, correspond to estimates of the time required to complete relief well drilling.

11.2.2 Oil Types

Two different crude oils discovered in the Beaufort Sea area were selected for the scenarios: Adgo F-28 crude for the above-sea blowout and Itiyok I-27 crude for the sub-sea blowout. Table 4 summarizes the properties of the Adgo crude oil, as analysed by Environment Canada (Bobra 1989), and the properties of the Itiyok oil. For the purposes of the oil spill fate and behaviour modelling exercise, the Itiyok crude is assumed to have the properties of Atkinson crude (Bobra 1989), an oil having similar API gravity and viscosity. Table 5 gives the equations and constants used by the computer model to determine the change in oil properties as a function of temperature and volume fraction evaporated (F_v). It should be noted that for purposes of creating a severe pollution problem these crudes were specifically chosen to be more persistent than Amauligak crude oil. This will provide different oil fate and behaviour predictions than those presented in recent studies (i.e., Gulf 1990, Esso et al. 1989).

TABLE 4
Properties of Adgo and Itiyok Crudes used in Blowout Scenarios

	Adgo	Itiyok
API gravity	16.8	20.5
Density, kg/m^3		
15°C	953	930
Viscosity, mPas = cp		
15°C	62	52*
Interfacial tensions @ 0°C		
mN/m = dynes/cm		
air/oil	33.3	30.5*
oil/seawater	16.8	18.7*
Pour Point, °C	-26	-30
Flash Point, °C	95	283*
Emulsion Formation		
Tendency and Stability @ 0°C	moderate tendency to form stable emulsion when fresh	assumed to form stable emulsion when fresh
Hydrocarbon Group		
Analysis (wt %)		
Saturates	79.8	82.7*
Aromatics	18.8	13.2*
Polars	0.9	1.5*
Asphaltenes	0.5	2.6*
Aqueous Solubility (g/m^3)		
in Saltwater @ 22°F	N.A.	2.5*
Sulfur Content wt%	0.19	0.86*
Weathering	equation 1	equation 2
(see Stiver and Mackay 1983)	below	below

1. $$F_v = \frac{\ln(1 + 2012.6\ \Theta \exp(6.3 - 5675.3/TK)/TK)}{(2012.6/TK)}$$

2. $$F_v^* = \frac{\ln(1 + 8039\ \Theta \exp(6.3 - 4591/TK)/TK)}{(8039/TK)}$$

where:
- F_v = fraction of oil weathered by volume
- ln = natural logarithm
- Θ = evaporative exposure
- exp = exponential base e
- TK = environmental temperature (° Kelvin = 273 + °C)

* assumed to be the same as for Atkinson crude (Bobra 1989)
N.A. not available

TABLE 5

Constants Used to Relate Weathering and Temperature to Oil Property Changes

Property	Units	Expression	Value of Constant For	
			Adgo	Itiyok*
Density	kg/m^3	$_{o}$ [1-C1 ($T-T_o$)] (1 + C2F)	C1 = 0.000420	0.000782
			C2 = 0.082	0.16
Viscosity	mPas (cp)	μ_o [exp (C3{$1/T - 1/T_o$})	C3 = 5490	5029
		x exp (C4F)]	C4 = 8.79	10.74
Aqueous solubility	g/m^3	S.exp (C5F)	C5 = N.R.	N.R.
Pour Point	°K	PP. (1 + C6F)	C6 = 0.0	0.354
Flash Point	°C	FIP. (1 + C7F)	C7 = N.R.	N.R
Fire Point	°C	FiP. (1 + C8F)	C8 = N.R.	N.R
Oil-water Interfacial Tension	mN/m (dyne/cm)	σ_{ow} (1 + C9F)	C9 = 0.0	0.0
Oil-air Interfacial Tension	mN/m (dyne/cm)	σ_{oa} (1 + C10F)	C10 = 0.0	0.0

* assumed to be the same function of F or T as Atkinson crude

N.R. not required for this modeling exercise

Source: Mackay et al. 1983, Bobra 1989

11.2.3 Environmental Conditions

The oil spill modelling techniques used in this report involve the use of seasonal average environmental conditions to predict the dimensions, behaviour and fate of the slicks generated by the scenario blowouts. The pertinent conditions are given in Table 6.

11.2.4 Oil Fate and Behaviour Modelling

The dimensions, behaviour and fate of the oil slicks in open water conditions were computer modelled using the model described in S.L. Ross and DMER (1988) under the average environmental conditions given in Table 6. A portion of the slick generated by the blowout was followed through time until either 99% of the oil had evaporated into the air and naturally dispersed into the water or the thick portions of the slick had thinned to 1 μm (a thin sheen). The distance travelled by this portion (calculated by multiplying the dissipation time by the surface current) until 99% has dissipated or spread to sheen was defined as the dissipation distance of the slick.

NB. The use of the Ross-DMER oil trajectory model in this report does not constitute endorsement by the government agencies, companies, or other stakeholders represented on Task Group 1.

TABLE 6

Summary of Scenario Environmental Conditions

Type	Average Dates	Mean Air T (°C)	Mean Wind Speed (m/s)	Mean Water T (°C)	Mean Ice Conc (tenths) Sub-sea	Mean Ice Conc (tenths) Above-sea	Mean Wave Height (m)	Mean Surface Current (cm/s)
Summer open water	July 20-Sept. 1	6	5.5	6	0.4	0.2	0.6	25
Fall open water	Sept. 1-Oct. 10	3	7.7	1	0.9	1.4	1.0	25
Ice Formation	Oct. 10-Oct. 25	-10	8	-1	5.4	10	0[a]	21[b]
Freeze-up	Oct. 25-Nov. 15	-15	8	-1	9.7	10	0[a]	21[b]
Winter	Nov. 15-May 1	-24	4	-1	10	10	0[a]	5[b]

a. Assumed due to presence of ice

b. Ice velocity

11.3 SPILL BEHAVIOUR AND RESPONSE DESCRIPTIONS FOR THE SUB-SEA BLOWOUT SCENARIOS

11.3.1 Sub-Sea Blowout: Summer Open-Water Conditions

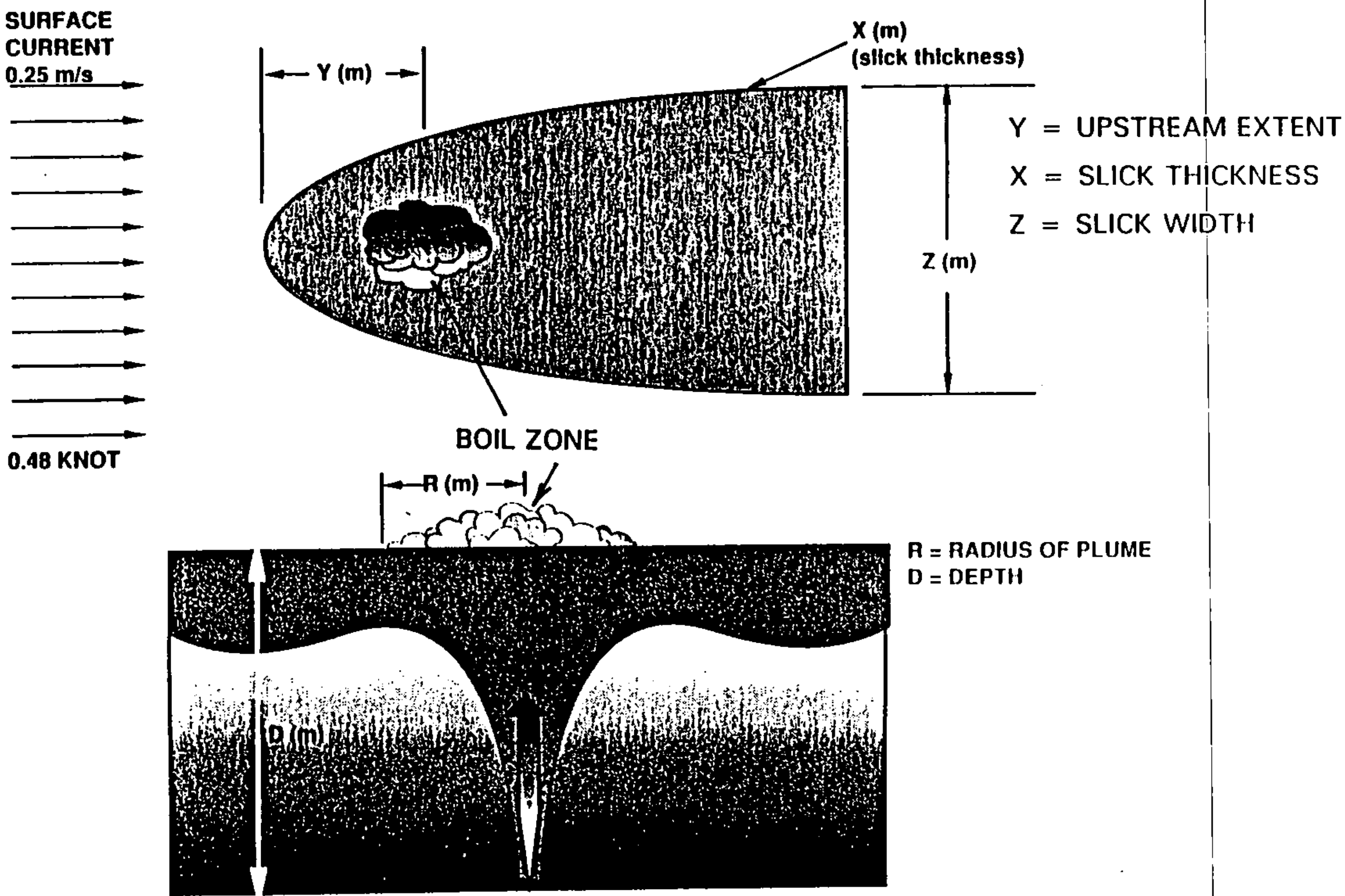
A subsea blowout is presumed to occur on July 20 at 70°6'N, 134°W, releasing 10,000 BOPD (1590 m^3/day) of Itiyok crude and 5.7 x 10^5 m^3/d of natural gas at the seabed in 30 m of water. The blowout lasts for 45 days until killed by a relief well.

11.3.1.1 Near-Source Slick Characteristics

The oil from the wellhead is shattered into small droplets (1-2 mm and smaller in diameter) by the high velocity gas release. These droplets are entrained by the water, drawn upwards by the rising gas, and rise towards the sea surface (Figure 4). As the entrained water nears the surface it turns outward, carrying the oil droplets with it; the oil droplets slowly rise upwards and coalesce on the surface to form a slick. Under the influence of the 0.25 m/s (½ knot) current the resulting slick is parabola-shaped (Figure 5). Table 7 gives the predicted dimensions and characteristics of the slick near the blowout site. The oil slick is about 360 m wide and 0.21 mm thick at the boil zone (where the gas escapes from the water into the atmosphere); further down-current the entrained water has spread the slick to 800 m in width; the thickness of the slick at this point has decreased due to spreading and evaporation. Emulsification of the oil has begun, reaching 21% water by volume, which proportionately increases the thickness. Taking into account the effects of spreading, evaporation and emulsification, the thickness of the slick when it is 800 m wide is 0.09 mm; oil weathering processes have increased the slick viscosity to 1250 cp at this point. After one hour on the sea surface, the slick is 1250 m wide, 0.067 mm thick and consists of a 42% water-in-oil emulsion with a viscosity of 5300 cp.

FIGURE 4

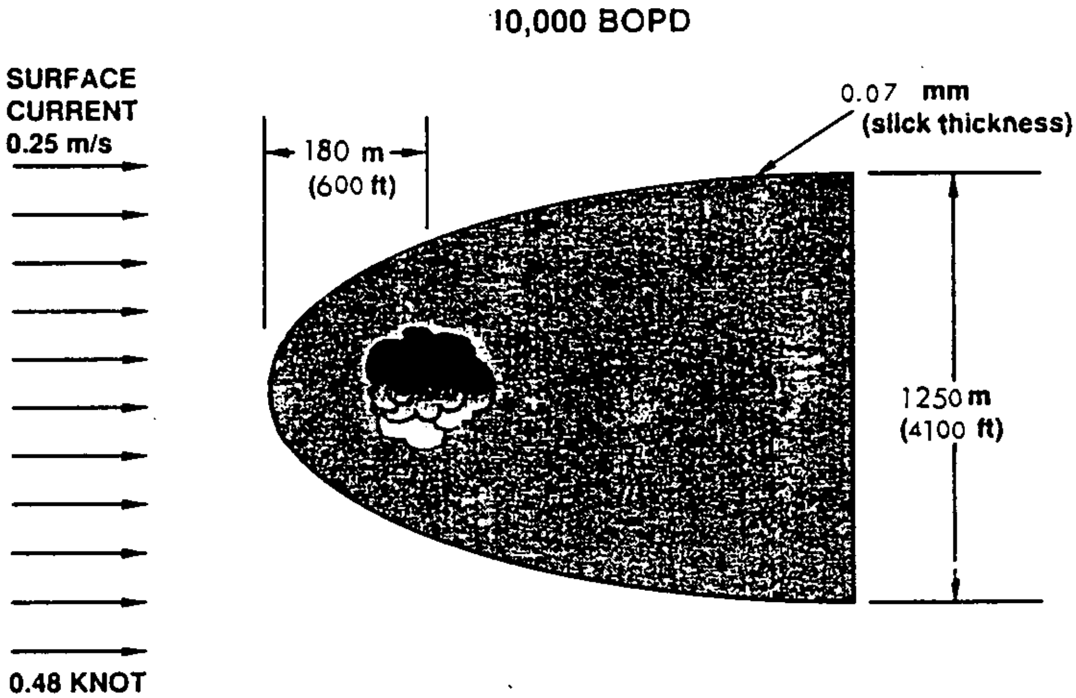
DIMENSIONS OF SUBSEA BLOWOUT



Adapted from Gulf 1990

FIGURE 5

PREDICTED DIMENSIONS OF HYPOTHESIZED SUBSEA BLOWOUT IN OPEN WATER



adapted from Gulf 1990

TABLE 7

Near Source Characteristics of Hypothetical Sub-Sea Blowout in Summer

	Width (m)			Thickness (mm)			Viscosity (cp)			Water Content (%)		
	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour
10,000 BOPD												
Open Water												
Summer	360	800	1250	0.21	0.09	0.067	100	1250	5300	0	21	42

11.3.1.2 Ultimate Oil Fate Assuming No Countermeasures

Under average, summer open-water conditions the slick is predicted to survive on the sea surface for 307 hours, equivalent to drifting 277 km from the site in a 0.25 m/s current. After 307 hrs the oil would be in the form of balls of widely scattered, heavily weathered emulsion and would have a viscosity of 550,000 cp and a density of 1021 kg/m^3. This density is sufficiently high for the emulsion balls to be temporarily submerged by wave action at sea, or sink to the pycnocline in areas of stratified water (such as where the Mackenzie River outflow results in a layer of freshwater on top of sea water).

Figure 6 shows the possible shoreline oiling that could result from the blowout assuming certain historical average wind conditions. In total some 395,000 bbls of viscous, water-in-oil emulsion (containing 99,000 bbls of weathered oil) could come ashore; most of this (about 270,000 bbls) could come ashore along the coasts of Richards Island, Kugmallit Bay and the Tuktoyaktuk Peninsula.

Of the slicks that do not eventually come ashore, about 34% of the oil evaporates and the remainder (66%) eventually disperses naturally into the water column in the form of very small (less than 100 μm diameter) droplets. In total some 199,000 bbls of weathered oil are predicted to be naturally dispersed. Table 8 summarizes the ultimate fate of the 450,000 bbls of oil released (10,000 BOPD x 45 days) if no countermeasures are undertaken.

11.3.1.3 Likely Effectiveness of Countermeasures

Table 9 shows the various individual and combined weather and sea state factors that are used to determine the overall effectiveness of the response operation. Table 10 summarizes the results of applying the Beaufort Sea Co-op's offshore containment and recovery equipment and the combination fireproof/fire containment/conventional in-situ burning boom system to the hypothesized blowout. Of the 450,000 bbls of oil released over the 45 day period: 106,000 bbls would evaporate almost immediately (while the oil is fresh and thin); 76,000 bbls could be recovered by the Co-op's Response Barge (intercepting 41% of the width of the slick and operating 55% of the time after a 24 hour response time to the site); and 80,000 bbls could be burned in-situ (43% of the width of the slick is intercepted

FIGURE 6 - POSSIBLE SHORELINE OILING FROM A 10,000 BOPD SUB-SEA BLOWOUT DURING SUMMER

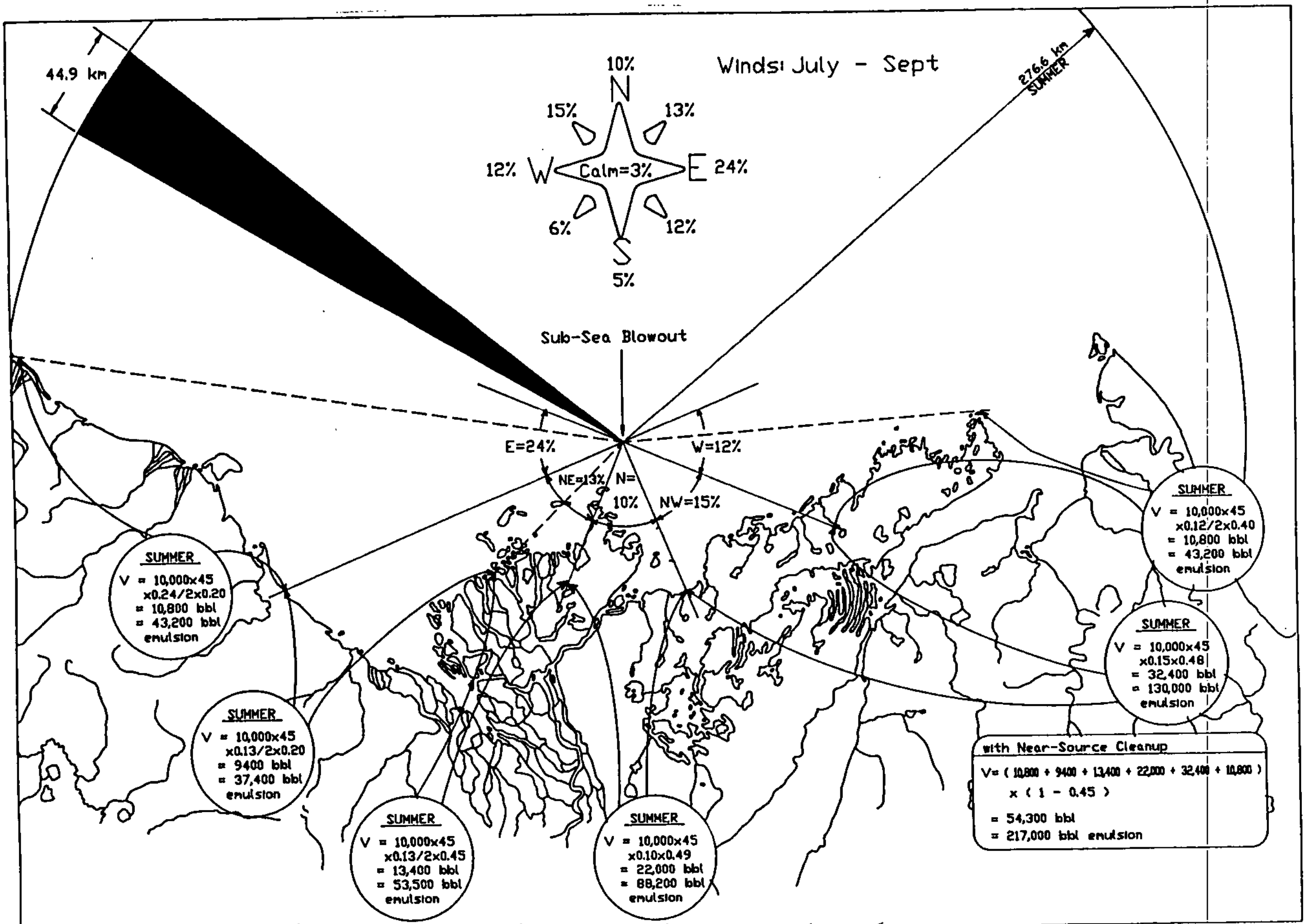


TABLE 8

Summary of Ultimate Oil Fates with no Cleanup for Sub-Sea Blowout Scenario in Summer

Blowout	Duration (days)	Season	Oil Released (bbl)	Oil[+] Evaporated (bbl/%)	Oil Dispersed[b] Naturally (bbl/%)	Oil on[a] Shore (bbl/%)	Oil in Ice (bbl/%)
10,000 BOPD	45	July 20-Sept 2 (summer x 45 days)	450,000	152,000/34	199,000/44[a]	99,000/22	0/0

a. calculated as per Figure 6

b. calculated by subtracting oil on shore from oil dispersed naturally without shoreline oiling

TABLE 9

Weather and Sea Response Factors for Scenario Near-Source Cleanup

Time	Daylight (% of time)	VFR (% of time)	Waves <1.5m (% of time)	Waves >calm (% of time)	Ice Conc.[a] <3/10 (% of time)		Overall Factor (% of time)	
					Sub-sea	Above-sea	Containment	Dispersant
Summer open water	83	83	80	85	100	100	55	20[c]
Fall open water	50	81	70	90	95	90	27	11[c]
Fall ice formation	25	85	100[b]	0[b]	30	0	6[d]	0
Fall freeze-up	20	85	100[b]	0[b]	0	0	0	0

a. estimated from Table 13

b. assumed due to presence of ice

c. includes a 33% efficiency factor; if dispersant used only when waves >1.5 m the overall factors are 5% in summer and 4% in fall open water conditions

d. applies only to sub-sea location; factor = 0 at above-sea location

TABLE 10

Summary of Open Water Near-Source Cleanup Using Beaufort Sea Co-op Resources
Sub-Sea Blowout in Summer

Blowout Rate	Duration (days)	Season	Oil Released (bbl)	Oil Initially Evaporated (bbl/%)	Oil Removed Near-Source Recovery (bbl/%)	Oil Removed Near-Source Burning (bbl/%)	Oil Remaining (bbl/%)
10,000 BOPD	45	summer open water	450,000	106,000/23	76,000/17[b]	80,000/18[b]	188,000/40[a,b]

a. of this some 62,000 bbls of oil (250,000 bbls of emulsion) may come ashore

b. the oil removed at source could be increased by 36,000 bbls (8%) to a total of 192,000 bbls (43%) by the use of additional containment and recovery or burning resources; the oil remaining would be reduced to 152,000 bbls (38%) and the volume coming ashore would be reduced to 54,000 bbl of oil (217,000 bbls of emulsion).

55% of the time after a 24 hour delay in getting the equipment on-site) and this burn could be entirely contained in the 77 m of fire proof boom.

It is noted that the combined encounter width of the Co-op recovery and in-situ burning resources is only 84% of the width of the slick. However, additional containment and recovery (i.e., the Coast Guard equipment in Tuktoyaktuk) or in-situ burning equipment could be brought to bear to intercept the entire width of the slick. Doing this could remove up to an additional 36,000 bbls of oil near-source.

Assuming the use of just the Co-op resources, some 188,000 bbls of oil would escape from the blowout site (comprised of the 16% of the slick not intercepted and all the slick during periods of nighttime, poor visibility, high ice concentrations and high seas). Of this, 62,000 bbls of oil (in the form of 250,000 bbls of emulsion) could come ashore and the rest (115,000 bbls) would evaporate and naturally disperse offshore. If additional offshore containment and recovery or burning resources are brought to bear on the slick near-source the volume of oil escaping would be reduced to 152,000 bbls, of which 54,000 bbls of oil (in the form of 217,000 bbls of emulsion) could come ashore.

It is therefore assumed that additional resources (the Coast Guard offshore boom and skimmer stored in Tuktoyaktuk) are quickly deployed and the entire width of the slick intercepted, permitting only 54,000 bbls of oil to come ashore.

11.3.2 Sub-Sea Blowout: Late-Season Conditions

The same blowout as described immediately above is presumed to occur on September 25. The blowout lasts for 65 days until killed by a relief well on November 28.

11.3.2.1 Near-Source Spill Characteristics

In fall open-water conditions the widths of the slick produced are the same as the widths produced by the same blowout in summer conditions. The thickness and properties of the resulting slick are, however, slightly different because of the colder temperatures, higher winds and higher sea states used for the average fall environmental conditions (Table 11).

At the point where the slick is 800 m wide the slick is 0.1 mm thick and consists of oil with a 29% water content with a viscosity of 1750 cp. At a point one hour's drift away from the site the slick is 0.09 mm thick and consists of a 59% water content emulsion with a viscosity of 17,900 cp.

Spill Characteristics During Ice Formation: During the period from October 10 to October 25 the blowout site is assumed to be covered by an average 5/10ths of new ice floes moving at 21 cm/s. As such, one half of the oil discharged is painted (as droplets) onto the underside of new ice in a strip 360 m wide and one half of the oil is released onto water between floes. About 270 linear km of ice/water are covered. The oil released under the ice is trapped there, does not weather and is quickly encapsulated by the downward growing ice; the oil released onto water between floes spreads and evaporates, but does not emulsify or naturally disperse (no waves are present to drive these fate processes). Eventually, over a one or two week period, the weathered oil originally released onto water is frozen, as very thin slicks, into the surface of newly forming ice.

Spill Characteristics During Freeze-up: From October 25 to November 15 (22 days) the oil is discharged under 10/10ths ice cover which is moving at 21 cm/s (18 km/day); the oil droplets are quickly encapsulated by the growing ice sheet in a meandering strip 360 m wide, 0.21 mm thick and 400 km long.

Spill Characteristics During Winter: For the last 13 days of the scenario (up to November 28) the oil is discharged under more slowly moving ice (5 cm/s = 4.3 km/day). This results in a meandering strip of oil frozen in the ice that is 1800 m wide, 0.21 mm thick and 56 km long.

TABLE 11

Near Source Characteristics of Hypothetical Late Season Sub-Sea Blowout

	Width (m)			Thickness (mm)			Viscosity (cp)			Water Content (%)		
	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour
10,000 BOPD												
Open Water												
Fall	360	800	1250	0.21	0.10	0.09	150	1750	17,900	0	29	58
Under Ice												
Ice Formation and Freeze-up	360	360	360	0.21	0.21	0.21	150	150	150	0	0	0
Winter	1800	1800	1800	0.21	0.21	0.21	150	150	150	0	0	0

11.3.2.2 Ultimate Oil Fate (assuming no countermeasures) for Late-Season, Sub-Sea Blowout

Due to the differences in oil fate depending on the prevailing ice cover, each period (i.e., open water, ice formation, freeze-up and winter) over the 65 day duration is addressed separately.

Oil Fate During Fall Open-Water Conditions: During the 15 day period of open water conditions the slick is predicted to survive 233 hours, or 210 km in a 0.25 m/s current. At this point the slick is comprised of small, widely scattered balls of 75% water-content emulsion with a viscosity of 675,000 cp and a density of 1021 kg/m^3. Using the summer shoreline oiling regime as a basis; 132,000 bbls of viscous, water-in-oil emulsion (containing 33,000 bbls of oil = 99,000 x 15/45) could come ashore during the 15 day open-water period. It is assumed that the remainder evaporates (50,000 bbls) or naturally disperses (67,000 bbls) prior to the stop of natural dispersion due to increasing ice concentrations.

Oil Fate During Ice Formation: The oil released onto water between floes loses 50% of its volume to evaporation prior to freezing into the surface of newly growing ice; over the 15 day ice formation period this amounts to 38,000 bbls. The remaining 37,000 bbls is frozen in. All the oil discharged under the ice is quickly encapsulated (75,000 bbls) until the following spring melt.

Oil Fate During Freeze-up and Winter: All the oil discharged in the last 35 days of the scenario is released under ice and encapsulated until the following spring; this amounts to 350,000 bbls of fresh oil.

Table 11 summarizes the fate of the oil released in fall. In total 88,000 bbls evaporate, 67,000 bbls naturally disperse, 33,000 bbls come ashore (as 132,000 bbls of emulsion) and 462,000 bbls are frozen in ice (425,000 bbls as fresh oil deposited under ice and 37,000 bbls as thin slicks frozen into the surface of the ice). The total length of the oiled ice strip is some 730 km and it contains 342 km^2 of oiled ice (270 km x 0.36 km from the ice formation period; 400 km x 0.36 km from the freeze-up period and 56 km x 1.8 km from the winter period). This oiled ice is presumed to be contained within an area some 70-90 km wide and 200 km long.

TABLE 12

Summary of Ultimate Oil Fates with no Cleanup for Late-Season Sub-Sea Blowout Scenario

Blowout	Duration (days)	Season	Oil Released (bbl)	Oil[b] Evaporated (bbl/%)	Oil Dispersed[b] Naturally (bbl/%)	Oil on[a] Shore (bbl/%)	Oil in Ice (bbl/%)
10,000 BOPD	65	Sept 25-Nov 28 (fall x 15 days + ice formation x 15 days + freeze-up x 22 days + winter x 13 days)	650,000	88,000/14	67,000/10	33,000/3	462,000/71

a. calculated from Figure 6 using 15 instead of 45 days

b. calculated by subtracting oil on shore from oil dispersed naturally without shoreline oiling

Oil Appearance and Fate in Spring: Over the winter, the area of oiled ice moves generally westward until, by late June/early July, it extends from Barter Island to Point Barrow (Figure 7).

At this time the oil begins to appear on melt pools as it is exposed by the downward-melting ice sheet (note that the melt and breakup occur somewhat later off Alaska than off Tuktoyaktuk).

The oil originally released onto water between floes during the ice formation period (37,000 bbls) appears in widely scattered, thin slicks. Since this oil was highly weathered when frozen in, subsequent evaporation in spring is negligible.

The 425,000 bbls discharged directly under ice in fall appears on melt pools as fresh oil; this oil is wind-herded into 1 cm thick slicks against the edge of melt pools and loses 20% of its volume to evaporation in 1 week and 25% in 5 weeks. Based on scaling the results of the 1979/80 McKinley Bay experiments (with an under-ice coverage of 1 mm - Dome 1981) to the scenario (with an under-ice coverage of 0.21 mm), about 45% of the oil on the ice surface would be in herded slicks 5 m^2 and greater in area.

As breakup progressed, the oil (319,000 bbl + 37,000 bbl = 356,000 bbl) would be released, in the form of thin sheens, from rotting floes; some of the 37,000 bbls of heavily weathered oil may eventually form to balls.

11.3.2.3 Likely Effectiveness of Countermeasures during Late-Season, Sub-Sea Blowout

As with the description of the fate and behaviour of the oil from the late-season blowout, the countermeasures effectiveness is analysed separately for each ice cover period. Table 13 shows a summary of the results.

FIGURE 7 - POSSIBLE LOCATION OF OILED ICE IN SPRING

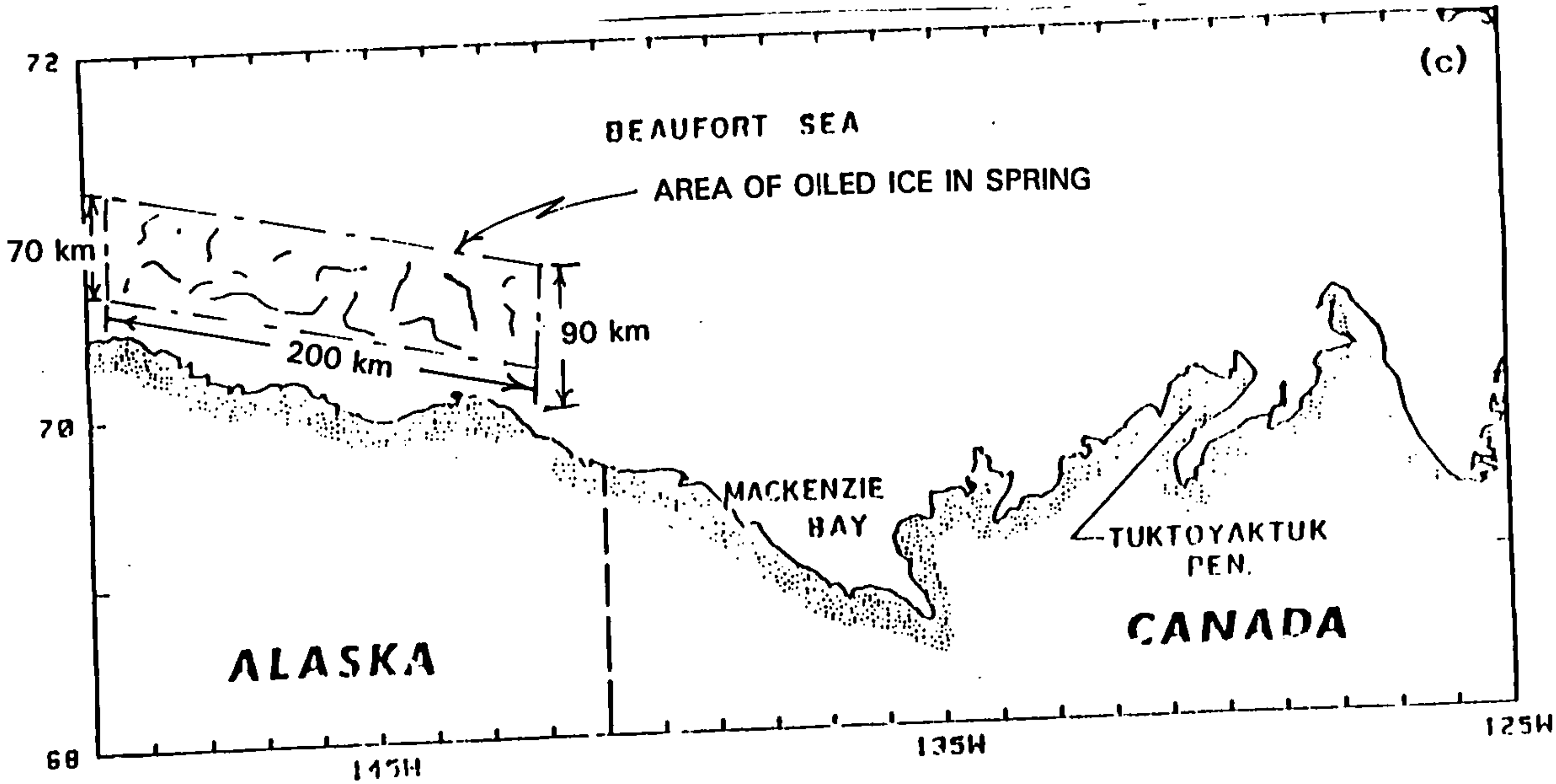


TABLE 13

Summary of Cleanup for Sub-Sea Blowout Occurring September 25

Blowout	Duration (days)	Season	Oil Released (bbl/%)	Oil Initially Evaporated (bbl/%)	Oil Removed		Oil Remaining (bbl/%)
					Recovery (bbl/%)	Burning (bbl/%)	
10,000 BOPD	15	fall open water	150,000/23	35,000/5	12,000/2	12,000/2	91,000/14[a]
	15	ice formation	150,000/28	38,000/6	3000/0.5[b]	3000/0.5[b]	106,000/16[c]
	22	freeze-up	220,000/34	0/0	0/0	0/0	220,000/34[c]
	13	winter	130,000/20	0/0	0/0	0/0	130,000/20[c]
			--	85,000/13[d]	--	122,000/19[d]	249,000/38[e]

a. oil may come ashore

b. removed near source during periods of low ice concentration

c. frozen in ice until the following spring

d. amounts evaporated (from oil originally released under ice) and burned on the ice the following spring

e. amount remaining at breakup

Countermeasures During Fall Open-Water Conditions: During the 15 days that these conditions persist 35,000 bbls of oil evaporates almost immediately; 12,000 bbls can be recovered by the Co-op Response Barge (encountering 41% of the width of the slick 27% of the time for 14 of the 15 days of open water); 12,000 bbls can be burned in-situ; and 91,000 bbls escape. Of this 91,000 bbls; 27,000 bbls (in the form of 109,000 bbls of emulsion) could come ashore and the remainder evaporate and naturally disperse offshore.

Countermeasures During Ice Formation: Only one-half of the oil discharged is available for near-source countermeasures; the other one-half is discharged under ice floes and is dealt with the following spring. Of the 75,000 bbls discharged on water; 38,000 bbls evaporates; 3000 bbls can be recovered by the Co-op Response Barge during periods of light ice conditions; and 3000 bbls can be burned in-situ. The remaining 31,000 bbls of oil on water eventually freezes into the surface of newly forming ice.

Countermeasures During Freeze-up and Winter: All the 350,000 bbls of oil discharged during this 35 day period is encapsulated under growing ice until the following spring.

Spring In-Situ Burning Operations: The following spring, the oil appears shortly after the melt begins (it was frozen in near the top of the ice sheet which melts from the top down) and remains on the ice surface for 4 - 6 weeks before breakup begins.

Only the 425,000 bbls of oil (75,000 bbls from the ice formation period + 350,000 bbls from the freeze-up and winter periods) originally released directly under ice is in a burnable state. Twenty percent (85,000 bbls) of this oil evaporates over a one-week period.

Based on an ignition success rate of 67% with 1.5 m^2 test pans (Spiltec 1987) the minimum oil pool size that can be hit 100% of the time is assumed to be 5 m^2; 45% of the oil is in pools this size or larger. Based on the results from the Mckinley Bay field trials (Dome 1981), an average combustion efficiency of 80% can be expected. Combining the two percentages, the achievable overall removal efficiency by burning is 36% (45% of 80%). The volume of oil removed would be 122,000 bbls (0.36 x (425,000 - 85,000)). At breakup there would be 249,000 bbls of oil remaining on the ice, consisting of: 31,000 bbls of 50% weathered oil; 187,000 bbls of unignited, 25% weathered oil; and, 30,000 bbls of tar-like burn residue. This oil would be discharged onto the water, as the floes rot, in the form of tar balls and sheens (which would further evaporate and eventually disperse naturally with wave action.

The number of helicopters and Helitorches (Figure 8) required to achieve the above overall removal rate is estimated as follows. One Helitorch load (the new 1130 L versions at a pump rate of 55 L/min) can cover 7.3 hectares in 20 minutes while being flown at an altitude of 15-20 m with a forward speed of 50 km/hr (25 knots). In order to attain the maximum achievable combustion removal efficiency approximately 4700 loads would have to be delivered (((270 km + 400 km) x 360 m + (56 km x 1800 m))/7.3 loads/ha). This would entail the use of approximately 5300 m^3 of gasoline (1130 L per load) and 63 tonnes of gelling agent (13.5 kg per load).

Table 14 summarizes the time required for a Helitorch sortie assuming a radius of operation of 90 km from a refuelling/reloading base on shore; about 2 hours is required.

In spring, VFR flying conditions exist more than 70% of the time, winds are less than 15 knots (the approximate maximum velocity for use of the Helitorch to ignite oil) 70% of the time and daylight exists 24 hours per day (D.F. Dickins 1987). The number of flying hours available in the 4-6 weeks is thus 330-500. Each helicopter and Helitorch could thus conduct between 165 and 250 sorties during the spring melt; between 19 and 28 helicopters with Helitorches, staged along the coast, would be required to cover the entire oiled area in the available time. The Co-op owns 4 Helitorches. During the 7 months before the oil appears on the ice surface for burning an additional 15 to 24 Helitorches and 19-28 medium lift helicopters would have to be procured and staged.

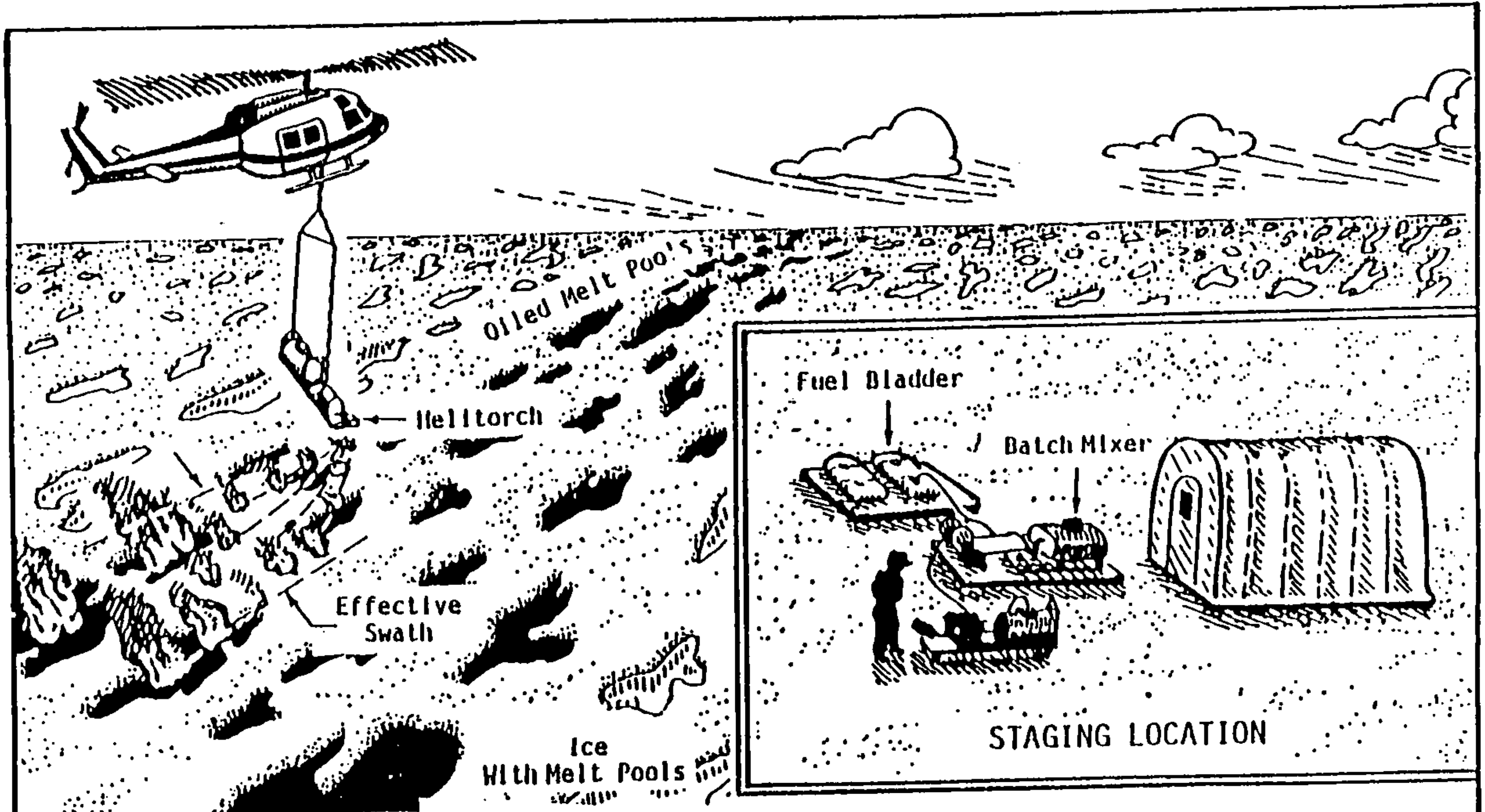


FIGURE 8 - APPLICATION OF BURNING GASOLINE FROM A HELITORCH OVER A CONTINUOUS ZONE OF OILED MELTPOOLS

TABLE 14

Time Required for One Helitorch Sortie to a Location 90 km Offshore

Operation	**Time Required**
Take off, pick up loaded Helitorch	5 minutes
Fly to site @ 150 km/hr (80 knots)	36 minutes
Position for Application	5 minutes
Apply ignitions (1130 L @ 55 L/min)	20 minutes
Return to refuelling/reloading base	36 minutes
Drop off empty Helitorch and land	5 minutes
	107 minutes*
Helicopter refuelling, reload and refuel Helitorch	15 minutes
TOTAL TIME PER SORTIE	122 Minutes
	= 2 Hours

* Maximum flying time with fully loaded Helitorch is 110 minutes.

11.4 ABOVE-SEA BLOWOUT SCENARIO

11.4.1 Above-Sea Blowout: Summer Open-Water Conditions

A blowout occurs on August 1 at an artificial island drilling site located at 69°39'N, 136°W, about 20 km west of Pelly Island. The surrounding water is about 7 m deep. The blowout sprays 5000 BOPD (795 m^3/day) of Adgo crude and 3.4 x 10^4 m^3/day of natural gas into the air. The blowout lasts for 30 days until killed by a relief well.

11.4.1.1 Near-Source Spill Characteristics for Above-Sea Blowout

Spill Characteristics During Open-Water Conditions: The gas exiting the pipe at the rig floor has a velocity of 200 m/s; this shatters the accompanying oil into droplets with an average diameter of 0.6 mm and shoots them up 15.5 m above the island's ground level. The wind carries the droplets away from the rig and they begin to "rain" onto the surrounding area. The first drops to reach the surface are predicted to do so 25 m downwind of the rig; the last drops to "rain" out are predicted to do so 57 m downwind of the rig in a swath 12 m wide. This oil is presumed to either fall directly onto the water surface or flow quickly off the island into the water; for the purposes of this scenario countermeasures to retain oil on the island (berming, diking, etc.) are not considered.

Figure 9 shows the predicted dimensions of the oil slick on water generated by this scenario and Table 15 summarizes the predicted slick characteristics for up to one hour's drift from the site. As the oil droplets "rain" down, they lose approximately 8% of their volume to evaporation, thus, 57 m away when all the droplets have hit the surface they form a slick 12 m wide and 2.8 mm thick in the prevailing 0.25 m/s current. The viscosity of the oil at this point is 225 cp. After one hour on the sea surface the oil has drifted a further 900 m from the site, has spread to a width of 260 m, has emulsified slightly to 25% water content. This emulsion has a viscosity of 480 cp.

FIGURE 9 - ABOVE-SEA BLOWOUT INITIAL SLICK DIMENSIONS

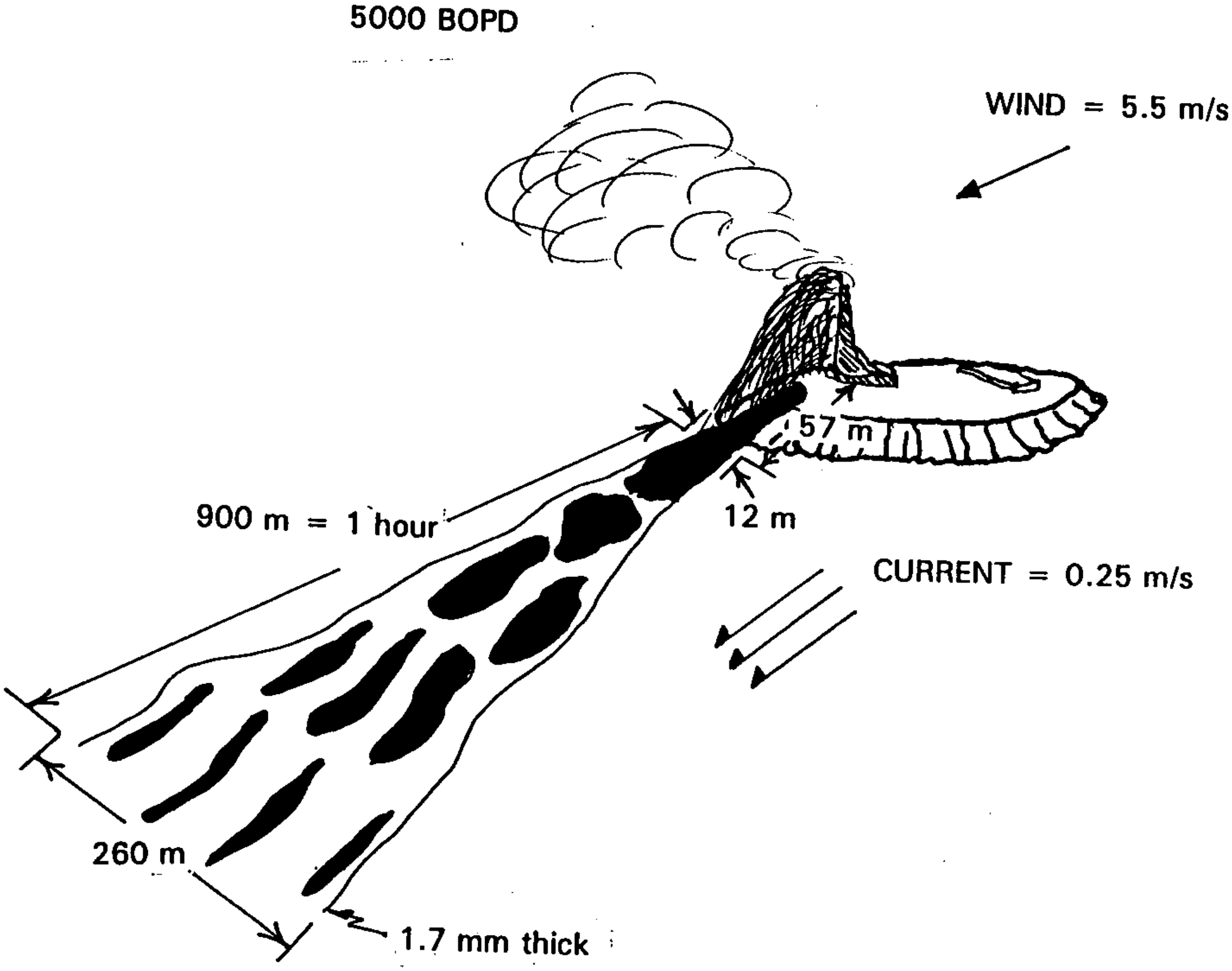


TABLE 15

Near Source Characteristics of Hypothetical Above-Sea Blowout in Summer

	Width (m)			Thickness (mm)			Viscosity (cp)			Water Content (%)		
	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour	at source	near source	one hour
5,000 BOPD												
Open-Water												
Summer	--	12	260	---	2.8	1.7	--	225	480	--	0	25

11.4.1.2 Ultimate Oil Fate (assuming no countermeasures) for Open-Water, Above-Sea Blowout

Under average, summer open-water conditions the slick is predicted to survive on the sea surface for about 132 hours, equivalent to drifting 119 km from the site. After 132 hours the oil would be in the form of small balls of widely-scattered emulsion spread over a 23 km wide area with a viscosity of 3,800,000 cp and a density of 1023 kg/m^3. This density is sufficiently high for the emulsion balls to be temporarily submerged by wave action at sea or sink to the pycnocline in areas of stratified water (such as where the Mackenzie River outflow results in a layer of freshwater on top of seawater).

Figure 10 shows the potential shoreline oiling that may result from this scenario. In total, some 145,000 bbls of viscous, water-in-oil emulsion (containing 36,000 bbls of oil) could come ashore; most of this (128,000 bbls of emulsion) could come ashore along the west-facing shores of the Mackenzie Delta and nearby islands.

Of the oil that does not come ashore, about 46% eventually evaporates and 54% naturally disperses into the water column in the form of fine droplets ($< 100\ \mu m$ diameter). In total some 45,000 bbl of weathered oil are predicted to be naturally dispersed. Table 16 summarizes the ultimate fate of the 150,000 bbls of oil released (5000 BOPD x 30 days) if no countermeasures are undertaken.

11.4.1.3 Likely Effectiveness of Countermeasures for Open-Water, Above-Surface Blowout

Table 17 summarizes the results of applying the Beaufort Co-op's offshore containment and recovery system or the combination fireproof/fire containment/conventional in-situ burning boom system to the hypothesized blowout. Since either system could intercept the entire width of the slick without limitation due to recovery capacity or burn efficiency. Over the 30 day period; 74,000 bbls of oil could be recovered by the Co-op Response Barge (operating 55% of the time after a 24 hour response time). Approximately 64,000 bbls of oil escape, of which 18,500 bbls (in the form of 74,200 bbls of emulsion) could come ashore. The remainder (38,500 bbl) evaporate or naturally disperse offshore.

FIGURE 10 - POSSIBLE SHORELINE OILING FROM A 5000 BOPD BLOWOUT DURING SUMMER

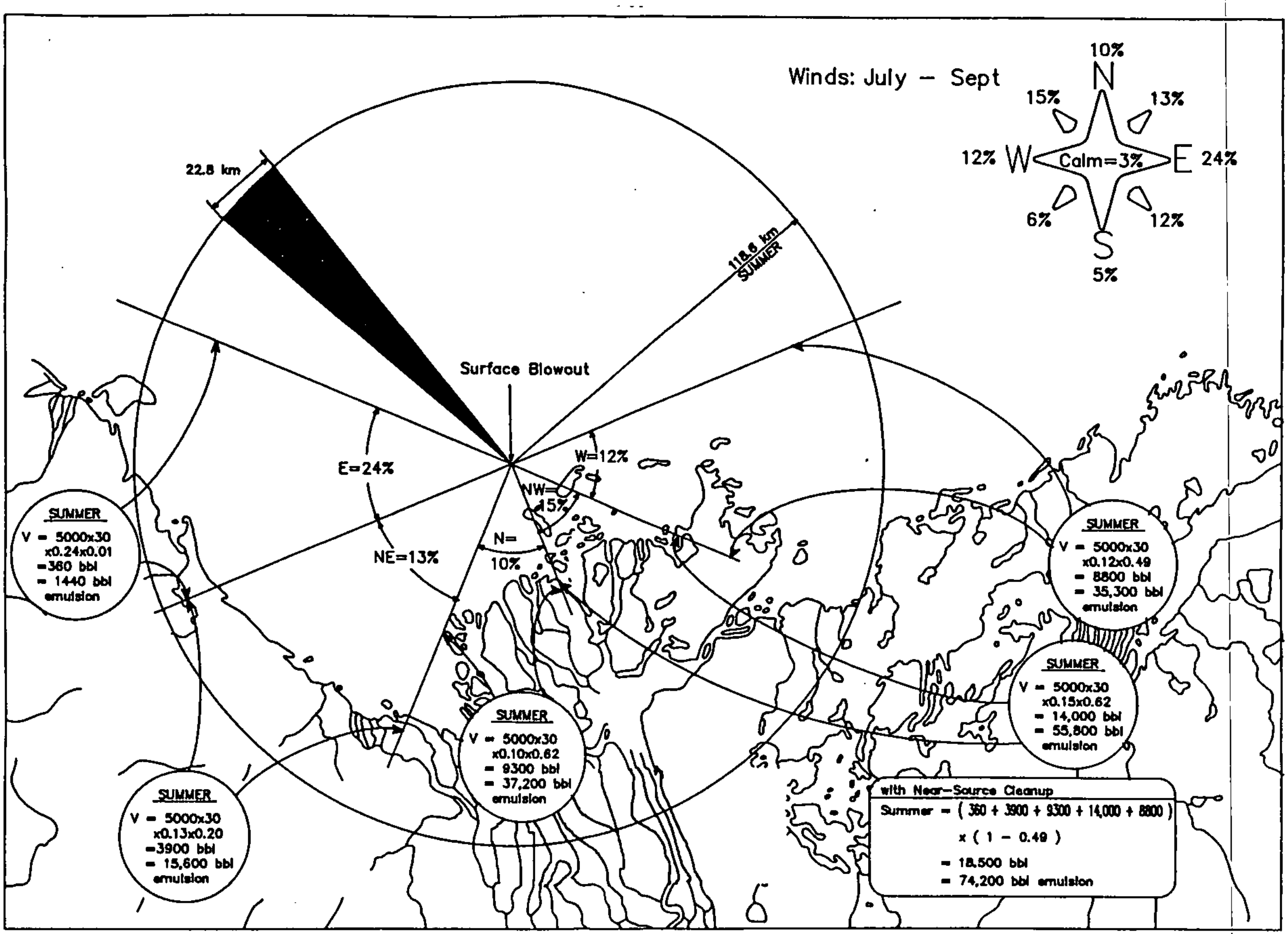


TABLE 16

Summary of Ultimate Oil Fates with no Cleanup for Above-Sea Blowout Scenario in Summer

Blowout	Duration (days)	Season	Oil Released (bbl)	Oil[a] Evaporated (bbl/%)	Oil Dispersed[a,c] Naturally (bbl/%)	Oil on[b] Shore (bbl/%)	Oil in Ice (bbl/%)
5000 BOPD	30	Aug 1 - Aug 31 (summer x 30 days)	150,000	69,000/46	45,000/30	36,000/24[b]	0/0

a. amounts evaporated and dispersed over the lifetime of the slick
b. in the form of 145,000 bbls of emulsion
c. includes dispersion of the final 1% of the slick remaining; calculated by subtracting volume on shore from volume dispersed naturally if no shoreline contacted

TABLE 17

Summary of Open Water Near-Source Cleanup Using Beaufort Sea Co-op Resources Above-Sea Blowout in Summer

Blowout Rate	Duration (days)	Season	Oil Released (bbl)	Oil Initially Evaporated (bbl/%)	Recovery (bbl/%)	Oil Removed Burning (bbl/%)	Oil Remaining (bbl/%)
5000 BOPD	30	summer open water	150,000	12,000/8	74,000/49[b]	0/0[b]	64,000[a]

a. 18,500 bbls of oil (74,200 bbl of emulsion) may come ashore

b. either containment and recovery or containment and burning could be used to remove 74,000 bbls.

The very high oil removal efficiency attributed to near-source countermeasures for this scenario is a function of:

i) the fact that the oil slick is thick, narrow and relatively non-viscous near source;
ii) the fact that sea states in the Southern Beaufort Sea are relatively calm; and,
iii) the long daylight hours available during summer.

11.4.2 Above-Sea Blowout: Winter Landfast Ice Conditions

The same blowout as described immediately above is presumed to occur on January 1. The blowout lasts for 100 days until killed by a relief well on April 10.

11.4.2.1 Near-Source Oil Behaviour for Winter, Above-Sea Blowout

The high velocity gas exiting the pipe atomizes the oil into droplets which subsequently "rain" down on the snow-covered island surface between 25 and 57 m downwind of the rig. Only about 0.5% of the oil evaporates in the extreme cold; the fresh oil hitting the snow has a viscosity of 2200 cp at the -24°C temperature assumed. Assuming that the wind blows constantly from one direction for 24 hours, 4975 bbls of oil per day of oil are sprayed onto the snow 5 m wide starting 25 m out from the rig and 12 m wide ending 57 m from the rig, an area of 280 m^2. This oil spreads to an equilibrium thickness of 7 cm (for the roughness of smooth sea ice or the island's frozen surface) and saturates 18 cm of snow. This would increase the daily oiled area from 280 m^2 to 11,300 m^2 on smooth surfaces. Should this oil spreading beneath the snow encounter barriers, such as rubble fields or pressure ridges around the island's perimeter, it would flow onto and/or around these features and fill any pockets available. If the oil should find its way into a tidal crack it would fill the crack and then flow under the surrounding ice (the oil's density at ambient temperatures of -24°C - 971 kg/m^3, exceeds that of sea ice - 910 to 920 kg/m^3).

11.4.2.2 Ultimate Oil Fate (assuming no countermeasures) for Winter, Above-Sea Blowout

The ultimate distribution of the spilled oil depends to a great extent on the wind direction and the surrounding ice topography. For the purposes of this scenario, the ice conditions around the Netserk F-40 artificial island in the winter of 1975/76 as described by Gladwell (1977) were used. Figure 11 shows the locations of rough ice around the island in early April 1976. From the north to the south east (clockwise on the drawing) a zone of relatively smooth, refrozen rubble extended from the island's edge out 15-30 m to 3-4 m ridges; at the ramp the width of this smooth zone had shrunk to zero. From the southeast (the access ramp) to the south-west (the flare tank) 3-6 m pileups and ridges existed adjacent to the islands edge. From the southwest to the north east, there was an area of relatively smooth refrozen rubble extending 15 - 30 m from the island's edge to the beginning of a large zone of 6 - 10 m high pileups and ridges. From the north-east to the north the zone of 6 m high pileups was within 6 m of the island's edge.

Based on winter wind direction frequencies (D.F. Dickins et al. 1987) over the 100-day period, 8% of the oil would be sprayed to the south of the rig; 17% to the south-west; 22% to the west; 12% to the north-west; 6% to the north; 7% to the north-east; 14% to the east; and 12% to the southeast. About 2% of the oil would fall around the rig during calm periods.

Figure 12 illustrates the possible distribution of the oil after April 1.

The surface of the island is covered with an average 7 cm of oil covered by snow (accounting for 31,000 bbls of oil). The zone of refrozen rubble from the ramp counterclockwise to the flare contains 9000 bbls of snow-covered oil with an average thickness of 15 cm. The ridges and pileups surrounding the island and extending to the north-east contain 225,000 bbls of snow-covered oil in pools and refrozen cracks with an average coverage of 30 cm of oil. Much of this oil has flowed and pooled inside ridge and pileup sails. From the north clockwise to the south west, the oil reached the tidal crack and spread outwards beneath the ice. With an assumed under-ice coverage of 30 cm (the oil slowly flows under the ice and is continuously frozen in) another 225,000 bbls of oil are encapsulated under the ice. The remaining 10,000 bbls of oil (to bring the total to 500,000 bbls or 5000 BOPD x 100 days) evaporate either during the time when the oil is sprayed into the air (2500 bbls = 0.5%) or as it evaporates slowly from beneath the snow (7500 bbls = 1.5%).

In late May or early June, when the spring melt begins, the oil/snow mixture on the surface of the island would melt and the oil would flow off the island onto, into and under the surrounding ice. By mid-to-late-June the oil encapsulated under the ice would have migrated to the surface to collect in very large, thick melt pools on the surface. Over the period of 4 weeks the oil would lose an additional 11% of its volume to evaporation. During breakup, the oil on melt pools would be released onto water as the ice rots. A considerable volume of weathered oil (some 200,000 bbls) would be released over a period of a few days, causing a large, thick slick.

The oil contained in ridges and pileups would be released more slowly, as these ice features would likely rot in place, but still, large amounts of oil would be released onto the surrounding water.

11.4.2.3 Likely Effectiveness of Countermeasures for Winter, Above-Surface Blowout

It is assumed that, until the blowout is killed, no countermeasures operations are undertaken near the well site for safety reasons, other than to build ice roads for access.

Once the well is killed, the first countermeasure undertaken would be to mechanically and manually scrape oiled snow from the island surface and the ramp. The recovered oil/snow would be transported to a nearby site and burned. This would be accomplished by placing the oiled snow onto doughnut-shaped piles and igniting the centre. As the oil burns in the middle the heat of the fire melts the snow in the surrounding inside walls of the doughnut releasing more oil to flow into the middle and fuel the fire. A combustion oil removal efficiency of 98% could be expected resulting in the removal of 30,000 bbls of oil; the 2000 bbls of viscous, tarry residue generated by this operation could be recovered for subsequent disposal.

The next step would be dismantling and removing the rig, camp and support facilities from the island in preparation for in-situ burning operations around the island.

Because of the rough ice around the island, attempts to remove oil prior to the commencement of melt would be highly inefficient. During the interim period, an ice coring program would be undertaken to delineate the extent of under-ice oiling. Once this is known, fire-containment boom could be slotted into the ice in a continuous circle around the contaminated area. Based on the oil distribution shown on Figure 12 about 3000 m would be required.

As the oil appears on the ice surface, it could be burned. Because of the high concentrations of oil under the ice and in the relatively smooth area between the island and the pileups, at least 95% of this oil could be burned over the 4-6 week melt. This would remove some 198,000 bbls of oil and leave some 9000 bbls of viscous, tarry burn residue behind.

As the same time, oil would be burned as it appeared in the rubble field to the north-east of the island. It is assumed that prior to breakup, 2/3 of the oil in the rough ice is released and burned, accounting for the removal of 127,000 bbl of weathered oil and generating 7000 bbls of burn residue.

After breakup, it is further assumed that the ice pileups north-east of the island remain behind to rot in place and slowly release an additional 67,000 bbls of weathered oil. Further assuming that containment and recovery or containment and burning operations around the melting rough ice are constrained by waves, nighttime, fog, etc. as they are during offshore countermeasures operations, about 55% of this oil (36,000 bbls) could be removed leaving 31,000 bbls to further evaporate, naturally disperse, emulsify. No shoreline impact is expected because the oil is released during breakup and moves offshore with the ice. Table 17 shows a summary of the cleanup effectiveness estimated for the winter above sea blowout.

TABLE 18

Summary of Cleanup for Winter Above-Sea Blowout

Blowout	Duration (days)	Season	Oil Released (bbl)	Oil Evaporated (bbl/%)	Recovery (bbl/%)	Oil Removed Burning (bbl/%)	Oil Remaining (bbl/%)
5000 BOPD	100	winter	500,000	10,000/2[a]	0/0	0/0	490,000/98[b]
		after kill	--	--	2000/0.4	30,000/6	458,000/92[c]
		melt	--	50,000/10[d]	--	325,000/65[d]	83,000/17[e]
		open water	--	--	18,000/4[f]	19,000/4[f]	47,000/9[g]

a. amounts evaporated as spray and from beneath snow over winter

b. under snow on and around island and under ice around island

c. amount remaining after cleaning island surface

d. amounts evaporated and burned during melt

e. includes 67,000 bbls of weathered oil in pileups and 16,000 bbls of burn residue

f. oil removed by offshore countermeasures equipment around pileups; dispersants not effective due to weathered oil viscosity

g. includes 31,000 bbls of weathered oil escaping countermeasures and 16,000 bbls of burn residue; some of which may come ashore

11.5 COSTS FOR OFFSHORE, NEAR-SOURCE CLEANUP

The following estimates the requirements and costs for the specific open-water blowout examples.

11.5.1 Sub-Sea Blowout in Summer Open-Water Conditions

This hypothetical 10,000 BOPD blowout lasts 45 days and involves the deployment of the Co-op's Response Barge, the combination conventional/fire containment/fire proof boom, an additional containment recovery system and, as such, temporary offshore storage for recovered oil.

The following vessels and personnel would be required to mount the prescribed near-source countermeasures:

1 Class 3 or 4 icebreaker
3 Class 2 supply vessels
3 Home Trade II vessels or tugs
1 Home Trade II tug
2 10,000 ton barges
1 600 ton barge
62 mgmt., supervisors and operators offshore
66 mgmt., pilots and base support staff onshore
20 x 737 flights and 10 Hercules C-130 flights

The cost of this operation, over a 45 day period, is estimated below.

$$C_{op,off} = 45\ (\$97,400 + \$47,000 + \$65,500 + \$40,500 + \$75,700) + \$500,000 = \$15,174,500$$

Warmup/Shutdown

$$C_{wrmp,off} = \$15,174,500\ (14/45) = \$4,565,400$$

Capital Costs

$$C_{cap,off} = \$1,600,000 + \$1,000,000 + \$2,500,000 + \$1,000,000 = \$6,100,000$$

TOTAL

$$C_{total,off} = \$15,174,500 + \$4,565,400 + \$6,100,000 = \$25,839,900 \text{ or } \$26,000,000$$

11.5.2 Late-Season Sub-Sea Blowout

The response to this hypothetical blowout is identical to the one discussed above except that the open-water response only lasts for 30 days until ice concentrations offshore reach 9^+ tenths. The same equipment and numbers of personnel as noted in the previous scenario are required. The operating cost (30 days + 14 days warmup/shutdown) is $14,000,000 and the capital cost is $6,100,000 for a total of approximately $20,000,000. Additional costs for the cleanup of oil released under ice from this scenario are given in Section 11.9.

11.5.3 Above-Sea Blowout in Summer, Open-Water Conditions

The response to this 30-day 5000 BOPD blowout involves deployment of either the Co-op Response Barge or the in-situ burning boom; the logistics and cost for the former system are estimated only.

The following vessels and personnel would be required to mount the prescribed near-source countermeasures:

2 Class 2 supply vessels (Note: the area in the scenario is too shallow for Class 3/4 icebreaker)

32 mgmt., supervisors and operators offshore

44 mgmt., pilots and extra base support staff onshore

13 x 737 flights & freight flights.

The cost of this operation, over the 30-day response, is estimated as:

<u>Operating Cost</u>

$$C_{op,off} = 30\ (\$97,400 + \$60,300) = \$4,731,000$$

<u>Warmup/Shutdown</u>

$$C_{wrmp,off} = \$4,731,000\ (14/30) = \$2,207,800$$

<u>Capital Costs</u>

$$C_{cap,off} = \$1,600,000$$

<u>TOTAL</u>

$$C_{total,off} = \$4,731,000 + \$2,207,800 + \$1,600,000 = \$8,538,800 \text{ or } \$9,000,000$$

11.6 COSTS FOR SHORELINE RESPONSE

The following estimates the costs for shoreline protection and cleanup using unit costs described in Chapter 5.

11.6.1 Sub-Sea Blowout in Summer, Open Water Conditions

This example (see Figure 6) involves the potential oiling of the entire coast from the Alaska/Yukon Border to Cape Dalhousie (although some oil could get past Cape Dalhousie, the volumes would be very small and for the purposes of this study are ignored).

Shoreline Protection

Along the hypothetically oiled coast there are 33 sites requiring the deployment of some 40,000 m of lightweight boom (Dickins et al. 1987) that could be accessed by small vessels (i.e., drawing up to 1 m) and a multitude of smaller protection sites that would require access with small boats with outboards. The seven available floatels (the other rigs are devoted to relief well operations or are unavailable in the time frame of the blowout) are not all immediately available. It is assumed that one floatel per week can be prepared, equipped, crewed and deployed to a section of shoreline. In order to take into account mobilization and demobilization costs, an additional 14 days of costs for each floatel is added. Over the 45 day period of this blowout, 6 floatels are assumed to be mobilized and deployed along the coastline. The estimated cost of this operation is $56,000,000 ($202,000 x (38 + 31 + 24 + 17 + 10 + 3) + 6 x 14 x $202,000 + $1,000,000 + 45 x ($10,500 + $15,000) + 2 x 38 x ($25,000 + 12,000) + 6 x $1,500,000).

Shoreline Cleanup

It is assumed that the shoreline cleanup operation involves areas along the entire coastline and lasts two seasons (112 days = 730/(25 x 3) + 225 x 0.5/(0.5 x 13) + 1470 x 0.5 x 0.5/(0.4 x 13)) using a total of 11 floatels and a floatel-sized crew at both Tuktoyaktuk and McKinley Bay. As estimated in Section 5.3 the cost is $308,000,000 (730 x 81,000 + 225 x 0.5 x $385,000 + 1470 x 0.5 x 0.5 x $505,000 + 112 x ($10,500 + $15,000) + $1,000,000 + 112 x 2 x ($25,000 + $12,000) + 13 x $640,000).

11.6.2 Sub-Sea Blowout in Fall

In this example, open water conditions last for only 15 days. Although it is impossible to quantify the potential differences in shoreline oiling between this scenario and the previous one, it is likely that the amounts of oil coming ashore would be less in fall (because of higher sea states and because shoreline oiling would be possible for only 15 days before fast ice begins to form). It is possible that the lengths of shoreline affected would also be considerably less. For the purposes of this scenario it is assumed that the volume of oil coming ashore in fall is 1/3 that predicted coming ashore in summer and the length of shoreline affected is 1/3 that predicted for summer conditions.

Shoreline Protection

Over the 15-day open water period, 2 floatels could be deployed. Including a 14 day allowance for mobilization and demobilization and one Class 2 supply vessel and one Twin Otter only for resupply, this effort would cost $10,000,000 ($202,000 x (8 + 1) + 2 x 7 x $202,000 + $1,000,000 + 15 x ($10,500 + $15,000) + 1 x 14 x ($25,000 + $12,000) + 2 x $1,500,000).

Shoreline Cleanup

The cleanup of the shoreline would commence the following year, involve 11 floatels and two floatel-sized crews at Tuktoyaktuk and McKinley Bay and last 38 days ((730/(3 x 2.5 x 13)) = 8 days for open coast beaches + (225 x 0.5/(3 x 0.5 x 3)) = 6 days for backshore beaches + (1470 x 0.5 x 0.5/(3 x 0.4 x 13)) = 24 days for mainland lagoon coasts. The cost for this cleanup effort is estimated as $89,000,000 (730 x $81,000/3 + 225 x 0.5 x $385,000/3 + 1470 x 0.5 x 0.5 x $505,000/3 + 38 x ($10,500 + $15,000) + $1,000,000 + 2 x 38 x ($25,000 + $12,000) + 13 x $640,000).

11.6.3 Above-Sea Blowout in Summer Open Water Conditions

This example (see Figure 10) involves the potential oiling of the Yukon coast (Alaska/Yukon border to Yukon/NWT border) and the Mackenzie Delta (Yukon/NWT border to Kittigazuit Bay).

Shoreline Protection

In the 30 day period that this blowout lasts, 4 floatels could be deployed. The cost of this operation is estimated at $31,000,000 ($202,000 x (23 + 16 + 9 + 2) + 4 x 14 x $202,000 + $1,000,000 + 30 x ($10,500 + $15,000) + 2 x 30 x ($25,000 + $12,000) + 4 x $1,500,000).

Shoreline Cleanup

The cleanup operations would involve areas along the Yukon coast and the Mackenzie Delta. Eleven floatels would be required (both Tuktoyaktuk and McKinley Bay are assumed to be too far from oiled shores to be useful as cleanup bases). The estimated time to clean the affected area is 80 days ((300 + 270)/(2.5 x 11) = 21 days for open coast beaches + (90 + 25) x 0.5/(0.5 x 11) = 11 days for backshore beaches + (20 x 820) x 0.5 x 0.5/(0.4 x 11) = 48 days for mainland lagoon coast) and would likely require operations over two seasons. This shoreline cleanup operation is estimated to cost $183,000,000 ((300 + 270) x $81,000 + (90 + 25) x 0.5 x $385,000 + (20 + 820) x 0.5 x 0.5 x $505,000 + 1,000,000 + 80 x ($10,500 + $15,000) + 80 x 2 x ($25,000 + $12,000) + 11 x $640,000).

11.6.4 Summary

The following summarizes the estimated shoreline protection and cleanup costs for the three examples that involve potential shoreline oiling.

Scenario	Est. Shoreline Protection Cost	Est. Shoreline Cleanup Cost
Sub-sea blowout in summer - 45 days	$56,000,000	$308,000,000
Sub-sea blowout in fall - 15 days	$10,000,000	$89,000,000
Above-sea blowout in summer - 30 days	$31,000,000	$183,000,000

11.7 EXAMPLE SURVEILLANCE COSTS

11.7.1 Sub-Sea Blowout in Summer Open Water Conditions

This example would require 45 days of surveillance and monitoring offshore and nearshore and 157 days (45 + 112) of shoreline surveillance and assessment. This is estimated to cost $10,000,000 (45 x $51,600 + 157 x ($40,100 + $11,000)).

11.7.2 Late-Season Sub-Sea Blowout

This example would require: 15 days of open-water surveillance and monitoring offshore and nearshore; 50 days of fall freeze-up surveillance and monitoring offshore and nearshore; the purchase of 25 Argos buoys and their tracking for 200 days; 10 weeks of SLAR overflights (4 in fall, 6 in spring); 8 weeks of CCRS Falcon jet time; 42 days of operational support for in-situ burning in spring; and, 53 days (15 + 38) of shoreline surveillance and assessment. This effort is estimated to cost $8,000,000 (15 x $51,600 + 50 x $16,000 + $100,000 + 200 x $1000 + 10 x $50,000 + 8 x $100,000 + 42 x $48,000 + 42 x 8 x $200 + 53 x $40,100 + 53 x $11,000).

11.7.3 Above-Sea Blowout in Summer, Open Water Conditions

This example would require 30 days of surveillance and monitoring offshore and nearshore and 110 days (30 + 80) of shoreline surveillance and assessment estimated to cost \$7,000,000 (30 x \$51,600 + 110 x \$40,100 + 110 x \$11,000).

11.7.4 Above-Sea Blowout in Winter

Since the only surveillance and monitoring activities associated with this blowout scenario are the coring of holes in the ice the cost of this activity has been included in the landfast ice cleanup section (Section 11.9).

11.8 EXAMPLE DISPOSAL COSTS

11.8.1 Sub-Sea Blowout in Summer, Open Water Conditions

In this example, the average oil recovery rate is 2500 bbl/day ((76,000 + 36,000)/45), far below the 4100 BOPD capacity of the Co-op Barge's flare system; no additional offshore disposal capacity is required.

This example involves 8625 m^3 of beached oil generating 216,000 m^3 of sediment for disposal (a pile 210 m square and 5 m high).

The example also involves the use of 13 floatels for 18 days on backshore beaches and 71 days on mainland lagoon beaches. The disposal operations associated with this scenario are estimated to cost \$49,000,000 (216,000 x 60 + 5 x \$2,000,000 + 5 x 180 x \$13,300 + 1 x \$16,000 x 180 + 13 x 18 x \$3500 + 13 x 71 x \$7000 + 13 x (\$60,000 + \$260,000)).

11.8.2 Sub-Sea Blowout in Fall

As with the previous example, no additional offshore disposal is required. This situation is assumed to involve 1/3 the oil/emulsion coming ashore, thus the disposal cost for oiled beach sediment would be 1/3 that of the previous example, or $13,000,000. The scenario also calls for the use of 13 floatels for 6 days for backshore beaches and 24 days for mainland coast beaches with an estimated disposal cost of $7,000,000 (13 x 6 x $4500 + 13 x $60,000 + 13 x 24 x $7000 + 13 x $260,000) for a total disposal cost of $20,000,000.

11.8.3. Above-Sea Blowout in Summer

As with the previous examples, no additional disposal capacity is required offshore for this situation. In total, 2950 m^3 of oil are predicted to come ashore generating 74,000 m^3 of sediment for disposal. As well, the example involves 11 floatels cleaning backshore beaches for 11 days and mainland lagoon coasts for 48 days. The disposal costs associated with these operations would be $23,000,000 (2950 x $60 + 2 x $2,000,000 + 2 x 155 x $13,300 + 1 x 16,000 x 155 + 11 x 11 x $35,090 + 11 x 48 x $7000 + 11 x ($260,000 + $60,000)).

11.8.4 Above-Sea Blowout in Winter

This example does not involve shoreline oiling.

11.9 COSTS FOR SPRING IN-SITU BURNING

11.9.1 Costs for Late-Season Subsea Blowout

In this example, 4700 sorties are required to cover the 342 km^2 of oiled ice.

Coastal-Based Operations:

Using this approach, as many as 28 helicopters operating for 6 weeks from 14 coastal bases would be required. This operation is estimated to cost $83,000,0000 (14 x (42 + 28) x $82,220 + 14 x $100,000 + 14 x $40,000).

Icebreaker Based Operations:

In this case the 4700 sorties could be accomplished (with a minimum of 330 flying hours in 6 weeks) with 15 helicopters flying one hour turnaround missions. Four icebreaker-units would be required for 6 weeks to accomplish this, with an estimated cost of $55,000,000 (4 x 42 x $274,000 + 4 x (14 + 14 + 14) x $50,000 + 4 x $80,000).

11.10 COSTS FOR THE CLEANUP ON LANDFAST ICE

The winter above-sea blowout response scenario lasting 140 days involves:

- 7 ha of oily snow on the island surface
- 13 ha of oil and oil/snow mixture on rough ice
- 12 ha of oil under ice

at a location off the Mackenzie Delta requiring some 100 km of ice road from the Inuvik/Tuktoyaktuk ice road. After breakup, 2 weeks of offshore open-water cleanup are used to recover oil seeping from grounded rubble.

The estimated cost of the cleanup for this scenario is:

$$C_{Indfst,melt} = 100 \times \$2000 + 2 \times (13 + 12) \times \$2100 + 7/2.5 \times (\$7300 + \$9100) + (3000/100) \times \$41,200 + 42 \times 16,600 + \$20,000 + 13 \times 12 \times \$1500/2 + 7 \times \$4700/0.5 + \$5000 + 14 \times 4200/0.5 + \$60,000 = \$2,571,270$$

$$C_{Indfst,brkup} = (14 + 14) \times \$97,400 = \$2,727,200$$

$$C_{Indfst,support} = 140 \times \$39,000 = \$5,474,000$$

TOTAL

$$C_{Indfst,tot} = \$2,571,270 + \$2,727,200 + \$5,474,000 = \$11,000,000$$

11.11 SUMMARY

Table 19 summarizes the volumes of oil spilled, recovered, dissipated and on shorelines for the four scenarios and shows the respective costs for each scenario.

Table 19

Scenario Summary

SCENARIO	VOLUME OF OIL (bbl)				ESTIMATED COST ($ millions) FOR							
	Released	Removed	Dissipated Naturally	On Shore	Offshore Cleanup	Shoreline Protection	Shoreline Cleanup	Surveillance & Monitoring	Disposal	Spring In-situ Burning	Landfast Ice Cleanup	Total
10,000 BOPD sub-sea blowout in open water for 45 days	450,000	192,000	204,000	54,000	26	56	308	10	49	0	0	449
10,000 BOPD late-season blowout for 65 days	650,000	152,000	480,000	18,000	20	10	89	8	20	83/55**	0	230
5000 BOPD island blowout in open water for 30 days	150,000	74,000	57,000	18,500	9	31	183	7	23	0	0	253
5000 BOPD island blowout in landfast ice for 100 days	500,000	394,000	106,000	0*	0	0	0	0	0	0	11	11

* assumed
** coastal-based/icebreaker-based

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13. ACRONYMS

AFE	authorization for expenditure - drilling budget
ATL	Arctic Transportation Ltd.
BOP	blowout preventer
BOPD	barrels of oil per day
BSOSC	Beaufort Sea Oil Spill Cooperative
CCG	Canadian Coast Guard
CCRS	Canadian Centre for Remote Sensing
FEL	front end loader
MODU	mobil offshore drilling unit
NTCL	Northern Transportation Co. Ltd.
SSDC	Steel Sided Drilling Caison (Canmar)