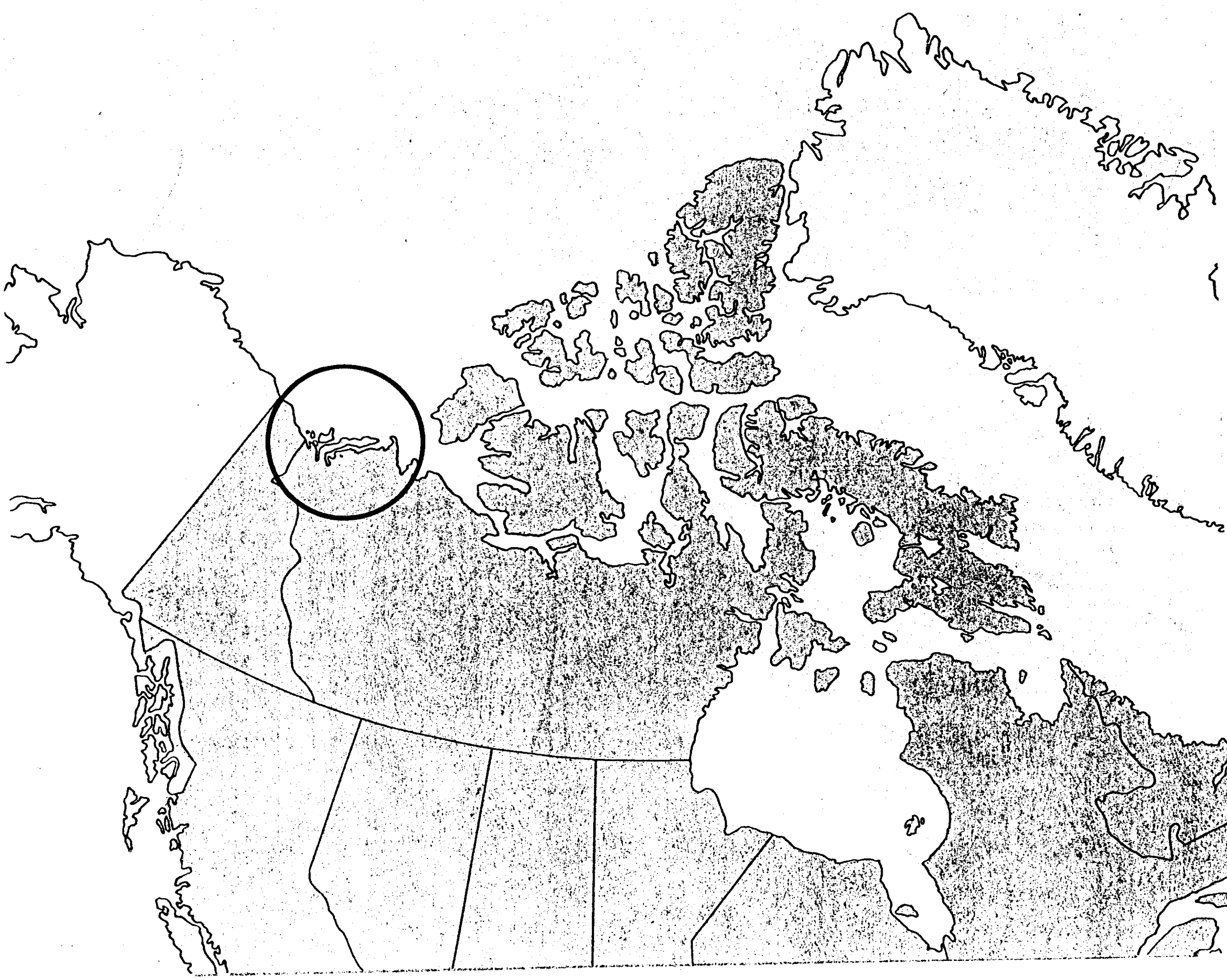
Hydrocarbon Development In The Beaufort Sea - Mackenzie Delta Region



ENVIRONMENTAL IMPACT STATEMENT

1982

VOLUME 6 ACCIDENTAL SPILLS

Complimentary / Complimentaire

ENVIRONMENTAL IMPACT STATEMENT

FOR

HYDROCARBON DEVELOPMENT

IN THE

BEAUFORT SEA - MACKENZIE DELTA REGION

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BEAUFORT SEA-MACKENZIE DELTA ENVIRONMENTAL IMPACT STATEMENT

The Beaufort Sea Production Environmental Impact Statement
was prepared by
Dome Petroleum Limited,
Esso Resources Canada Limited
and
Gulf Canada Resources Inc.
on behalf of all land-holders in the
Beaufort Sea-Mackenzie Delta region.

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ENVIRONMENTAL IMPACT STATEMENT

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INTRODUCTION

The purpose of this volume of the Environmental Impact Statement is to describe the potential for and the fate, cleanup and effects of accidental spills of oil and hazardous materials. The geographical regions addressed in this volume are within Canadian lands and waters north of 60°N latitude, and include the Beaufort Sea-Mackenzie Delta region, the Mackenzie Valley and the Northwest Passage, the regions potentially involved in hydrocarbon development (Beaufort Sea Environmental Assessment Panel, 1982). In accordance with the EARP guidelines, the information presented has been summarized as much as practical, while recognizing the importance of providing sufficient information to permit a satisfactory evaluation to be completed.

Volume 6 was prepared by the proponents with the assistance of several consulting firms. Major external contributors included:

S. L. Ross Environmental Research Ltd. -
Preliminary Draft and Technical Advice

Arctic Sciences Ltd. -
Oil Spill Computer Modelling
Oil Spill Modelling Data Base

Meteorological Environmental Planning Ltd. -
Beaufort Sea Wind Data

Woodward-Clyde Consultants -
Shoreline Countermeasures

Intera Environmental Consultants -
Remote Sensing

ESL Environmental Sciences Limited
Biological Effects of Oil Spills
Impacts of Oil Spills in the Beaufort Sea

LGL Limited -
Impacts of Oil Spills in Lancaster Sound

In-house expertise, the majority of the text, and project coordination was provided by engineers, scientists and specialists from Dome Petroleum Limited. Esso Resources Canada Limited and Gulf Canada Resources Inc. personnel provided technical and editorial input.

The focus in this volume is on large crude oil spills, as these are perceived to be a potential major impact associated with the proposed development. Smaller, minor spills of other refined and waste oils and spills of hazardous materials are also discussed at the end of the volume.

Background

Since 1973 much research and development work has been done in Canada to understand and deal with major oil spills in Canada's Arctic. The first major undertaking was the Beaufort Sea Project (Milne and Smiley, 1975), a $12 million environmental assessment of proposed exploration drilling programs in the Beaufort Sea. One of the major issues addressed in this project was that of the fate, effects and countermeasures (cleanup) techniques for a subsea oil well blowout. This prompted research and development projects by both industry and government. The purpose of these projects was to develop spill countermeasures for the Beaufort Sea and to ensure that appropriate equipment was available to respond to spills.

Close coordination and cooperation on these projects has been ensured by joint industry-government working groups set up by the Arctic Petroleum Operators Association (APOA) and Environment Canada's Arctic Marine Oil Spill Program (AMOP).

AMOP was set up in 1976 with a budget of $7 million, with the mandate to research and develop Arctic oil spill countermeasures. In 1980 the Canadian offshore oil industry set up the Canadian Offshore Oil Spill Research Association (COOSRA) to fund research and development of Arctic spill countermeasures.

The total investment in Arctic spill research and development to date is approximately $35 million. The results of this research and development and their application to actual spills, form the basis for this volume.

Scope

Chapter 1 of this volume is a brief review of the industrial setting of the proposal. A brief history of Beaufort Sea oil and gas exploration is given, followed by a discussion of some of the proposed development, production and transportation of crude oil. The chapter ends with a summary of the environmental conditions of the Arctic, as they relate to oil spills.

Chapter 2 presents, in detail, the probabilities of spills from the proposed systems and the steps that will be taken by the proponents to ensure that the occurrence and effects of spills are minimized. The chapter begins with a discussion of the worldwide sources of oil pollution. This is followed by sections on historical oil spills from tankers, on studies carried out by the proponents on the causes and consequences of these spills, and finally the spill safety features proposed for an Arctic oil tanker and the effectiveness of the features.

The history of spills from worldwide offshore oil and gas operations is addressed next. Data are presented on the rates, causes and consequences of accidental releases of hydrocarbons such as crude oil, refined products and natural gas. The chapter concludes with recommendations on how to reduce the rate and consequences of potential accidents of a similar nature as they relate to the Beaufort Sea Development proposal.

Chapter 3 deals with the behaviour of spilled oil in an Arctic marine environment. The expected behaviour of oil on water and in the various kinds of ice is documented. The behaviour of a subsea oil well blowout is addressed specifically. This chapter concludes with an analysis of Beaufort Sea crude oil and a discussion of how this oil could be expected to behave if spilled.

Chapter 4 provides a summary of the biological effects of past oil spills on plants, animals, fish and birds. Case histories of past spills and laboratory studies of the effects of oil on each species are used to postulate what the impact of a major spill in the Beaufort Sea might be. The times required for recovery from the effects of oil are also estimated. These projected impacts are used in Chapter 6 to estimate the biological consequences of several hypothetical large oil spills from blowouts, and tanker accidents.

Chapter 5 begins with a discussion of the basics of oil spill cleanup. This is followed by a description of the use and limitations of available oil spill countermeasures equipment. Sub-sections describe techniques to be used in open water; in ice conditions; for monitoring and surveillance and for shoreline protection, cleanup and restoration. A short discussion of contingency plans follows. The chapter concludes with an abstract of the countermeasures equipment still at the research and development stage which shows promise for Arctic spill cleanup.

Chapter 6 is the most important chapter of the volume. It is here that all the information presented in previous chapters is used to describe the behaviour, fate, effects and countermeasures for ten hypothetical major marine crude oil spills.

The ten major spills are formulated as case-studies and comprise oil spills from two marine blowouts, one marine storage facility spill, and seven tanker accidents. These are presented as follows: The circumstances surrounding the hypothetical accidents are described, followed by descriptions of the fate of the oil spills assuming no countermeasures are undertaken. This includes computer model predictions of the movement of the oil on water, the amounts of oil lost to evaporation, dissolution and natural dispersion, and the location, timing and volume of oil that reaches the shores. This is followed by a summary of the predicted biological effects (for four of the key hypothetical spills) based on the computer model trajectories and available biological information. These predictions also assume that no countermeasures take place.

Each scenario concludes with a discussion of what countermeasures would be deployed to reduce the effects of the spill. The deployment of offshore equipment is covered as well as the potential use of *in situ* burning and chemical dispersants. Applicable shoreline protection, cleanup and restoration techniques are also discussed.

The application of oil spill countermeasures, in the case-studies described in Chapter 6, would in many cases reduce the predicted biological impacts; for example, if sensitive shoreline habitat can be protected and if much of the oil overwintering in sea ice can be burnt off. The circumstances governing the effectiveness of oil spill countermeasures, in real life situations, are so varied - weather, sea state, logistics -that estimates of effectiveness in terms of reducing the seriousness of the impact of oil on a particular wildlife species could be misleading. Rather, the approach in the case studies is to provide details on how biological impacts are estimated; then having given the reader information on countermeasures devices and how they are expected to improve, the reader is able to draw his or her own conclusions on their possible effectiveness in reducing or eliminating impacts on the species considered.

Chapter 7 covers hypothetical spills from both subsea and onland pipelines. Onland pipeline spills are addressed separately from offshore spills as the behaviour and cleanup of oil spilled on land is different than for oil on the sea.

The chapter begins with a description of the setting of the proposed pipeline and then discusses the risk of spills from overland pipelines and the prevention of these spills. The chapter ends with brief scenarios of hypothetical major spills, and includes descriptions of their fate, behaviour, effects and cleanup methodology.

Chapter 8 deals with minor spills - those which are generally small and individually have little environmental impact. The chapter begins with a history of minor spills in the Beaufort Sea region. This is followed by a presentation of the methods used to prevent minor spills. The chapter concludes with a discussion of countermeasures for minor spills.

Chapter 9 covers other environmental emergencies that may result from the Beaufort Sea Development, specifically sour gas well blowouts and spills of chemicals determined to be hazardous. The countermeasures for these incidents are discussed.

This volume is a summary of the information and knowledge contained in a great many reports, papers and books. Many of these are in the public domain and are available from libraries across the country or from the government. Some, however, were proprietary industry studies done by the proponents or specifically prepared for the writing of this Environmental Impact Statement. For this reason several works referenced in this volume have been reproduced as support documents for those readers wishing more technical information. These include the following:

- Oil Spill Computer Model Environmental Data Base (Marko, *et al.*, 1981)

- Oil Spill Computer Model Trajectories (Marko and Foster, 1981a and 1981b)

- Analysis of Beaufort Sea Crude Oil (Mackay, *et al.*, 1980)

- Arctic Tanker Risk Analysis (Rev. 1981) (Bercha and Associates, 1981)

- Arctic Tanker Oil Spill Analysis (DNV, 1979)

- Analysis of Accidents in Offshore Operations (Gulf, 1981)

- Prospectus on the Biological Effects of Oil Spills (Duval, *et al.*, 1981)

- Biological Impacts for Oil Spill Scenarios in the Beaufort Sea (ESL, 1982)

- Biological Impacts for a Tanker Collision in Lancaster Sound (LGL, 1982).

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CHAPTER 1

SETTING

1.1 INDUSTRIAL SETTING

This section presents a brief summary of the information contained in Volume 2 which describes the proposed hydrocarbon development. Exploration drilling for hydrocarbons began in the Beaufort Sea-Mackenzie Delta region in 1965 and has resulted in the drilling of about 100 onshore and 38 offshore wells (Volume 2). Of the latter, 23 have been drilled from 19 artificial islands and 15 from drillships. Since 1970 alone, seven offshore and six onshore discoveries have been made with the most significant oil finds occurring since 1979.

Artificial islands have been used as platforms for exploration drilling since 1973. Their construction has followed a logical and methodical development, beginning in shallow areas and progressing into greater water depths. This process has provided a sound basis for the design and operation of production islands in the Arctic.

Another phase of the exploration program began in 1976 with drillships in the Beaufort Sea. They are capable of operating in water depths ranging from 18 to 180 m and can maintain their position in 100% thin ice cover with support from icebreakers. Operating experience has been gained with each season.

The proposed development calls for conventional inland and marine facilities including well site clusters, flowlines, processing facilities and crude oil storage. Other facilities are being designed for the Arctic such as island production platforms, subsea flowlines, icebreaking tankers and pipelines. The alternatives for hydrocarbon transportation are described in Volume 2. A description is also included of the drilling and production systems and design features that relate directly to spill prevention.

The technologies that will be utilized to produce Beaufort Sea crude oil have been applied for many years. The spill prevention systems in particular, including well control practices, are well established. These systems become increasingly effective as knowledge continues to be gained on the geological structures being drilled so that the possibility of spills decreases.

One production platform concept is an integrated platform called the Arctic Production and Loading Atoll (APLA). It is depicted in Figure 1.1-1. The APLA would form a protected harbour and would be used by icebreaking tankers for loading oil. It would also house production, processing and storage units. Other variations of the APLA concept are described in Volume 2.

The proposed icebreaking tankers to be used to transfer crude oil to southern markets year-round, are an important transportation option. These would incorporate numerous spill prevention features, which are outlined in Chapter 2. The icebreaking tankers would be double-hulled, with a cargo capacity of 200,000 DWT (Dome, 1981a). The round trip distance of 12,800 km between the Beaufort Sea and east coast ports could be covered approximately 12 times per year by a single tanker, to deliver the equivalent of 6,000 m^3/day. Tanker shipment of crude oil to the west is also being considered over the long term.

An alternative proposal for moving crude oil south is a Mackenzie Valley pipeline. Spill prevention has been incorporated into its design, features of which are presented in Chapter 7. As proposed, the pipeline will traverse about 2,200 km and would connect North Point on Richards Island to Edmonton. The diameter of the proposed pipeline has yet to be finalized and could range from 33 to 115 cm in diameter (12 in. to 42 in.). The diameter chosen will depend, in part, on the rate at which oil reserves are proven in the Beaufort Region.

1.2 ENVIRONMENTAL SETTING

The selection of spill countermeasures and strategies is dictated by the environment in which a spill could occur. For the Beaufort Sea Production region, the environment is Arctic in nature, but in transportation corridors it becomes more temperate further south. Environments include those in a corridor down the Mackenzie River Valley for the pipeline option and those along tanker routes that traverse the Northwest Passage east to Baffin Bay and the Labrador Sea or alternatively west to the Chukchi and Bering seas. Figure 1.2-1 shows the production region and possible transportation routes. A detailed account of the entire environmental setting including the Arctic's marine and terrestrial environments is provided in Volumes 3A, 3B and 3C.

A brief discussion of the major factors on which the accident scenarios and countermeasures are based follows. Those environmental factors which have a direct bearing on the fate of spilled oil and its cleanup are ice conditions, oceanographic and meteorological conditions, hours of daylight and shoreline type. Hydrographic and coastal conditions constitute two other areas of significance. Much of this information has already been summarized for the Arctic with particular reference to oil spills. An atlas was compiled for Environment Canada in 1978 (Fenco &

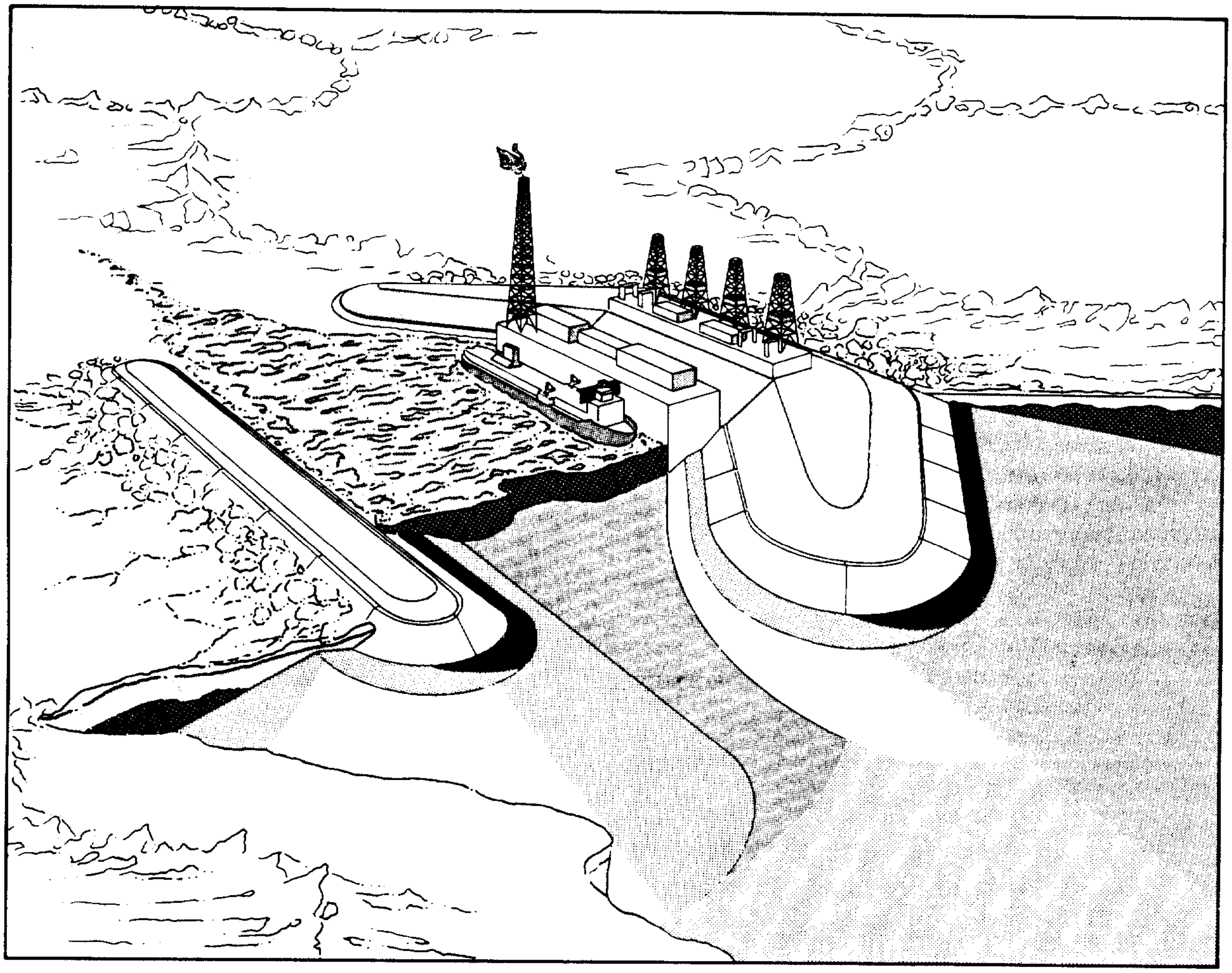

FIGURE 1.1-1 *The Arctic Production and Loading Atoll (APLA). The APLA is an integrated platform concept for medium depth waters. It would house drilling rigs, accommodation, processing and storage facilities. The inner harbour of the APLA would be used for loading tankers.*

Slaney, 1978). In addition to physical data, the atlas also includes maps and listings which portray the Arctic's wildlife and human communities. Manuals and atlases are available to assist the application of countermeasures, resources and manpower to the most important coastal stretches of the southern Beaufort Sea (Worbets, 1979). Shoreline protection and cleanup exercises and training programs have been conducted to ensure this information is properly utilized. Through the use of video tapes (Dome, 1980) and mapping techniques, other regions of the Arctic through which the proposed tankers could pass are being similarly addressed.

Lancaster Sound has also been recently studied and the physical, biological and sociological components have been mapped (Indian and Northern Affairs Canada, 1980). A review of the physical and biological environment of the Northwest Passage, including Lancaster Sound, is given in Volume 3B, and of the socio-economics of the Northwest Passage in Volume 5.

The remainder of this chapter is a summary of environmental factors that are fundamental to the design of spill countermeasures.

1.2.1 TEMPERATURE

Air temperatures vary widely throughout the Arctic ranging from higher than 30°C in summer to lower than -50°C in winter. In contrast, water temperatures during the year remain relatively constant near 0°C. Exceptions are during the summer months, when surface water temperatures in shallow coastal areas along the continental shelf can be higher, particularly where rivers enter the sea and in inland watercourses.

Temperature directly affects the physical properties of oil. The extreme cold has the most dramatic effect on spilled Beaufort crude, increasing its viscosity very quickly (Mackay *et al.,* 1980). Of all temperature-related considerations, perhaps the most significant is the selection of hardware that can function in sub-zero air temperatures.

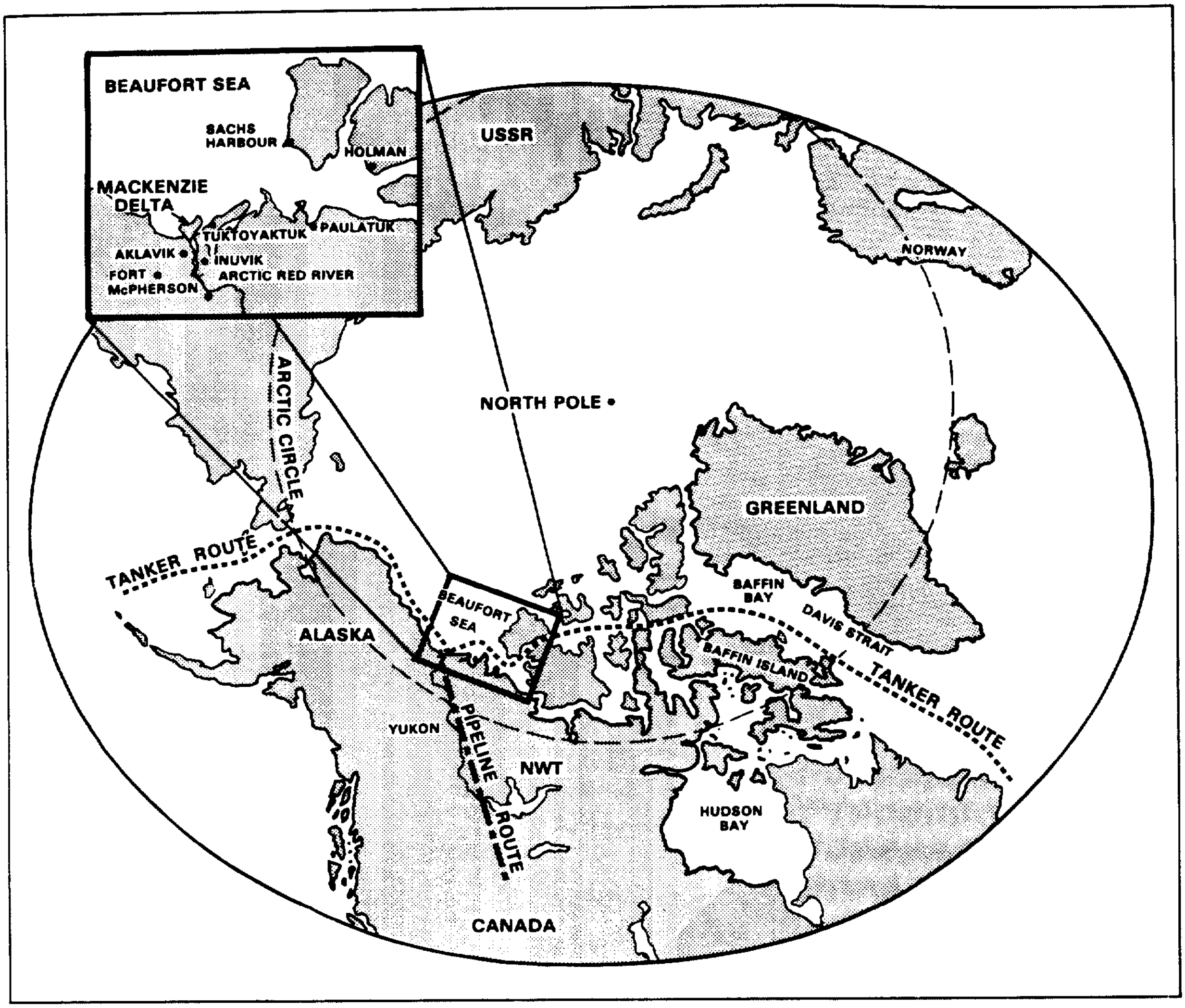

FIGURE 1.2-1 *Crude oil transportation routes from the Production Zone. Crude oil from the production zone in the Beaufort Sea-Mackenzie Delta region could be shipped to southern markets by either an eastern route through the Northwest Passage or by a western route north of Alaska and through the Bering Strait. Alternatively, or possibly in addition to tankers, oil could be transported overland to the south through a Mackenzie Valley pipeline.*

1.2.2 ICE CONDITIONS

Ice covers most of the Beaufort Sea, Northwest Passage and eastern Baffin Bay from November through June. During the remaining months, open water is present to some extent in the proposed production region, and along the proposed tanker routes. Conditions may differ substantially from year to year and as yet, predictions of expected ice cover concentrations remain imprecise.

In the Beaufort Sea, three ice regimes dominate in the winter (see Section 1.1, Volume 3A). These are: landfast ice, the outer edge of which usually coincides with the 18 to 20 m isobath; seasonal pack ice or transition zone ice in which first year ice predominates but includes multi-year floes and sometimes ice island fragments; and polar pack ice, composed mainly of multi-year ice, which over the longer term moves according to a clockwise gyral circulation. Figure 1.2-2 illustrates these winter ice zones in the Beaufort Sea. Most of the shearing between the moving polar pack and the landfast ice takes place in an active shear zone, essentially part of the transition zone.

In the Northwest Passage, concentrations of ice can be expected throughout the year, particularly in the west. In the eastern Arctic, and off the east coast icebergs can be present (see Section 1.1, Volume 3B).

It is important to understand how ice influences the behaviour of spilled oil. In general, sea ice will limit the spread of spilled oil depending on the ice concentration, and where there is landfast ice, oil on the sea cannot pollute the shores. Equally important, is that oil rising up under sea ice - which could happen from

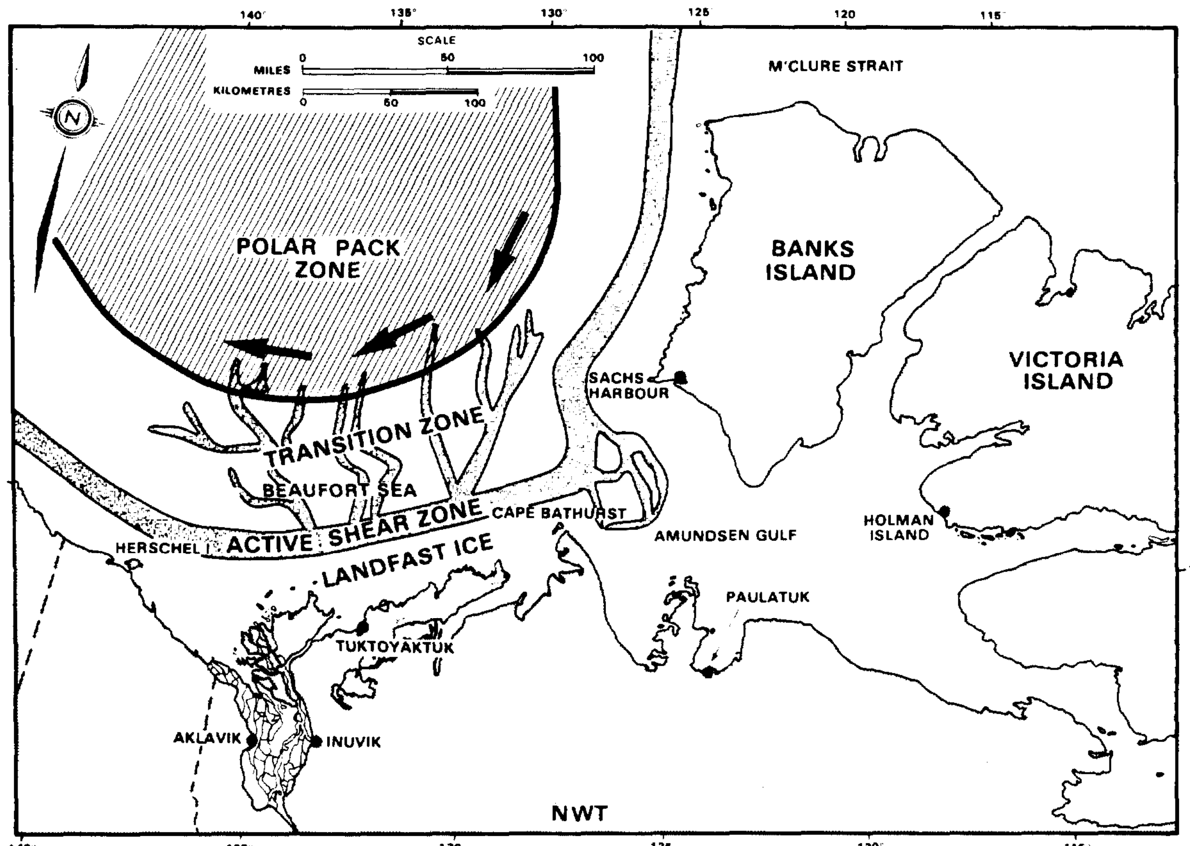

FIGURE 1.2-2 *Winter ice regimes in the Beaufort Sea. (Source: Kovacs and Mellor, 1974). Landfast ice generally extends seaward to the 20 m isobath in late winter. It is mostly first year ice which grows and expands seaward in winter and breaks up and melts in summer. The offshore polar pack, comprised mainly of multi-year ice, drifts westward at the southern rim of a clockwise gyre. The transition zone and the active shear zone includes various concentrations of multi-year and first year ice along with new ice and open water.*

a subsea pipeline break or a subsea oilwell blowout -will be frozen into the ice. This feature permits the oil to be easily burned in the spring when it migrates upward through the ice in a fresh state. These features will be described in more detail in Chapter 3.

1.2.3 CURRENTS, WAVES AND WINDS

Ocean current directions and speeds, wave heights and frequencies, and other oceanographic data have been compiled for portions of the Arctic, notably the southern Beaufort Sea and Lancaster Sound (Fenco & Slaney, 1978; Indian and Northern Affairs Canada, 1980; also see Volumes 3A and 3B). The physical oceanographic data base varies across the Canadian Arctic, being sparse in the western part of the Northwest Passage and relatively more dense in the southeastern Beaufort Sea and Lancaster Sound. Wind data are similarly distributed, with most marine wind observations being available in the Beaufort Sea and in the eastern Northwest Passage (Marko and Foster, 1981).

Ocean current and wind data are basic inputs to computer models used to forecast the drift of oil slicks. Such models are used as real-time response tools. In this volume, computer modelling is used in case studies of hypothetical oil spills to predict environmental impacts.

It is noteworthy that in the production region and in Parry Channel, low sea states are frequent enough to permit the use of conventional countermeasures systems a high percentage of the time.

1.2.4 HOURS OF DAYLIGHT

There are long periods of darkness during the winter months and extended hours of daylight in the summer. The darkness and cold of winter are compensated for by ice on the seas, which will contain and preserve spilled oil so that it can be dealt with in the spring; then during the summer months, the long days will provide extra time to undertake cleanup activities.

1.2.5 SHORELINE TYPE

Features unique to Arctic coasts are permafrost, ice-rich sediments and ice-push zones; they also have gravel, tundra, eroding cliffs, rocky bluffs, beaches and mudflats. The coastline varies much as it does in other more southerly regions.

The detail with which shorelines have been examined with respect to specific oil spill cleanup techniques varies across the Canadian Arctic. The southeastern Beaufort Sea coast has been examined in detail (Worbets, 1979) but less detail is available in Amundsen Gulf and along the Northwest Passage. The latter areas will be the subject of future research programs and are described in Volume 7 of the Environmental Impact Statement.

1.2.6 BIOLOGICAL FACTORS

The biological setting comprises an important part of spill response and planning. Chapter 4 of this volume reviews the effects of oil on marine and coastal biological communities. Potential biological impacts of hypothetical oil spills have been projected in specific accident case studies in Chapter 6. The biological resources at risk largely determine when and where spill response efforts are concentrated.

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CHAPTER 2

OCCURRENCE AND PREVENTION OF OIL SPILLS

The purposes of this chapter are to review the risks of major oil spills and, more importantly, to describe how oil spills can be prevented.

Although Chapter 6 describes ten separate hypothetical major oil spill accidents, there is no certainty implied that these or similar accidents will occur. By studying historical offshore accidents, the frequency of occurrence of different types can be determined and also what caused such accidents. Then measures can be devised to reduce the possibility of similar accidents in the future. It is these measures that the proponents are pledged to employ that will make every facet of development systems as safe as possible.

2.1 WORLD SOURCES OF OIL POLLUTION

An estimate of the oil discharged into the world's oceans annually, compiled by the U.S. National Academy of Sciences in 1972-3 (Wilson & Hunt, 1975; Butler, 1978a) is shown in Table 2.1-1. It can be seen that the total amount of oil from all sources is

TABLE 2.1-1

ESTIMATES OF THE OIL DISCHARGED ANNUALLY INTO THE WORLD'S OCEANS

Source	Input (million tonnes per annum)	%
Natural Seeps	0.6	9.8
Offshore production	0.08	1.3
Transportation		
LOT* Tankers	0.31	5.1
Non-LOT Tankers	0.77	12.6
Dry Docking	0.25	4.1
Terminal Operations	0.003	.05
Bilges Bunkering	0.5	8.2
Tanker Accidents	0.2	3.3
Non-tanker Accidents	0.1	1.7
Coastal Refineries	0.2	3.3
Atmosphere	0.6	9.8
Coastal Municipal Wastes	0.3	4.9
Coastal Non-refining, Industrial Waste	0.3	4.9
Urban Run-Off	0.3	4.9
River Run-Off	1.6	26.2
Total	6.113	100.00

*LOT = load on top.
Sources: Wilson and Hunt (1975), Butler (1978a).

about 6 million tonnes. Of this amount approximately 34% is attributed to tankers and other vessels. About 54% comes from non-marine operations such as industrial and petrochemical plants, refineries, and the disposal of automobile crankcase oil.

Since this study, the Inter-Government Maritime Consultative Organization (IMCO, 1981) has reported that the amount of oil entering the oceans annually from shipping operations has decreased by 30% from 1971 to 1981, even though the amount of oil being transported increased by 17%. One of the biggest reductions was in discharges from tank cleaning and ballast water.

Offshore oil and gas operations contribute about 1.3% of the total oil discharged, and tanker spills contribute about 3.3%. It is clear that accidental discharges from offshore production units and tankers, although potentially involving hundreds of thousands of tonnes of oil annually, represent a small fraction of the total amount of petroleum hydrocarbons entering the ocean from other sources. Nevertheless it is known that large oil well blowouts and tanker spills can cause environmental damage, and therefore are addressed.

Reported tanker spills greater than 20,000 tonnes since World War II are listed in Table 2.1-2. None were reported before 1967. Since 1967, thousands of tanker voyages involving billions of tonnes of oil have taken place around the world, and tens of thousands of wells have been drilled in the offshore regions. Yet only 39 large spills have occurred during this period (Butler, 1978b).

The largest spills from worldwide offshore oil and gas operations are listed in Table 2.1-3. Although fewer in number than large tanker spills the volume spilled is much greater.

In the remainder of Chapter 2 each potential source of major marine oil spills associated with Beaufort Sea oil production and transportation will be analyzed to determine possible causes and solutions.

2.2 OIL TANKERS

One method by which the proponents propose to deliver Beaufort oil to market is by using tankers. The present design calls for each oil tanker to be 390 m long, have a double hull of thick steel and be powered by a 150,000 hp plant. These vessels could independently navigate Arctic waters on a year-round basis.

TABLE 2.1-2

THE 33 LARGEST OIL SPILLS FROM TANKERS 1942-1978

Tankers Name	Location	Approximate Spill Size (Tonnes)	Year
Amoco Cadiz	France	220,000	1978
Torrey Canyon	England	117,000	1967
Sea Star	Gulf of Omen	115,000	1972
Othello	Baltic Sea	100,000	1970
Hawaiian Patriot	Pacific Ocean	99,000	1977
Urquiola	Spain	88,000	1976
Jakob Maersk	Portugal	84,000	1975
Wafra	S. Africa	63,000	1971
Metula	Straits of Magellan	51,500	1974
Ennerdale	Indian Ocean (Seychelles)	41,000	1970
World Glory	Durban, S. Africa	45,600	1968
(unidentified)	SE Atlantic	37,000	1971
Napier	SE Pacific	36,000	1973
Texas Oklahoma	NW Atlantic	35,000	1971
Trader	Mediterranean	34,000	1972
St. Peter	SE Pacific	34,000	1976
Irene's Challenge	Pacific	34,000	1977
(unidentified)	Pacific	30,000	1972
Golden Drake	NW Atlantic	31,000	1972
Chryssi	NW Atlantic	31,000	1970
Keo	NW Atlantic	30,000	1969
Pacocean	NW Atlantic	30,000	1969
Caribbean Sea	E. Pacific	30,000	1977
(unidentified)	NW Atlantic	30,000	1972
(unidentified)	NW Atlantic	29,000	1970
Grand Zenith	NW Atlantic	29,000	1976
Cretan Star	Indian Ocean	29,000	1976
(unidentified)	Indian Ocean	28,000	1969
Argo Merchant	Cape Cod (USA)	30,000	1976
(unidentified)	NW Atlantic	28,000	1969
(unidentified)	NW Atlantic	28,000	1971
Giuseppe Guiletti	NW Atlantic	26,000	1972
Venoil/Venpet	S. Africa	24,000	1977

Source: Butler (1978b).

TABLE 2.1-3

SIX LARGEST OIL SPILLS FROM OFFSHORE OIL & GAS OPERATIONS (1967-1980)

Area	Type Spill	Approximate Spill Size (Tonnes)	Year
Mexico	Blowout	430,000	1979
Dubai	Blowout	290,000	1973
France	Blowout	71,000	1971
Nigeria	Blowout	29,000	1980
U.S.	Pipeline	23,000	1967
Norway	Blowout	23,000	1977

Source: Gulf (1981).

The design philosophy is "that a single mistake in design, construction, operation, or navigation will not be allowed to develop into a disaster, and that even after a series of mistakes there will still be an adequate margin of safety left." (Johansson and Stubbs, 1980).

Before discussing the Arctic tanker, it is useful to review why conventional tankers have spills so as to highlight the proposed spill prevention features which will be incorporated into future Arctic tankers.

2.2.1 TANKER ACCIDENT ANALYSIS

In the four year period 1969 to 1973 there were over 3,000 recorded accidents of tankships, 51 of which discharged a total of over 770,000 tons of oil into the sea (Butler, 1978a).

2.2.1.1 The Nature of Tanker Accidents

Numerous studies and analyses of tanker accidents have demonstrated that at least 75% of them have been due to human operating errors (Anon, 1977; Det Norske Veritas, 1979; Devanney *et al.*, 1979; Van Poelgeest, 1978; and Wheatley, 1972). In a recent study involving ships larger than 10,000 DWT and spills greater than 200 tons (180 tonnes), one of the world's leading ship classification societies, Norway's Det Norske Veritas (DNV, 1979), analyzed 18 major tanker accidents from 1968 to 1978. They found that 11 of them were the direct result of human action and in three of them the initial cause was a mechanical failure but a major accident could have been avoided by proper corrective action. In three of the remaining four accidents involving structural failures, it was concluded that the ships were being operated in an inappropriate manner. Only one case was found where human action or inaction did not appear to have any influence on the disaster.

Most accidents involved groundings and took place in restricted waters only a few miles from land (DNV, 1979; Devanney *et al.*, 1979). The overwhelming majority of groundings occurred as a result of navigational and conning (steering) errors. For the cases involving navigational errors, either the vessel crew was using out-of-date charts or misreading the chart. For the conning-error cases, the crew knew where it was but still got into trouble due to misjudgement of turning radius, current or wind drift, or current shear. In a large number of cases grounding occurred either while the vessel was slowing to pick up, or drop off, the pilot, or immediately upon resumption of its course after doing so. Most groundings occurred at night with the tanker in a loaded condition. Visibility was generally good.

Most collisions, on the other hand, occurred during periods of poor visibility. In a study of 174 collisions in the Straits of Dover, it was found that 82% of the collisions occurred in thick fog (Wheatley, 1972). The colliding ship's crews were usually aware of each others presence well before the collision took place, in plenty of time to avoid an incident by taking the appropriate evasive action. The vessel collision problem relates to misinterpreted rules of the road, poorly trained crews, and a failure of vessels to have or to use bridge-to-bridge radio-telephone communications to establish a passing agreement.

The most common collision scenario involves two ships in a head-on encounter, proceeding at fairly substantial speeds in poor visibility and manoeuvering directly into a collision. Often one ship reverses the rules of the road and at the last moment throws the throttle astern (Devanney *et al.*, 1979).

Although most tanker spills result from collisions and groundings, structural failures caused by weather, explosions, fires and general breakdowns have contributed their share as shown in Table 2.2-1. In almost all of these cases the problem can be related back to a human failure. For the cases involving structural failures, the accidents could probably have been prevented by a change in course to avoid the stresses which produced the failure. For accidents involving fires or explosions, the problem often related to the ship being in a neglected condition and operated with poorly trained personnel (DNV, 1979).

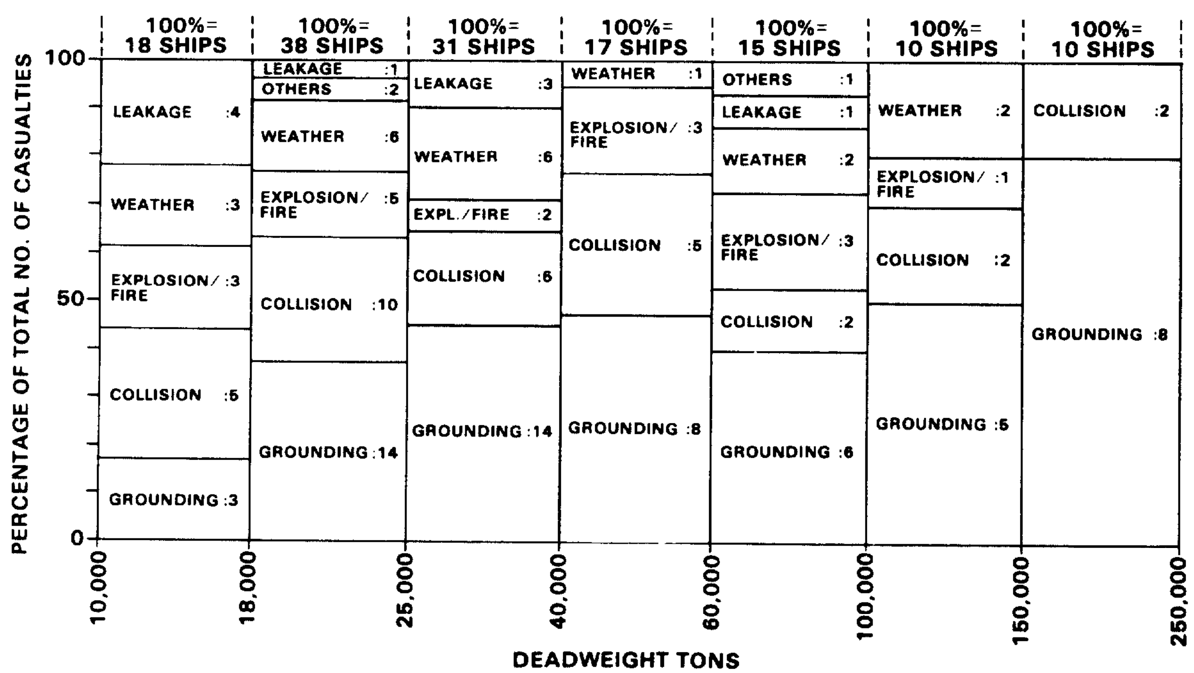
The human causes of tanker accidents can be linked to the management policy of the ship's owner. He is largely responsible for the quality of the crew and the overall safety of the vessel. In general, about 60% of the world's tankers are owned by independents (many "One-Ship Limited" companies) and the rest by the oil industry. A recent study showed that the proportion of accidents with oil company-owned vessels relative to those associated with independently-owned vessels is very low (Van Poelgeest, 1978). As shown in Table 2.2-2, the ratio is 1 in 7.

The oil companies good record is not just due to their larger and newer ships (smaller and older tankers account for most accidents, DNV, 1979). The age of the tonnage owned by the oil majors is close to the world average as shown in Table 2.2-3. The quality of management and crew is the deciding factor.

TABLE 2.2-1

TYPE OF CASUALTY

No. OF AND PERCENTAGE OF TOTAL No's. OF CASUALTIES IN GIVEN DEADWEIGHT RANGES



SOURCE: DNV, 1979

TABLE 2.2-2

TANKER SPILLS
INDEPENDENTS VS. OIL COMPANY OWNED
No. of Accidents / No. of Tankers in a group vs years

Year	Independents	Seven Majors or Oil Companies
1972	1.50	0.18
1973	1.38	0.37
1974	1.54	0.15
1975	1.62	0.07
1976	1.52	0.23
Average	1.51	0.20

Source: Van Poelgeest (1978).

TABLE 2.2-3

THE SEVEN MAJORS - TANKER AGE DISTRIBUTION (EXPRESSED AS A % OF No. OF TANKERS OF A GIVEN AGE GROUP FOR EACH COMPANY

Company	0-5	6-10	11-15	16-20	21-25	25+
BP	35.0	22.0	27.0	15.0	1.0	—
Exxon	34.0	20.6	19.5	19.0	6.0	.5
Gulf	20.0	13.3	28.3	23.3	1.7	13.5
Mobil	41.0	8.0	27.4	17.6	6.0	—
Shell	22.0	22.0	12.4	34.6	9.0	—
Standard	43.3	11.3	13.4	6.2	9.3	16.5
Texaco	14.0	15.3	22.3	23.5	6.0	19.0
Average age	29.9	16.1	21.5	19.9	5.6	7.0
World average	26.1	19.3	21.3	21.7	8.6	3.0

Company Vessel Age Ranges (years)

Source: Van Poelgeest (1978)

In summary, conventional tankers can be constructed and operated far more safely than they have been until now. Poor management, poor crew selection and training, and poor vessel safety have been the main cause of accidents along with a lack of control on an international or national basis to correct the problem.

2.2.1.2 The Consequences of Tanker Accidents

Less than half of all tanker accidents result in oil spills (Bercha, 1981). Table 2.2-4 shows the size distribution of tanker spills greater than 180 tonnes (200 tons) in the years 1967 to 1978 (DNV, 1979). The majority of spills (59%) are less than 15,000 tons but the majority of the total oil spilled (89%) comes from the few remaining large accidents. It has also been shown that larger conventional tankers tend to spill more of their cargo than do smaller tankers (DNV, 1979).

2.2.2 DEVELOPING THE ARCTIC TANKER

Arctic tankers are one means of delivering oil from the Beaufort Sea to southern markets. They not only have to propel themselves through heavy ice year-round but must be built to minimize the chances of accidents causing oil spills. The latter requirement has benefited from the analysis of worldwide tanker accidents described previously in Section 2.2.1.

The Arctic tanker is being designed as a 200,000 DWT double-hulled, twin screw very large crude carrier (VLCC) of all-welded construction, consisting of forecastle and forward accommodation deckhouse, midbody oil cargo tanks, segregated ballast tanks and with all machinery mounted aft. The tanker is shown in Figure 2.2-1 and further design details may be found in Volume 2.

2.2.2.1 Oil Spill Safety Features

The distinctive spill safety features of this vessel are:

- Containment of the cargo tank area within a double hull and located inboard beyond limits of the worst IMCO* damage assumptions on ship's bottom and sides.

- Twin, independent engine control systems isolated in separate compartments.

- Cargo oil transfer system using deep-well pumps.

- Forward-mounted accommodation and navigating bridge for best forward visibility.

- Containment of oil between hulls in the event of inner-hull damage.

- Constant-draft operational capability.

- Special materials for Arctic operation.

- Dual steerage system.

- Flotation system, in event of grounding.

Most conventional tankers constructed to date could not be used for Arctic service due to the high risk of spills because the oil cargo is carried against the outside hull. In order to provide some protection against oil outflow in the event of a hull rupture, new

*The International-government Maritime Consultative Organization (IMCO) is the most important and influential international organization in the field of marine safety.

TABLE 2.2-4

OIL SPILL TANKER ACCIDENTS

No. OF VESSEL ACCIDENTS AND SIZES OF OIL SPILLS

Size Range of Oil Spill 'S'	Accidents No. of	Accidents % of Total	Total Oil Spilled Tons	Total Oil Spilled % of Tot. Spilled
200 T< S≤ 1,000 T	17	21.8%	9,750 T	0.6%
1,000 T< S≤ 2,000 T	5	6.4%	6,620 T	0.4%
2,000 T< S≤ 5,000 T	13	16.7%	47,255 T	2.9%
5,000 T< S≤ 15,000 T	11	14.1%	118,250 T	7.2%
15,000 T< S≤ 30,000 T	19	24.3%	444,880 T	27.0%
30,000 T< S≤ 50,000 T	6	7.7%	232,819 T	14.2%
50,000 T< S≤100,000 T	4	5.1%	327,000 T	19.9%
S >100,000 T	3	3.8%	457,000 T	27.8%
Total =	78	Total =	1,643,574	Tons

Source: DNV (1979).

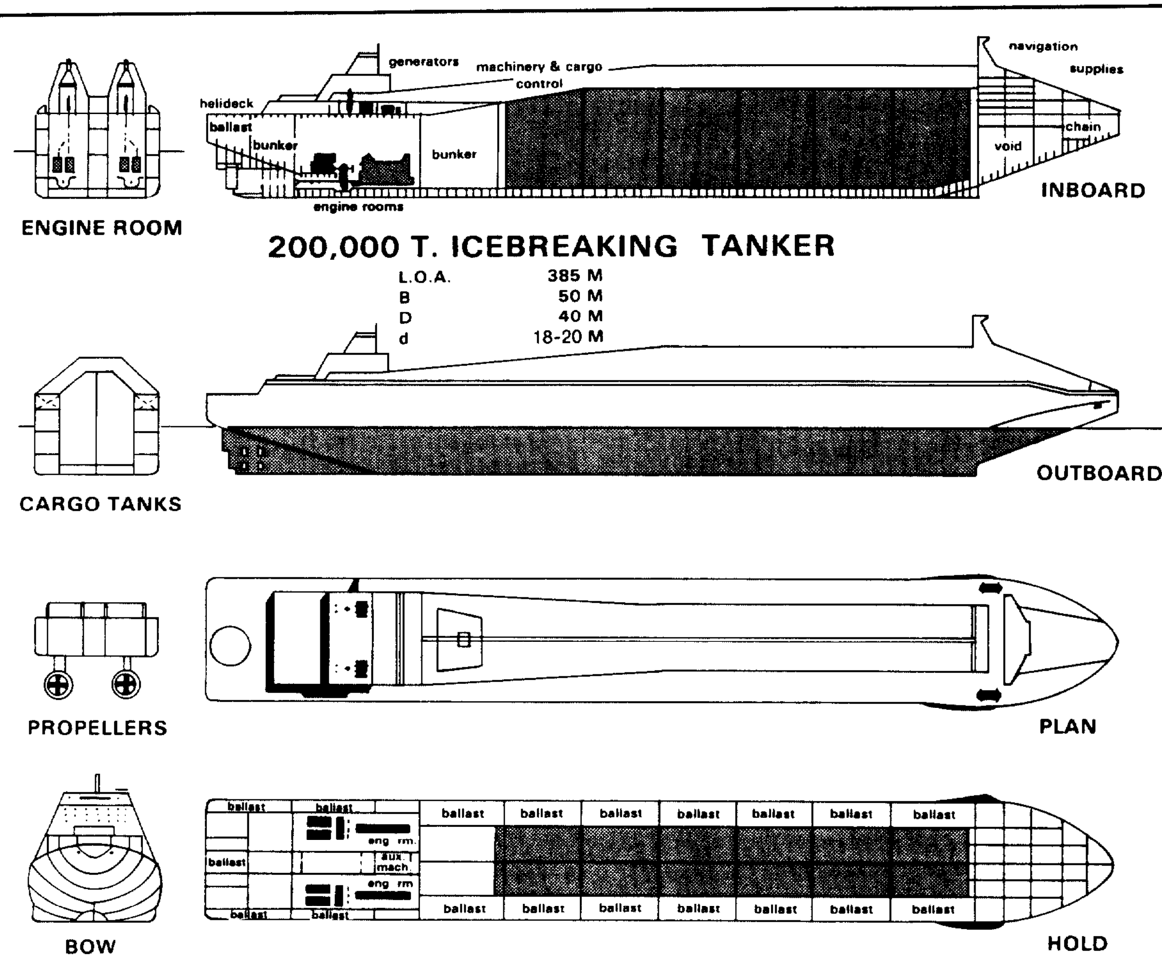


FIGURE 2.2-1 *Conceptual 200,000 DWT Arctic Tanker (Source: Johansson and Stubbs, 1980). The Arctic tanker will be designed to take into account the causes and consequences of past tanker mishaps. It will also be constructed as a Class 10 icebreaker, having a double hull, which will significantly reduce the possibility of a spill due to grounding, collision or heavy weather. As well, it will be fitted out with deep well pumps and inert gas systems to prevent explosions, twin independent propulsion and steering systems to reduce the chance of loss of control, and the latest sophisticated navigation systems to reduce positioning errors. Most importantly the tankers will be owned and operated by a responsible company and run by experienced, well trained officers and crew.*

larger tankers have been constructed with some of the against-hull tankage devoted exclusively to ballast. These designs provide clean tanks so that water ballast need not be put into cargo tanks as in normal practice. This arrangement eliminates pollution by removing the necessity to discharge oily ballast water.

There are many ways of providing segregated ballast spaces on a ship, including double bottoms and double hulls. Using conventional wing or centre tanks is the least expensive method of complying with the latest international IMCO agreements regarding segregated ballast.

The proponents have chosen the approach that the Arctic tanker will be double-hulled. If the outer hull is holed, the ballast tanks within the double hull would flood. Even if two adjacent compartments were flooded, the ship would safely remain afloat in a stable level condition. This surpasses even passenger ship requirements.

Oil outflow from the hull should not occur should the case ever arise where penetration of the inner hull occurs due to grounding. Model tests have shown that it is possible to contain oil outflow from the cargo tank within the space between the outer and inner hulls (Johansson and Stubbs, 1980). Sufficient volume for this purpose is provided between the hulls. Lost buoyancy can be recovered by introducing compressed air to depress the air-water interface to such a point that cargo pumps may be used to empty the tank, compressed air gradually replacing pumped oil (Figure 2.2-2). The net result is that the oil is transferred to a safe compartment while the ship remains afloat with very little loss of buoyancy.

2.2.2.2 Hull Strength

In order to meet the Canadian Arctic Shipping Pollution Prevention Regulations, hull strengthening is added by increasing the shell plating thickness and adding support members to withstand the high localized ice forces exerted on the hull. Not only would it be much more difficult to puncture the hull but in the event of a failure, damage would be minimized.

The extra heavy steel over the ship's length, together with the double hull, results in a hull girder about three times stronger than a similar conventional ship. Large oil spills generally occur as a result of a grounding, collision or hull deterioration in heavy seas where large cyclic loads are imposed on the damaged hull girder. In time, the girder weakens and eventually fails. This is not probable with the Arctic tanker design since, even with damage to the outer hull, the girder strength of the inner hull is still greater than that of a conventional tanker.

Another safety feature will be an array of hull-mounted instruments which will measure actual stresses in critical parts of the hull, and transmit this information to monitors on the bridge. Excessive stress will be detected and remedial action such as reduction in speed or a change of course can be taken immediately before a failure has a chance to occur.

2.2.2.3 Vessel Propulsion and Manoeuverability

Most conventional tankers have single screws for greater hydrodynamic efficiency and lower cost. To improve the manoeuverability of these ships, bow or stern thrusters or rudders can be installed (Anon., 1977). Althought more expensive, twin screw propulsion with twin rudders results in improved manoeuverability (Johansson and Stubbs, 1980). By reversing one engine (propeller) and going ahead on the other while putting the rudders hard over, an increased turning force is produced. These twin screws will be of a controllable pitch design. The propeller pitch may be changed very quickly and full power reverse thrust obtained with a minimum delay for rapid stopping.

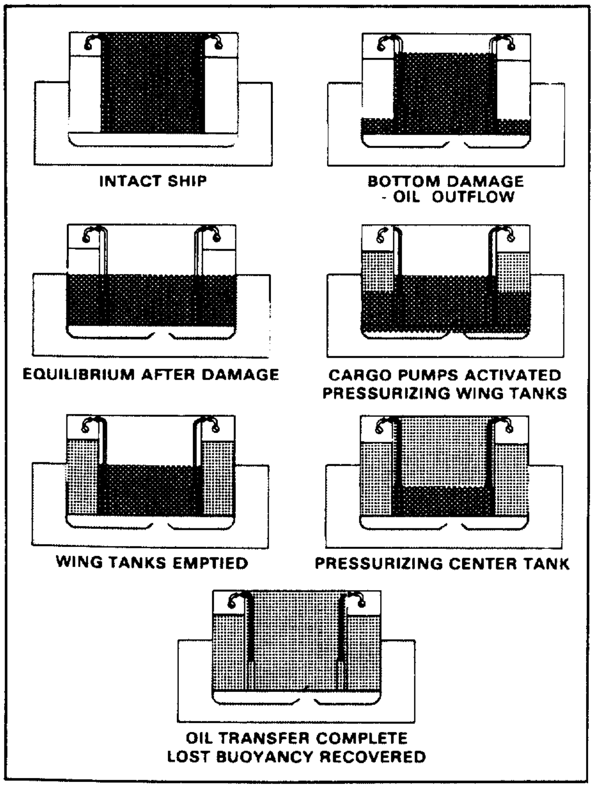


FIGURE 2.2-2 *Safe oil removal using compressed air after a severe grounding of an Arctic tanker (Source: Johansson and Stubbs, 1980). Oil will be transferable from a damaged oil compartment in the Arctic tanker, by pumping compressed air into the ballast wing tanks, and then into the main compartment. In so doing the oil is displaced by air, and transfered into an adjacent empty tank. The wing tanks have sufficient volume to retain oil spills from a compartment inside the ship.*

Another important design feature is the tankers installed shaft horsepower. This extra power provides a safety margin in case of an emergency situation. The power of the Arctic tanker is about five or six times greater than that installed in conventional tankers of the same size, and about twice that recommended by the U.S. Coast Guard in recent pollution prevention proposals, viz., 1 Shaft HP per 2.5 Dead Weight tons (DWT) (Anon., 1977).

Although this power is needed to break ice, in open water service it will drive the Arctic tanker at speeds of 20 knots rather than the more conventional 16 knots. As a result of this, one would expect a much larger stopping distance. This, however, is not the case since the time lag of 15 seconds to apply full reverse thrust is only 1/6th of that required for a conventional steam plant and the astern power available is about 10 times that of a conventional tanker.

Reduced stopping distances are possible because of these features as well as due to extra drag from ducts, independent rudders and controllable pitch propellers. Crash astern manoeuvres performed on very large tankers result in unpredictable trajectories because of loss of directional stability. Because of this, the preferred manoeuvre in an emergency is to turn. The Arctic tanker, being twin screw, will have a predictable behaviour while crash stopping. This has been demonstrated with 550,000 ton tankers which have twin screws. Turning manoeuvres at full power and maximum rudder for the Arctic tanker are expected to be better than for a conventional ship (Johansson and Stubbs, 1980).

2.2.2.4 Cargo Oil Handling System

Conventional transfer systems are generally of two types. The first consists of an in-hull system with piping leading from each tank to a cargo pump room. There would be serious drawbacks for the Arctic tanker with this system because a large amount of piping would be located within the double hull, and the tank-mounted remote control valves would be inaccessible. The pump room could also be a source of explosions. The second conventional system is similar to this but does not have the in-hull piping. In this system the valves are bulkhead-mounted and oil flows by gravity to suction pumps in the aftermost tanks. Inability to selectively pump out tanks is a major drawback of this system.

The proponents have chosen a system of deepwell pumps mounted in each tank. This is the preferable solution since the tanks can be selectively pumped, the pumproom is eliminated, and no in-hull piping is required.

2.2.2.5 Safety of Navigation

The Arctic tanker will contain all the latest electronic systems for navigation. These include:

- Collision Avoidance System: A computerized radar data processing and plotting aid will assist in correctly interpreting radar data in a manner that will avoid collisions. Using data from the ship's radar, gyrocompass and speed indicator, the system automatically locates a ship on radar, computes its course and speed, and determines how close it will pass. The equipment will sound an alarm if another vessel is coming too close.

- Loran-C Navigation System: The ship's position is determined from measurements of the differences in times of arrival of radio signals transmitted from pairs of shore stations at known locations. The maximum range is about 1,400 nautical miles (2,600 km). The system can fix positions to within ¼ of a nautical mile.

- Radar: Marine radars give information on the range and direction of objects from the ship. Almost all tankers have radar equipment.

- Doppler Speed Device: This is a sonar device that transmits sound waves down from the hull of the ship into the water, where sound waves are reflected back to the hull by the bottom or water mass. Through a principle known as "doppler shift," the speed of the ship can be determined to an accuracy of 0.1 knots or 1% of indicated speed. Doppler speed devices improve the accuracy of computerized collision avoidance systems, since a ship's speed is a key parameter in avoidance calculations.

2.2.2.6 Ice Prediction and Ship Control

The efficient and safe use of Arctic tankers requires two distinctly separate systems for ice prediction, namely:

- a strategic system for long-term routing, and

- a tactical system for short-term decisions onboard the ship.

The strategic system centre will be centrally located, and will be in constant communication with the ships and production platforms via satellites. This centre will compile all environmental data including ice conditions, wind speed and direction and iceberg tracks. Based on these data, directions will be issued to the tankers. The centre will also continuously monitor the location of the tankers to warn of possible collisions and groundings.

The tactical system will be designed to give the ship's crew a high quality, all-weather picture of the area in front of the ship up to a distance of 20 kilometres. At intervals, this picture will be relayed back to the control centre. The system will consist of several sensors including marine radar, Synthetic Aperture Radar (SAR), laser and infrared sensors, all connected to a computer.

2.2.3 ARCTIC TANKER SAFETY

To obtain information on the spill safety of a proposed Arctic tanker design, a study was commissioned in 1977 of the spill risks associated with the Arctic tanker design, compared to conventional tankers operating in ice-free waters. The study identified those tanker features which would be more prone to causing accidents than others. Encouraged by the results of this study the concept of the icebreaking tanker was pursued. In 1981, the study was updated to consider additional design features. The 1981 risk analysis takes into account such items as stronger hull plating, dual propulsion and steerage, deep well pumps, the compressed air system for flotation, hull stress monitoring and additional navigational equipment (Bercha, 1981).

The most important findings derived from both the 1977 and 1981 work are summarized as follows:

- an Arctic tanker that is designed and equipped as described in Section 2.2.1, will operate with a spill risk estimated to be 120 to 160 times less than that of a conventional well maintained tanker operating on a southern Canadian route;

- much of the reduction in spill risk for the Arctic tanker is attributed to the vessel's double hull which is strengthened for icebreaking and which would provide much greater protection to cargo tanks in a collision or grounding;

- a further reduction in grounding and collision spill risk results from the Arctic tanker's navigation systems, which would eliminate many of the navigation errors that result in grounding accidents. The vessel's manoeuverability, which compensates for its large size, also reduces the risk of spills by collision;

- the risk of spills due to collision with icebergs will be minimized by the Arctic tankers's sophisticated ice detection and prediction systems, and by the icebreaking hull's resistance to damage;

- the Arctic tanker's combination of complete tank inerting (replacement of the air in the cargo and ballast tanks with an inert gas) and segregated ballast tanks results in a large reduction in spill risk due to explosions;

- the Arctic tanker's strong hull and stress monitoring systems reduce the risk of structural failures to a very low level.

The results of the risk studies show that the Arctic tanker will be much safer than conventional tankers. However, as the study of past accidents has shown human error is closely linked to accidents. The proponents will also ensure that the officers and crew are:

- well trained and experienced,

- regularly tested in classrooms and actual situations,

- exposed to emergency procedures using computer training simulators (as used for aircraft pilots) and,

- alert on the job through provision of entertainment, recreation and regular, periodic shoreleave to reduce boredom.

In order to ensure that the tankers are continuously operated in a safe manner there will be:

- regular and random maintenance, operations and safety inspections of the ship by supervisory personnel, and

- instant and constant monitoring of the tanker operations by the control centre.

Further specific procedures may be found in the DNV study (DNV, 1979).

2.3 THE PRODUCTION SYSTEM

The production scheme for development of Beaufort oil consists of a number of offshore and onshore facilities, as discussed in Volume 2. On land, the production system would be conventional, but designed to take into account Arctic conditions. For example, wells would be clustered on gravel pads to minimize surface disturbance. The offshore production system would use artificial island platforms of various types, complete with drilling rigs and oil processing equipment. Bulk storage units, living quarters and tanker loading facilities will also be built. The Arctic Production and Loading Atoll (APLA), an integrated platform concept for the

Beaufort Sea, may be built to form a protected harbour which would be used by icebreaking tankers for loading oil. Drilling barges, production and processing barges and storage units could be positioned around the interior of the atoll.

The details of the production scheme are continuously evolving, however both the onshore and offshore facilities ultimately built will largely be of conventional design. Offshore production facilities have been in operation off the U.S. Gulf Coast for over 25 years, and more recently in the North Sea, Cook Inlet and other parts of the world.

Except for having to operate in the extreme cold and surrounded by sea ice and continuous darkness for a portion of the year, the Beaufort drilling and production operations will be basically the same as used in other areas. The oil will be transported from artificial islands by subsea pipelines to either an APLA or to a storage facility located onshore; then the oil will be loaded aboard tankers or transported south through an overland pipeline. These proposed facilities are similar to those used in offshore operations elsewhere in the world where drilling, production and processing takes place on a platform and the oil is transported either to an offshore terminal by subsea pipelines where it is loaded aboard tankers, or it is transported to destinations by subsea and overland pipelines.

2.3.1 OFFSHORE PRODUCTION ACCIDENT ANALYSIS

Several studies have reported on accidents in offshore production operations over the last 25 years (Danenberger, 1980; Kash, *et al.*, 1973; Snider, *et al.*, 1977).

A recent comprehensive study forms the basis of the following discussion (Gulf, 1981). The objective of the study was to identify and specify the circumstances, causes and consequences of individual accidents in worldwide offshore operations. Recommendations were formulated from the analysis which are to be incorporated into future Beaufort production systems so as to make them as safe as possible.

During the study, information was collected from 2,501 accidental releases of hydrocarbons that took place between 1955 and mid 1980, worldwide.

The data for the U.S.-Gulf of Mexico-Outer Continental Shelf (US-GOM-OCS), the North Sea-United Kingdom, and Alaska State waters were analyzed and discussed separately and compared in the report. With minor exceptions, the results and conclusions from all areas were found to be similar, therefore, only the US-GOM-OCS analysis will be summarized here (Gulf, 1981). These data cover 1,949 of the 2,501 accidents analyzed. (A detailed analysis of the spills that have occurred from Beaufort operations is included in Chapter 8).

Considering the long history of drilling for and production of oil and gas, the safety and pollution control record of the oil industry in offshore operations has been good. Nonetheless infrequent accidents have occurred of serious consequence, some of which have led to large oil spills. Thousands of people are employed offshore operating a massive amount of equipment. Thousands of individual components and extremely large amounts of energy are handled. Thus, the potential for serious accidents exists.

There have been an average of 2.5 accidents per 100 wells drilled and operated per year that resulted in the release of hydrocarbons. The consequences of these accidents of particular interest to this Volume are oil spills and blowouts. These will be discussed as well as the types of operations in which the accidents occurred. The causes of the accidents will be shown and finally the actions to reduce the incidence of accidents in Beaufort operations will be outlined.

2.3.1.1 Operations Underway when Accidents Occurred

In order to determine whether or not a specific phase of oil and gas development is particularly prone to accidents an analysis of the various operations underway was conducted. The types of operation underway when accidents occurred are shown in Figure 2.3-1. The sum of the separate percentages shown above each bar exceeds 100% since sometimes more than one operation was underway when the accidents happened. Some specific operations, such

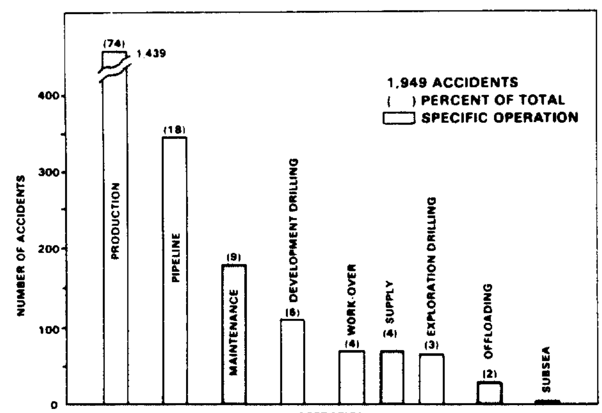


FIGURE 2.3-1 *An analysis of all accidents that released hydrocarbons while production operations were underway (Source: Gulf, 1981). Production operations accounted for 74% of all the accidents in the U.S.-Gulf of Mexico offshore area that released hydrocarbons. Pipeline operations were the next highest category accounting for 18% of all the accidents. Of the specific operations (shaded bars), maintenance, predominantly welding, accounted for the most accidents (9%).*

as maintenance (often welding) and supply, which have a significant incidence of accidents are shown separately from the major operations of production, pipeline, exploration and development drilling and workover.

Production operations accounted for 74% of the accidents. Offshore pipeline operations were the next largest source followed by maintenance operations. Exploration and development drilling accidents account for less than 10% of all accidents. Workovers, often considered to be high risk operations, account for only 4% of the accidents although each well is worked over from two to four times during the several years it is on production. Although the chance for an accident in workovers is considered to be two to four times greater than that for development drilling, it turns out that the number of workover accidents is almost half that for development drilling. This reflects the fact that workover operations are considered to be dangerous and are treated accordingly.

2.3.1.2 Probable Cause of Accidents

In order to prevent accidents an analysis of the causes was undertaken with the results shown in Figure 2.3-2. The sum of the causes exceeds 100%, as in many cases one or more of the causes resulted in a single accident. The seven causes of accidents are discussed below:

- Inattention to Operations (cause for 56% of all accidents) is exemplified by: overfilled fuel tanks; safety equipment pinned out of service while wells and equipment were operated; exhaust gas vented where it could be ignited by sparks; the fluid level allowed to fall in a wellbore until a blowout occurred or oil and gas was present while welding or cutting.

- Inadequate Maintenance (cause for 54% of all accidents) is exemplified by: level controls that do not function; sump pumps that fail; lines to or from sumps clogged with sand or other debris; small leaks that catch fire; hoses, lines, and valves that leak; sumps and traps that overflow; blowout preventers (BOP's) that do not close or seal due to worn, damaged, or missing seals; valves that do not close or will not seal when closed; and equipment on the platform that is internally eroded or externally corroded.

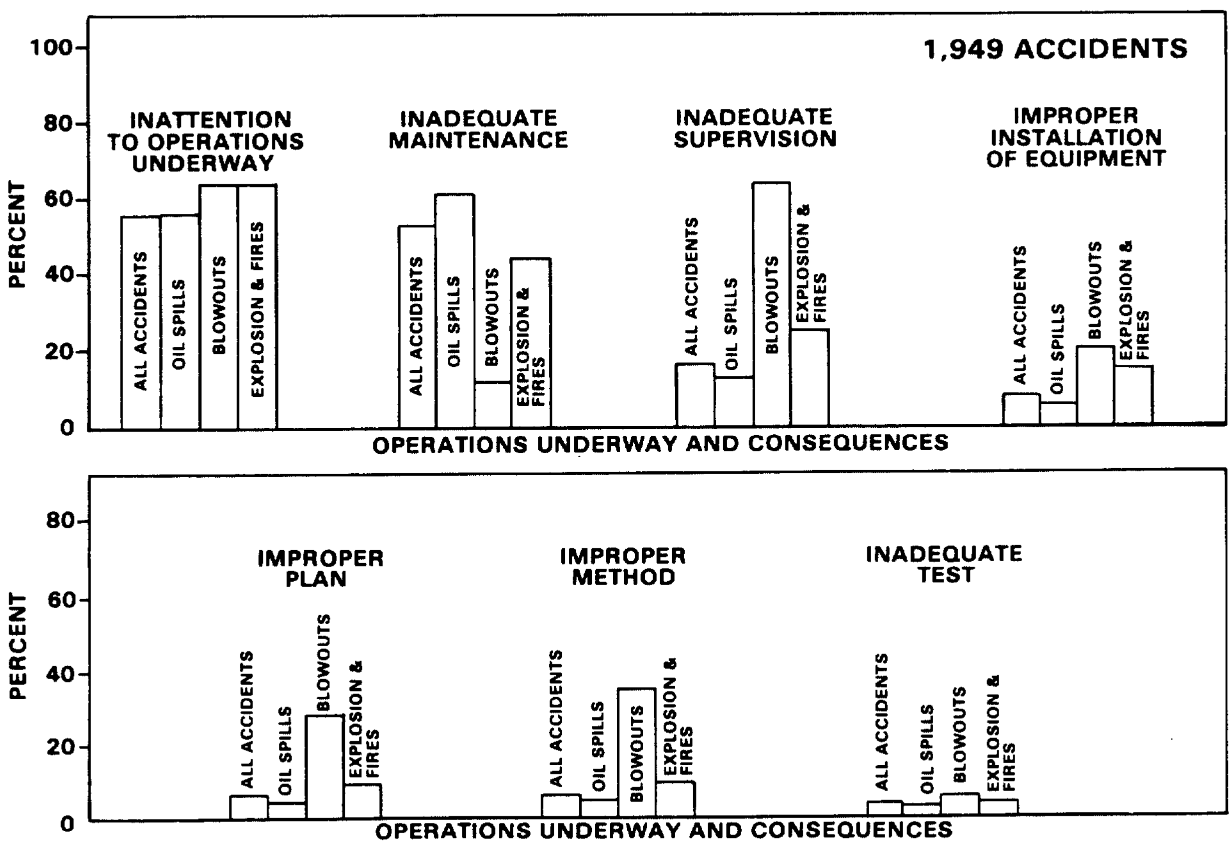


FIGURE 2.3-2 *An analysis of causes of accidents while production operations were underway in the U.S.-Gulf of Mexico (Source: Gulf, 1981). All the accidents analyzed (with the exception of some pipeline accidents) were caused by human action or inaction. The major causes of accidents were found to be inattention, inadequate maintenance and inadequate supervision. In order to reduce accidents these are the important areas to concentrate on.*

- Inadequate Supervision (cause of 15% of all accidents) is exemplified by not ensuring that field operators know how to do the task assigned to them; that proper equipment is not on site before a task is started; that equipment is not tested before it is used; that the proper work plan has not been developed and in the hands of the people doing the work; that the correct procedures are not used; and that they, themselves, fail to follow safe procedures and insist that others act on the principle that safety is of paramount importance in their work.

- Improper Installation of Equipment (cause of 7% of all accidents) is exemplified by: engine or heater exhaust lines placed near sources of fuel and the hot surfaces not insulated or isolated; pump or compressor discharge or suction lines not installed so as to prevent vibration and subsequent fatigue cracks or breaks; and gas from starters not vented or not vented properly.

- Improper Plan (cause of 6% of all accidents) is exemplified by: hydrocarbons vented while welders worked nearby; casing set at insufficient depths where shallow gas was known to be a drilling hazard; ignition sources placed near fuel sources without any means of isolation; and hydrocarbons not removed from equipment before work commenced when ignition sources were nearby.

- Improper Method in Use (cause of 5% of all accidents) includes: wet strings of pipe pulled without a mud saver; lines or fittings removed without first draining them; valves opened or closed without counting the turns of the stem required to open or close the valve; gases vented over boats tied to the downwind side of the platform; ignition sources used near open vessels that contained hydrocarbons; and casing cemented incorrectly when shallow gas and water zones were vertically close to each other in the wellbore.

- Inadequate Test (cause of 2% of all accidents) includes: the installation and use of new equipment before calibration of the level controls or removal of manufacturing debris; newly installed equipment not pressure tested before its use; functional tests on essential control equipment such as BOP's not performed before the equipment was used; and not performing tests that would have revealed holes in casing or heater tubes or other equipment before it was used.

Clearly, human failure is the cause of accidents. A similar analysis to search for mechanical causes for the accidents showed that no single mechanical cause was outstanding except possibly level controls. Thus it has been concluded that:

- The mechanical equipment in use is reliable in design and function and mechanically adequate for the operations underway. In consideration of all the mechanical components and thousands of people operating the equipment, the accident rate of 2.5 accidents per year per 100 wells drilled and operated, is clear evidence that the mechanical equipment is adequate.

- The mechanical failures that have occurred are the result of inadequate maintenance and improper use of the equipment.

- The installation of additional sophisticated control equipment may not decrease accidents. On the contrary, controls, and the devices controlled are now involved in more accidents than any other single mechanical item.

- The accident frequency rate could be reduced by the use of better preventative maintenance programs and better training and supervision of the people involved at all levels of operations.

Accidents in offshore pipeline operations are also caused by human errors, but in a manner that is different from the other major operations such as drilling, production, and workover. The cause of a pipeline accident may have been initiated many years before it occurred or may not have been at all related to the operator at the time.

To be specific: a leak caused by a kink in a line may have been initiated by a dragged boat anchor or trawl board that did not initially break the pipeline, or by a mud slide, or by soil removal from under the line due to currents or wave action. The corrosion that caused a leak may have been internal or external to the line. Furthermore, the external coating on the line may have been damaged or removed earlier by an anchor or trawl board or some other activity. The movement that causes abrasion may be due to temperature cycles, currents or waves. The collision from surface craft that caused a leak may have been unavoidable except at a greater risk to the craft.

It therefore appears, the cause of most pipeline accidents is not controllable by the operations personnel in the field. Rather, responsibility for the accidents and their prevention reverts to those responsible for the design, installation and maintenance of the lines.

2.3.1.3 Consequences of Accidents

In order to evaluate the impact of accidents the consequences were analyzed, as shown in Figure 2.3-3.

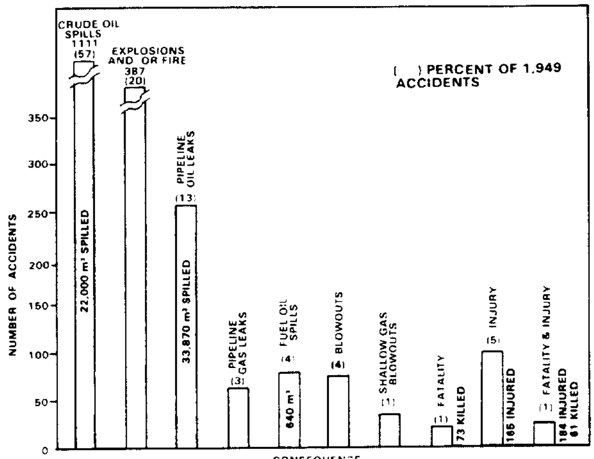


FIGURE 2.3-3 *Consequences of all accidents during production operations in the U.S.-Gulf of Mexico (Source: Gulf, 1981). The most common consequences of an accident releasing hydrocarbons in the U.S.-Gulf of Mexico was a crude oil spill (5% of all accidents). Explosions and fires were the next most common consequence. Of a far greater importance is the fact that 134 people died and 349 were injured as a result of the accidents.*

There were oil spills in 74% of the accidents of which 13% were offshore pipeline oil leaks, 57% were from other crude oil sources, and 4% were fuel oil spills. A total of 55,650 m^3 (350,000 bbl) were reported spilled in all accidents and offshore pipelines accounted for 33,870 m^3 (213,000 bbl) of this volume. Blowouts accounted for 5% of the volume spilled.

(a) Oil spills

Oil spills are one consequence of offshore accidents, and will be discussed to provide some perspective on their frequency and size. There have been a total of 100 to 120 spills reported per year, greater than 1 bbl (0.159 m^3) in size, averaging annually some 1,000 to 2,000 bbls (159 to 318 m^3) spilled during the last decade. The majority of these spills (91%) involved less than 50 bbls (8 m^3), however, the 1.5% of the spills greater than 1000 bbls (159 m^3) accounted for 95% of the total volume (Figure 2.3-4). Approximately 350,000 bbls (55,650 m^3) of oil were spilled as a result of 1,441 accidents reported.

The operations which were underway when spills occurred, and the amount of oil spilled are shown in Figure 2.3-5. Production operations accounted for three quarters of the oil spills but for less than one quarter of the total volume spilled. Offshore pipeline operations were responsible for 20% of the spills but 61% of the volume of oil spilled. In fact, seven offshore pipeline spills accounted for 59% of the total reported volume of oil spilled in all accidents. Supply operations accounted for essentially all fuel oil spills (4% of all oil spills) but for only 1% of the total volume spilled. The results for workover related spills (3% of the reported spills accounting for 15% of the total volume) were dominated by one accident which resulted in a 52,000 bbl (8,300 m^3) spill.

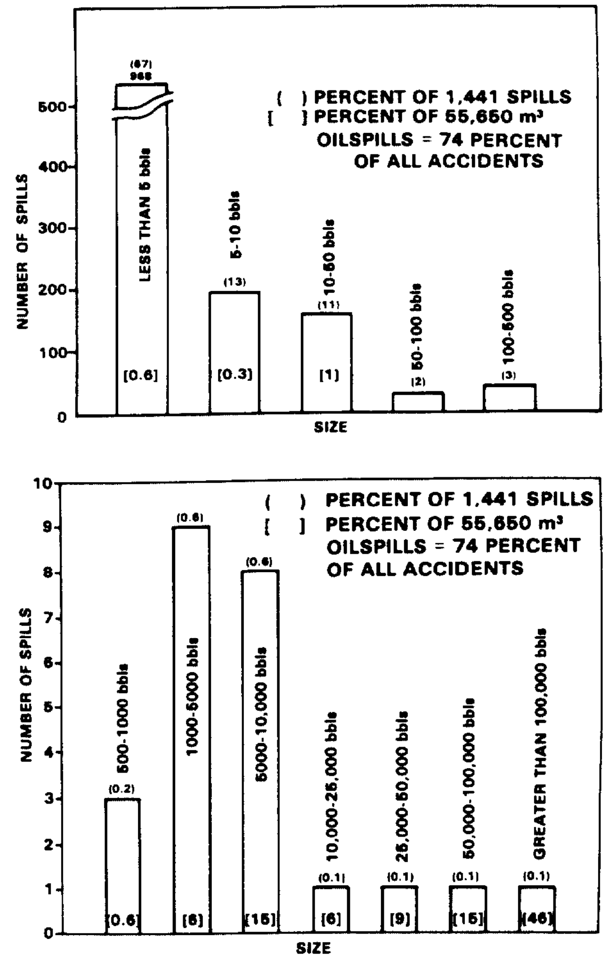


FIGURE 2.3-4 *The frequency and size of oil spills in the U.S.-Gulf of Mexico (Source: Gulf, 1981). The vast majority of spills are small in volume. In the U.S.-Gulf of Mexico of the 1,441 spills reported in the last 25 years 93% have been less that 100 bbls. (16m³), however, 76% of the total volume of oil spilled was released in a few large incidents which accounted for only 0.4% of the total number of spills.*

It is shown in Figure 2.3-2 that oil spills resulted from the human causes of inadequate maintenance and inattention to operations.

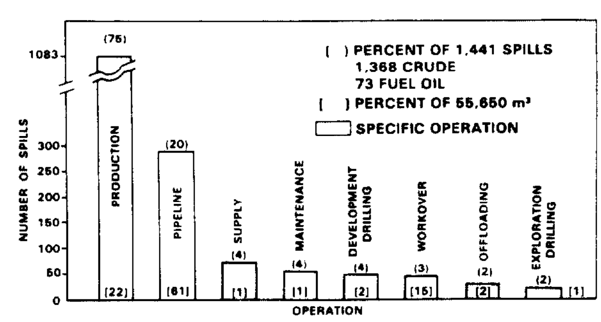


FIGURE 2.3-5 *Types of operations underway during spills in the U.S.-Gulf of Mexico and the amount of oil spilled (Source: Gulf, 1981). Production operations accounted for by far the largest number of spills, however, pipeline operations accounted for the largest volume of oil spilled. Of the specific operations (shaded blocksO, supply, maintenance and offloading accounted for the largest number of spills while workovers accounted for the largest volume of oil spilled.*

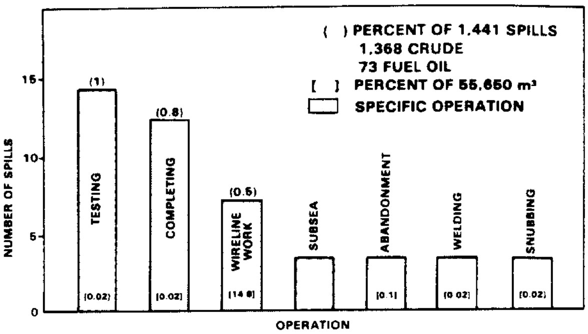


Figure 2.3-5 (continued)

(b) Blowouts

Blowouts are a conspicuous consequence of accidents, however, as shown in Figure 2.3-3 they occurred in only 4% of the accidents. The average frequency (blowouts per year per 100 wells) over the past nine years for the major operations was: Exploration Drilling 1.0; Development Drilling 0.4; Production 0.03; and Workover 0.03. The combined average for offshore operations was 0.13 blowouts per year per 100 wells.

The distribution of blowouts that occurred in drilling, production and workover operations are shown in Figure 2.3-6. There were 31 blowouts while drilling 4,794 exploratory wells and 37 blowouts while drilling 12,390 development wells. A total of 32 blowouts in 25 years occurred from production and workover operations. During this time an average of 4,630 wells were in operation per year. Oil spills occurred in

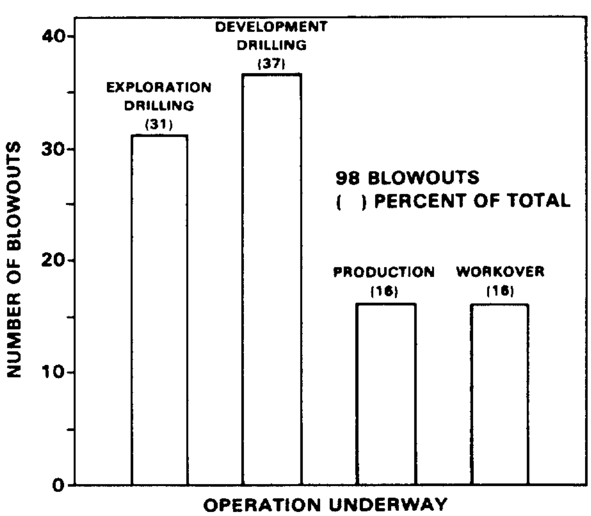


FIGURE 2.3-6 *The distribution of blowouts that occurred during drilling, production and workover operations (Source: Gulf, 1981). Of the 98 blowouts that occurred in the U.S.-Gulf of Mexico, 68 happened during exploration and development drilling. Surprisingly only 16 of the 98 occurred during workovers which are generally considered one of the most dangerous operations. The perceived danger apparently motivates workers to be more careful.*

12% of the blowouts (Figure 2.3-7) and spilled 69,000 bbl (11,000 m³) of oil. One blowout resulted in a spill of 52,000 bbl (8,300 m³).

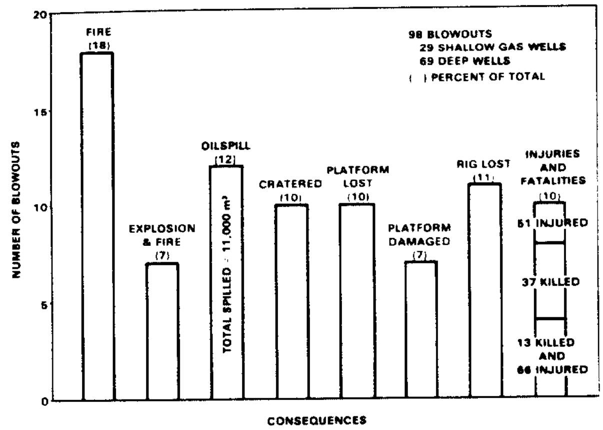


FIGURE 2.3-7 *The consequences of blowouts (Source: Gulf, 1981). Only 12% of all blowouts in the U.S.-Gulf of Mexico have resulted in oil spills, the rest involved gas or water. Explosions and fires are the most common consequence (25%). The greatest loss is human. The 98 blowouts have resulted in 50 deaths and 116 injuries.*

The methods by which the blowouts stopped are shown in Figure 2.3-8. Half of all blowouts ceased naturally either by depletion of the reservoir or by clogging of the hole by debris. Another 41% were stopped by closing a valve or BOP or by pumping fluids into the existing well. The remainder required the drilling of a relief well or the installation of a valve. Of all these blowouts 77% lasted less than 30 days, 57% lasted les than five days and 28% lasted less than one day.

The major causes of blowouts, as shown on Figure 2.3-2, were inattention to operations (65%) and inadequate supervision (63%).

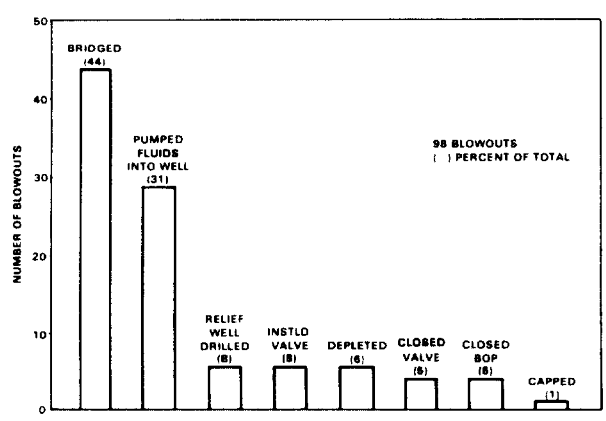


FIGURE 2.3-8 *Methods by which blowouts stopped (Source: Gulf, 1981). Of the blowouts which have occurred in the U.S.-Gulf of Mexico, 50% of them ceased naturally, either by debris or rock plugging the well or by the reservoir depleting. Only 8 required the drilling of relief wells. A total of 20 relief wells were required.*

2.3.2 DEVELOPING SAFE BEAUFORT PRODUCTION OPERATIONS

The following measures will be implemented, based upon the analysis of the 2,500 offshore accidents, to reduce the risk of oil spills occurring during Beaufort operations.

2.3.2.1 General Measures

- There will continue to be a clear corporate statement by the top management of the proponents as well as visible practice throughout the chain of command that safety has the highest priority.

- The operators for Beaufort Sea installations will establish the philosophy and procedures for design, installation, operation, maintenance, safety, and staffing before the design process starts in order to reduce the risk of accidents.

- The operators will conduct the steps of design, installation, operation, maintenance, and staffing with full recognition that accidents may occur in all phases and parts of the operations due to human causes. Therefore, efforts in design of equipment and operational procedures will be directed towards two major objectives: 1) to minimize opportunities for people to err, 2) to minimize the consequences of the errors that may occur.

- The installations will be staffed with trained and experienced people. There will be a continuous personnel training and selection program at all levels of the organization.

- Performance standards will be established for the work force. There will be periodic tests of the competence of this staff to assure that these standards are satisfied.

- Remote and automatic devices to control hydrocarbons will be used only after deliberation and evaluation of the relative costs and benefits of their installation, maintenance, and potential for failure.

2.3.2.2 Specific Measures

At the present time, specific measures that will be employed in production systems to minimize accident occurrences cannot be detailed as was done for Arctic tankers in Section 2.2.2. This is because the design of production systems has not evolved to the extent that the Arctic tanker design has. The support document, which analyzes causes of offshore accidents (Gulf, 1981) is, and will continue to be used as a valuable source of information for the design of production installations to minimize accidents. The forty-two recommendations, listed in the study detail design, equipment and operational safety features. These include recommendations on: the arrangement of wells, equipment and accommodations on an island; equipment design and selection; pipelines; offloading; and operations and emergencies. These recommendations will be considered during the design of Beaufort production facilities.

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CHAPTER 3

BEHAVIOUR OF SPILLED OIL IN THE ARCTIC ENVIRONMENT

This chapter discusses the behaviour and fate of oil released in Arctic waters under various environmental conditions. The information is presented by types of oil spills, such as "oil on open water," "oil in ice" and so on. In Chapter 6 this information is used in conjunction with computer modelling of oil slick trajectories to illustrate the likely fate of oil in a series of hypothetical spill case-studies.

The behaviour and characteristics of spilled crude oil depends on its chemical and physical properties and on the physical environment into which it is spilled. A section at the end of this chapter describes the properties of Beaufort Sea oils which will affect their behaviour and cleanup.

3.1 GENERAL BEHAVIOUR OF OIL SPILLS

3.1.1 OIL SPILL ON OPEN WATER

Oil discharged on open water, such as from a tanker spill, undergoes several processes that affect its fate and behaviour. Of prime importance is that it will spread quickly, resulting in a thin slick covering a large area of the ocean's surface (Fay, 1971; Mackay *et al.*, 1979). Figure 3.1-1 illustrates the spread of oil on water as a function of time and volume. The slick will also drift with wind-induced surface currents and be transported by the residual water movements in an area (Audunson, *et al.*, 1979; Fallah and Stark, 1976; Mackay *et al.*, 1979; Murray, 1975; Schwartzberg, 1970). Turbulence in the near-surface water will break up the the oil slick into patches once it is thin enough. These patches will generally be surrounded by thin sheens that appear to be fed by the patches (Mackay *et al.*, 1979).

Along with spreading and movement, the slick will weather, altering its composition. Weathering processes include emulsion formation - a relatively stable mixture of oil and water - which increases the slick's viscosity and its volume on the water surface; dispersion which reduces the volume of oil on the water surface by mixing some of it into the water column; evaporation which results in the rapid loss of the lighter fractions of the oil into the atmosphere; sedimentation - the sinking of oil droplets by their attachment to suspended sediment; dissolution which leaches out the water soluble oil fractions; and finally, various oxidation and biodegradation processes which result in a very slow alteration of the

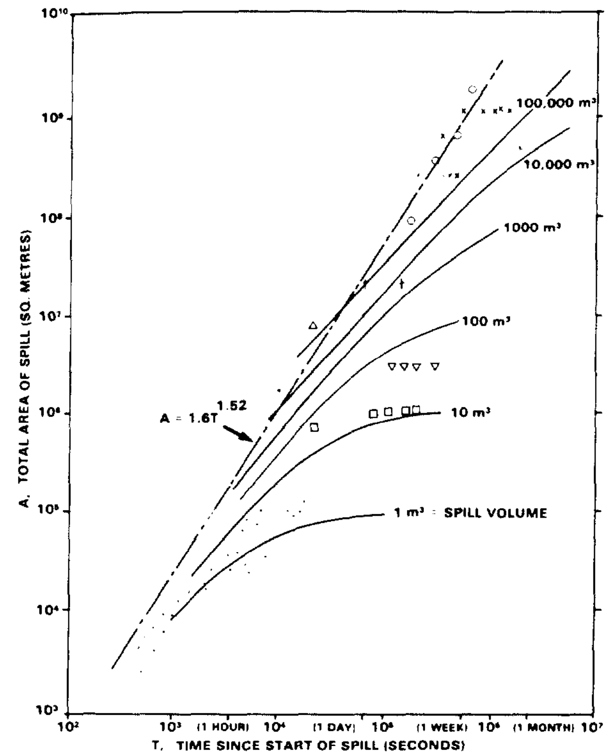

FIGURE 3.1-1 *The relationship between the volume of crude oil spilled and the area the slick covers on open water as a function of time (Source: Mackay et al., 1979). The various symbols represent experimental results and the equation A is built into the oil spill computer model used in Chapter 6. Oil on water spreads rapidly in the first few hours but eventually ceases to spread. In one day 10 m^3 (2,100 gallons) can cover one square kilometre (250 acres). As the volume of oil spilled increases the area covered and the length of time the slick spreads also increases.*

oil's chemical makeup and are ultimately responsible for the removal of oil from the sea.

The long-term result of oil left on water is "tar balls," consisting mainly of the very heavy ends of the oil. These heavy ends, which are often in an emulsified form with included detrital material, can have a density equal to or greater than water, and may be suspended throughout the water column or settle onto bottom sediments. Figures 3.1-2 and 3.1-3 schematically illustrate the fate of an oil slick on open water.

3.1.2 SUBSEA OIL BLOWOUT IN OPEN WATER

Exploration and delineation wells will continue to be drilled during the open water season on the Beaufort Sea's continental shelf using floating platforms such as ice strengthened drillships and extended season drilling systems (Volume 2). Consequently, a subsea oil well blowout is possible in open water, generally in water depths ranging between 25 and 100 metres. If this were to occur, expanding gas would drive the oil up the well bore and into the water column above it, after which the gas would escape into the atmos-

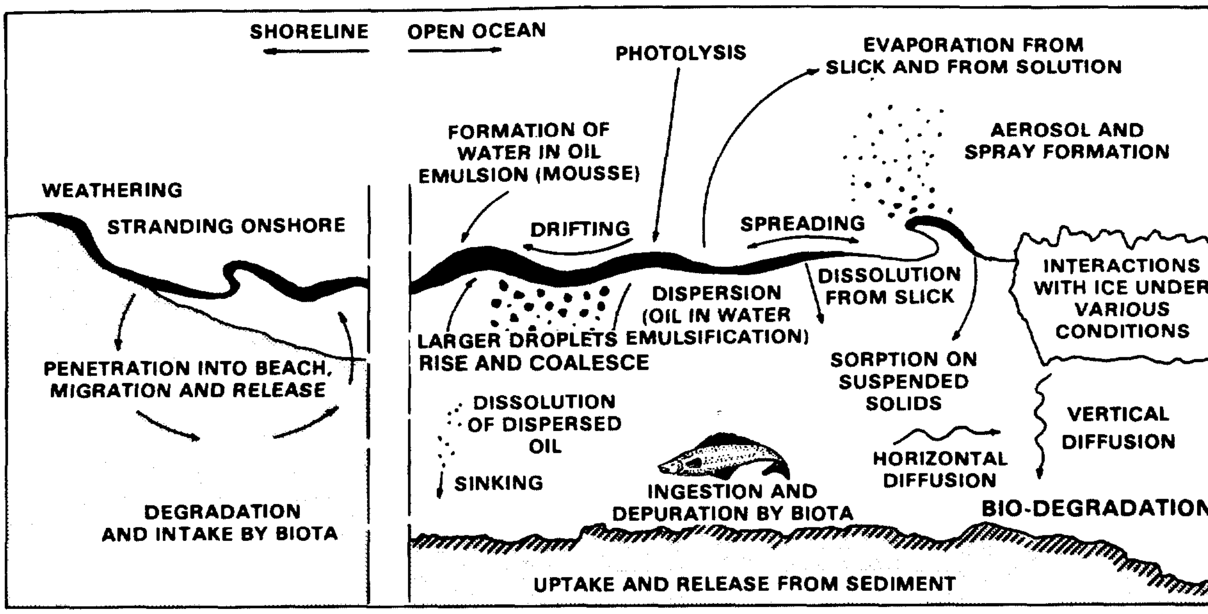

FIGURE 3.1-2 *The various fates of an oil slick on open water (Source: Mackay et al., 1978). Oil spilled on water in an Arctic marine environment can undergo many processes to alter its form. On the open water it can drift, spread, evaporate, disperse, emulsify, sink, dissolve, interact with ice, photolyze, biodegrade and be ingested by biota. Also, oil near shorelines can become stranded on beaches, penetrate into sediments, contact biota and undergo weathering.*

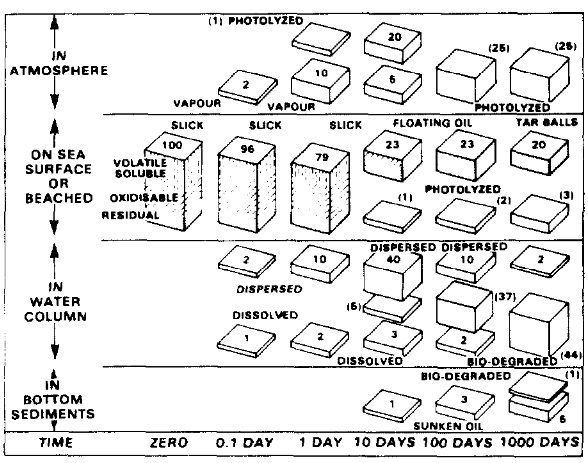

FIGURE 3.1-3 *An accounting of the various fates of an oil slick on open water as a function of time (Source: Mackay et al., 1978). The numbers on the blocks refer to the percentage of the oil in various conditions where 100% of the oil was spilled at zero time. In this example, 1,000 days later, 45% would be biodegraded, 28% would be photolyzed, 20% would be in the form of tar balls, 2% would have dispersed and 5% would have sunk to the bottom.*

phere. The resulting gas plume would modify the oil before it reaches the sea surface making the oil discharge significantly different from one released on the sea surface.

A major difference is that the oil is initially broken down into small droplets, ranging in diameter from several millimetres (10^{-3}m) down to several micrometres, (10^{-6}m) (Dickins and Buist 1981; Topham, 1975). This oil, lifted upward by the rising gas plume, will rapidly come to the sea surface, and some of it may subsequently be mixed into the water column by water circulation patterns set up by the gas plume (Topham, 1975). If the gas ignites, the fireball above the water may burn off some of the lighter components of the oil as it rises beneath it (Ross *et al.*, 1979). As a result, the oil on the sea may initially be in an emulsified form as it drifts away from the area of the blowout. The smaller droplets of rising oil will drift with surface currents some distance from the blowout site before floating to the water's surface, as shown in Figure 3.1-4. This figure illustrates the situation observed at the Mexican IXTOC 1 blowout (Ross *et al.*, 1979). The gas fireball formed one focus of a partial ellipse aligned with the prevailing water currents. As the oil left the plume area it spread and eventually broke up into separate patches.

3.1.3 OIL SPILL ON SEA ICE

Artificial islands are now being used for year-round exploration drilling in the Beaufort Sea and are proposed as platforms for year-round production drilling. In addition, oil storage will be necessary at offshore Arctic tanker loading terminals. Therefore it is possible to spill oil onto the surface of the sea ice surrounding such platforms.

Oil spilled onto sea ice will spread slowly as the low air temperatures of winter increase its viscosity. Its spread will be limited by the surface roughness of the sea ice and by the snow on top of the ice. Figure 3.1-5 is a nomogram relating the theoretical radius of an oil spill of a given size on ice to the effective surface roughness height of the ice (McMinn, 1972). This figure shows that oil spilled onto rough ice, of the kind that forms around artificial islands, would not spread far. Snow on the ice will be permeated by the oil and will act as a barrier to its spread; also, blowing

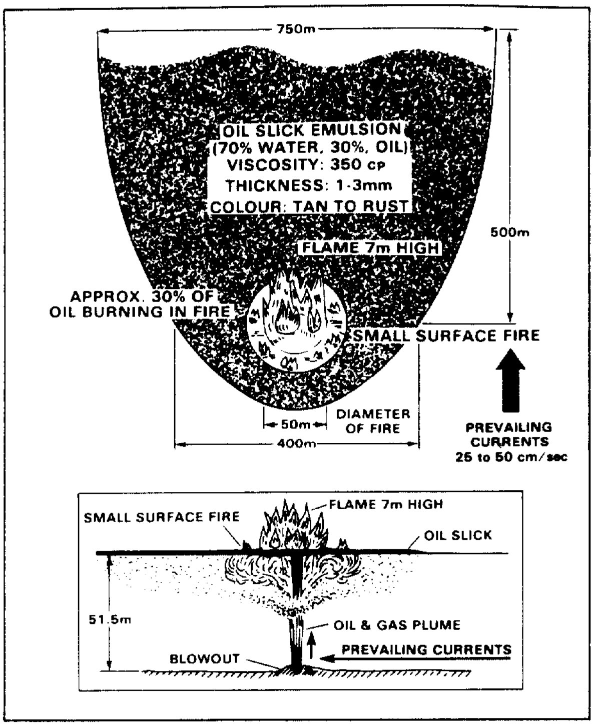

FIGURE 3.1-4 *The situation at the Mexican IXTOC 1 blowout (Source: Ross et al., 1979). The gas fireball formed at one focus of a partial ellipse aligned with the prevailing water currents. The action of the gas at the surface combined with the heat from the burning gas created an emulsion which drifted away with the currents.*

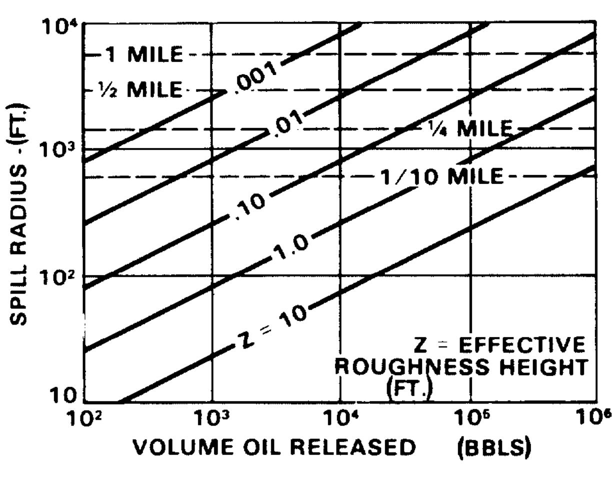

FIGURE 3.1-5 *The theoretical radius of an oil spill (bbls) on ice vs the effective surface roughness height of the ice surface (Source: McMinn, 1972). Oil spilled on rough ice does not spread nearly as much as does a spill on water. The cold ice also makes the oil more viscous further reducing its tendency to spread. A 160 m^3 (1000 bbl) spill on open water would eventually spread to cover an area of almost 10 km^2. The same spill on ice with an effective roughness height of 0.1 ft (3 cm) would only cover 0.03 km^2.*

snow settling onto and mixing with the oil will retard its spread. Hot oil spilled on snow covered ice will be chilled quickly and the remaining unmelted snow will retard its spread (Mackay *et al.*, 1974).

Even at low air temperatures, the light ends of the oil will evaporate in about one week.

3.1.4 OIL DISCHARGE, UNDER FIRST YEAR ICE

Proposed production islands situated over offshore oil fields will be linked by subsea pipelines to offshore production facilities. In turn, crude oil would be transported to offshore tanker terminals or to shore for onward transport south by an overland pipeline. Therefore a spill under first year sea ice would be possible should there be a break or leak in a subsea oil pipeline. A subsea blowout could also occur under first year ice and is discussed separately in Section 3.1-7.

Oil pipeline breaks are also possible under freshwater ice at river and stream crossings in the Mackenzie Valley where an overland oil pipeline may be built.

Oil discharged under growing first year ice will be frozen into the ice sheet within several hours (Bell, 1974; Dickins and Buist, 1981; and NORCOR, 1975). The oil will travel in the general direction of the currents and will fill under-ice cavities until the source of oil ceases flowing (Cox and Schulze, 1981; NORCOR, 1975). Any dispersed oil droplets will rise to the under-ice surface down current of the oil source. The areal coverage of oil under first year ice is a direct function of the depth and spacing of under-ice cavities, and has been estimated at 0.03m^3/m^2 (Kovacs, 1977; NOAA, 1978) Coverages of 0.02 m^3/m^2 for 64 cm thick ice in December and 0.045 m^3/m^2 for 154 cm thick ice in April have been reported (NORCOR, 1975) Coverages of 0.02 m^3/m^2 have been reported for freshwater ice (Greene *et al.*, 1977). Oil that encounters first year ridges may be incorporated into void spaces between the blocks of ice forming the keels of the ridges (Logan *et al.*, 1975).

Several studies in the past have investigated the movement of oil under ice by currents (Acres, 1980; Cox and Schulze, 1981; NORCOR, 1975; Rosenegger, 1975) and have concluded that there is a critical current speed below which oil does not move. For a perfectly flat under-ice surface, this speed is determined by the properties of the oil, and ranges between 5 and 10 cm/s. For ice with a small-scale roughness typical of newly-formed sea ice, the threshold speed increases to between 15 and 25 cm/s. For ice with numerous cavities the geometry of the cavities and the volume of oil in the cavities determines the threshold velocity, generally between 25 and 45 cm/s. Equations exist to predict oil movement and ice containment capabilities for various currents and ice roughnesses (Cox and Schulze, 1981).

Some oil floating upward may enter open water leads directly or a lead may form as contaminated ice separates, allowing oil into the lead. Oil in a lead will be driven to the downwind ice edge by wind. At the edge, the oil may be splashed onto the ice by waves. Also, if the oil slick is thick enough, or if under-ice currents exceed 0.5m/s it may flow under the ice. If the lead should close, the oil may flow onto or under the ice, or be trapped in a ridge. All oil exposed to the atmosphere in the ice or in open water will undergo some or all of the weathering processes outlined in Section 3.1.1.

Once spring arrives, first year sea ice warms toward the freezing point. In doing so, it becomes porous as brine leaches downward through the crystalline ice. If oil layers are beneath or frozen in the ice, the oil will float up slowly through the porous ice and appear on its surface. Once on the surface, the oil floats on water puddles where the wind can then splash it onto the surrounding snow and ice. Figure 3.1-6 shows that between June 1 and June 7, 1975, oil in an experimental test area increased its coverage from 12% to almost 50% as it floated up through first year sea ice (NORCOR, 1975). Once the oil is exposed to the atmosphere, the weathering processes of evaporation, emulsification and oxidation take place.

Once ice break-up occurs, the oil on the surface, will enter the water as a tarry residue. The fresh oil remaining in the ice at break-up will also be released. Thin sheens of oil will trail from melting floes. The ultimate fate of this oil is the same as that for oil in the open water case described in Section 3.1.1.

3.1.5 OIL DISCHARGE UNDER MULTI-YEAR ICE

Oil discharged under multi-year ice will spread under the same influences as oil released under first year ice.

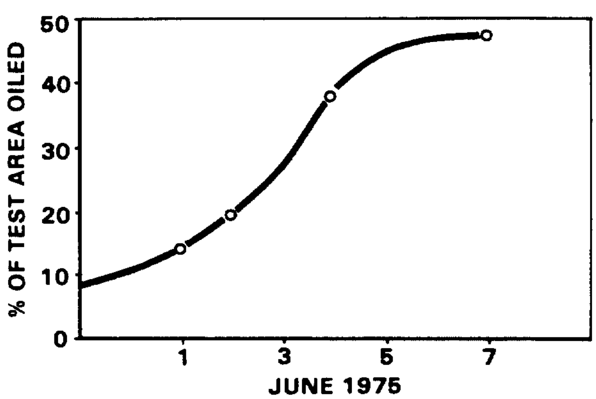

FIGURE 3.1-6 *Percentage of a test area which became oiled as a function of the date in June, 1975 (Source: NORCOR, 1975). Oil was discharged under first year sea ice in winter within a skirted circular test area. The sea ice continued to grow under the oil. In the following spring, oil began to rise through brine channels in the ice until by the 7th of June, 50% of the surface of the ice in the test area was covered by oil.*

It has been estimated that the thickness of oil which could be contained under multi-year ice will be, on average, about ten times thicker than that for first year ice. Multi-year ice would contain approximately 0.3 m^3/m^2 of oil, but, there are few data to substantiate this. (Comfort and Purves, 1980)

A study has shown that multi-year ice is permeable to oil but the upward migration process takes longer than through first year ice (Comfort and Purves, 1980). An experimental spill under multi-year ice in the High Arctic was initiated in 1978 and oil was still rising very slowly to the surface in 1981. It has been estimated that 90% of the oil rose to the surface during the first summer.

The oil that rises to the ice surface will collect in melt pools until the fall when freezing begins again. The surface oil, highly weathered from its exposure to the atmosphere, will be covered with snow and frozen-in until the next thaw cycle begins. In the event that a multi-year floe breaks away from the pack and begins to melt completely, it can be expected that the floe would leave a very thin sheen of oil in its wake, accompanied by patches of weathered oil residue.

3.1.6 OIL SPILL IN BRASH ICE

Oil spilled in brash ice, such as from the KURDISTAN spill in Cabot Strait in March, 1979, will be contained by the ice to some extent, but will eventually spread to cover the water surface between the floes and may contaminate the undersurface of the ice (Metge, 1978). The grinding action of ice has been observed to cause the oil to be dispersed into droplets less than 1 mm in diameter, throughout the resultant brash ice, and onto the edges of floes (C-CORE, 1980). As the oil weathers and the ice deteriorates and moves, a thin sheen and patches of heavily weathered oil will remain on the water.

3.1.7 SUBSEA OIL BLOWOUT UNDER ICE

The following description of how a subsea blowout would behave under sea ice is based on data obtained from a major experimental simulated blowout which was conducted in the Beaufort Sea at McKinley Bay during the winter of 1979-80 (Dickins and Buist, 1981).

In a subsea oilwell blowout, assumed to occur on the Beaufort Sea's shelf, oil would be discharged with large volumes of gas. Turbulence at the wellhead will break up the oil into droplets of various sizes, which will be carried toward the underside of the sea ice in the buoyant gas plume, along with entrained sea water and loose sediments. Figure 3.1-7 illustrates the general character of the blowout plume (which in the experiment was simulated in 20 m of water).

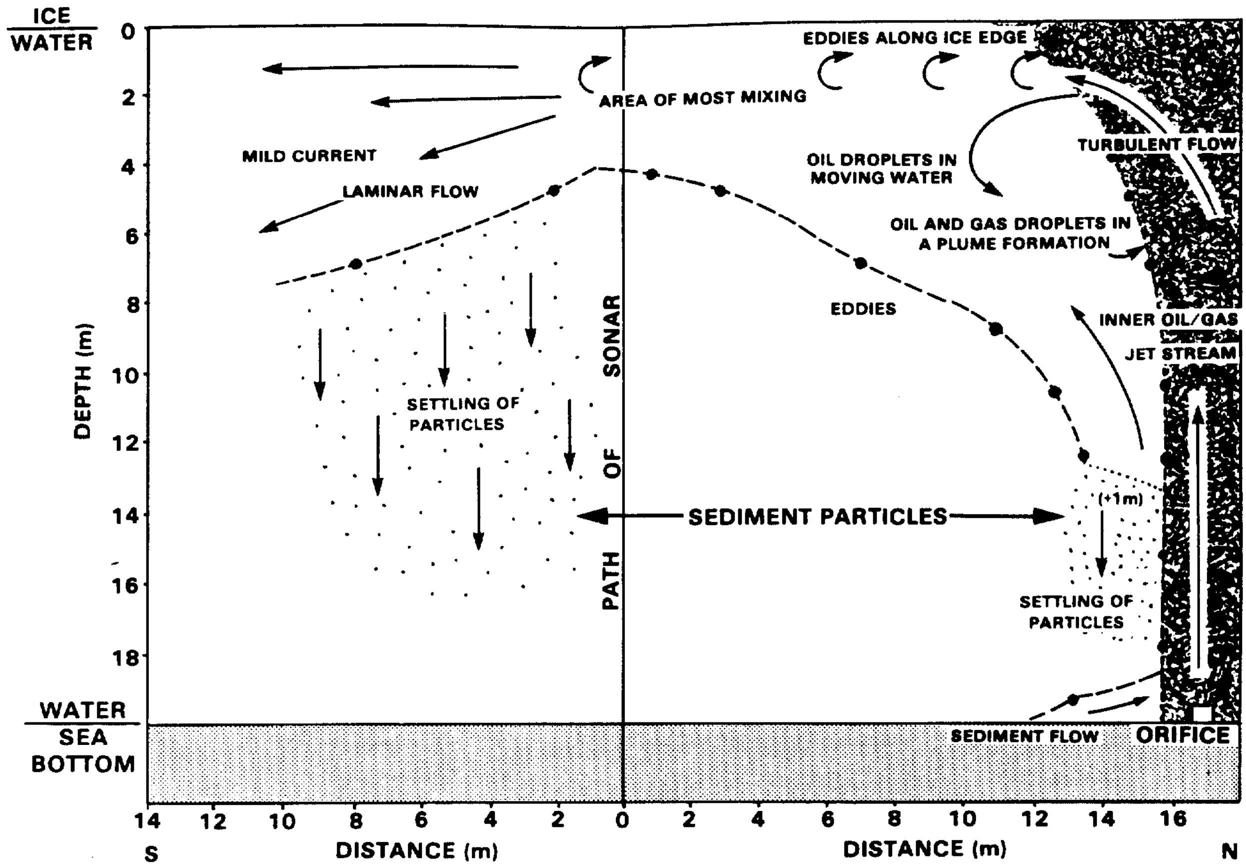

FIGURE 3.1-7 *Features observed in a simulated subsea oil well blowout under first year ice (Source: Dickins and Buist, 1981). In the winter of 1979-1980 an oil well blowout was simulated in order to examine the fate and behaviour of the oil and gas and means to cleanup the oil. The plume, delineated by a sonar device lowered through the sea ice, consisted of gas which broke up the oil into droplets and drew water and sediment upward toward the ice. The oil and gas settled under the ice and the sediment sank back to the bottom.*

At the underside of the ice, the entrained water carrying oil droplets turns 90° to create radial outward-going currents. These radial currents would normally be composed of water having a greater density than the near-surface waters so that they will sink, carrying with them small oil droplets. Under certain conditions, dependent on the gas flowrate and water depth, a semi-closed recirculation of water occurs. Larger oil droplets, comprising 80 to 90% of the oil, will initially settle under the ice in an area approximately the size of that influenced by the radial currents.

The gas appears to exert little influence on oil movement under the ice. In general, the gas will flow up-slope, possibly in a completely different direction than the residual currents and collect in under-ice depressions. If the ice is less than 1 m thick, the ice sheet could be ruptured by the gas.

If the blowout occurs under new ice with few cavities, such as first year ice in early winter, the oil will remain in droplet form under the ice. Under thicker, older ice most of the droplets will coalesce into pools under the ice.

If the postulated blowout occurs in winter, the oil in pools will soon be encapsulated by new ice growing beneath it. Scattered droplets will be frozen-in similarly. There is evidence that the gas will be encapsulated by new ice growth. After this the gas may slowly vent through the ice.

In spring, the encapsulated oil will become exposed on the top surface of the ice, either by the ice melting down to the oil droplets which had been deposited under new flat ice, or by oil from pools migrating through brine drainage channels forming in the warming ice.

Figure 3.1-8 illustrates the rate at which oil arrived at the ice surface from three separate simulated short-term blowouts initiated in December, April and May of the winter of 1979-80. In early June, the first oil

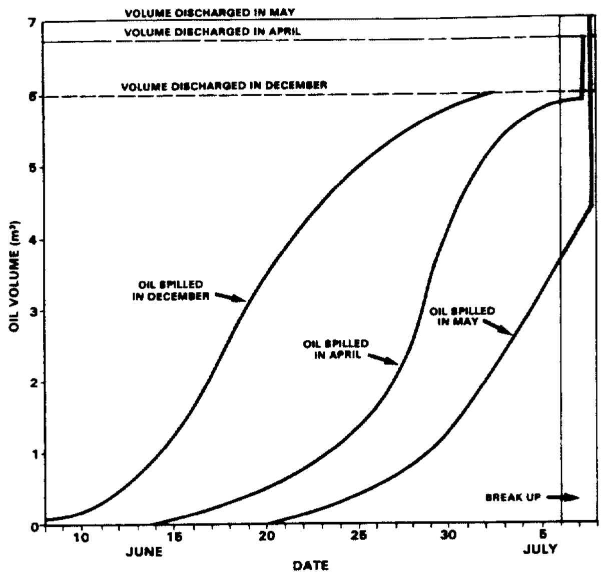

FIGURE 3.1-8 *The rate at which oil arrived at the surface of first year sea ice from three separate spills of oil and gas under the ice initiated in December, 1979, April and May, 1980 (Source: Dickins and Buist, 1981). The following June, oil began appearing on the surface of the ice, by break-up in July, most of the oil had surfaced comprising all of the December spill, 85% of the April spill and 60% of the May spill. The later spills were under progressively thicker ice, thus taking longer to surface.*

appeared from the December discharge, having been encapsulated under thinner ice than the oil in later discharges.

Figure 3.1-9, from the experiment, shows the size distribution of the resultant oil slicks on melt pools on the ice surface in spring; most of it was contained in large pools. As the oil emerged it was in a fresh state and was easily set on fire by using igniters.

3.2 PROPERTIES OF BEAUFORT SEA CRUDE OIL

Although the descriptions in Section 3.1 apply to crude oils with a range of physical and chemical properties, it is nevertheless important to know the properties and behaviour of oils for which countermeasures systems are to be designed.

The following describes some properties of Beaufort Sea oil. It must be remembered that oils with a range of properties are commonly extracted from a producing region, or for that matter, from a single well. Once blended and processed, the oil properties may change.

Physical analysis of a sample of Kopanoar crude oil has been carried out at the University of Toronto (Mackay *et al.*, 1980). Table 3.2-1 presents the important characteristics of this oil. The oil could be classified as a "medium gravity" crude, is relatively low in

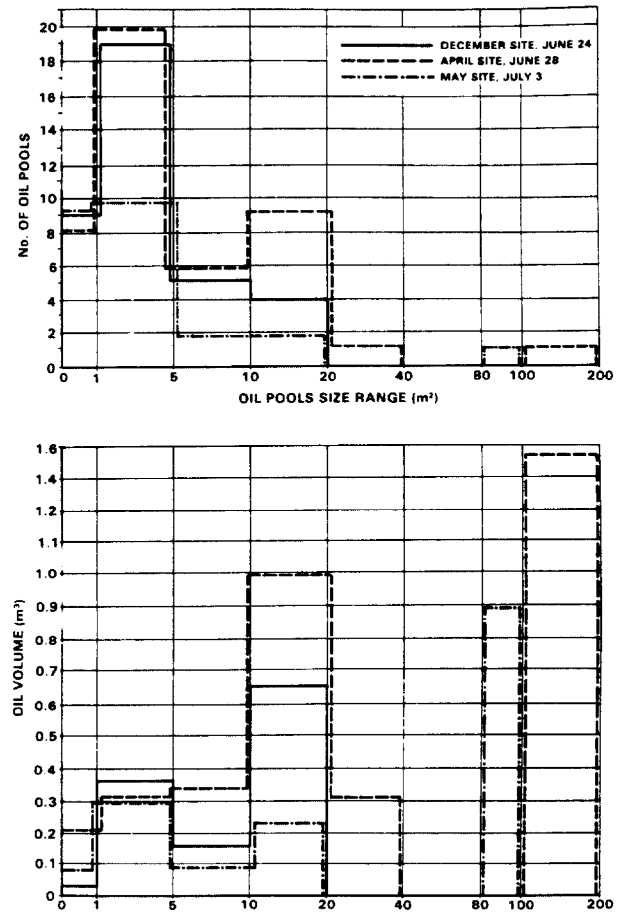

FIGURE 3.1-9 *The number of oiled melt pools (upper graph) and the volume of oil contained in these pools (lower graph) versus the size of the pools resulting from an experimental subsea oil blowout under ice (Source: Dickins and Buist, 1981). Although the largest number of pools are small most of the oil is contained in the few large pools. This is advantageous in terms of aerial deployment of igniters as the large pools can be more effectively ignited and the burning of only these few large pools will dispose of most of the oil.*

TABLE 3.2-1

SOME PROPERTIES OF KOPANOAR CRUDE OIL

% Mass Loss due to evaporation	Pour Point (°C)	Flash Point (°C)	Specific Gravity (g/cm³)	Viscosity (cps) 0°	15°	25°C
0	-37	75	.900	57	33	175
3.7	-28	86	.901	75	41	24
11.6	-19	118	.902	104	54	30

Definitions:

1. Pour Point: the temperature at which the oil becomes a semi-solid or "plastic" and will not flow.
2. Flash Point: the temperature at which the oil's vapours will ignite when exposed to an ignition source such as an open flame.
3. Specific Gravity: the ratio of the mass of the oil to the mass of an equivalent volume of water.
4. Viscosity: viscosity is a measure of the flow resistance of the oil, the lower the viscosity, the easier it flows. Fresh water has a viscosity of 1 cps at 20°C.

Source: Mackay et al (1980).

viscosity and will flow at the temperatures of Arctic waters. This means that this oil if discharged under sea ice, will easily migrate upward through brine drainage channels in the ice for subsequent recovery or burning in the spring. It will also remain fluid on water for subsequent physical recovery and can be chemically dispersed. In fact, comparative laboratory tests have shown that this oil is relatively easy to disperse using available chemical dispersants.

It is not as soluble in water as other crude oils and thus it may be less toxic (Mackay *et al.*, 1980). It also tends to form stable water-in-oil emulsions under certain conditions. These emulsions are often formed when oil is vigorously mixed with water such as on a rough sea or in a blowout plume. Stable water-in-oil emulsions are extremely viscous, difficult to pump, disperse, and sometimes, ignite. The fate, behaviour and cleanup of water-in-oil emulsions in ice are the subject of an ongoing research program detailed in Volume 7.

Four oils from the nearshore area and onshore discoveries have been analyzed by Esso. These data are summarized in Tables 3.2-2 and 3.2-3. The viscosity data indicate that skimming, processing and pumping of Issungnak oil may be difficult at low temperatures. The other oils, when weathered, also have high viscosities at low temperatures. This would indicate that *in situ* burning would be a suitable alternate countermeasure. The fire points are well within the range of crude oils burned *in situ* on ice (Dickins and Buist, 1981).

It should be noted that the density of even the heavily weathered crudes does not approach the density of water. As such the oil can be expected to float.

The distillation data given in Table 3.2-3 indicate that both Issungnak and Mayogiak oils contain a significant fraction of volatile components and would be expected to evaporate readily. This has been confirmed by gas chromatography (Esso, 1982). The Adgo oil would not be expected to evaporate significantly.

As further data are collected through ongoing exploration programs, the spill response equipment will be optimized for the range of oils expected.

3.3 SUMMARY

The fate and behaviour of oil in both water and ice is generally well understood. Similar weathering processes are undergone by the oil upon its exposure to the atmosphere whether it is on ice or water. The incorporation of oil within growing ice and its appearance on the ice surface in spring have been documented. The information contained in this chapter is used to evaluate countermeasures equipment (Chapter 5), to delineate response strategies (Chapter 6) and to determine the possible impacts of oil (Chapters 4 and 6) spilled into Arctic ecosystems.

TABLE 3.2-3
BEAUFORT OIL DISTILLATION DATA

Sample	TEMPERATURES (°C)								
	0% WEATHERING			4% WEATHERING			12% WEATHERING		
	IBP	50% OFF	FBP °C (%OFF)	IBP	50% OFF	FBP °C (%OFF)	IBP	50% OFF	FBP °C (%OFF)
Issungnak	-5	254	448 (FBP)	38	276	544 (96%)	83	283	538 (98%)
Mayogiak	-2	318	555 (94%)	55	336	554 (88%)	146	376	558 (83%)
Atkinson	40	372	555 (81%)	88	383	553 (79%)	131	404	556 (77%)
Adgo	159	329	535 (93%)	170	326	542 (96%)	205	348	538 (87%)

Source: Esso, 1982

TABLE 3.2-2
BEAUFORT OIL PROPERTIES

WELL NAME	STATE of WEATHERING	Viscosities (mm²/sec) -10° C	0° C	15° C	25° C	FLASH-POINT (° C)	FIRE-POINT (° C)	POUR POINT (° C)	DENSITY @ 20° C
Atkinson	0°	304.8	136.2	57.28	34.94	10	26	-38	.9060
	4°	762.7	317.0	113.6	62.05	32	50.5	-35	.9172
	12°	2506	783.7	245.0	124.4	75	95	-28	.9239
Adgo	0°	661.3	233.9	73.01	39.83	95	116	-26	.9520
	4°	724.5	263.6	79.08	42.72	94	123	-26	.9526
	12°	1302	413.8	103.2	53.58	126	129	-26	.9546
Mayogiak	0°	752.1	67.27	17.04	9.702	-12	-12	-30	.8625
	4°	1023	98.35	29.88	18.33	47	64	-26	.8727
	12°	d.f.	414.3	56.37	30.41	66	76	-18	.8848
Issungnak	0°	d.f.	199.4	3.652	3.005	-10	-10	5	.8284
	4°	d.f.	d.f.	6.008	4.564	-16	-16	6	.8459
	12°	d.f.	d.f.	6.248	4.566	48	57	7	.8469

d.f. — did not flow
Source: Esso, 1982

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CHAPTER 4

BIOLOGICAL EFFECTS OF OIL SPILLS

One of the greatest concerns with oil spills is how and to what extent the environment may be damaged. Volumes 3A, 3B, and 3C of this EIS describe the animals and plants of the regions and how they have and are continuing to be influenced by natural variables. This chapter provides a summary of the scientific literature on the effects of oils on the biota and how this information might be relevant to the animals and plants of the Arctic. This information is used in Chapter 6 to assess the possible impacts of hypothetical spills. Special emphasis has been placed on the biota inhabiting the marine environment, where most activities involving oil production and the transfer thereof are projected to take place. A review of the literature on biological effects of major marine oil spills around the world (approximately 100 incidents) is available as a support document to this Volume (Duval *et al.*, 1981).

The possible effects of oil spills and the duration of damage are dependent on many factors including the type and volume of oil spilled, the time of the year, the success of the spill response, and the type of habitat oiled. This makes it difficult to predict the impact of future spills, although a range of effects can be anticipated. Assessment of the potential impacts of oil spills is further complicated in Arctic marine environments by the limited number of case histories and laboratory data available for Arctic regions. Of the 100 case histories reviewed (Duval *et al.*, 1981) only 19 events occurred north of 55°N latitude and only five of these (SEALIFT PACIFIC*, Deception Bay, JOS. SIMARD, U.S.N.S. POTOMAX and BRITISH MALLARD) occurred in Arctic waters. One purpose of the Baffin Island Oil Spill program (BIOS) (see Chapter 5) is to provide more information on the effects of oil in nearshore and shoreline Arctic environments. There are enough data to allow assessment of some of the potential impacts of Arctic oil spills, particularly on some bird and marine mammal populations.

The following briefly summarizes the knowledge on the impacts of oil on the different biological resources. For more comprehensive information, the reader is referred to Duval *et al.* (1981).

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* all ships are named with upper case letters place names or fixed platforms are lower case

4.1 TERRESTRIAL PLANT COMMUNITIES

In low-lying regions of the coastal Arctic, the potential for contamination of shoreline and backshore plant communities exists because of the occurrence of storm surges, waves and high onshore winds (Owens, 1977). Driftwood in McKinley Bay, Tuktoyaktuk Peninsula, has been observed at about 2.5 m above mean sea level and up to 300 m inland (Mackay, 1974). This indicates the distance oil could move inland. Videotape records of the entire Beaufort Sea coastline from Herschel Island to Cape Bathurst (Woodward Clyde Consultants, 1980) indicate other locations where spilled oil could be deposited up to 500 m inland. The potential for contamination of terrestrial plant communities is generally limited to the brief open water season. It has been suggested that oil deposited in areas above those affected by normal wave activity could persist for a long time. The slow rates of microbial degradation in Arctic environments (Westlake, 1981) would also contribute to the persistence of this oil.

The oil spill literature reviewed is of limited use for the prediction of possible oil spill impacts on Arctic backshore vegetation. The TORREY CANYON, AMOCO CADIZ and ESSO ESSEN spills all resulted in damage or mortality to terrestrial plants. Recovery was evident after a few weeks in the ESSO ESSEN spill (Stander and Venter, 1968) but required several years in the case of the TORREY CANYON grounding (Southward and Southward, 1978). The impacts of oil spills on Arctic terrestrial vegetation would likely be greater than those observed in temperate latitudes because of the slow growing mosses, grasses and sedges, and the presence of permafrost. For assessing the potential impacts of oil on backshore vegetation along the Arctic coast, the accidental and simulated spills that have occurred in Alaska and Yukon are the best predictive tool.

Hunt *et al.*, (1973) reported extensive mortality of vegetation following several spills from ruptured pipelines. These authors reported little evidence of recovery of terrestrial vegetation at sites of either JP-4 aircraft fuel or diesel fuel spills after 5 to 15 years. The best recovery occurred on hummocks and in areas where abundant rainfall leached (washed) the petroleum hydrocarbons from the soil. Similar contact mortality and slow recovery of terrestrial vegetation was also observed after a diesel spill in the Yukon (Swader, 1975). In another study, Atlas *et al.*, (1976) reported that terrestrial habitats near Prudhoe Bay where natural oil seepages occurred were virtually devoid of vascular plants (such as grasses and sedges). Experimental applications of crude oil have also caused widespread damage and subsequent slow recovery of Arctic terrestrial plant communities (eg.

Hutchinson and Freedman, 1975). Similar results were also found for plants and algae along the margins of a subarctic lake (Hellebust *et al.*, 1975). Laboratory studies have indicated that petroleum hydrocarbons affect vascular plants in several ways including decreased root and shoot growth, delayed and reduced flowering, and disruption of respiratory and photosynthetic processes (Blackenship and Larson, 1978; Baker, 1970, 1971).

Another potential concern with respect to Arctic backshore plant communities is damage to permafrost integrity caused by oil, or more often, by cleanup activities. Soil types which are especially susceptible are ice-rich silty substrates which tend to slump when melted (Hunt *et al.*, 1973). These authors reported that permafrost was not affected at those oiled sites where the hydrocarbons did not penetrate the surface vegetation mat or the substrate was not disturbed by the use of heavy cleanup equipment.

An oil spill which contaminates backshore tundra environments would likely cause the mortality of most vegetation contacting the oil. The damage would be greater with fresh crude or refined fuels (Craddock, 1977), such as jet fuel, gasoline or No. 2 diesel. The damage could be relatively long-term, requiring up to a decade or more for recovery of heavily contaminated sites along the Beaufort coast. Impacts on vegetation would probably be increased if the cleanup response involved the use of heavy equipment. Recovery would probably be most rapid in areas where the oil was left to naturally weather and degrade. This could increase the risk of additional and relatively long-term indirect impacts on birds and mammals using these habitats.

4.2 PLANKTONIC COMMUNITIES

This section discusses the effects of oil on plankton, the small, free-floating plants (phytoplankton) and animals (zooplankton) that live in water.

The effects of oil on phytoplankton have been reviewed by Corner (1978), Vandermeulen and Ahern (1976), Johnson (1977) and Snow (1981). Observations of changes in phytoplankton communities were also taken following the Mizushima, Santa Barbara, TSESIS, TORREY CANYON, ARGO MERCHANT and SANSENINA spills (see Duval *et al.*, 1981). These literature sources indicate that there have been considerable differences in the responses of phytoplankton to oil, ranging from stimulated growth to marked reductions in productivity and changes in species composition. These effects are generally short-term.

Several trends reported in past spills provide information for the assessment of the potential impacts of oil spills in northern environments. The water-soluble components of crude oils and refined products, particularly volatile aromatics, tend to be responsible for most toxic effects. As a result, refined products such as diesel fuel reduce phytoplankton growth and production more than crude oils (Anderson *et al.*, 1974a). Studies conducted by Hellebust *et al.* (1975) and Kauss and Hutchinson (1975) indicate that the inhibitory effects of oil on phytoplankton growth diminish with weathering of the oil.

The effects of oil on phytoplankton also vary with the concentration of water-soluble components. Low concentrations often stimulate growth and high concentrations generally retard growth (Dunstan *et al.*, 1975). Studies done with Beaufort Sea phytoplankton suggest that some (flagellates) are more resistant to crude oil than others (centric or pennate diatoms) (Hsiao, 1978). The effects of petroleum hydrocarbons on phytoplankton may also vary with season (Snow, 1981).

The impacts of oil spills in Arctic marine environments such as the Beaufort Sea are likely to be variable. They will be influenced by many factors including the species present at the time of the spill, the type and concentration of oil and its weathered state. The initial response of the Beaufort Sea phytoplankton community would probably be a localized decrease in the growth and productivity of diatoms. This would likely be followed by the stimulated growth of flagellates as the water column concentration of oil gradually decreases (eg. Hsiao, 1978; Lee *et al.*, 1977; Dickman, 1971). Any changes in the community structure, productivity and abundance of phytoplankton would be relatively short-term due to the weathering and dissipation of the oil and replacement of phytoplankton from unaffected areas by ocean currents. The gradual release of oil trapped in shoreline areas could however, result in longer term but localized effects on nearshore phytoplankton.

In the Beaufort Sea, seasonal and geographic differences in the sensitivity of phytoplankton to oil spills can be expected due to their variation in distribution. The more susceptible ones (diatoms) predominate in spring and in nearshore waters (Volume 3A).

4.2.1 ZOOPLANKTON

The effects of oil on zooplankton have been reviewed by Kuhnhold (1977), Corner (1978) and Wells (1981). The impacts of oil spills on zooplankton were also examined following the Santa Barbara and Ekofisk Bravo blowouts and the TORREY CANYON, Anacortes, USNS POTOMAC, SANSENINA, TSESIS, ARGO MERCHANT, AMOCO CADIZ and ARROW spills (see Duval *et al.*, 1981). As with phytoplankton, laboratory and field studies have indicated that oil has a range of effects on zooplankton. Since crustaceans account for most of the zooplankton in the Beaufort Sea, this section focuses on the impacts of oil spills on these invertebrates. The young (larvae) of worms (annelids), clams and snails (molluscs) and starfish (echinoderms), are discussed in Section 4.4, while the effects of oil on fish eggs and larvae are discussed in Section 4.2.2.

Laboratory studies are important in the assessment of the potential impacts of oil spills on planktonic crustaceans in Arctic waters. For example, there are marked differences in the sensitivity of copepods (a small shrimp like creature) to the water-soluble fractions of oil. Wells (1981) reports that the water-soluble fractions cause paralysis of copepods at concentrations as low as 0.2 to 0.5 mg/L, and dispersed oil is lethal at concentrations from 0.05 to 100 mg/L. Dispersed light fuel oils are more toxic to copepods than are dispersed crude oils (Wells, 1981).

Studies following the grounding of the ARROW in Nova Scotia (Conover, 1971) and the TSESIS spill in Sweden (Linden *et al.*, 1979) show that some copepod species ingest particles of oil. Zooplankton feeding on algae and dispersed oil may be a natural method of removing oil from the water column. In the process of ingesting this oil the copepods can accumulate hydrocarbons in their tissue. The results of this can be reduced reproduction and longevity (Ott *et al.*, 1979).

Other crustaceans which form major proportions of the zooplankton community during some months are the larval stages of amphipods, mysids and decapods. Larval amphipods are more sensitive to oil than are adults (Wells, 1981). Laboratory research indicates that juvenile mysids and decapods in the plankton are even more sensitive to dispersed oil than amphipods, and may show a range of sublethal effects when exposed to low hydrocarbon concentrations. These include paralysis, reduced rates of development and feeding, and delayed moulting (Wells, 1981).

With the exception of the TORREY CANYON spill (Duval *et al.*, 1981) where large quantities of toxic first-generation dispersants were used, only localized and short-term impacts on zooplankton have been reported from oil spills. However, many of the sublethal effects observed in laboratory studies were probably undetected in the field. Given the relative sensitivity of many species, particularly the larval stages of amphipods, decapods and mysids, some mortality of zooplankton is probable after most oil spills.

The impacts of oil spills on Arctic zooplankton would be highly dependent on the time, size, location and duration of the spill, as well as the amount and type of oil spilled. Subsea blowouts would likely have greater effects on zooplankton than a single surface spill. It would be a continuous and longer term source of unweathered crude, and the oil would have a greater opportunity to dissolve into the water column before reaching the surface. Impacts would be greater at locations and during months when the planktonic stages of mysids, decapods and amphipods were present. An oil spill or blowout early in the open water season could result in localized impacts which persist for much of the year due to residual sublethal effects such as decreased feeding and reduced rate of development. The tendency for zooplankton to accumulate naphthalenes (a component of oil) in their tissues could also result in indirect impacts on members of higher trophic levels. It is anticipated that the impacts would be relatively short-term due to recruitment of individuals from uncontaminated areas.

4.2.2 FISH EGGS AND ICTHYOPLANKTON (Larval Fish)

This section discusses the effects an oil spill in Arctic waters could have on the planktonic eggs and larvae of marine fish.

Laboratory studies and literature from actual spills indicate that oil can cause direct mortality and abnormal development of fish eggs and larvae. Mortality of eggs or larval stages of herring, pilchard, cod, pollock, sandlance and redfish was documented after several oil spills including those from the ARGO MERCHANT, TSESIS, and TORREY CANYON tanker accidents, and the recent Ixtoc I blowout in the Gulf of Mexico (see Duval *et al.*, 1981).

Laboratory studies indicate that ichthyoplankton are generally more sensitive to oil than are adult fish (Craddock, 1977; Penrose, 1981). Wells (1981) reported that fish eggs are usually less sensitive to oil than are larvae. The most vulnerable period appears to be during and immediately after hatching. Struhsaker (1977) found that survival of Pacific herring eggs was reduced if spawning females were exposed to an aromatic hydrocarbon for several weeks. Herring are particularly susceptible to oil because they generally deposit their eggs in shallow subtidal areas which are most likely to be oiled (Wells, 1981). Other effects of oil which have been observed in the laboratory and which may occur following oil spills are slower embryonic growth, changes in heart activity, decreased hatching success, irregular swimming behaviour, paralysis, tissue damage, reduced feeding, altered respiration rates and various external and internal body deformities (Wells, 1981; Smith and Cameron, 1979; Stoss and Haines, 1979).

An oil spill in Arctic waters could affect the eggs and planktonic larvae of marine fish species such as polar cod, Arctic cod, various flounders and soles. Larvae of certain anadromous species such as boreal smelt could also be affected as they are common off the Mackenzie Delta in summer. In all cases, the lethal and sublethal impacts of oil spills on fish eggs and planktonic larvae would be highly dependent on the degree of exposure to oil, and the location and time of a spill. In a local context, such as in a lagoon these effects could be relatively serious, affecting a substantial portion of a local population of some marine species. However, recruitment and transport of eggs and larvae from unaffected areas would minimize the regional impact of oil spills in Arctic environments.

4.3 EPONTIC BIOTA

Epontic biota are the small plants and animals associated with the under-ice surface. Effects of oil on epontic life have been documented following simulated oil spills in the field. Acreman *et al.* (1980) observed abnormal deposits and possibly oil or tar particles inside diatoms as well as extensive diatom mortality in a limited number of ice cores from an oil under-ice experiment near McKinley Bay.

Epontic life would be particularly vulnerable in the event of a winter subsea blowout. Oil initially trapped beneath the ice would likely result in the mortality of flora and fauna contacted. The area of impact would depend on the duration of the blowout, the irregularity of the under-ice surface, water currents and the rate of oil encapsulation as described in Chapter 3. Once encapsulated, the impact of the oil on the epontic community would be expected to be minimal.

Unlike the situation with plankton, there would be less opportunity for recruitment of epontic flora and fauna from adjacent uncontaminated areas. The impacts on epontic communities would be most serious in late spring and early summer prior to break-up when they are more abundant. In addition, impacts on epontic biota could have further indirect impacts on members of higher trophic levels known to feed on them during this period. The significance of these secondary impacts would depend on the size and location of the area contaminated.

4.4 BENTHIC FLORA AND FAUNA

The effects of oil on benthic life (living in or on the seabottom) have been the subject of intensive laboratory research and field investigations following oil spills (Duval *et al.*, 1981; Percy, 1981; Craddock, 1977; Johnson, 1977).

Two major factors will minimize the impacts of oil spills on intertidal communities in the Arctic and particularly the Beaufort Sea. First, the vertical extent of the intertidal zone (area between the high tide mark and low tide mark) is very small, averaging less than 1 m throughout most of the region (Owens, 1977). Secondly, it is virtually devoid of biota for much of the year as a result of ice (Clark and Finley, 1977; Owens, 1977). In the intertidal zone of the Beaufort and Chukchi seas only fish and epibenthic invertebrates are present during the summer. However, some eastern Arctic and subarctic shores which are not subjected to as much ice scour have a more varied and plentiful life.

Both Percy (1981) and Duval *et al.*, (1981) have noted that impacts of past oil spills on benthic and intertidal organisms have ranged from little or no observable biological damage to extensive habitat damage and massive mortalities. Percy (1981) reports that the intertidal zone and adjacent shallow subtidal areas in the Beaufort Sea are particularly vulnerable to contamination, at least in those low energy habitats not subjected to much wave action or tidal flushing.

4.4.1 BENTHIC MACROPHYTES (Seaweeds)

The effects of oil on benthic plant communities have been documented following several spills, but there are limited data available for Arctic and subarctic environments.

The most serious and long-term damage to intertidal plant communities has resulted from some large bunker or crude oil spills, particularly when first generation dispersants were used nearshore during the cleanup program. For example, extensive mortality of *Fucus* (a brown alga found in some Arctic coastal waters) was reported after the grounding of the tanker ARROW in Chedabucto Bay, Nova Scotia. Persistent effects were still apparent after two years (Anon., 1970). In the case of the TORREY CANYON and Coryton spills in England, major damage to *Fucus* and other intertidal algae was caused by use of first generation dispersants (Duval *et al.*, 1981). However, more recent experience with new dispersants, such as those used during the Ixtoc I incident, showed that little environmental damage resulted from their use (Ross *et al.*, 1979).

Visible damage to subtidal kelp communities resulted from the TAMPICO MARU, GENERAL M.C. MEIGS, UNIVERSE LEADER, ARGEA PRIMA spills and the Santa Barbara blowout (North *et al.*, 1965; Clark *et al.*, 1973; Cullinane *et al.*, 1975; Diaz-

Piferrer, 1962; Foster *et al.*, 1971). Impacts of these spills included detachment of plants from the seabottom, bleaching and direct mortality. The results of several laboratory studies with marine algae also suggest that sublethal effects of oil may include reduced RNA and DNA synthesis (Davavin *et al.*, 1975), induction of cancerous growths (Boney, 1974) and decreased germination and growth of young plants (Steele, 1977).

Benthic macrophytes are not as prevalent in most of the Canadian Arctic as they are in temperate waters. This is due to the small tides, intensive ice scour and soft substrates found in most areas of the Arctic. In the Beaufort Sea, benthic macrophytes are usually restricted to the few areas where there is rock such as Elson Lagoon and Stefansson Sound in Alaska, and Liverpool Bay. Consequently, the potential impacts of oil spills on seaweeds would be very localized. The dominant subtidal kelp in the Arctic are *Laminaria* spp. which would be susceptible to damage from oil spills.

4.4.2 BENTHIC WORMS

The effects of oil on marine worms are relatively well documented as a result of numerous laboratory investigations (Craddock, 1977; Johnson, 1977) and several oil spill case histories. Worms are common in shallow, sedimentary marine environments, particularly in the Beaufort Sea because of the soft sediments (Volume 3A).

A number of worm species found in the Arctic are known to be resistant to oil pollution (Carr and Reish, 1977; George, 1971; Sanders, 1978). Other species have been found to be very sensitive to oil in laboratory studies and field investigations (Prouse and Gordon, 1976; Rossi and Anderson, 1978; Wharfe, 1975). Atlas *et al.*, (1978) reported that three species of Beaufort Sea worms seemed to prefer oil-contaminated sediments while a fourth preferred clean sediments.

Among the most frequently observed sublethal effects of oil have been immobilization, narcosis, disorientation, convulsions and also reduced feeding, growth and reproduction, (Chia, 1973; Carr and Reish, 1977; Kasymov and Aliev, 1973; Prouse and Gordon, 1976; Akesson, 1975; Rossi and Anderson, 1978; Lyles, 1979).

In the Beaufort Sea, the potential for serious and long-term impacts on marine worms may be higher due to the shallow nature of most areas. These shallow depths would increasehe likelihood of considerable quantities of oil reaching the substrate. The high sediment load of the Mackenzie River could also increase the amount of oil reaching the seabottom due to the sediment's sinking effect on small oil droplets. The oil may persist for long times in the sediments due to the potentially slow rates of biodegradation in the Arctic. Relatively minor indirect impacts on higher members of the food chain would be expected from reductions or increases in the abundance of worms (LGL and ESL, 1982).

4.4.3 BENTHIC CRUSTACEANS

Impacts of oil spills on benthic crustaceans in Arctic environments would likely be greatest when larval forms are most abundant, since it is generally accepted that juvenile stages are most susceptible to both emulsified oil and soluble petroleum constituents (Craddock, 1977).

Numerous laboratory and field studies have shown that the most serious impacts of an oil spill in the Beaufort Sea would result when shallow nearshore habitats were contaminated with oil (Duval *et al.*, 1981). The impacts of spills on Arctic benthic crustaceans would vary with season, oil type, and location. Conditions which favor the dispersion of oil throughout the water column would tend to increase the degree of impact on amphipods, isopods and mysids, since concentrations of soluble fractions of the oil would be higher and the opportunity for incorporation of oil is greater. The presence of high suspended sediment concentrations in nearshore waters of the Beaufort Sea during the spring and summer could also increase the amount of oil reaching bottom habitats due to sinking, and increase the degree of impact of an oil spill on benthic crustaceans in these areas. Several species are known to be indiscriminate particle feeders and may ingest oil as part of the normal feeding process.

An oil spill in the nearshore region could result in a reduction of amphipods and mysids, which are important food items in the diet of various species of fish, birds and marine mammals. The case histories of past spills indicate that recovery of mobile species would be relatively rapid, with the rate of recovery being dependent on the disappearance of oil from contaminated sediments, or the burial of contaminated sediments by clean sediments brought down by rivers draining into the Beaufort Sea. Benthic crustaceans from adjacent uncontaminated areas would recolonize affected areas, with the more oil resistant groups such as isopods rebounding earlier than the sensitive juvenile stages and adults of amphipods and mysids.

Numerous sublethal effects of oil exposure on benthic amphipods, isopods and mysids may also occur. A variety of physiological and behavioral dysfunctions have been observed with these organisms (Duval and Fink, 1980; Duval *et al.*, 1980; Anderson *et al.*, 1974a, b,, 1979; Percy and Mullin, 1975; Johnson, 1977; Percy, 1977, 1978; Milovidova, 1974; Ott *et al.*, 1978 and others). Although many of the sublethal effects have been shown to disappear once oil concentrations in the water are reduced (Duval *et al.*, 1980), long-term sublethal effects may occur when oil persists in sediments. Of greatest concern in this regard are those sublethal effects which may be considered ecologically significant (Percy, 1981); these effects include decreased growth, delayed moulting, decreased carbon assimilation and any interference with reproductive processes.

4.4.4 BENTHIC MOLLUSCS

The effects of oil on snails (gastropods) and clams (bivalves) have been well documented in both laboratory investigations and oil spill case histories. There was extensive mortality of the clam *Mya arenaria* following the grounding of the tanker ARROW in Chedabucto Bay, Nova Scotia, while the intertidal snail *Littorina* spp. was still relatively abundant in areas that were not heavily contaminated. Major mortality of mussels *(Mytilus)* was reported following the Deception Bay and IRINI refined fuel spills, while only sublethal effects including uptake of hydrocarbons were reported after the T.T. DRUPA crude oil spill and TSESIS bunker fuel spill. All of these events, except the ARROW incident, occurred in waters north of 55°N latitude (Duval *et al.*, 1981).

A variety of sublethal physiological and behavioral effects, including loss of attachment, narcosis and decreased respiration, have been noted in snails (Dicks, 1973; Ehrsam *et al.*, 1972; Griffith, 1970; Hargrave and Newcombe, 1973; Linden, 1977; Baker, 1973; Jacobson and Boylan, 1973; Blake, 1960; Eisler, 1975; Brown *et al.*, 1974). Similar sublethal effects on snails inhabiting Arctic waters can be expected, although none have been reported.

The sublethal effects of oil have been examined in at least four genera of bivalves known to occur in the Beaufort Sea *(Macoma, Mya, Mytilus and Pecten* spp.). A wider range of sublethal effects have been observed in bivalves than in snails, and many of these behavioural and physiological aberrations are considered ecologically critical (Percy, 1981). Although many of these effects have also been shown to be completely reversible, persistent exposure of bivalves to low levels of petroleum hydrocarbons could result in long-term behavioural and physiological effects which decrease overall productivity and reproductive success.

Oil spills in Arctic marine environments could result in both acute lethal and chronic sublethal effects on snails and bivalves. As in the case of most benthic invertebrates, the severity and duration of these impacts as well as recovery of affected habitats would vary with the amount of oil reaching the substrate and its subsequent breakdown. The most susceptible molluscs would probably be the bivalves due to their relative immobility. Recovery of snail populations would likely begin more quickly than for bivalves because of their ability to move in and recolonize from adjacent uncontaminated areas. Depending on the degree of persistence of oil in the sediments, initial recolonization by more oil-resistant snail species could begin within a year, while complete recovery of bivalve populations could require several years. The indirect effects of loss or contamination of molluscs or higher members of the food chain in the Beaufort Sea would probably be less than that for benthic crustaceans similarly affected, since crustaceans tend to be preferred food items for a much larger number of fish, birds and marine mammals. Nevertheless, indirect impacts on fish such as whitefish and flounders, birds such as eiders, oldsquaw, scaup and scoters, and mammals such as bearded seal and walrus could result from decreased abundance or contamination of molluscs in the Beaufort Sea region.

4.4.5 BENTHIC ECHINODERMS (such as Starfish and Sea Urchins)

An oil spill or blowout in the Beaufort Sea would probably be less serious for echinoderms in this region than for other major invertebrate groups. Firstly, echinoderms are generally not found in waters less than 15 m deep (Wacasey, 1975) where some of the oil could be expected to be sedimented and secondly, their relatively high mobility would allow recolonization from adjacent unaffected habitats. In addition, echinoderms are not important food items for vertebrates in the Beaufort region, thereby minimizing potential indirect impacts on other members of the food web.

4.5 FISH

There is a substantial body of literature documenting the toxic and sublethal effects of oil on marine fish, although direct mortality has rarely been observed following actual oil spills. It is generally accepted that larval fish are far more sensitive to oil than are adults. Numerous sublethal effects of oil on fish have been observed in the laboratory.

Fish were included in followup studies initiated after four northern spills examined by Duval *et al.* (1981). After the TSESIS bunker fuel spill in Sweden no mortality of adult fish was observed. Temporary tainting of several species was documented as a result of the Ekofisk Bravo blowout in the North Sea.

McCain *et al.* (1978) exposed a northern flatfish species to experimentally oiled sediments over a four month period to assess the uptake and distribution of crude oil components within the fish. Flatfish maintained in sediments containing 700 μg oil/g of dry sediment readily absorbed alkane and aromatic fractions and accumulated them in their skin, muscle and liver. After two months, less than 2% of the initial aromatic hydrocarbons could be detected, and then only in the livers of flatfish which were continuously exposed to oiled sediments. During the period of high hydrocarbon content in the body, the researchers noted weight loss and pathological changes in liver cells.

The most important sublethal effects of hydrocarbons which may be of ecological significance to Arctic marine fish populations are the possible uptake of aromatic hydrocarbons by tissues, particularly the brain and liver (DeMichele and Taylor, 1978; Collier *et al.*, 1978; Roubal *et al.*, 1978; Duval and Fink, 1980; and others), the destruction of blood cells and damage to the spleen and kidney (Waluga, 1966), the induction of developmental abnormalities (Smith and Cameron, 1979; Stoss and Haines, 1979), the development of eye cataracts (NMFS, 1979), reduced hatching success (NMFS, 1979), and reduced feeding activity (Korn *et al.*, 1979; Wang and Nicol, 1977). As was often the case with many sublethal effects observed with invertebrates, many of the abnormalities found after exposure of fish to petroleum hydrocarbons are completely reversible. For example, fish appear to have a great ability to metabolize and cleanse themselves of hydrocarbons, even better than most invertebrates (e.g. Duval and Fink, 1980; Penrose, 1981).

Although some species of fish avoid low concentrations of oil, other species apparently do not automatically avoid harmful levels of petroleum, even if they are able to detect them (Penrose, 1981). For example, pink and coho salmon fry showed avoidance responses at oil concentrations as low as 1.0 to 1.6 ppm in seawater (Rice, 1973; Duval and Fink, 1980), while both pink salmon fry and rainbow trout in fresh water did not avoid sublethal oil concentrations (Rice, 1973; Sprague and Drury, 1969). Similar variability in avoidance capacities and thresholds may be expected in Arctic fish species.

One of the greatest concerns with respect to Beaufort Sea fish resources would be the potential for disruption of the spawning migration of anadromous species including ciscos and whitefish. Studies completed by the National Marine Fisheries Service (1978) indicated that exposure of fish to sublethal oil concentrations caused a delay in their return to the streams where they hatched. Upstream migration of adult salmon was prevented when oil concentrations in nursery streams reached 0.7 ppm or greater.

Both oil spill case history and laboratory test literature can be used to assess the potential impacts of oil spills on fish species found in the Beaufort Sea. The general tendency for oil to be less toxic in seawater than in fresh water (Anderson and Anderson, 1976) suggests that the greatest potential acute toxic and sublethal effects may occur in coastal areas influenced by the Mackenzie River and other fresh water drainages. These coastal areas are important rearing and feeding habitats of several anadromous fish species (Volume 3A), and at the same time have a high oil retention capacity due to the fine sediments. The most common anadromous species which could be affected by oil in this region are Arctic cisco, least cisco and Arctic char. Boreal smelt, humpback whitefish, broad whitefish and inconnu are also relatively abundant in some coastal areas and could be affected. Oil reaching coastal areas of the Beaufort Sea east of the Mackenzie Delta along the Tuktoyaktuk Peninsula to Liverpool Bay could impact Pacific herring populations which spawn in this region. Marine species such as fourhorn sculpins and flounders could be affected in coastal habitats, while Arctic cod may be exposed to oil in the open ocean, particularly in leads along ice-edges, where they concentrate. In most cases damage to Arctic fish populations would likely take the form of sublethal effects including tainting, and short-term behavioural and physiological abnormalities.

The rates of recovery of affected fish populations would depend primarily on the persistence of oil in shallow coastal areas where anadromous species would occur, or in offshore sediments where marine species would more likely be present, as well as the opportunity for recruitment from adjacent uncontaminated populations.

4.6 MAMMALS

Mortality of marine mammals as a result of oil spills has been relatively rare. In a recent extensive review of the effects of oil on marine mammals, Smiley (1981) reported that although California sea lions, northern elephant seals, harp seals, grey seals and other unidentified seals have been affected to some extent by oil spills, there is little evidence to confirm that deaths, when encountered, were related to the oil.

Smiley (1981) makes a distinction between the sensitivity and vulnerability of marine mammals to oil. Sensitive species are those which may be harmed by or are intolerant of oil for physiological and/or behavioural reasons. Sea otters and ringed seals are examples of sensitive species. Some marine mammal populations are "vulnerable to oil spills since their life histories (specialized food habits, colonial breeding behaviour, preferred travel routes and traditional haunts) are likely to ensure contact with accidental and chronic oil pollution. White whales which congregate and probably calve in a few selected Arctic embayments, or polar bears which retire to popular late summer retreats to await freeze-up, fall into this vulnerable category" (Smiley, 1981).

Smiley (1981) also reviewed laboratory and field investigations which have examined the specific effects of oil on marine mammals. Several observations from past investigations are important in the assessment of potential impacts of oil spills on Arctic marine mammal populations. Effects of oil contact on the body of marine mammals may include fouling of flippers and body openings (Warner, 1969; Davis and Anderson, 1976; Geraci and Smith, 1977; Anon., 1970). Heavy bunker fuels are most likely to cause clogging of nose and mouth openings, and fresh crude and refined fuels containing volatile fractions are more likely to result in eye irritations (Geraci and Smith, 1976). The latter authors reported only transient eye irritation in seals exposed to crude oil for short periods (24 hours), but also suggested that longer exposures could lead to permanent eye disorders or blindness. Oiling of marine animals which depend on fur for insulation and buoyancy may result in hypothermia and cause swimming difficulties (Kooyman *et al.*, 1977; Williams, 1978).

Fur seals, sea otters and muskrats are sensitive to oiling of their fur, while those species having a combination of blubber and fur (e.g. harp and ringed seals, sea lions) are considerably less senitive to oiling. Very young harp and ringed seals which have little blubber and thick white fur (lanugo) are sensitive during the spring moult and haul-out period (Smiley, 1981). Whales, dolphins, porpoises and walruses are least sensitive to oil contact causing hypothermia due to their thick insulative layer of blubber (Smiley, 1981). This loss of insulation can cause an increase in metabolic rate and may lead to exhaustion, cessation of feeding and weight loss (Kooyman *et al.*, 1977; McEwan *et al.*, 1974).

Marine mammals may also ingest oil when grooming, suckling or feeding (Smiley, 1981). Brief contact of ringed seals with oil causes rapid absorption and accumulation of petroleum hydrocarbons in their body tissues and fluids. Smith and Geraci (1975) suggest that the main pathways of oil uptake by ringed seals are through the skin or respiratory surfaces. There is some evidence that petroleum hydrocarbons are detoxified in the liver and excreted by the kidney (Smith and Geraci, 1975). It is not known what levels of oil in ringed seals will affect metabolic processes. Ingestion of oil-contaminated prey by ringed seals leads to temporary stress and elevated levels of aromatic hydrocarbons in the blood (Englehardt, 1978; Geraci and Smith, 1976).

The impacts of oil spills in the Beaufort Sea on marine mammals would be highly dependent on the time of the event, the areas contaminated and the species present. Bowhead and white whales would be most vulnerable to oil spills during their spring migrations, when they follow open water leads. If these leads contained oil, the whales may not be able to avoid it. There is little evidence to suggest that an oil spill would result in direct mortality of these whales, although indirect sublethal effects resulting from ingestion of oil-contaminated prey, avoidance responses during periods of other stress (e.g. calving), or fouling of baleen in bowhead whales could occur.

A winter blowout which contaminated important breeding habitats where ringed seals are concentrated could result in mortality of juvenile and possibly adult seals. The most serious impacts would occur if oil reached the primary pupping habitat in the large bays of Amundsen Gulf, and the inshore landfast ice areas along the Tuktoyaktuk Peninsula and west coast of Banks Island (Volume 3A). Impacts of oil on this species during the open water period could result from direct contact with surface slicks or from oil stranded in shoreline areas, as well as through the ingestion of oil-contaminated prey (pelagic invertebrates and Arctic cod).

On the basis of the apparent ability of the Beaufort Sea's ringed seal population to recover from natural decreases (Stirling *et al.*, 1980) and in the absence of additional stresses being imposed in subsequent years, recovery from population losses caused by an oil spill in the Beaufort Sea might require 5 to 10 years. Bearded seals, although not as abundant as ringed seals, could also be affected by oil spills in the Beaufort Sea.

Polar bears and, to a lesser extent, Arctic foxes could be affected by oil spills in the Beaufort Sea. Arctic foxes could be impacted through the ingestion of oil-contaminated prey. Polar bears could be affected by ingestion of contaminated prey or through direct contact with oil. In addition to potential affects on thermal insulation, recent studies also indicate that grooming of oil-contaminated fur can result in serious physiological disorders leading to mortality (Engelhardt, 1981). However, extensive mortality of polar bear populations is unlikely due to their widespread distribution. The most serious impacts on polar bears would result during the winter and spring when most occupy the transition zone ice to hunt ringed seals (Stirling *et al.*, 1975).

4.7 BIRDS

Birds have been the most visibly damaged species following past oil spills. Duval *et al.*, (1981) indicate that the extent of bird contamination and mortality depends primarily on seasonal habitat use rather than on the volume or type of oil spilled. Those groups which have been most severely affected in past spills are alcids such as murres, puffins and dovekies, as well as diving ducks, loons, grebes, coots, cormorants, fulmars, shearwaters, black-legged kittiwakes, pelagic gulls and phalaropes.

The primary effect of oil on birds is to break down the feather structure which provides waterproofing and thermal insulation (Holmes and Cronshaw, 1977; Brown, 1981). Increases in the effective body weight of birds due to oil-fouling hinders swimming, diving and flight, and may simultaneously increase energy requirements. Mortality usually results from exhaustion, hypothermia or drowning (Holmes and Cronshaw, 1977). Oil ingestion during the preening of contaminated feathers and/or feeding may also cause mortality or sublethal effects which decrease their ability to fly and to avoid predators. Brown (1981) also reports that oil may indirectly impact certain species of birds by affecting reproduction. Such effects, if they were to occur, could reduce the chances of survival of individual birds and breeding populations.

An oil spill during the period from April to September could have considerable impacts on a number of species of birds which annually migrate to the Beaufort Sea. A blowout during winter, resulting in the contamination of open water leads in spring, could also result in serious impacts since offshore spring migrants, including oldsquaw, eiders, loons, guillemots, murres and glaucous gulls, use these for feeding and resting.

Concentrations of nesting birds along the Beaufort Sea coast would be susceptible to oil during early June and July. Brant, snowgeese, shorebirds and eiders that nest in the littoral (intertidal) zone of the Beaufort Sea are highly susceptible to oil spills, particularly during storm surges.

Several species of ducks, geese, swans and alcids moult and are flightless for at least 2 to 3 weeks during their residence in the Beaufort Sea, and would be particularly vulnerable to oil spills during this period. The major species likely to be affected at this time are oldsquaw, white-winged and surf scoters, greater scaup, brant, thick-billed murres and black guillemots. Moulting usually takes place in sheltered bays and coastal lagoons along much of the mainland coast during the period from mid July to mid August. The most serious impacts would result if moulting alcids or oldsquaw were contacted, with the recovery of affected alcid populations requiring a decade or more due to their relatively low reproductive potential. Oldsquaw have a relatively high reproductive potential and their populations would probably recover in a shorter period.

In summary, if a major oil spill were to occur in the Arctic marine environment, birds would generally be the most likely to be affected by contact with oil. This being the case, much of the oil spill cleanup and countermeasures effort (described in Chapter 5) would be directed towards preventing oil from reaching the more important known bird concentration areas; likewise attempts would be made to prevent or minimize the number of birds coming in contact with oil, by trying, for example, to land on it.

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CHAPTER 5

ARCTIC OIL SPILL COUNTERMEASURES: EXISTING AND FUTURE SYSTEMS

This chapter describes existing oil spill cleanup equipment which is currently available for use in the Arctic and its capabilities, and the equipment under development which may become operational soon.

First, the basic techniques of oil spill cleanup are covered with emphasis on methods and equipment usable in the Arctic environment. Next, the existing open water cleanup technology is discussed, starting with how spilled oil is contained on the water surface, removed from the water, transferred to where water is separated from the oil and the oil finally disposed of. The text for each of these topics begins with a discussion of the general principles of how specific operations are conducted, followed by descriptions of the existing equipment owned by the Beaufort Sea CO-OP (an inter-industry spill equipment co-operative operated by Dome and supported by Esso and Gulf). Finally, other equipment available from nearby areas is described. A complete list of the Beaufort Sea CO-OP's equipment and other equipment available for use in the western Northwest Territories is provided in the proponents' contingency plans (e.g. Dome, 1981), and through Environment Canada's National Emergency Equipment Locater System (NEELS).

Following the open water cleanup section, countermeasures that have been developed for ice-infested waters are discussed. Then a discussion is given on the methods available to detect, monitor and predict the movement of oil both on water and in ice, after which the techniques available to protect, cleanup, and restore Arctic shorelines are described.

The chapter concludes with discussions of countermeasures concepts at the research and development stages and contingency planning.

5.1 BASICS OF ARCTIC OIL SPILL CLEANUP

Oil spill cleanup is simple in theory. Once a spill has been identified the first step is to stop the source and then activate the appropriate contingency plan. The spill is reported and a physical response to the spill is initiated to minimize potential environmental damage. The spill may be contained by mechanical barriers or by natural means, such as sea ice, and then removed by skimmers and pumps, or incinerated by *in situ* burning. Removal of oil from the water's surface can also be done, under certain circumstances, by dispersing the slick into the water column using chemicals. The final countermeasures steps involve disposing of collected oil by incineration or burial, and restoration of shorelines damaged by the spill. The theory is simple but the practice is not and the control of a large oil spill is a difficult task even under ideal conditions. In the Arctic there are additional challenges, these are reviewed before discussing existing technologies.

Special Considerations in the Arctic

Ice, temperature and location are three major factors influencing the cleanup of spills in Arctic waters.

Floating ice serves to contain oil much like a mechanical barrier placed around a spill. Also, oil trapped in growing ice remains in a fresh state during the winter, and then is released in thick pools as the ice melts in spring where it can be picked up or burned. Furthermore, the presence of the polar pack ice in the Beaufort Sea in summer usually results in calmer seas than are found elsewhere offshore. Large waves do not generally have a chance to develop. Such relatively calm waters mean that conventional open water cleanup equipment can be effective 80 to 90% of the time during the open water season (Pistruzak, 1981).

The low air temperatures experienced in the Arctic winter are a definite hindrance to the conduct of spill countermeasures. They cause equipment to freeze-up, materials to become brittle, and of most importance, they reduce human efficiency.

Canada's Arctic waters are remote and the North is sparsely populated. This means that, particularly along the northern portion of the tanker route, quick response and access for both men and equipment will be more difficult then in the south near large urban centres. Consequently the support of working parties will be a large undertaking.

5.2 EXISTING COUNTERMEASURES TECHNOLOGY

The oil spill control technologies that are now in place in Canada for dealing with Arctic oil spills are described under the following headings:

- Open Water Cleanup,
- Cleanup in Ice,
- Monitoring and Surveillance, and
- Shoreline Protection, Cleanup and Restoration.

5.2.1 OPEN WATER CLEANUP

5.2.1.1 Containment

Once oil has escaped the confines of a drilling or production platform, or has been discharged from a tanker or pipeline, the initial response is to limit the spread of the slick. To achieve this, numerous types of containment booms are available. They are designed to act as floating fences or barriers to prevent the further spread of oil, concentrate it, and thicken it for removal. Booms consist of ballasted skirts which hang in the water below flotation chambers (Figure 5.2-1). Normally a certain freeboard is provided above the flotation chamber to minimize splashover of oil. Oil booms come in three size ranges, defined by the total height of the boom below and above the surface of the water, where size defines their purpose and applicability as follows:

- 30 to 60 cm booms are generally constructed of PVC coated nylon with styrofoam floats. These booms come in 15 to 30 m long sections that can easily be joined by connector bars attached to each end of a section. Their use is restricted to calm water such as that found in protected harbours and quiet river backeddies. Their main advantages are their light weight and compactness, allowing hundreds of metres of boom to be stowed in portable boxes for quick deployment by helicopters.

- 60 to 90 cm booms are also constructed of the PVC coated nylon with styrofoam floats, similar to the 30 to 60 cm booms. These booms have proportionately more flotation than their smaller counterparts for a better response to waves. They are also more rugged in design and are used in nearshore waters to protect shorelines. Larger booms in this class are also used offshore, such as in the lee of a ship or island.

- 90 to 155 cm booms are constructed of heavy rubber or conveyer belt material with large foam or air-inflated floats. These extremely strong, large booms are designed for use offshore in waves up to 1.5 m high. Their large size generally means they must be deployed and supported by offshore vessels and they cannot be quickly placed or relocated.

Oil containment booms may fail to halt the spread of oil for a number of reasons. Excessive winds, waves, and currents can lead to the splashover and underflow of oil. Underflow occurs when a boom does not have sufficient draught or when high currents, usually above 0.4 m/sec, or 0.8 knots, are present. Other oil losses from booms result from mechanical or structural failures as well as from their improper deployment. Figure 5.2-1 illustrates several boom failure modes (Fingas *et al.*, 1979).

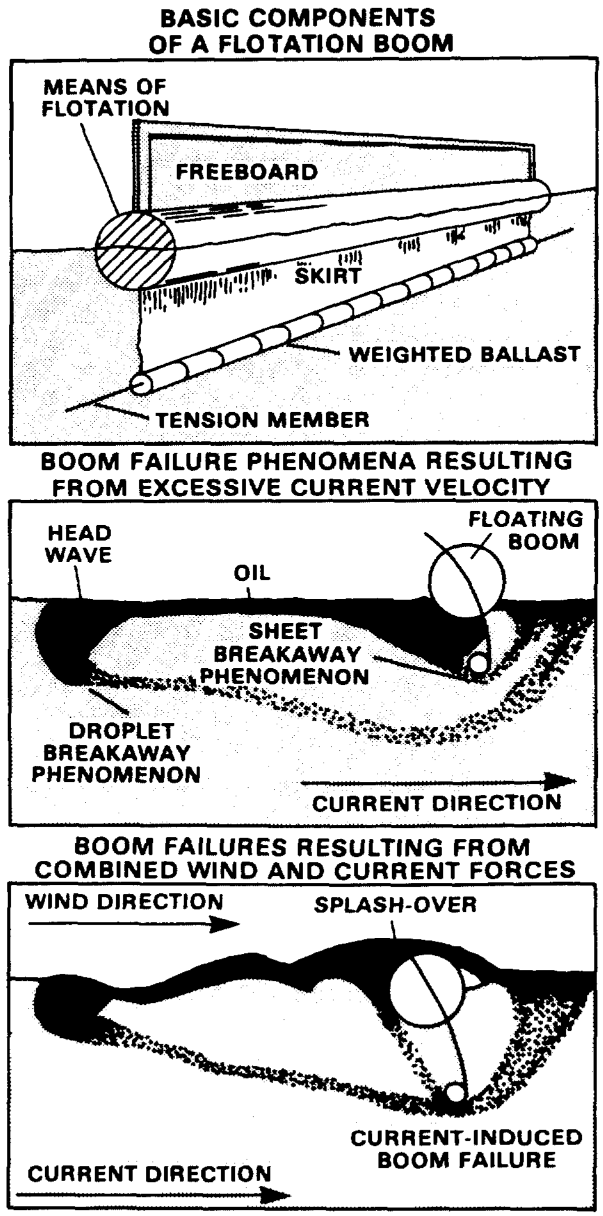


FIGURE 5.2-1 *Basic components of a flotation boom (Source: Fingas, et al., 1979). An oil boom is used to retain oil floating on water and thicken it for recovery. Booms can fail to retain all the oil when high currents, greater than about 50 cm/sec can draw off oil droplets under the boom; also winds and waves can splash oil over the top of the boom depending on its size.*

(a) Beaufort Sea CO-OP Booms

The CO-OP has in excess of 4,000 m of all the previously mentioned types of booms stockpiled in Tuktoyaktuk for spill response (approximately 330 m of 30 cm boom, 3,330 m of 90 cm boom and 730 m of a specially designed 155 cm Arctic boom).

PLATE 5.2-1 *The Arctic boom has been tested in Kugmallit Bay in the Beaufort Sea. Styrofoam beads were used to simulate oil. The boom contained the beads in 1.5 m high seas and survived a storm with 3 m high seas.*

The Arctic Boom was specifically designed for the offshore control of oil in ice-infested waters and is shown in Figure 5.2-2, and Plate 5.2-1. This boom uses a V-shaped configuration housing a solid flotation chamber so that some contact with ice will not damage the boom. The barrier material of the boom consists of neoprene-impregnated conveyer belting having a high tensile strength, durability and cold-weather endurance. Its smooth sides minimize icing while vertical stiffeners and lead weight ballast maintain the boom in a vertical position (Dome, 1981). About 490 m of Arctic Boom is available for use with the Response Barge (See Section 5.2.1.5).

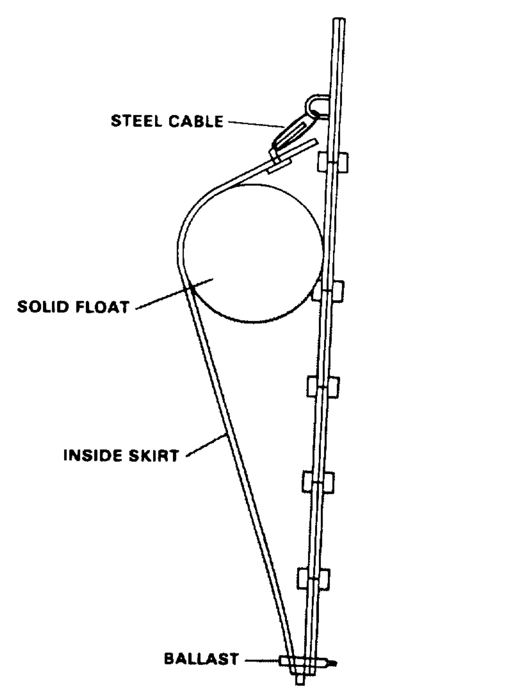


FIGURE 5.2-2 *Arctic Boom Profile. The Arctic boom was designed and constructed with special materials to ensure that it could withstand contact with small ice floes.*

(b) Other Booms Available Nearby

The Canadian Coast Guard, Esso Resources and Dome Petroleum maintain oil spill countermeasures equipment stockpiles near Tuktoyaktuk. The Coast Guard stockpile includes 3,790 m of 90 cm boom and 970 m of offshore boom. This offshore boom, the Vikoma Seapack, is an air-inflatable boom capable of being stored and deployed from a towable boat hull. this boom can be used effectively during the open water season in the southern Beaufort Sea. Dome maintains an additional 1,210 m of 90 cm boom (Plate 5.2-2) while the Esso stockpile includes

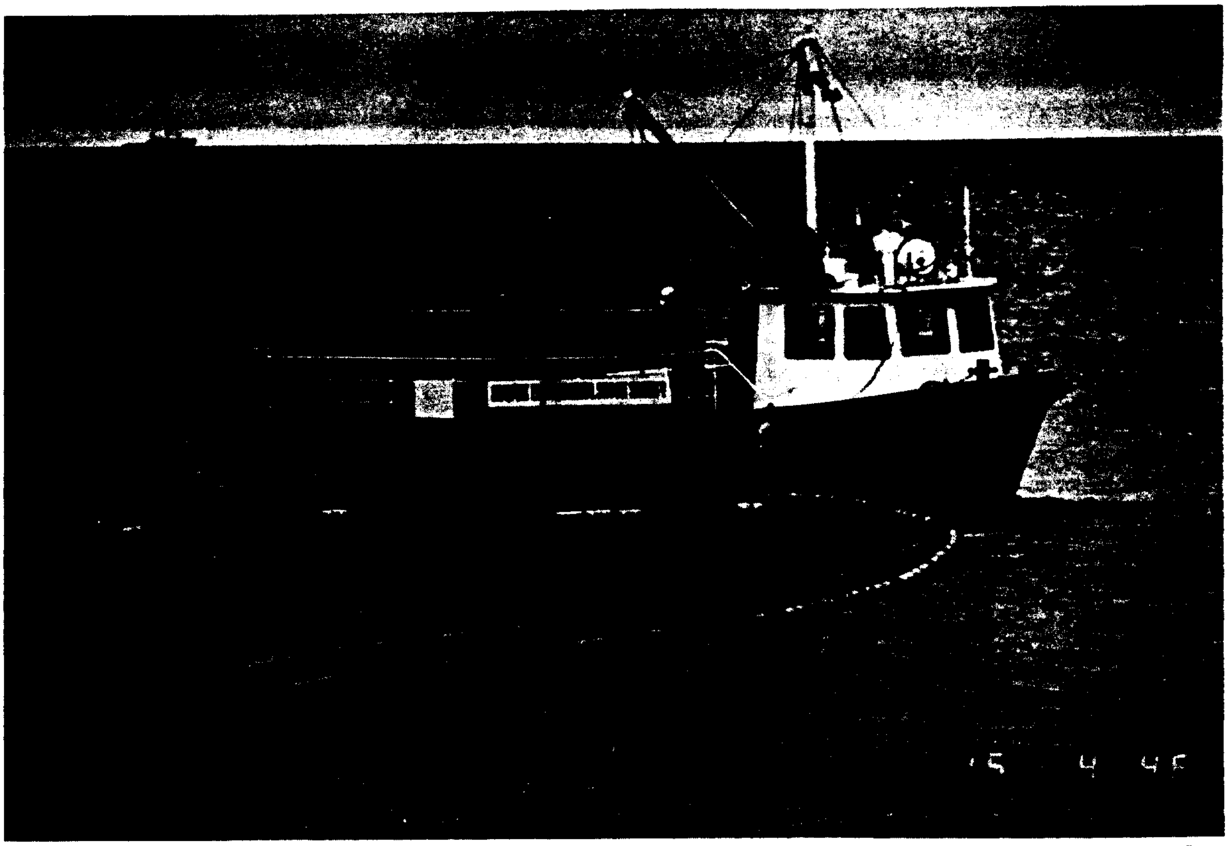


PLATE 5.2-2 *A 90 cm oil boom is deployed in a U-shape in the lee of a drillship in the Beaufort Sea as part of an exercise. The dedicated oil spill response boat NEAKOOLIK is used to operate a skimmer where oil would collect, simulating the recovery of spilled oil. The output of the skimmer is connected to the drillship via a pump and floating hose.*

150 m of 30 cm boom, 640 m of 45 cm boom, 100 m of 60 cm boom and 330 m of 100 cm boom. A listing of other stockpiles in the western Northwest Territories can be found in the proponents' contingency plans (e.g. Dome, 1981) and through NEELS.

5.2.1.2 Physical Removal

Once the oil is contained, the next step is the removal of oil from the water surface. Numerous mechanical devices are available to skim oil from rivers, coastal waters and the open sea. These devices are classified according to their basic principles of operation and include weir, suction, sorbent surface, and submersion devices (see Figures 5.2-3 a, b, c, d, and e).

Skimmers are available in various sizes ranging from those installed on large, self-contained, self propelled vessels to small units that can be handled and operated by a single person. A suitable oil recovery device is identified by considering where it is to be used, such as near-shore or offshore; the properties of the oil to be recovered such as its temperature, viscosity, pour point, etc.; anticipated sea states and available modes of transportation (Fingas *et al.*, 1979).

(a) Weir Skimmers

Weir skimmers could be deployed to remove oil in calm water (Figure 5.2-3a). Many varieties of this type of skimmer are available and have been tested and used to recover light oils (Abdelnour *et al.*, 1978; Solsberg *et al.*, 1977). The Beaufort Sea CO-OP stockpile includes two weir skimmers for cleaning up harbour spills. Seven more are available nearby from Coast Guard, Esso and Dome stockpiles.

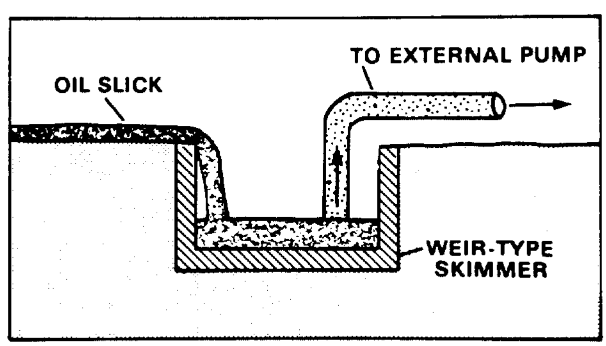


FIGURE 5.2-3a *Operating principle of weir skimmers (Source: Fingas, et al., 1979) These operate by allowing oil to fall over a weir placed in the slick. The oil is then pumped out of the sump.*

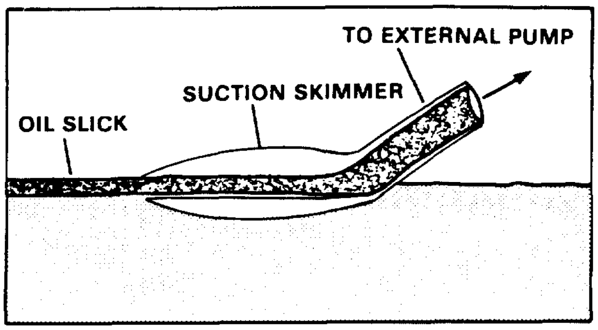


FIGURE 5.2-3b *Operating principle of suction-type skimmers (Source: Fingas, et al., 1979). These operate like a vacuum cleaner and draw oil directly off the water surface.*

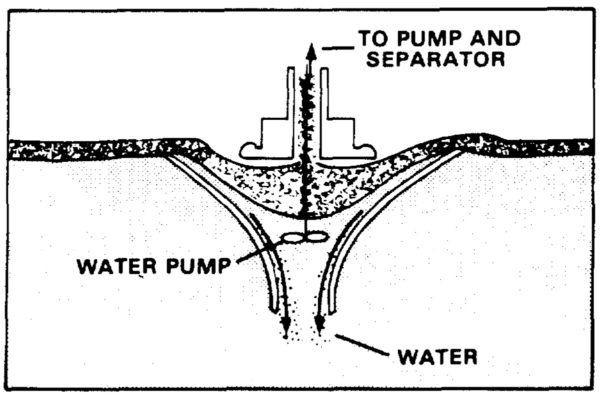


FIGURE 5.2-3c *Operating principle of centrifugal or vortex type skimmer (Source: Fingas, et al., 1979). A depression is created in the water surface into which oil flows and is pumped out of.*

(b) Suction Devices

Large capacity vacuum units, which could be used in the Arctic, have been used in many regions of the world to remove oil (Figure 5.2-3b). Their main advantage lies in their capability to recover heavy oil. Vacuum-type recovery units can be operated from a platform or vessel.

(c) Sorbent Surface Devices

Skimmers incorporating an oil-adsorbing surface are the most effective devices for use in Arctic waters for light oils. Several forms of such skimmers exist as seen in Figure 5.2-3d. The rotating disc type skims by adsorbing oil or an oil-and-water emulsion to a series of discs which are scraped or wiped. The oil is then deposited in a sump and pumped to storage. The advantages of this type of skimmer are its ability to efficiently pick up viscous oil and to function in the presence of limited ice conditions, debris and waves. The offshore skimmer on the CO-OP Response Barge described later in Section 5.2.1.5 is a version of this type as is the Canadian Coast Guard's offshore

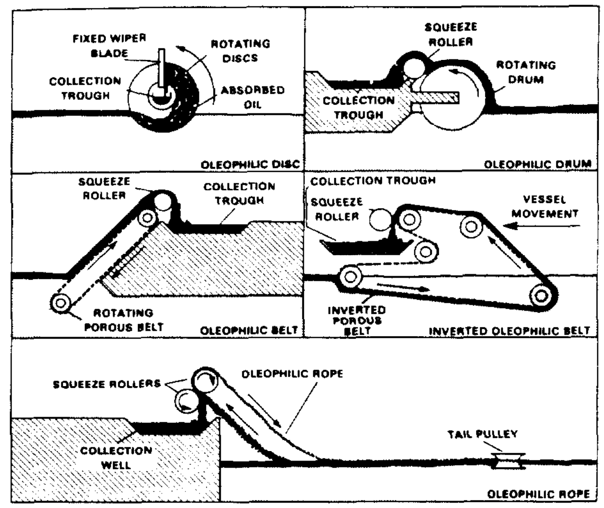


FIGURE 5.2-3d *Operating principles of various sorbent surface skimmers (Source: Fingas, et al., 1979). Sorbent skimmers use materials that adsorb oil and repel water such as aluminum and polypropylene. Sorbent disc skimmers function by rotating metal or plastic discs through the slick. Oil clinging to the discs is scraped off by wiper blades and deposited in a collection well. Sorbent drums operate similarly. Sorbent belt skimmers operate by immersing an oil-adsorbing belt in the slick. The oil is then carried upward by the belt and scraped or squeezed off into a collecting trough. Sorbent rope skimmers use floating oil-adsorbing rope-mops which pick up oil as they travel through the slick around a pulley. The oil is then squeezed-off by rollers into a collection well.*

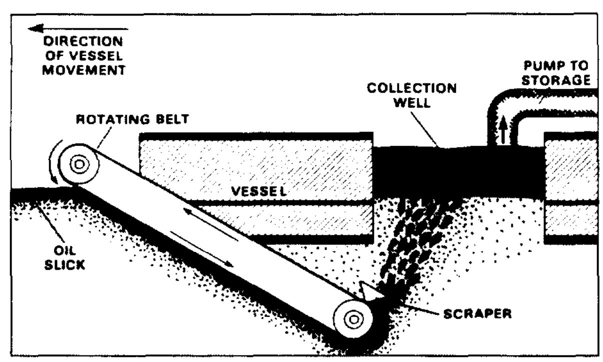


FIGURE 5.2-3e *Operating principle of submersion skimmers (Source: Fingas, et al., 1979). These use a rotating belt to force oil beneath a collecting well. The oil then floats up and can be pumped off.*

skimmer. Other smaller disc skimmers are available at Tuktoyaktuk for use in nearshore waters.

Another type of sorbent-surface skimmer, the rope mop, consists of polypropylene strands woven into a rope. Oil adheres to the rope mop and is squeezed off by a wringer. Two types of these skimmers are stockpiled, including one mounted as a self-contained unit on a Seatruck. The rope mop functions well in low sea-states and can operate in low ice concentrations. It can also recover viscous oils.

(d) Submersion Devices

Submersion skimmers push oil underwater and then allow it to rise into a protected collection well (Figure 5.2-3e). Recently a submersion skimming device was acquired for the CO-OP Response Barge as a possible replacement for the bladed drum skimmer. The device has been successfully demonstrated to recover oils with a range of viscosities in wave conditions rarely exceeded in the Beaufort Sea (Abdelnour *et al.*, 1978). The machine will undergo testing to determine its usefulness in Arctic waters.

Plates 5.2-3 through 5.2-7 show some of the skimmers available at Tuktoyaktuk.

5.2.1.3 Transfer Systems

Pumps are a key component of most oil spill cleanup systems and a wide range of pumps have been tested and acquired for use in Arctic waters. Requirements include the ability to self-prime, to tolerate debris mixed in the oil, to be portable, to tolerate cold weather, not to emulsify an oil and water mixture, and to be easy to maintain. High volume lightering or offloading pumps are also available. These types of pumps can be placed on board a stricken tanker to transfer its cargo and fuel to another vessel. The Canadian Coast Guard have this type of pump.

5.2.1.4 Water Separation

Separators are used to remove water from oil recovered from a spill in order to reduce storage and disposal requirements. One type uses gravity separation where a simple but effective container is constructed of drums or sheet metal and fitted with a drain (Esso, 1981). The oil and water mixture is allowed to settle and the water drained off the bottom, leaving the concentrated oil to be pumped from the container to storage or to a disposal unit. Natural or excavated pits can also be used as gravity separators. Other types of separators, based on a variety of separating principles, are generally used for larger flowrates. These are commercially built units, such as the ones mounted on the CO-OP Response Barge.

5.2.1.5 Disposal

Methods to ultimately dispose of recovered material, including oil and oiled debris have been intensively studied for the Arctic (Pistruzak, 1981). Such studies have resulted in the development of specialized incinerators and burners, and the identification of

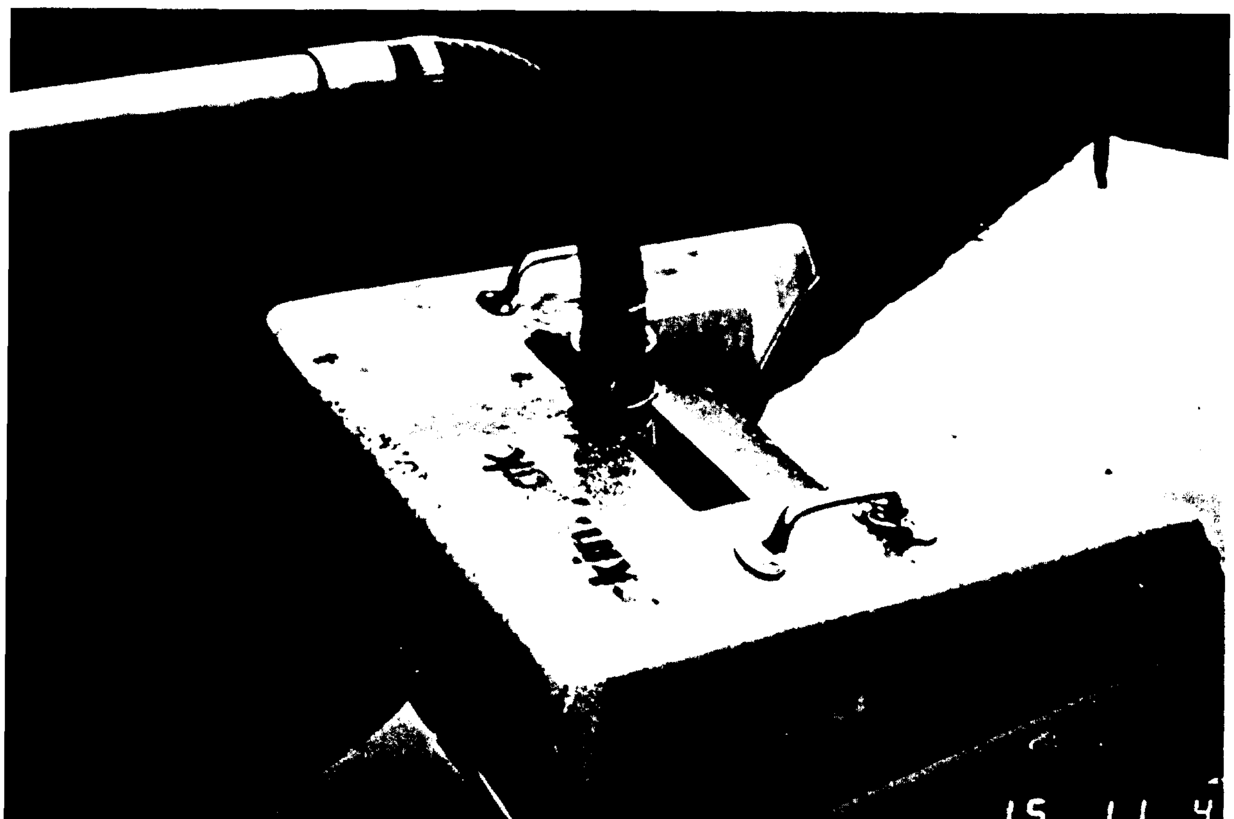


PLATE 5.2-3 *This weir-type skimmer, the "Skim-Pak" is used to collect contained oil in calm waters. It has a self-adjusting weir that sinks lower if the pumping rate is increased.*

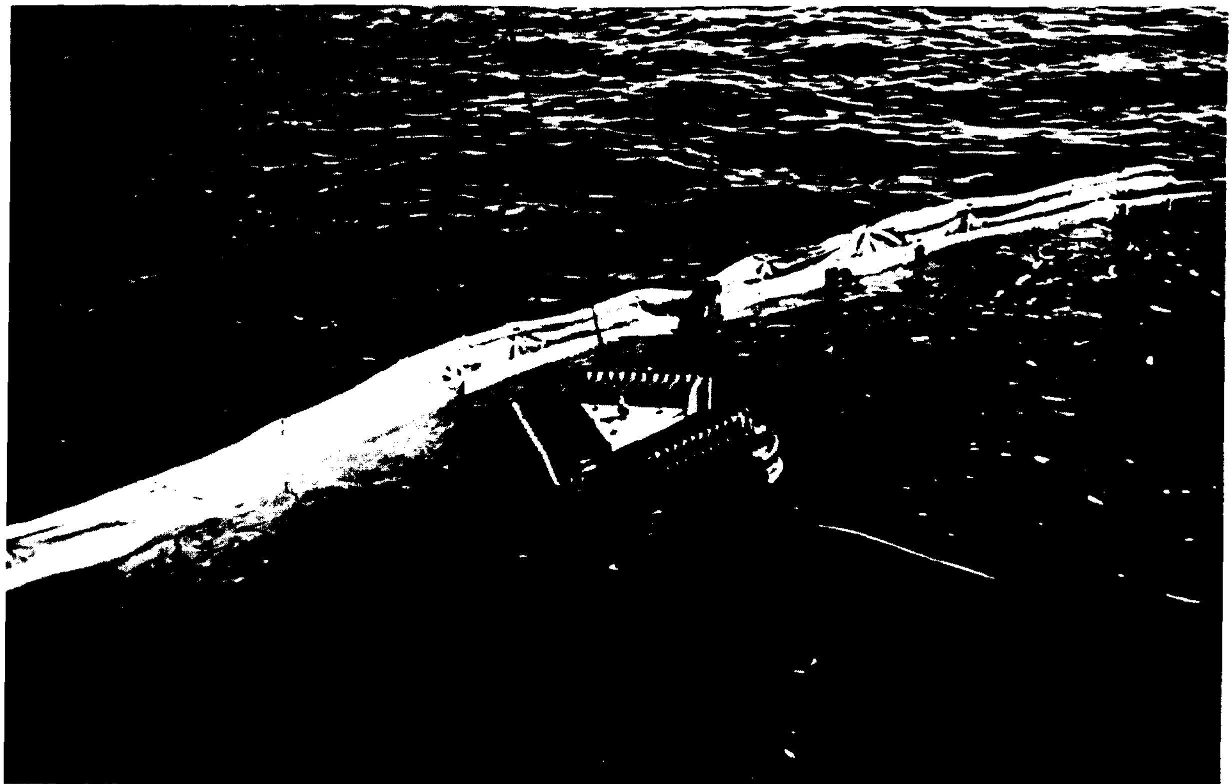


PLATE 5.2-4 *This sorbent disc skimmer, the "MI-30", can be used in light wave conditions to recover contained oil. These skimmers are well suited for day-to-day use on minor spills in the Arctic. The collected oil is pumped to storage by a built in positive displacement pump.*

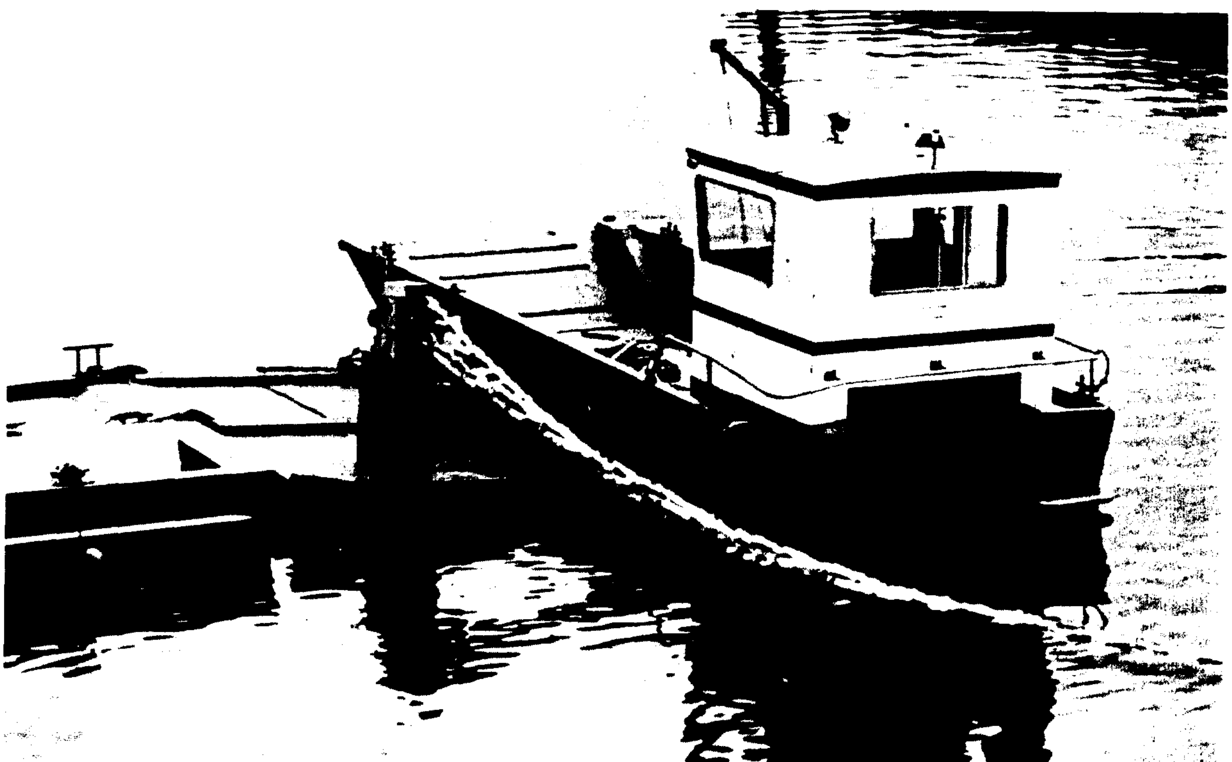


PLATE 5.2-5 *The "Oil Mop" skimmer. This sorbent rope skimmer collects oil as the rope-mop is drawn across the slick. The wringers squeeze oil into the drum. Larger models of this skimmer can be mounted on Sea-Trucks, such as the one in the background and can be used to recover uncontained slicks. These skimmers can also be used where there is oil in leads and cracks in ice.*

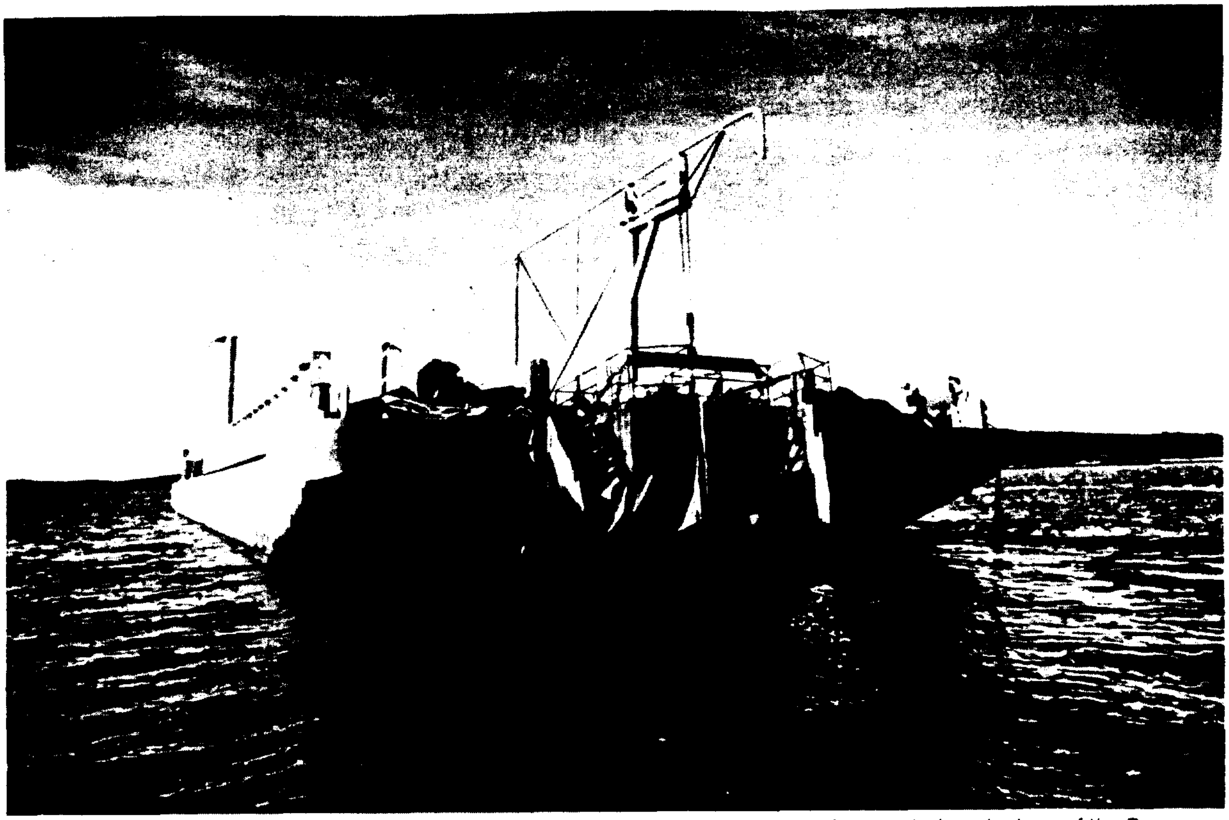


PLATE 5.2-6 *The Lockheed 12-2003 skimmer. This sorbent-bladed drum skimmer is mounted on the bow of the Response Barge. This unit has been specially modified to operate in light ice conditions.*

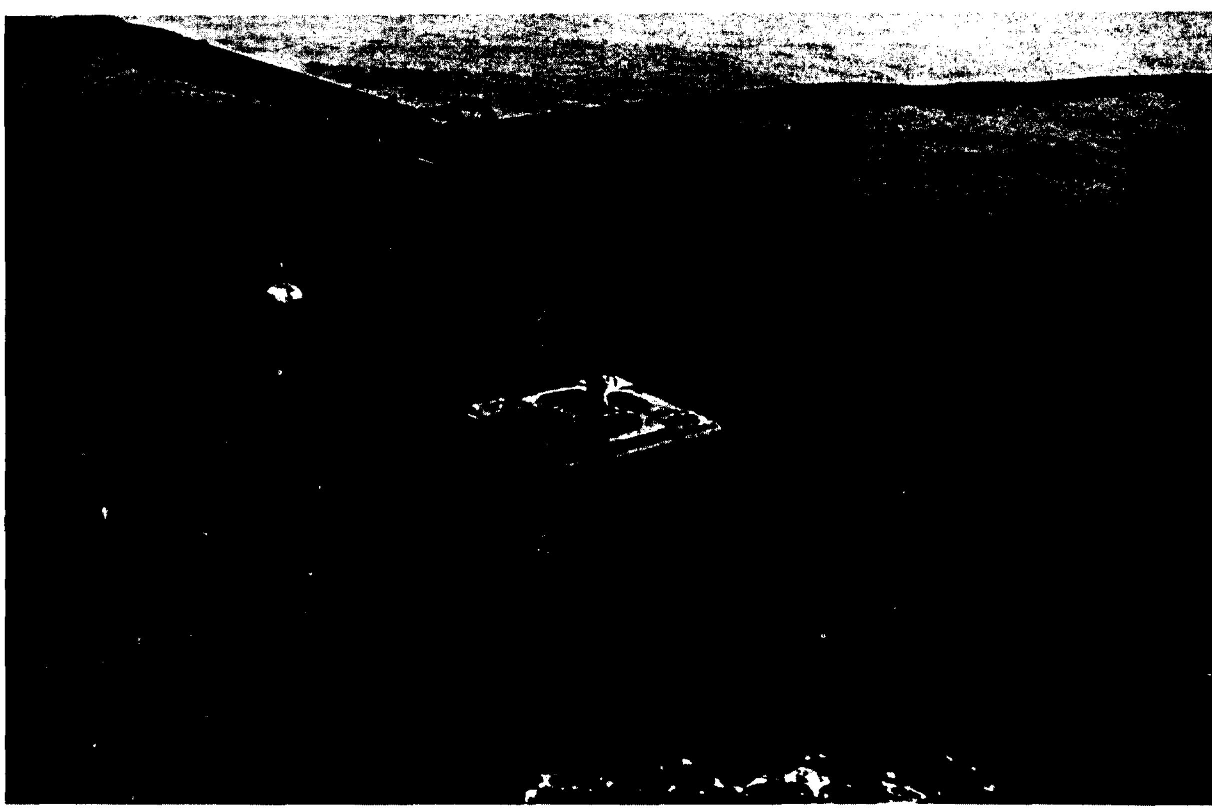


PLATE 5.2-7 *The Coast Guard Framco-ACW 400 offshore skimmer is a large sorbent disc type device. It also contains a weir for higher recovery rates in thick slicks. The special hydraulic arm and gimbals allow the skimmer to operate in moderate waves. Positive displacement pumps are built into the skimmer head.*

temporary coastal storage sites (Hardy and Associates, 1979).

(a) Incinerators

Beaufort Sea CO-OP equipment can incinerate recovered oil using either the Response Barge burning equipment (Dome, 1981) or a portable SAACKE burner (Buist and Vanderkooy, 1982).

The CO-OP Response barge is equipped with a complete treatment system which includes oil-water separators, pumps, a generator, an air compressor and a burner mounted on a 18-metre long boom (Figure 5.2.4 and Plate 5.2-8). The barge has a storage capacity of 970 m^3 and can burn 800 m^3/day of oil containing up to 40% water. When a fluid exceeding 40% by volume water is recovered, heat-treating and separating can be undertaken to reduce the water content to make this recovered fluid combustible. The main advantages of this disposal system are its direct link to an oil skimmer recovery system, its mobility and its efficient combustion.

The SAACKE burner is a unique helicopter-portable burner that is available in Tuktoyaktuk. The device atomizes the fluid to be incinerated in a rapidly spinning cup and the atomized fluid is ignited by a pilot light fueled by propane (Figure 5.2-5 and Plate 5.2-9). About 80 m^3/day of a 60% water-in-oil emulsion can be disposed of using this burner.

Several other incinerators are available. The Northern Transportation Company Ltd. (NTCL) at Tuktoyaktuk has a small incinerator capable of burning oil and contaminated debris including oiled sorbent material. This unit could dispose of material shipped to the Tuktoyaktuk area in oil drums. The Canadian Coast Guard has a Kenting incinerator stationed in Tuktoyaktuk which can dispose of oil-contaminated debris and sorbents. It is also located in the NTCL yard along with the NTCL incinerator but could be transported for on-site use.

Other incinerators which show promise and can be made available include an air portable open pit incinerator that has been designed and tested by the Environmental Protection Service (Lombard, 1979) (Figure 5.2-6). The main advantages of this incinerator are its ability to burn heavy oil and sludges, its portablity, and its ease of assembly in remote areas (Plate 5.2-10).

Also, an incinerator has been developed for use in remote regions by the Prairie Region Oil Spill Containment and Recovery Advisory Committee (PROSCARAC, 1980). It consists of a high capacity blower and ducts which push air down into a pit containing burning debris and is called an Air Curtain Pit Incinerator. The blower and ducts are helicopter-transportable. The pit incinerator has successfully burned 20 metric tons of oil waste per hour, however, this device is not suitable for use in ice-rich soils (Plate 5.2-11).

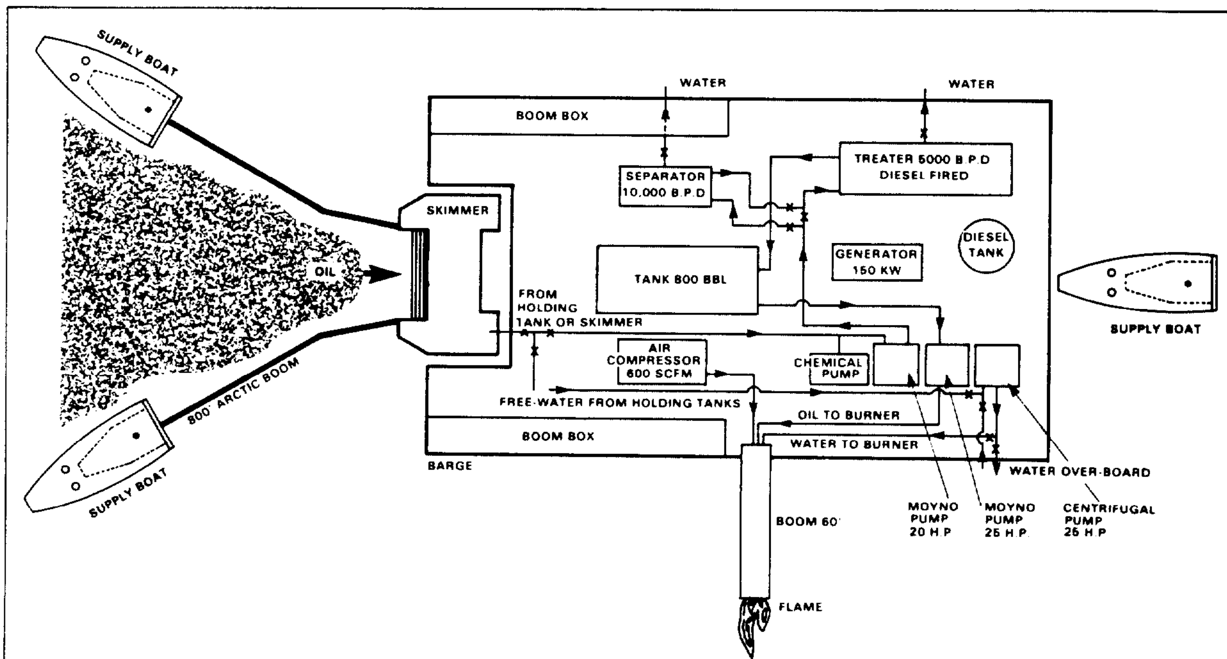


FIGURE 5.2-4 *The CO-OP Response Barge cleanup system. Oil on the water is directed towards the Lockhead skimmer on the Response Barge by two lengths of Arctic boom. Once the oil is picked up by the skimmer it can be put in the barge's tanks or processed to remove excess water and then flared off. The system has a nominal capacity to recover and dispose of 800 m^3 (5,000 bbls) of oil per day.*

PLATE 5.2-8 *The Response Barge, with booms deployed is simulating the recovery and disposal of oil from a blowout at a recent exercise. Oil directed to the Lockheed Skimmer by the Arctic boom is treated to remove water and then burned off with the Baker burner. This system, mounted on the Response Barge, can dispose of up to 5,000 barrels of oil per day.*

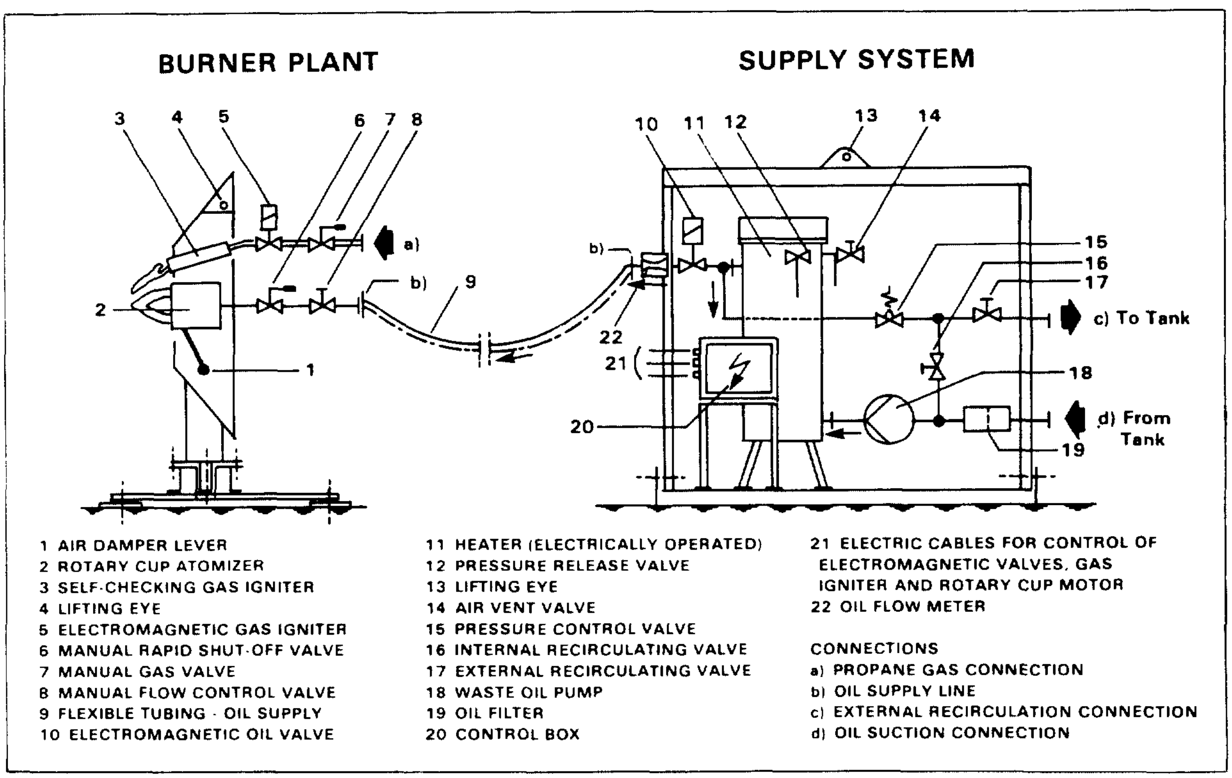


FIGURE 5.2-5 *Portable waste-oil burner. The portable burner was designed and constructed in two helicopter portable units. The supply system module contains filters, pumps, preheaters, flow controls and combustion controls. The burner module consists of a rotary cup, atomizer, pilot flame and air supply system capable of burning up to 80 m³ (500 bbls) per day of a 60% water-in-oil emulsion. The system also serves a day to day operational role as a slops-oil disposal plant.*

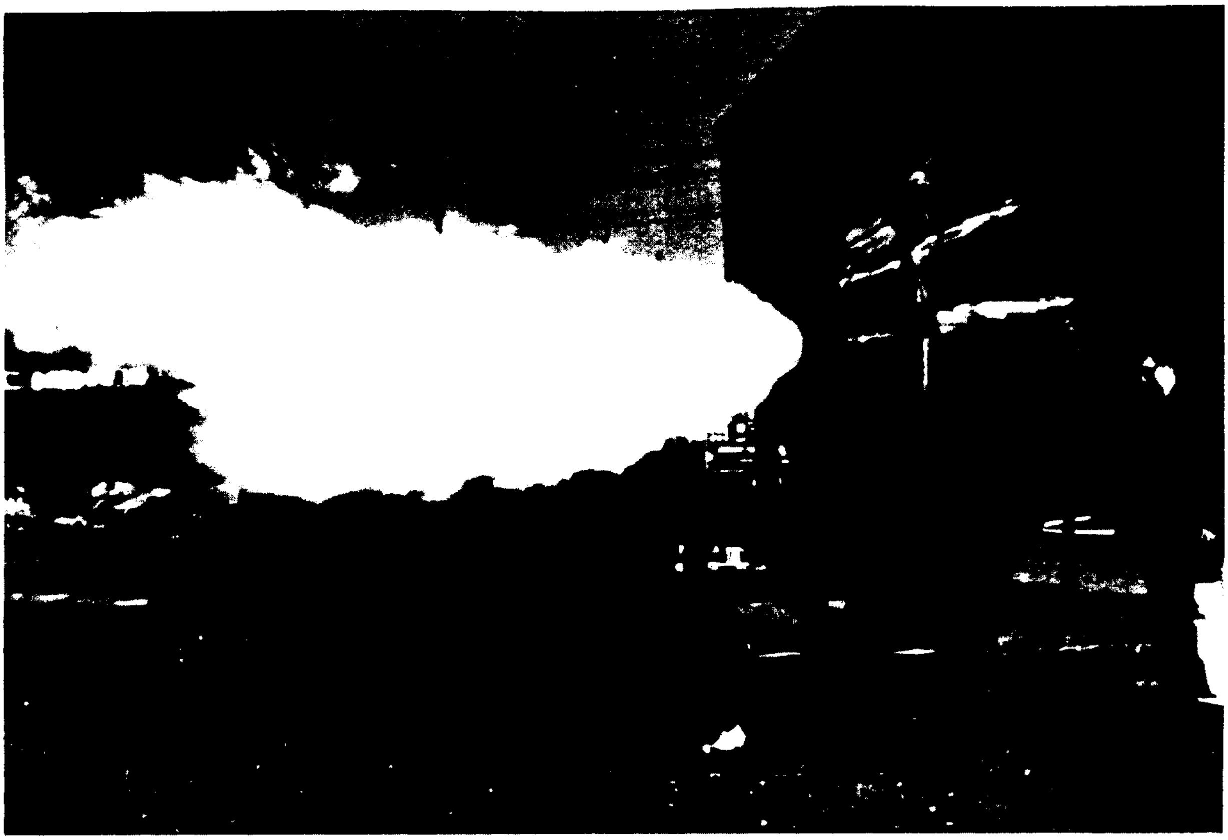


PLATE 5.2-9 *The SAACKE rotary cup burner. The portable burner, seen during its factory trials, can burn a wide variety of contaminated oil and fuels, up to 80 m^3 (500 bbls) per day, with very little visible emissions. The conical air duct can be easily rotated through 360° to ensure that the wind is providing maximum combustion air.*

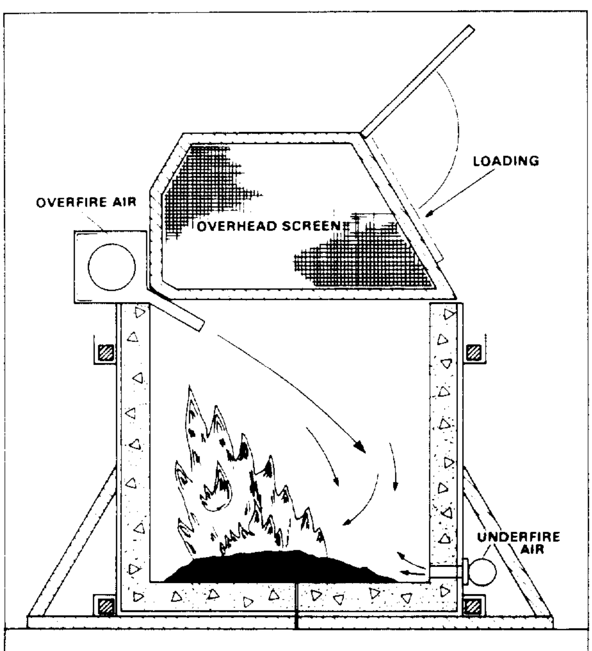


FIGURE 5.2-6 *Air Portable Incinerator cross-section (Source: Lombard, 1979). This portable incinerator is transportable by helicopter in several loads. Air is supplied by a small diesel driven fan and oiled debris is loaded into the top of the box. This device can be moved to any remote shoreline clean-up operation.*

Finally, a unique reciprocating kiln incinerator has been developed to clean oiled beach material (Ewing, 1979). The incinerator is constructed of empty drums and can be slung by a light helicopter to a disposal site and bolted together. Its total weight is about 1,360 kg. This inexpensive kiln is a practical method for cleaning oiled sand and rock and for disposing of oily sludges.

An alternate disposal method is to bury the oil and oil-contaminated debris. Areas along the Beaufort Sea coast have been designated as potential landfill disposal sites available for use in the event of a major spill (Hardy and Associates, 1979). Guidelines specify site selection, design, construction and reclamation for both summer and winter burial. Approximately 217 permanent and 223 temporary storage sites have been identified on the shoreline extending from the Alaska-Yukon border west to Cape Bathurst.

5.2.1.6 Chemical Dispersion

Dispersants are chemicals which, when sprayed onto an oil spill, reduce the cohesiveness of the slick (Exxon, 1980). Any mixing energy added to the slick will then speed up the breaking of the oil into small droplets and its dispersal into the water column. The

PLATE 5.2-10 *The portable box incinerator is seen here undergoing tests with oiled debris. Burning rates of 900 kg/hr have been achieved. It is helicopter portable and can be set up on level ground near a cleanup operation.*

PLATE 5.2-11 *This pit incinerator consists of a square pit dug in the ground and a blower/duct unit that forces combustion air into the pit. Although this unit is simple and effective it could not be used in ice-rich soils.*

small droplets have a large surface area to volume ratio so that soluble fractions are quickly dissolved in the water and the natural biodegradation process is accelerated on the remaining oil (McAuliffe *et al.*, 1981).

The use of dispersants likely involves different environmental consequences; oil is removed from the ocean's surface to prevent damage to birds and shorelines but introduced into the water column possibly threatening organisms there. Dispersants are useful if used intelligently and only for the purposes of minimizing overall environmental damage (Mackay and Wells, 1981a; IES, 1981; Sprague *et al.*, 1981; Koons, 1978; Ross, 1979; Mackay and Leinonen, 1977; IPIECA, 1980). For a dispersant to be used in Canadian waters it must meet government criteria (EPS, 1973) and to be used on an oil spill, government approval is required.

The effectiveness of approved dispersants is low for heavy, or viscous oil and water-in-oil emulsions compared to light oils (Mackay *et al.*, 1979; Wells and Harris, 1979). Experiments have shown that some Arctic crude oils can be effectively dispersed with approved dispersants in Arctic waters (Cox and Schulze, 1981).

Small slicks can be dispersed using boat-mounted spraying equipment. Large oil slicks can be sprayed from aircraft with some of the approved dispersants presently available (Cox and Shulze, 1981; Mackay and Wells, 1981b; Wells and Harris, 1979; Ross, 1979; Mackay *et al.*, 1977; Sekerak and Foy, 1978; Lindblom, 1981). Extensive research and development has established that aerial application techniques are a promising method for dealing with large ocean oil spills (Hildebrand *et al.*, 1977; Exxon, 1980; Dennis and Steelman, 1979; Smedley, 1981).

A supply of about 15,000 litres of government approved dispersants is stockpiled by the Beaufort Sea CO-OP at Tuktoyaktuk. Application equipment for the supply vessels is also stored. If required, spray aircraft could be chartered and more dispersants flown in by freight aircraft.

5.2.1.7 In Situ Combustion

Oil floating on water can be ignited using igniters dropped from aircraft, but to effectively burn most of the oil it is necessary to confine and thicken the oil. For a subsea oilwell blowout, the gas can be ignited and will burn a portion of the oil (Topham, 1975; Arctec, 1977). For more effective burning a fireproof boom is needed to contain and thicken the oil. Several devices have been suggested in the past (McAllister, 1979; Comfort *et al.*, 1979; Buist and McAllister, 1981) and recently one has been constructed and successfully tested (Buist and McAllister, 1981). The fireproof boom is not yet fully operational, so it is discussed later in Section 5.4 which deals with research and development.

5.2.2 CLEANUP IN ICE

5.2.2.1 Combustion Techniques

It has been demonstrated that oil discharged beneath sea ice will ultimately appear in melt pools (Dickins and Buist, 1981). The *in situ* combustion of this oil, and other oil trapped or contained by ice, is a prime oil removal technique in ice covered waters. *In situ* burning is a one-step removal process and eliminates the need for containment, mechanical recovery, transfer, concentration and disposal.

Several approaches to igniting oil are available. One that has been successfully tested in Arctic ice is the air-deployable igniter (Pistruzak, 1981; NORCOR, 1976; Energetex, 1977; ARCTEC, 1977; Dickins, 1979; Energetex, 1980). Several different models have recently been field tested (Miekle, 1981b; Dickins and Buist, 1981). The igniter illustrated in Figure 5.2-7 and Plate 5.2-12 was developed primarily to deal with possible subsea blowouts in the southern Beaufort Sea that may continue to release oil under ice throughout the winter. Feasibility studies have shown that it is possible to remove most of the oil from the blowout by dropping tens of thousands of

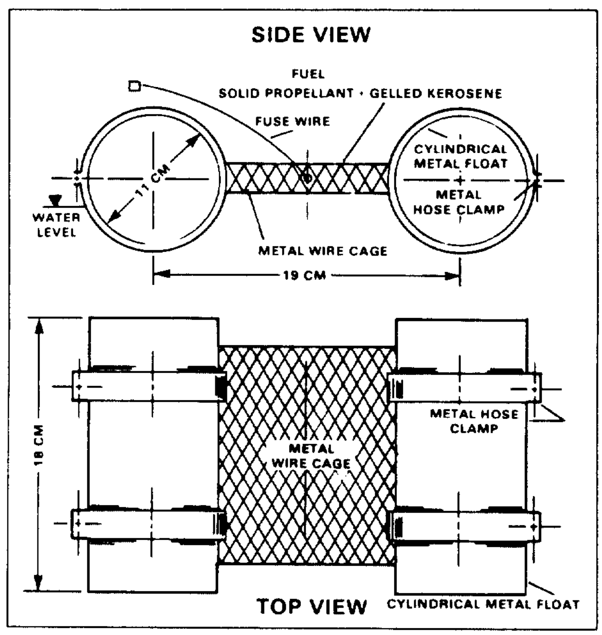


FIGURE 5.2-7 *Air deployable igniter (Source: Dickins and Buist, 1981). This air deployable oil slick igniter is constructed using simple materials. A metal wire cage containing the fused fuel package is slung between two metal 48 oz. juice cans. When dropped from a helicopter the unit will always land in the correct position. Its small size and light weight minimize disturbance of the slick when it hits and allow hundreds of igniters to be carried in medium sized helicopters.*

PLATE 5.2-12 *An air deployable igniter burning in a melt pool. After the igniter lands in an oiled melt pool the fuse ignites a small amount of solid propellant. This material burns at a very high temperature for 15 to 30 seconds and preheats and ignites the oil beneath the unit and also sets two slabs of gelled kerosene on fire. This gelled kerosene continues to burn for 5 to 10 minutes to ensure that ignition of the oil takes place.*

thousands of these igniters during spring into melt pools containing the oil (S.L. Ross, 1981).

Air deployable igniters are able to deal with oil in or on different types of ice and their use is not restricted to the southern Beaufort Sea. In the case of an oil well blowout, igniters and their deployment logistics could be prepared during the winter, providing months of lead-time to work out operational details, during which time relief well drilling to stop the blowout would be proceeding. During winter, the igniters could be used to burn oil contained in leads between ice floes or on ice. It is possible to ignite and burn fresh, weathered or emulsified oil at temperatures as low as -35°C, in winds with speeds in excess of 45 km/hr and with as much as 70% snow or ice mixed into the oil (Dickins and Buist, 1981; Energetex, 1981). *In situ* burning at a recent experimental spill (Dickins and Buist, 1981) is shown in Plate 5.2-13.

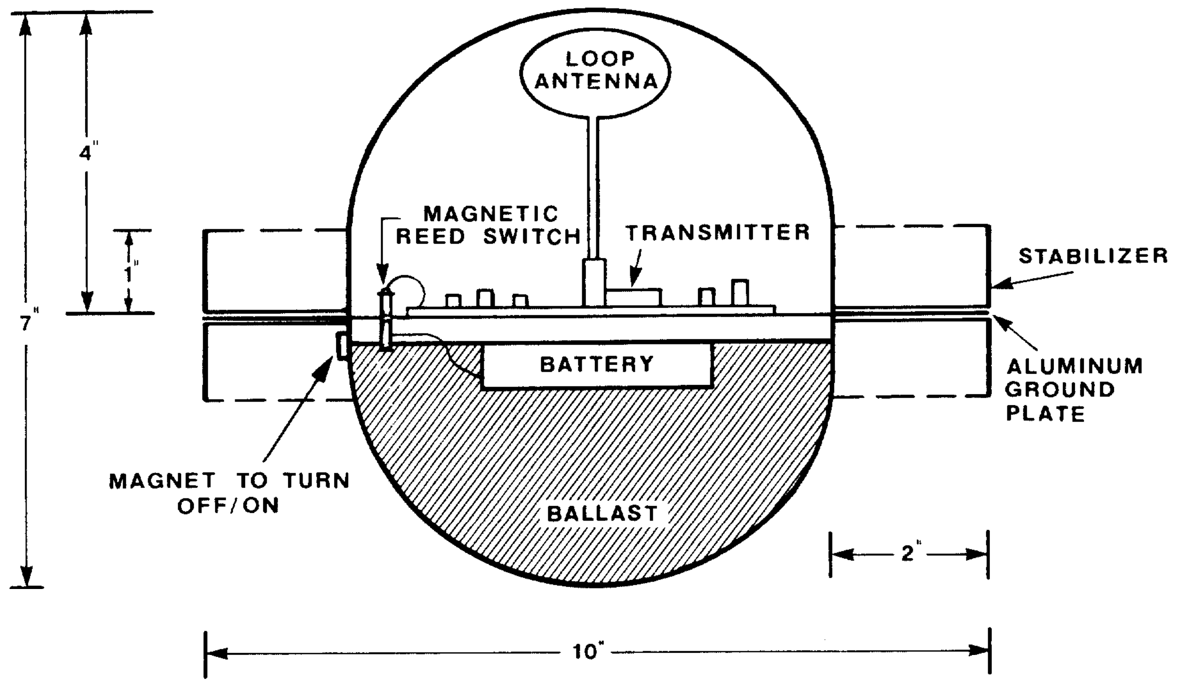
5.2.3 MONITORING AND SURVEILLANCE

Detection and tracking of an oil slick is an essential operation for managing an oil spill. This is because an oil slick can cover a large area, making a combination of aircraft surveillance and radio-tracking buoys necessary to monitor the slick. In the following sections, this combination of detection and tracking is described as well as the capabilities of remote sensing technology.

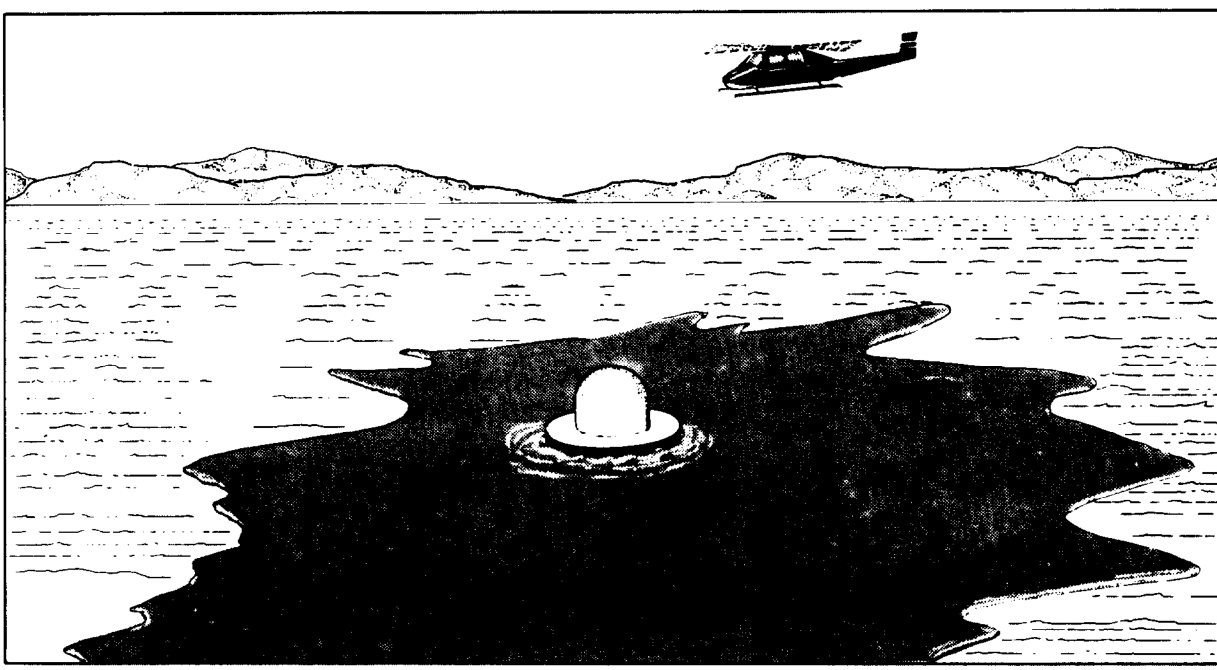
5.2.3.1 Tracking

Direct visual observations from aircraft and ships would be made during all phases of a major spill control operation to determine the extent and movement of the slick. Should poor visibility exist, or the spill cover a large area, air droppable radio-tracking buoys would be dropped in the slick to track its drift (Figure 5.2-8). The position of the buoys can be monitored from land, sea, or air, using a simple receiver (Fingas *et al.*, 1979). The Beaufort Sea CO-OP maintains a stockpile of these buoys.

The tracking of oil-contaminated ice is an important initial countermeasures step. Satellite-tracked positioning buoys have been successfully deployed on Arctic ice to study its movement (McGonigal and Wright, 1977). In the event of a blowout in the transition zone ice, the use of these buoys would permit the



CROSS SECTION OF LOCATOR BUOY



**SKETCH OF LOCATOR BUOY DRIFTING IN OIL SPILL
AFTER PLACEMENT BY HELICOPTER**

FIGURE 5.2-8 *Air droppable radio tracking buoy. These spill tracker buoys can be dropped from ships or helicopters into slicks and will drift with the oil. The buoys, and thus the oil, can be relocated using a simple radio signal receiver that can be mounted in aircraft.*

PLATE 5.2-13 *Demonstration of how an oil spill in ice would be cleaned up. Small and medium sized helicopters flying at an altitude of 5 m at slow speeds are used to drop the igniters into oiled melt pools. A pool ignition success rate of 75% is possible. Studies have indicated that up to 150,000 igniters could be dropped from as few as 10 helicopters during the spring melt and result in the disposal of 50 to 70% of the oil from a "worst case" winter subsea blowout.*

accurate positioning of oiled ice. Satellite ice tracking buoys would be deployed at regular intervals and the oil track accurately chartered; this same approach would apply equally well to oil released from a tanker into moving ice.

5.2.3.2 Remote Sensing

There are four basic applications for the use of remote sensing in a marine oil spill countermeasures program. These are the detection and identification of oil on water, snow or ice; the measurement of the areal extent, distribution and volume of an oil slick; the monitoring of the movement of an oil slick; and the routine surveillance of pipelines for leak detection.

Remote sensing techniques for monitoring an oil slick on water use aircraft and satellite mounted systems. While satellites offer the advantage of extensive areal coverage, aircraft are essential for tactical support. At present, there are no operational remote sensing systems capable of detecting oil in ice. This is an area for future research.

The following remote sensing systems are available for installation in aircraft (O'Neil *et al.*, 1982; Dome, 1981):

- Photographic cameras- These are the most often used sensors, but are limited by visibility and light availability.

- Low light level television- This sensor is also limited by visibility but can provide an instant picture even in very low illumination.

- Laser fluorosensor- This device, which bounces a laser beam off the oil, can detect oil on the surface and in the water. It is not limited by darkness and can identify the type of oil spilled.

- Electro-optical scanners- These devices are not limited by poor visibility and see oil in ultra-violet and infrared wave lengths which are invisible to the human eye.

- Imaging radars such as Synthetic Aperture Radar (SAR) and Side Looking Airborne Radar (SLAR), can provide images of oil slicks in large areas in darkness and poor visibility.

Several satellites which traverse the Canadian Arctic as well as the east and west coasts provide routine pictures of large areas. These pictures are available in both visible light and IR wavelengths, however, they generally cover too large an area to be able to detect oil slicks.

5.2.3.3 Spill Simulation Models

In addition to the physical and electronic methods available for detecting and tracking oil spills, computer spill simulation models exist for predicting their movement. Spill simulation models can be used as both a planning tool (as in the preparation of the scenarios contained in Chapter 6) and as a real-time method for forecasting the location and characteristics of oil slicks. Parameters affecting the fate and behaviour of spilled oil that are incorporated in the models include temperature, ocean currents, wind speed and direction, oil properties, evaporation, dispersion, emulsification, spreading, and horizontal and vertical water column diffusion. Such models have been used in the formulation of countermeasures strategies and techniques. In conjunction with weather forecasts, they are used to forecast the areal extent of an oil slick; the quantity of oil remaining within the slick; the expected trajectory and speed of the slick, and the location and timing of shoreline contact.

The Beaufort Sea CO-OP has at its disposal, two operational models, the Canmar Oil Spill Tracking Model (COST) (Dome, 1977), a relatively simple model, and the more detailed revised Atmospheric Environment Service (AES) model (Atmospheric Dynamics, 1980) which has also been provided to the Arctic Weather Centre in Edmonton. Both of these models concentrate on slick movement and shoreline impacts of oil. At present, there are no models available that predict the motion of oil in ice infested waters.

5.2.4 SHORELINE PROTECTION, CLEANUP AND RESTORATION

The goal of any spill cleanup is to do everything possible to prevent oil from coming ashore. This is accomplished by dealing with as much of the oil as possible at its source offshore before it nears the shoreline, however, it is not always possible to prevent all the oil from reaching shorelines. The following section describes how shoreline protection priorities and cleanup methods are chosen.

5.2.4.1 Protection Priorities

The prediction of slick movement allows sections of coast that may be affected by spilled oil to be identified This identification, in conjunction with maps of the shore-zone character enable response strategies to be selected. Coastal areas that could be seriously affected by a spill have been identified and mapped for the Beaufort Sea in order that the available equipment and manpower can be deployed efficiently to minimize the effects of a spill (APOA, 1979). Similar maps which identify areas where spilled oil could cause damage are being prepared for the coasts of the Northwest Passage and for the overland pipeline route. These maps rank the relative importance of the activities of man, the relative importance of ecological habitats and the biological characteristics of various areas.

Although detailed maps of the kind now available for the Beaufort coastal zone are not yet available elsewhere in the Canadian Arctic, shoreline spill response information on the physical character of the shore zone from the Alaska border to Lancaster Sound is available on a continuous series of videotapes (Dome, 1980). Currently, ESSO is producing videotapes along the Mackenzie River. These videotapes will be used to identify countermeasures options as part of contingency planning, and would also be used in a spill situation to select protection and cleanup tactics. Response plans take into account not only the deployment of equipment and personnel to sites with protection and cleanup priority, but also the disposal of contaminated material.

5.2.4.2 Response Selection

Where shorelines are threatened by an oil spill, the choice of coastal protection and cleanup methods is usually limited by logistics. The primary response techniques would be manual or mechanical removal of oil on beaches and flushing of oil from marshes. Such techniques are well established and would be followed so that adverse effects would be kept to a minimum (Dome, 1981).

Arctic coasts have numerous sand or gravel beaches (Woodward-Clyde, 1981). Oil stranded on such beaches usually has little impact; however, it may be necessary to clean these beaches to prevent recontamination of the water. Migratory birds frequent lagoons, estuaries and marshes and, although these are difficult areas to clean, the impact of oil can be minimized by preventing it from entering such areas while birds can be temporarily discouraged from entering oiled areas using a variety of deterrents (Dome, 1981).

Often oil spill countermeasures can result in more damage to shorelines than that caused by the oil alone (Fingas *et al.*, 1979), so that in some situations the "no-cleanup" option will be exercised (Siva, 1979). Excessive sediment removal could result in coastal erosion (Owens and Drapeau, 1973). Marsh environments, in particular, are highly productive habitats that can be easily disrupted by cleanup operations (Cejka, 1975; Robilliard *et al.*, 1980). The decision whether to and how to cleanup would be based upon an assessment of how much damage the oil could cause if it were left on the shore, the length of time the oil would persist, the effectiveness of cleanup, and the potential damage that cleanup could cause.

5.2.4.3 Shoreline Restoration

The decision to restore a shoreline would be guided by the objectives of preventing accelerated erosion, minimizing disturbance of permafrost and minimizing biological impacts. Replacement of removed sediments will in most cases prevent substantial deterioration of the beach equilibrium (Dome, 1981). The aim of shoreline protection, cleanup and restoration will be the minimization of disturbance to the Arctic. Communication with northern residents would also be maintained during the entire response effort so that their knowledge of the area could be used to the greatest extent possible.

5.3 COUNTERMEASURES CONCEPTS AT THE RESEARCH AND DEVELOPMENT STAGE

This section describes areas of research in spill response that may result in improvements to the existing capabilities in the Arctic. (These areas of research are enlarged upon in Volume 7).

5.3.1 REMOTE SENSING

The two areas that could benefit from a major research and development program are the detection of oil under ice and improving the capability to detect oil from the air in poor visibility conditions.

Oil under ice detection techniques using acoustics and radar, have shown some promise (Worsfold *et al.*, 1980; Goobie *et al.*, 1981; Dickins and Buist, 1981; Jones and Kwan, 1982). Further work on these techniques is being undertaken.

Work on data processors and real time displays of remote sensor outputs is underway to improve the availability and thus usefulness of the data.

5.3.2 FIREPROOF BOOM

A fire-proof containment boom has been researched and developed (Buist and McAllister, 1981). Its purpose is to contain oil for *in situ* combustion, allowing a one-step oil containment and removal process in open water. The boom is made of stainless steel with corrugated panels connecting its rigid flotation sections which allow it to move with waves. Plate 5.3-1 shows the boom undergoing burn tests. The boom's design criteria include operating in a sea state rarely exceeded in the southern Beaufort Sea. Field testing has indicated that fresh crude oil can be burned with very high efficiencies within the boom. Currents of up to 0.4 m/s and moderate seas (sea state 2 to 3) do not inhibit the combustion process. Work on refining the boom design is continuing.

5.3.3 SUBSEA BLOWOUT CONTAINMENT

As a result of a recent international workshop, research on the containment of oil and gas from a subsea blowout is underway (Meikle, 1981a). Specific areas of research include flow in risers, system loads, system design, safety considerations, burning off of the collected oil and gas, and model tests. Research to assess the feasibility of a system to operate year-round in the Beaufort Sea is continuing.

5.3.4 SOLIDIFYING ADDITIVE

The BP Research Centre in Middlesex, England has been studying the treatment of spilled oil with a unique solidifying agent (Meldrum *et al.*, 1981). The company has developed a two component system composed of polymers and cross-linking chemicals which react with each other to form a molecular network capable of entrapping oil. Oil thus treated becomes a relatively dry material that is rubber-like. In this form, its recovery is more manageable and the threat of further contamination is reduced.

The polymer additives appear to be effective for a wide range of crude and fuel oils as well as high viscosity products including emulsions. Since they are effective at Arctic temperatures, their use is possible under ice cover. Although very much in the research stage, BP's solidifying additive shows promise, particularly as it might apply to shoreline protection and cleanup in the Arctic.

5.3.5 CHEMICAL DISPERSANTS

Research and development into the use of dispersants on oil spills is continuing. The specific issues being addressed are:

- cold temperature effectiveness, through field testing and laboratory development (IES, 1981);
- application techniques through the analysis and testing of aircraft and boat spray systems (Smedley, 1981);
- decision making models, developed to quantify the pro's and con's of dispersant use in specific aquatic environments (Trudel and Ross, 1982);
- use of dispersants in nearshore environments (Blackall and Sergy, 1981).

The use of dispersants in nearshore environments and on shorelines is the subject of a major field

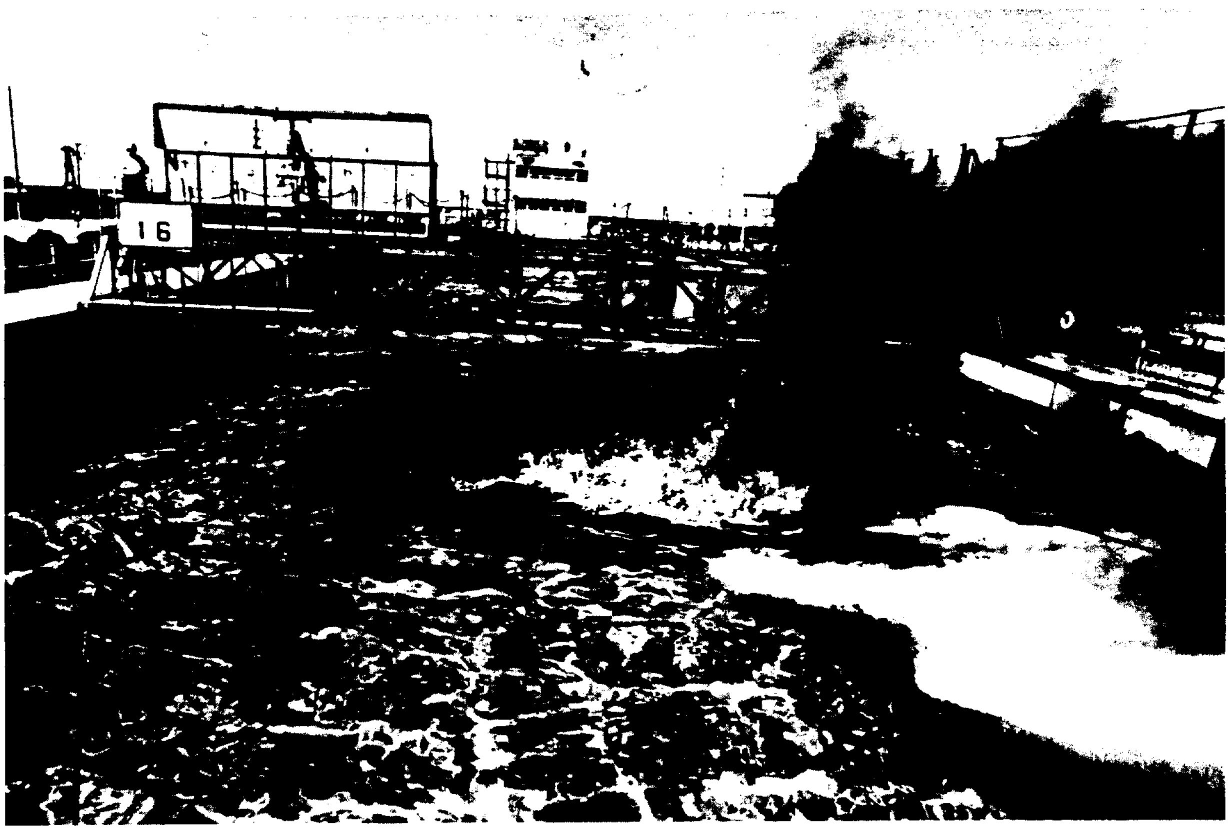


PLATE 5.3-1 *Fire proof containment boom tests. The boom, seen here undergoing trials at a U.S. Environmental Protection Agency test tank, is a recent promising development for oil spill countermeasures. Deploying the boom down drift of an oil spill and using it to collect and burn the slick in situ will be an effective spill countermeasure. This boom will allow far larger oil flowrates to be dealt with than has previously been possible and does away with the requirements for skimming, pumping, processing, storage and disposal of the oil.*

program, the Baffin Island Oil spill (BIOS) experiment (Blackall and Sergy, 1981). Experimental spills of both oil and dispersant-and-oil mixtures have taken place in an effort to compare impacts. These data should assist in establishing criteria for the use of dispersants near shorelines. If dispersants are shown to have relatively little impact their use could greatly reduce shoreline cleanup efforts and the associated damage.

5.4 CONTINGENCY PLANNING

An important step in spill response planning is developing a contingency plan. As described by the Canadian Oil and Gas Lands Administration (COGLA, 1982) a contingency plan must: outline the response organization, lines of authority and responsibility, communications, and define key response members; define duties and responsibilities of the response organization; outline main decisions that must be made; detail the spill reporting network; provide information, and sources of information required in the event of a spill; and identify the resources available to deal with the spill. The purpose of a contingency plan is to ensure that a swift, coordinated response can be made to a spill.

5.4.1 EXISTING INDUSTRY CONTINGENCY PLANS

At present, Dome, Esso and Gulf have approved contingency plans in place for Beaufort Sea exploration activities. As an example, Dome's Contingency Plan is set up in two volumes as follows:

Volume 1 covers the action plan. The introduction describes the corporate commitment to spill response, the area the plan covers, and the response philosophy. Definitions are given of spill types expected and technical terms. Responsibilities are described where the spill response organization is set out, key jobs are defined and personnel identified to fill key jobs. Initial actions required are layed out. These comprise internal reporting procedures, external (government) reporting procedures and how the spill is to be classified. Monitoring and tracking capabilities are described comprising open water techniques, ice conditions techniques and spill modelling. Detailed countermeasures response techniques are described for: land spills, harbour spills, vessel spills, sea spills, blowouts and associated relief well plans. Next, detailed shoreline countermeasures responses are described comprising shoreline protection, cleanup and restoration. The disposal of recovered oil is described including burning and burial techniques. This is followed by the post-operational analysis procedure which provides for a debriefing and review of each spill response, a report to government, and how contingency plans are to be updated. Chemical spills are a possibility so that details of all procedures and techniques to be followed in the event of a chemical spill are described. Finally, site-specific countermeasure plans are provided as requested by governments.

Volume 2 of the contingency plan mainly provides contact lists and equipment lists. Names, positions and phone numbers for key industry and government personnel are provided. There is a dispersant contact list where names and phone numbers of government contacts are recorded who have the responsibility to approve the use of dispersants. Canada Customs procedures are given for importing equipment and contractors into Canada. Oil spill tracking equipment, methods and capabilities are described. There are three equipment lists: one lists national equipment available in the western Northwest Territories, another lists U.S. equipment available in Alaska and on the west coast, and the third lists all CO-OP and Dome equipment available in the Beaufort Sea area. Equipment specifications are given on booms, skimmers, pumps, sorbents, burners and igniters. A section then describes possible impacts of oil on the marine environment and how wildlife might be rehabilitated. *In situ* burning of oil on ice is described and finally, a description is given of how oil and oiled debris could be stored and disposed of.

5.4.2 EXISTING GOVERNMENT PLANS

At present there are two types of plans available for an Arctic Spill Response. There are national-local contingency plans and international plans.

National-local plans detail the response organizations and resources put in place by government in the event of a spill in the Canadian Arctic. The most important facet of these plans are the lines of communication with industry contingency plans and other government contingency plans. Unless requested, (or in the opinion of the appropriate governing body, it is required) these government response organizations would only monitor the response, not undertake it. In the event of a spill in Arctic waters the Government of Canada Arctic Seas Contingency Plan may be activated to provide the focal point for all response activities. This plan also serves to coordinate the other government contingency plans including those listed below: (EPS, 1980).

- Spill Observation Team Contingency Plan
- National Marine Contingency Plan
- Arctic Marine Contingency Plan
- Regional Intergovernmental Contingency Plan
- Scientific Response Plan
- Government of the Northwest Territories (GNWT) Emergency Control Contingency Plan
- Yukon Territory Contingency Plan for Oil and Hazardous Materials
- Departmental Contingency Plans for Emergency Situations
- Department of National Defence (DND) Plan P55
- Federal HQ Coordination Contingency Plan for the Arctic

International plans can be activiated in the event of a spill threatening to cross an international border. These include the Joint Canada - US Maritime Pollution Contingency Plan and the Joint Canada - Denmark Maritime Pollution Contingency Plan administered by the respective Coast Guards.

5.4.3 PLAN INTERRELATIONSHIPS

Figure 5.4.1 illustrates how the various contingency plans relate to the Government Arctic Seas Contingency Plan. Figure 5.4-2 illustrates the areas of application of existing major contingency plans in the Arctic.

Of prime importance is the interface between industry and government contingency plans. This interface becomes active when the spill is first reported to the government 24 hour spill line in Yellowknife. If a major spill is involved, the industry On-Scene Commander further notifies the Canadian Coast Guard (if a vessel is involved), the Canadian Oil and Gas Lands Administration (COGLA), the Environmental Protection Service (EPS) and the Department of Indian Affairs and Northern Development (DIAND). Continued liaison between industry and government is the responsibility of the Industry Spill Control Director who communicates with the government's Deputy On-Scene Commander. Technical consultation between both industry and government also takes place at lower levels in the response organizations.

The decision process on the relationship between industry and government response organizations is illustrated in Figure 5.4-3.

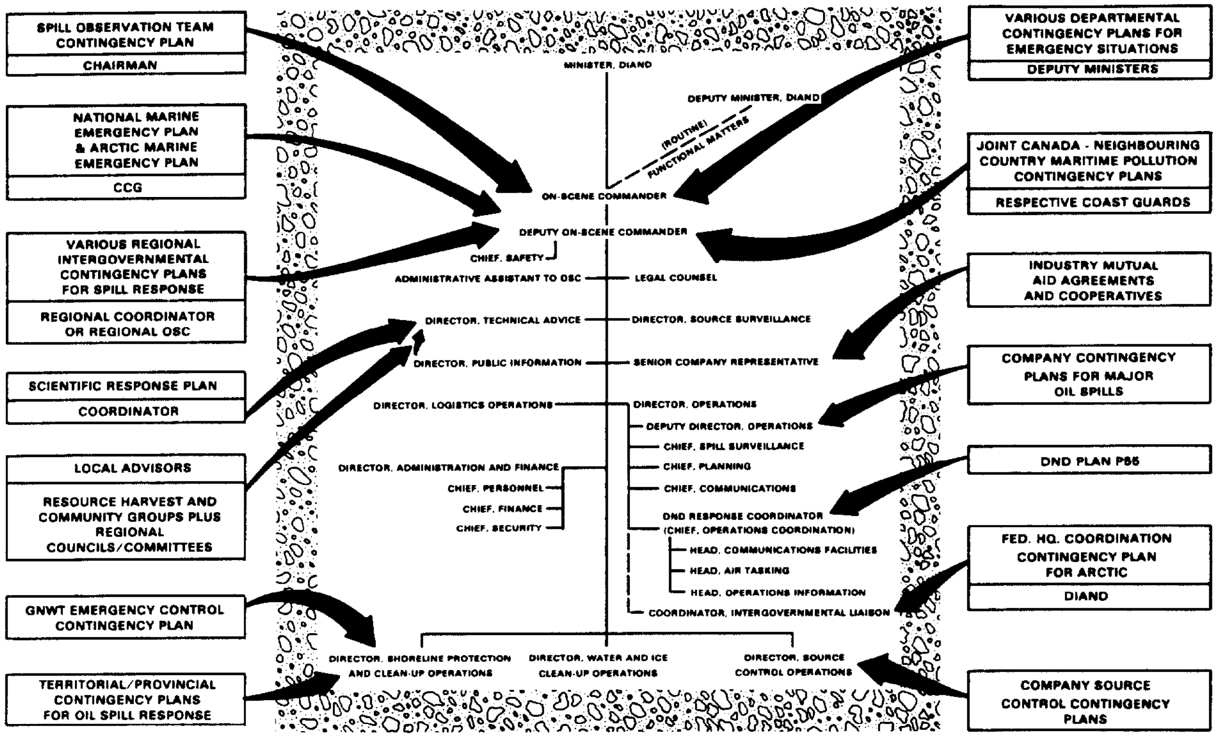


FIGURE 5.4-1 *How various contingency plans relate to the government's Arctic Seas Contingency Plan. In the event of any spill the government may enact the "Arctic Seas Contingency Plan" to monitor and/or command the spill response. This plan coordinates a multitude of other government and industry contingency plans to ensure an effective response is made (source: EPS, 1980).*

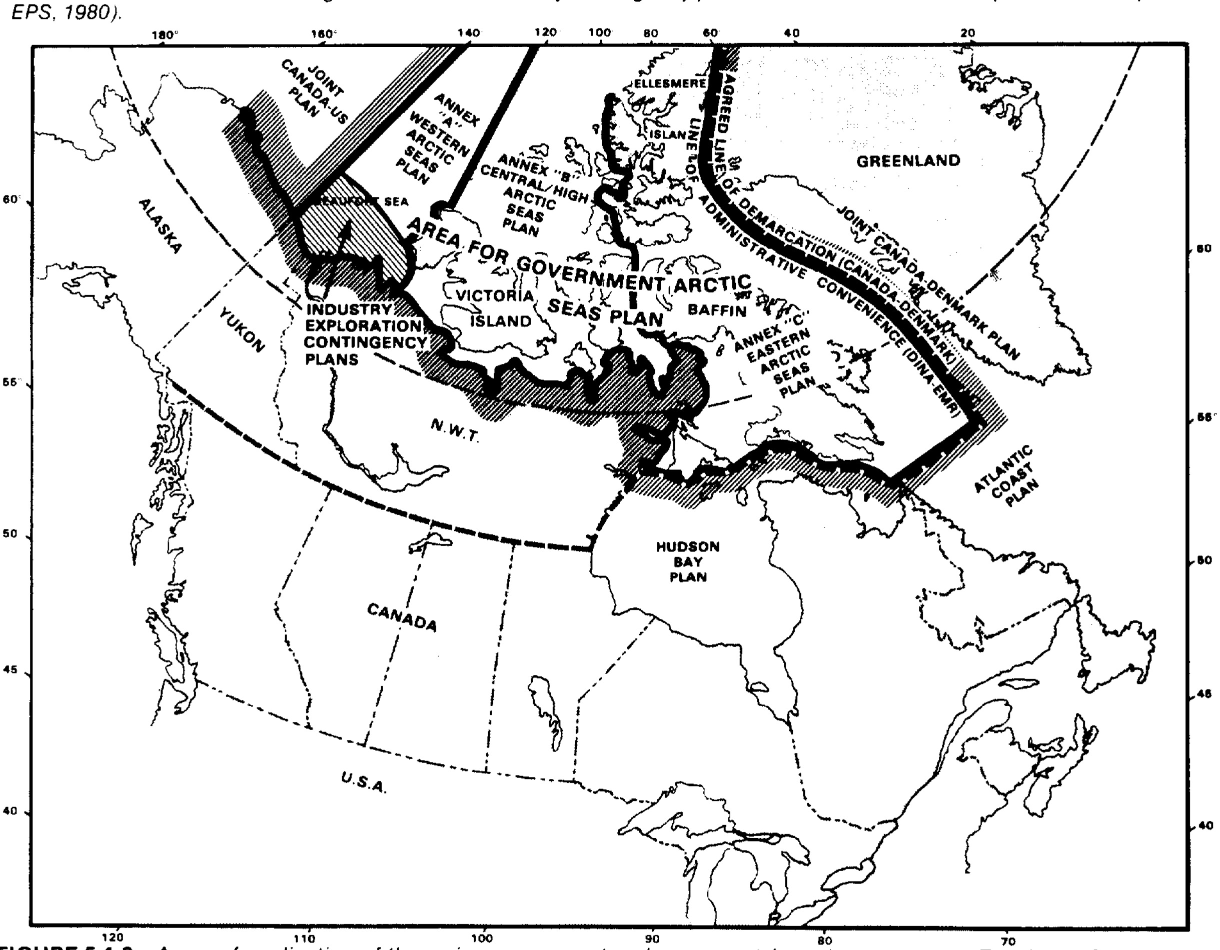


FIGURE 5.4-2 *Areas of application of the major government and proponents' contingency plans. The Arctic Seas Plan is split into three areas, the Western Arctic, the Central/High Arctic and the Eastern Arctic. For spills threatening international boundaries the appropriate Joint Canada-U.S. or Joint Canada-Denmark Plans can be initiated.*

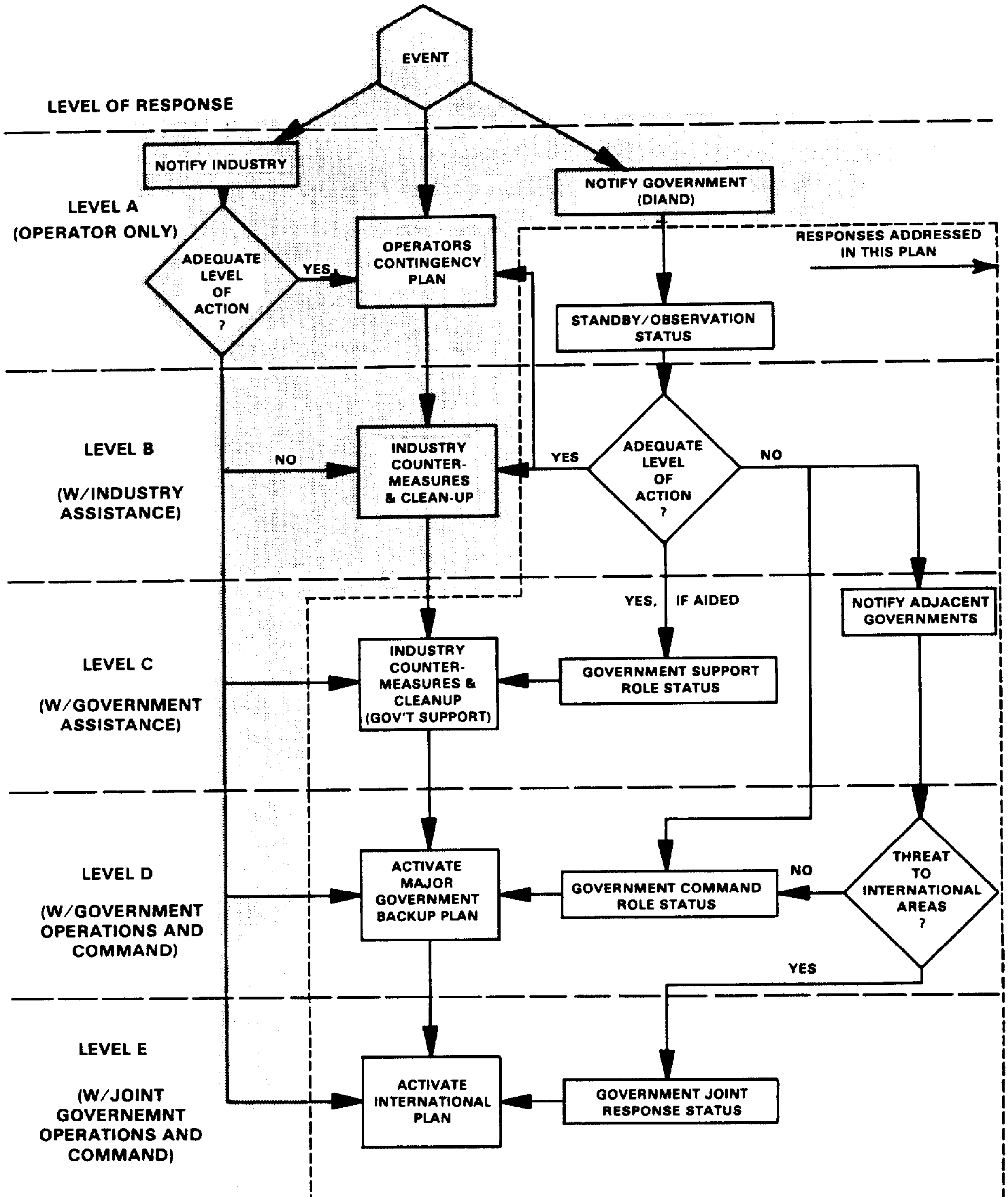


FIGURE 5.4-3 *The Arctic Seas Plan has 5 levels (A to E) which involve increasing degrees of government participation in the spill response. At level A the government monitors the operators' spill response efforts. At level B, which assumes that the operator has called in other industry assistance, the government continues to monitor the response and decides whether or not a sufficient effort is being made. If the decision is that an insufficient response is being made, level C can be enacted which involves government resources being placed under the command of the operators. If an insufficient response is still being made the government may assume command of the response by escalating to level D. If the spill threatens international areas, such as the U.S. or Denmark, level E can be instituted which involves enactment of the appropriate Joint Government Plan and joint command of the response by the two governments (Source: EPS, 1980).*

5.4.4 CONTINGENCY PLAN TESTS AND UPDATING

The proponents carry out mock response exercises on a regular basis to ensure that the existing exploration contingency plans are workable, useful, up-to-date documents. These exercises take two forms. The first of these is a classroom-type paper exercise in which the response management organization practices the decision making procedures required in the event of a spill. This type of exercise exposes the players to their responsibilities in the event of a spill and allows for an evaluation of the organization and its communications and highlights any changes required. The second type of exercise tests the response team and its equipment. These tests involve actually deploying equipment and manpower in response to a hypothetical spill such as an offshore blowout or a beached barge leaking oil. This allows for an evaluation of the response techniques and provides valuable practice in the techniques. The exercises are used to revise and update the industry contingency plans on a yearly basis ensuring the best possible response to any spill. In addition to exercises, training programs, both in-house and at spill control schools, are continuously carried out to ensure that every member of the response team understands how to use spill control equipment in an efficient and safe manner.

5.4.5 FUTURE CONTINGENCY PLANS

In close cooperation with the appropriate regulatory organizations, the proponents will write spill contingency plans covering all aspects of the proposed developments. Based on the proven existing exploration spill contingency plans they will ensure that an effective response can be made to any spill in the areas of interest. The on-going training and exercise programs will continue and expand to maintain and improve industry's high level of response capability.

A specialized computer assisted learning program has been developed for the Beaufort Sea to simulate the time pressures associated with oil spill response (Gillfillan *et al.*, 1982).

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CHAPTER 6

OIL SPILL SCENARIOS AND COUNTERMEASURES STRATEGIES

The threat of a major oil spill in the Arctic continues to be one of the greatest concerns shared by people from all sectors of our society. The chances of such a spill are remote as every reasonable step is being taken to minimize the risk. Nevertheless, a major spill could take place, and therefore contingency plans must be developed to address such an event.

To assist in the planning process, hypothetical oil spill trajectories can be generated. With the aid of computer modelling, and information on the nature of the physical and biological environment, general predictions regarding the possible impacts associated with hypothetical spills, and the countermeasures strategies needed to clean up spills and minimize impacts, can be developed.

This chapter describes the possible fate of a number of large hypothetical marine oil spills. These spills are postulated to take place in various locations extending from the Beaufort Sea, where production operations are planned, and through the Northwest Passage, where icebreaking tankers are proposed to travel. For each hypothetical accident resulting in a spill, the projected fate and behavior of the oil is described, with the assumption that no countermeasures are employed. For certain key hypothetical accidents, which include three in the offshore Beaufort area, and one in the Lancaster Sound portion of the Northwest Passage, the possible biological impacts are briefly examined, again while assuming that no countermeasures are employed. Each oil spill scenario is then followed by a short section outlining the kinds of countermeasures strategies which could be employed to reduce possible impacts.

Each scenario describing an accident, the fate and effects of the oil, and the application of countermeasures, is a case study only. The events which would follow a real accident, even in a similar location, would likely be different, mainly as a result of the different winds, currents and other factors operating at the time, which would affect the fate of the oil. The value of the case study approach is to describe the countermeasures strategies that would be employed for similar accidents but in different locations and under different weather conditions.

Figure 6-1 shows the sites selected for the hypothetical oil spill accidents. The symbols indicate the different types of accident scenarios. The case studies or accident scenarios to be examined in the following sections are:

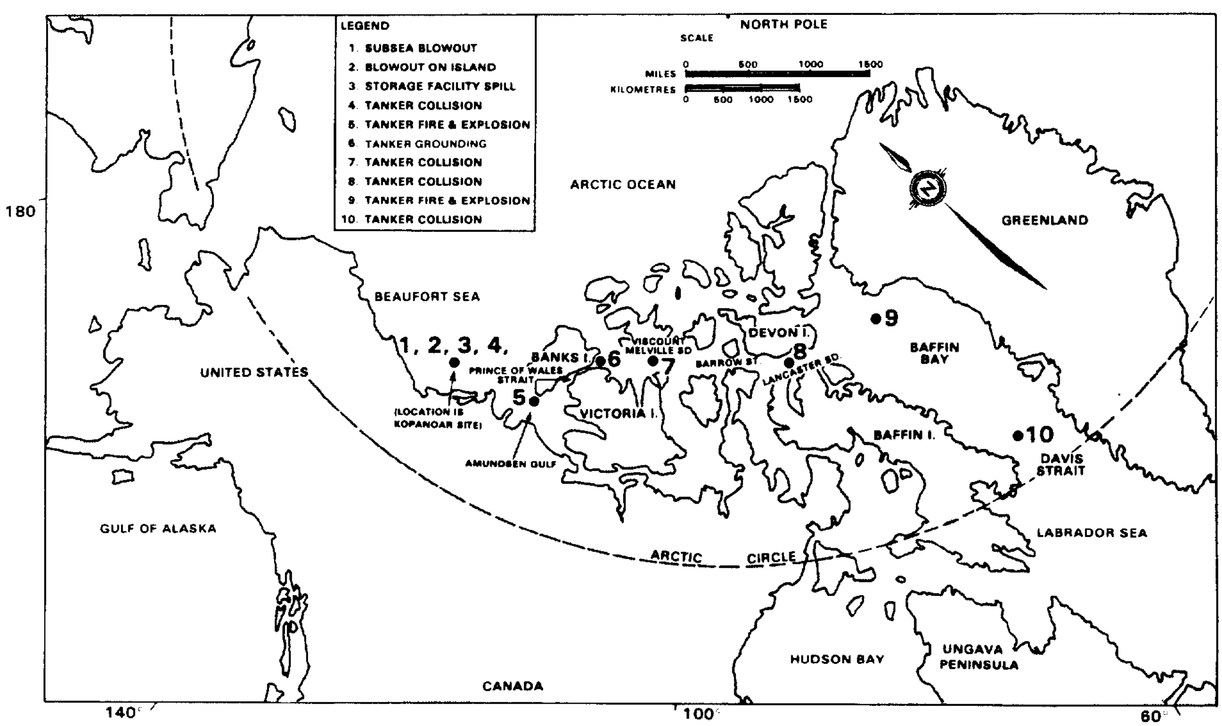


FIGURE 6-1 *Sites selected for ten hypothetical major marine oil spills in the Canadian Arctic.*

- #1 A subsea blowout at the Kopanoar site in the Beaufort Sea.

- #2 A blowout from a production well on a production island at the Kopanoar site in the Beaufort Sea.

- #3 An oil storage facility spill at a tanker loading terminal in the Beaufort Sea.

- #4 A spill after a tanker collision in the Beaufort Sea.

- #5 Tanker fire, explosion and oil spill in Amundsen Gulf.

- #6 A spill after a tanker grounding in northern Price of Wales Strait.

- #7 A spill after a tanker collision in Viscount Melville Sound.

- #8 Tanker collision in Lancaster Sound off the Brodeur Peninsula.

- #9 Tanker fire, explosion and oil spill in Baffin Bay.

- #10 A spill after a tanker collision in Davis Strait.

Each of these hypothetical accidents is described in the following manner:

- The cause of the spill, the amount and rate of oil discharged, and the behaviour of the oil is described.

- An open water oil slick trajectory is presented describing the movement and fate of the oil over a period of several weeks (for tanker spills) or several months (in the case of a blowout).

- For selected scenarios, a summary is given of the potential biological impacts of the spill assuming no countermeasures were undertaken. The areas selected for biological impact analysis are the Beaufort Sea and Lancaster Sound because of the better data available on the biological resources of these regions and because these regions are known to be more biologically productive. The impacts predicted are based on the kind of information contained in Chapter 4, and are summaries of more detailed impact analyses contained in support documents referenced in each scenario examined.

- A countermeasures strategy is presented which describes proposed cleanup operations. Although such a strategy is presented for each hypothetical incident a prediction of response effectiveness would be unrealistic. The success of cleanup operations at a spill site depends on such things as local ice and weather conditions, type and quantity of oil, logistics support and shoreline character. In addition, to protect the environment, under certain circumstances the best method for dealing with spilled oil may be to do nothing but to monitor the situation and to let the oil dissipate through natural processes.

6.1 MODELLING ASSUMPTIONS AND BIOLOGICAL IMPACT DEFINITIONS

6.1.1 THE OIL SPILL TRAJECTORY MODEL AND ITS LIMITATIONS

A slick trajectory model has been used to describe the movement of oil on the sea after the hypothesized accidents.

The details of the model and the oceanographic and meteorological data are not discussed here but are included as support documents (Marko and Foster, 1981; Marko *et al.*, 1981). Its basic features are the same as those included in other contemporary scenario-type spill models. The model represents the oil discharge as a series of instantaneous, discrete releases or "oil parcels." The specific compositions and physical locations of each parcel are then calculated over a series of time intervals to give an approximation of the fate of the oil.

The interaction of oil and ice is not taken into account since the prediction of ice movements, types and concentrations is not yet understood well enough to be incorporated into the model. This has been identified as an area for further research, and is described in Volume 7 of the Environmental Impact Statement.

Two presentation formats have been used because the hypothetical tanker spills and blowouts differ significantly in time and volume. A typical diagram for one of the tanker spills is shown in Figure 6.1-1. This presentation uses colour coded lines to represent the projected motion of the slick over the entire time interval of the scenario. Projected volumes of oil impacting shorelines are indicated using color coded symbols.

The blowout scenarios in the Beaufort Sea are shown in smaller scale to permit a more detailed examination of shoreline contamination (Figure 6.1-2). The model simulations are also shown in the form of a

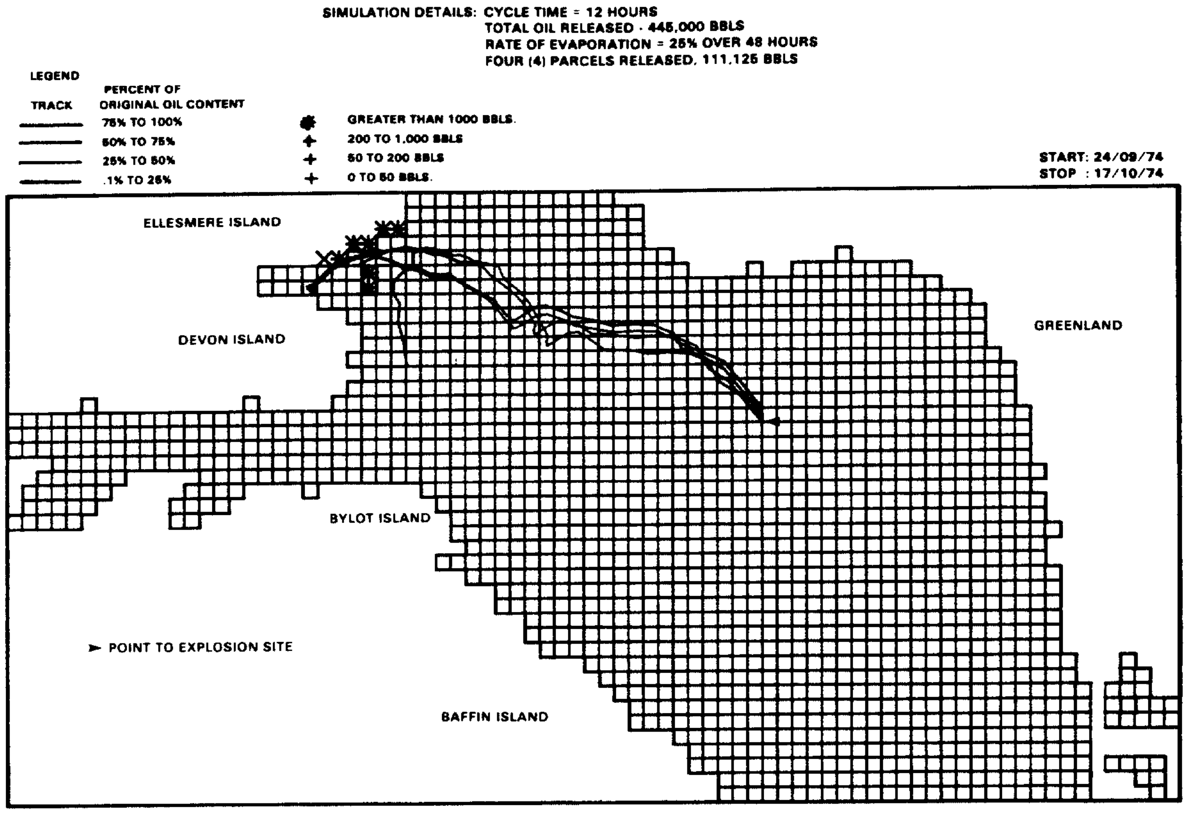


FIGURE 6.1-1 *Example of the presentation format for a hypothetical tanker spill. Colour coded lines represent the projected motion of the oil slick over the entire time interval of the scenario.*

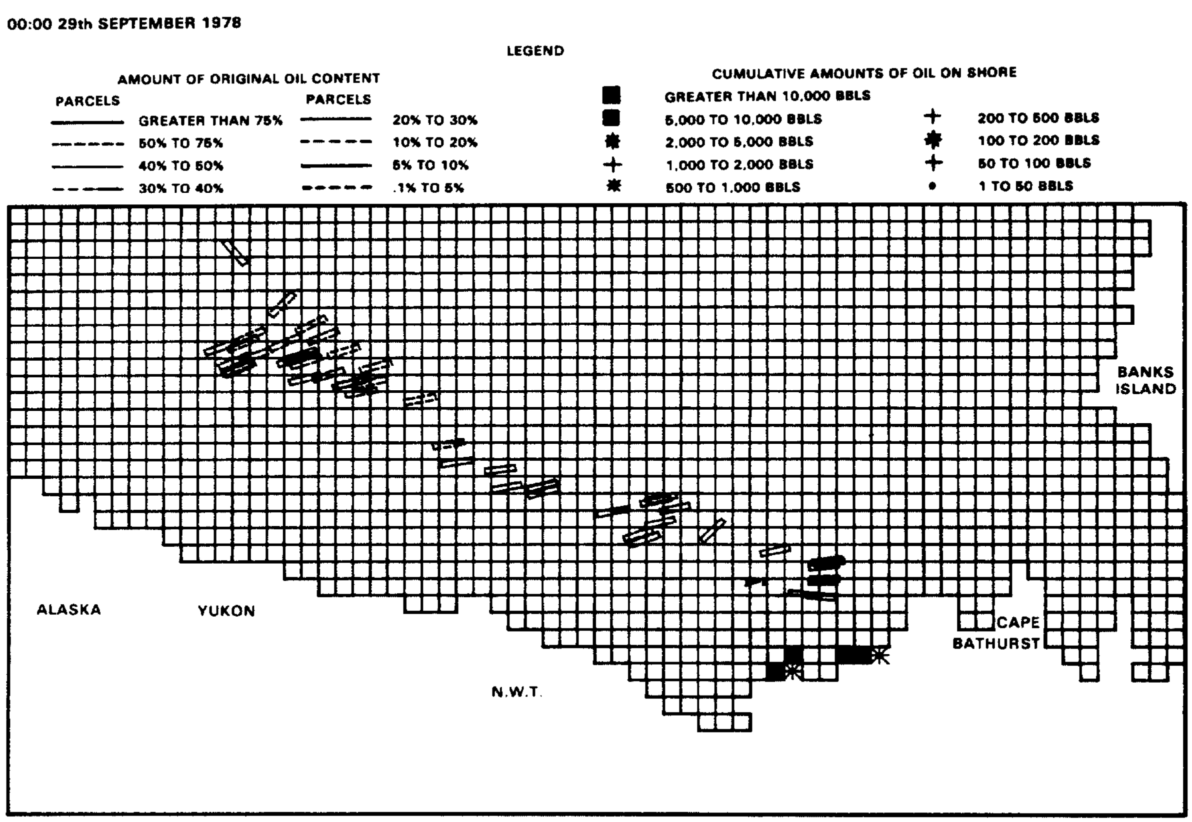


FIGURE 6.1-2 *Example of the presentation format for blowout scenarios. The model simulations are shown in the form of a series of "snap-shots". This example shows one particular "snap-shot" of oil slick locations.*

series of "snapshot" diagrams of the slicks at specific time intervals. This format was chosen due to the relatively long time frames involved in blowout scenarios.

The model uses simple mathematical approximations of very complex natural phenomena and is not precise. The environmental data sets used (winds and currents) for the various scenarios selected were the best available but they are limited. Thus the trajectories are presented only as examples to provide a basis for the discussion of possible impacts and countermeasures.

6.1.2 BIOLOGICAL IMPACT DEFINITIONS

For four of the key hypothetical marine oil spill scenarios, which includes three in the offshore Beaufort area, and one in Lancaster Sound, the possible biological impacts have been examined and summarized in this volume. The complete biological impact scenarios are presented in supporting documents (ESL, 1982a; LGL, 1982) and should be examined by those readers with a particular interest in this subject.

To carry out the biological assessment, it was deemed necessary to use a "standard" set of definitions which describe the degree of potential biological impact(s) which could be expected relative to the oil spill scenarios. It should also be noted that the definitions used here are the same as those employed in Volume 4.

The definitions for degree of potential biological impact were modified from definitions previously used by Esso Resources in the Davis Strait EIS (Imperial Oil *et al.*, 1978). These definitions were modified to focus the biological assessment on regional populations of specific resources (a requirement of a regional assessment such as this) rather than on local groups of individuals.

The definitions used are as follows:

A MAJOR impact exists when a regional population or species may be affected to a sufficient degree to cause a decline in abundance and/or a change in distribution beyond which natural recruitment (reproduction and immigration from unaffected areas) would not likely return that regional population or species, or any population or species dependent upon it, to its former levels within several generations.

A MODERATE impact exists when a portion of a regional population may be affected to a sufficient degree to result in a change in abundance and/or distribution over more than one generation of that portion of the population or any population dependent upon it, but is unlikely to affect the integrity of any regional population as a whole.

A MINOR impact exists when a specific group of individuals of a population at a localized area and over a short time period (one generation) may be affected, but other trophic levels are not likely to be affected in a manner which is considered regionally significant, or the integrity of the population itself is not significantly affected.

A NEGLIGIBLE impact exists when the degree of the anticipated biological effects is considered less than minor.

Like all such definitions, the ones used here must have the built in flexibility to allow their use for a wide range of biological resources (plankton to whales) and sources (and durations) of potential impact. As a result, the definitions were used primarily as a set of guidelines, rather than as a fixed and inflexible mechanism to determine degree of impact.

6.2 SCENARIO #1: SUBSEA BLOWOUT AT THE KOPANOAR DRILL SITE IN THE BEAUFORT SEA

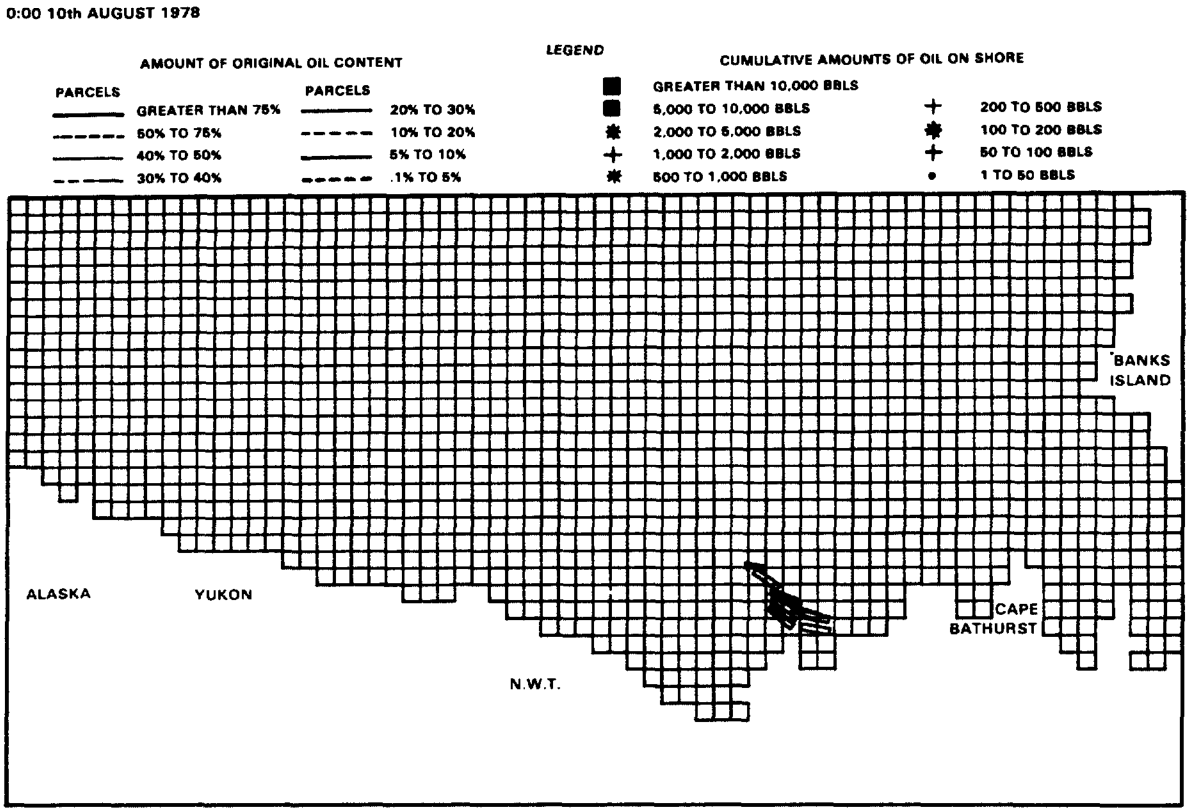
6.2.1 ACCIDENT DESCRIPTION

Two scenarios are presented: one in summer and one in winter.

Summer

In the summer scenario, a development well is being drilled in August from a floating platform located in 75 m of water. It is assumed that a high pressure formation has been penetrated by the downhole tool and a kick occurs. Control of the well is lost, the riser is disconnected and the platform moves off location. The well is assumed to flow unabated for 60 days at a rate of 1,900 m^3/day (12,000 barrels of oil per day), with a gas-to-oil ratio of 160 to 1 (900 ft^3 of gas/bbl of oil). The gas ignites and burns when it reaches the surface. After two months, the drilling of a relief well is completed and the flow of oil is stopped. Figure 6.2-1 shows the location of this hypothetical incident. The top view of the plume would appear as an elliptical area with an approximate diameter of 80 metres, in the centre of which would be a fireball about 10 to 20 m in diameter (see Figure 3.1-4 in Chapter 3).

The oil and gas discharged from the blowout rises in a gas driven plume of water through the water column. The gas erupts into the atmosphere while the oil spreads outwardly with radial currents generated by the plume. Under the influence of the gas-fed fireball the light ends, or 35% of the oil, are flashed off and the turbulence may create a water-in-oil emulsion with the remaining oil. The computer



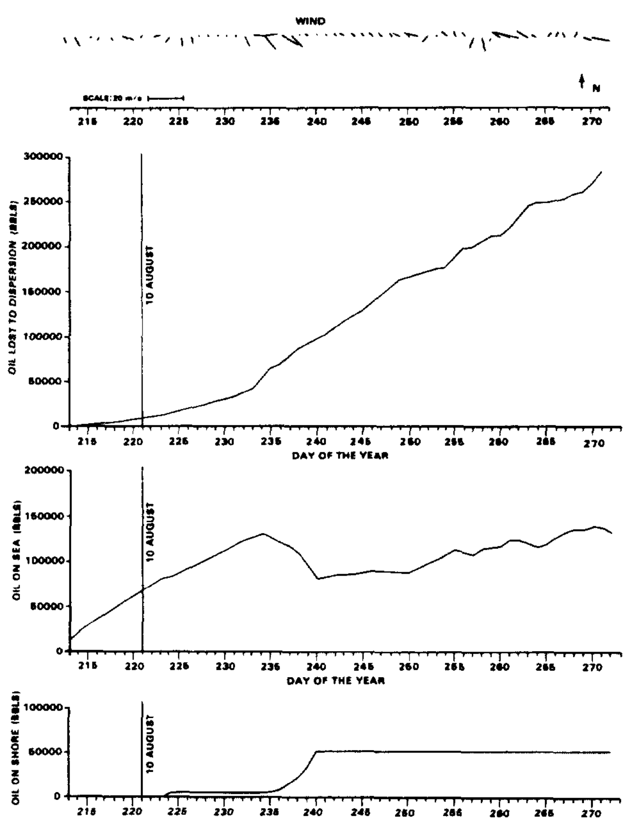


FIGURE 6.2-1 *Projected location of the slick from a subsea blowout at the Kopanoar site assumed to occur on August 1, 1978, 10 days after the blowout. The graphs show the wind regime and the disposition of the oil vs time.*

model assumes that 1% of the oil volume is dissolved into the water column.

Some fraction of the oil or emulsion is mixed down into the water by the turbulence and, under the influence of the residual currents, comes to the surface some distance downstream of the blowout site. The surface oil or emulsion spreads and moves away from the blowout site. The total oil volume released in this scenario over a period of 60 days is 114,000 m^3, and the volume of emulsion that may be formed is estimated at 247,000 m^3. Ice does not play a role in this particular incident.

Winter

If a blowout occurs during late season drilling and there is not enough time to complete a relief well to stop it, ice drifts over the site and escaping oil is "painted" on its underside. The turbulent energy available in these ice covered waters is small compared to the open water scenario, thus the possibility of forming a water-in-oil emulsion is low and, if formed, it would not be nearly as viscous as one formed during open water. As the ice drifts over the blowout site, it is expected to be heavily oiled in a strip approximately 150 m wide. This oil, which accounts for 90% of the total discharged, would be frozen into the underside of the ice as it continues to grow in thickness. The remaining oil, present as very small droplets, is distributed over a much wider area in a direction coinciding with the under-ice currents, expected to have speeds of less than 5 cm/s, as the ice passes over the site.

If one assumes that the winter lasts for 200 days and that the blowout does not cease, the result is that oil is painted under and encapsulated into broken strips of ice with a total length of 500 km and width of 150 m containing 342,000 m^3 of oil. Adjacent to these strips will be a relatively lightly contaminated area containing 38,000 m^3 of oil. In spring most of this oil appears on the ice surface and loses its volatile components to the atmosphere (35% by volume). This eventually results in the presence on the surface of the ice of 247,000 m^3 of oil in narrow strips. With break-up, most of the oil would be released into the water, and would exist as widely separated patches of weathered oil surrounded by a thin sheen.

6.2.2 OIL SPILL TRAJECTORIES

The following summarizes the predicted trajectories of the oil spills emanating from hypothetical subsea blowouts in the offshore Beaufort Sea during summer and winter. The reader is once again reminded that the data and assumptions used to develop these and subsequent trajectories are provided in detail in Marko and Foster (1981), Marko *et al.* (1981), and ESL (1982a).

Summer

Figures 6.2-1 to 6.2-3 describe the projected location of the slick released from a subsea summer blowout in the southern Beaufort Sea as a function of time. The three "snapshots" of the oil represent its distribution 10, 20 and 60 days after the August 1st blowout. The figures illustrate how the oil would be distributed if no countermeasures operations were in effect at the blowout site. However, as is shown later, in reality this would not be the case.

Winter

In contrast to the summer scenario, because of the more limited information base, no computer trajectory analysis was carried out to predict the likely fate of oil for the winter subsea blowout scenario. Rather, a series of assumptions pertaining to most likely weather patterns (Environment Canada, 1975), surface ocean currents (Giovando and Herlinveaux, 1981), and the behavior of oil in ice and water (Dome Petroleum Ltd., 1981; Marko and Foster, 1981) were combined by ESL (1982a) to produce the following trajectories.

Since the possible biological impacts of the winter subsea blowout will be examined in Section 6.2.3, it is appropriate to discuss the likely oil trajectory and behavior of oil from this spill in some detail.

As stated previously, all the oil contacting the undersurface of both first and multi-year floes would become encapsulated in the ice as either droplets or pools within the first 24 hours. This process is expected to continue for the duration of the blowout, and would result in the immobilization of much of the oil in a virtually unweathered state throughout the winter. The majority of the oil released during this hypothetical blowout is expected to be concentrated in narrow strips of contaminated ice totalling about 500 km in length, each about 150 m wide.

Shearing of floes within the transition zone ice could result in some oil reaching the water surface in temporary leads and cracks in the ice. These surface slicks would then be transported by winds and currents , until they either contacted an ice edge, or the leads refroze. Similarily, wind and current-induced polynyas formed within oil-contaminated areas could also allow redistribution of ice-encapsulated oil throughout the winter months. The predominantly westward movement of ice within the transition zone during winter (Marko, 1975), together with the redistribution of oil in temporary leads and polynyas, is assumed to result in an oil distribution similar to that

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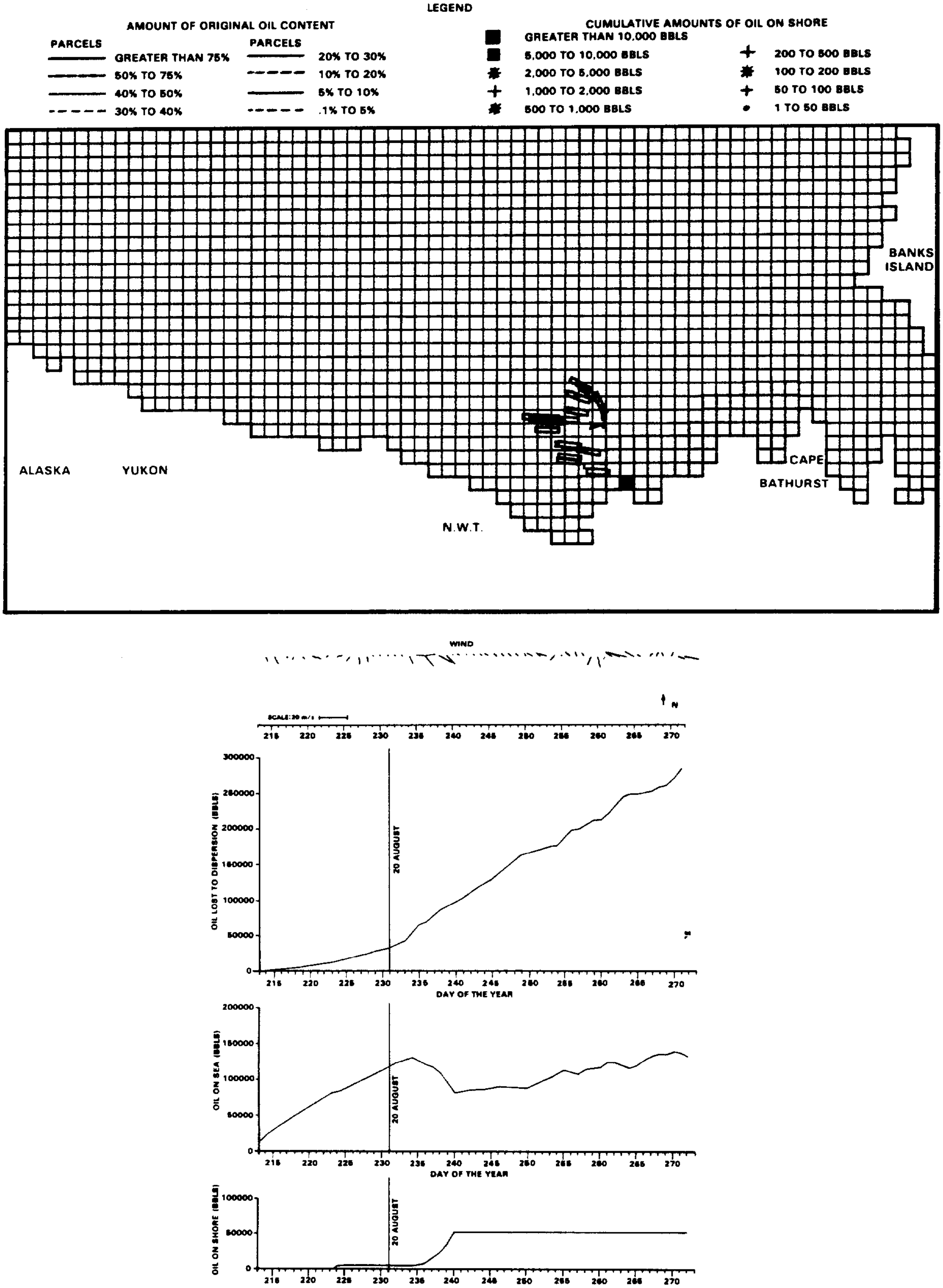


FIGURE 6.2-2 *Projected location of the slick from a subsea blowout at the Kopanoar site assumed to occur on August 1, 1978, 20 days after the blowout. The graphs show the wind regime and the disposition of the oil vs time.*

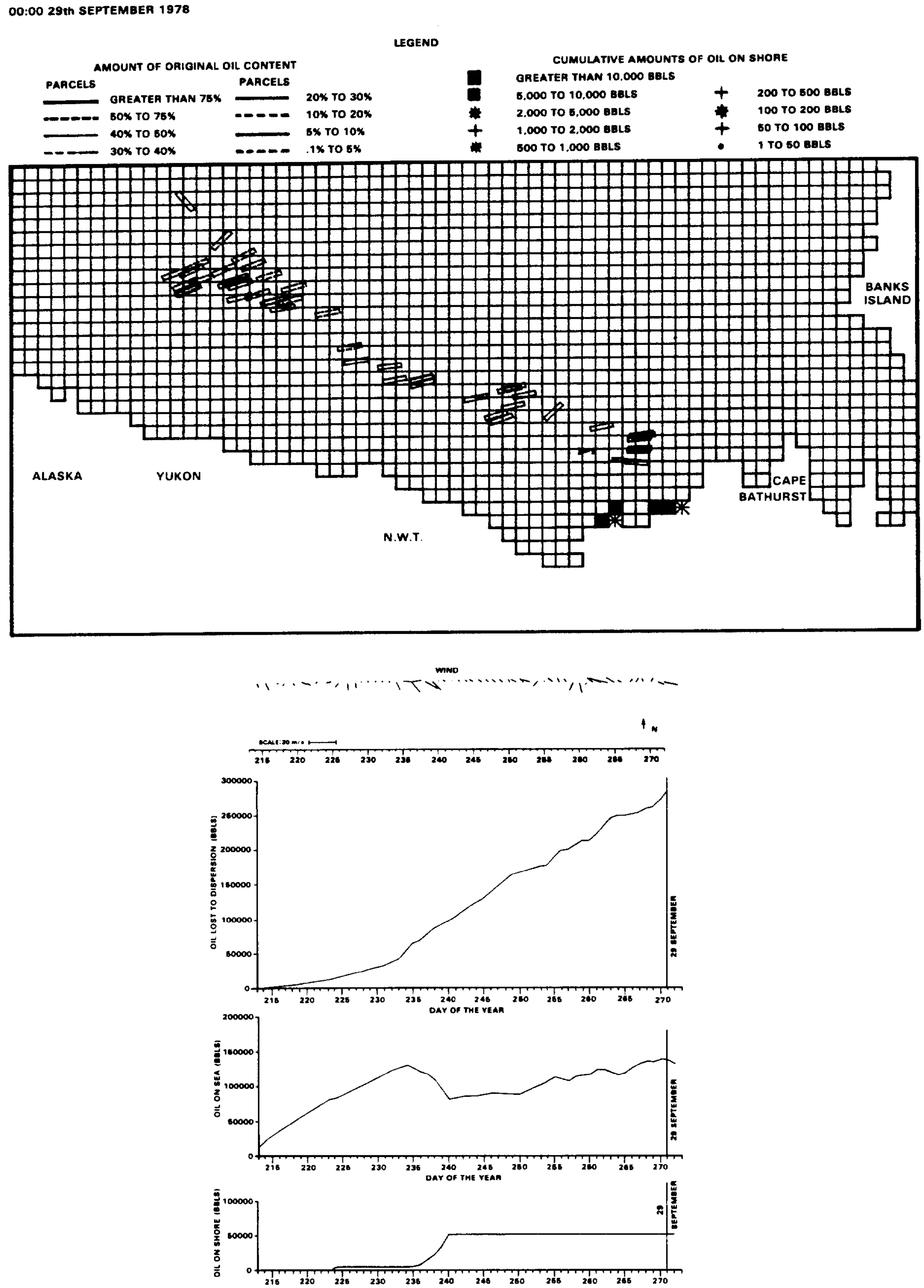


FIGURE 6.2-3 *Projected location of the slick from a subsea blowout at the Kopanoar site assumed to occur on August 1, 1978, 60 days after the blowout. The graphs show the wind regime and the disposition of the oil vs time.*

shown in Figure 6.2-4 prior to break-up, where an area of relatively high oil contamination is surrounded by an area of relatively low contamination.

It is important to emphasize that the oil coverage in these two areas is discontinuous. Within the approximately 2,400 km^2 central area shown in Figure 6.2-4, only some 75 km^2 would actually be oiled, while in the outer zone of roughly 12,000 km^2 only small amounts of oil which has been redistributed by winds and currents in open water areas during winter, are likely to be encountered.

Unlike surface oil which rapidly begins to weather during the first few days after release, ice-encapsulated oil is expected to weather very slowly or not at all. Although a small initial loss of volatile or soluble components can be anticipated between the time that oil and gas are released at the sea floor and the oil is encapsulated in ice (Dome Petroleum Limited, 1981), oil overwintering in sea ice will be basically in the form of fresh crude at spring break-up.

During May, oil surfacing in freshwater melt pools will likely weather rapidly, and prior to break-up, 480,000 barrels or 20% of the total volume of oil released during the hypothetical blowout is assumed to have evaporated (Buist *et al.*, 1981). Further evaporation may be prevented by the formation of stable or partly stable water-in-oil emulsions (mousse), and by the herding effect of wind, which is expected to pile up thick layers of oil and mousse on the downwind side of the melt pools (Dome Petroleum Limited, 1981). As the specific gravity of mousse approaches the density of sea water, some of it may sink to the bottom of the melt pools where it will remain until break-up (Dome Petroleum Limited, 1981). Approximately 24,000 barrels of oil or 1% of the total volume of oil released in this hypothetical blowout is assumed to be dissolved in the water column during the blowout. At break-up, 1,900,000 barrels of oil (80% of the total volume of oil released) are assumed to be present in the following forms: 1,540,000 barrels (65%) as partly weathered crude and mousse in melt pools on the ice surface in the

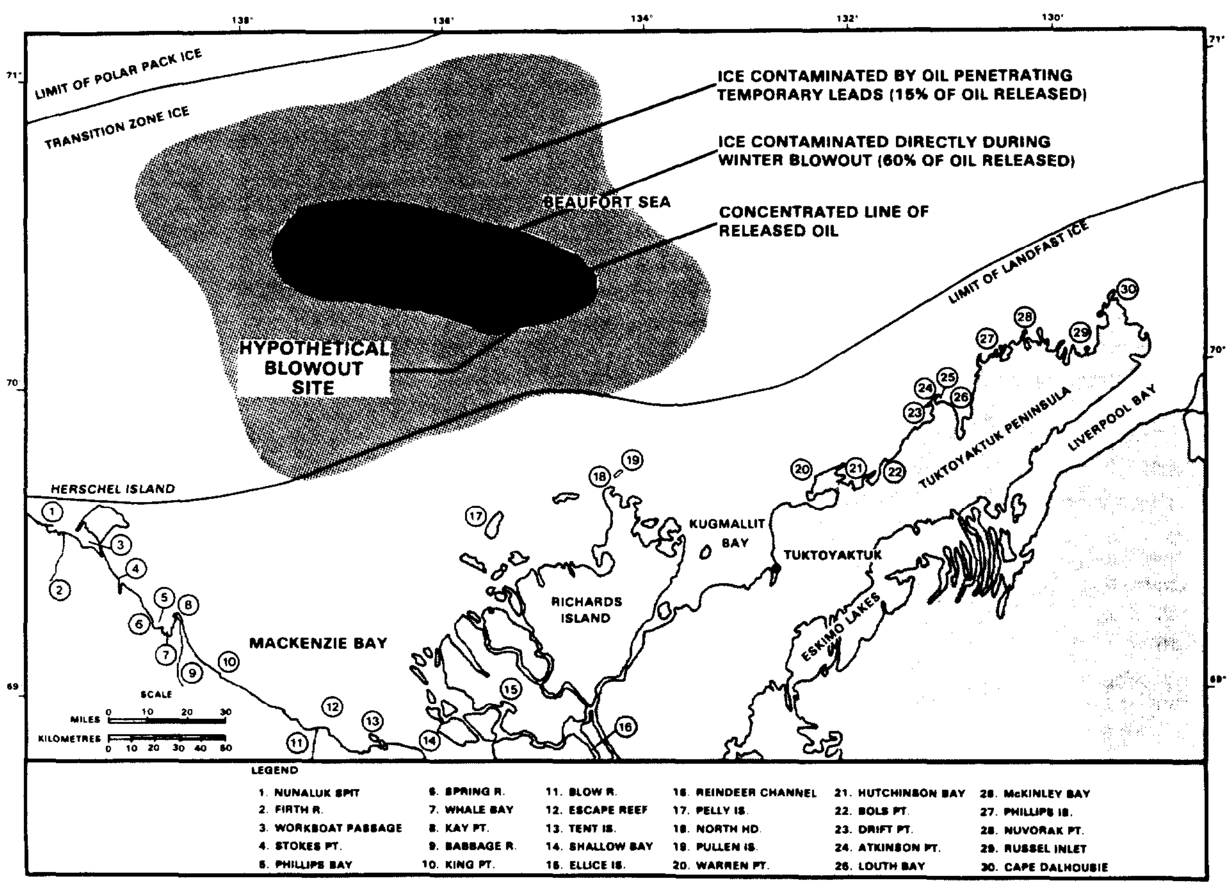


FIGURE 6.2-4 *An assumed distribution of oil in and under the ice before breakup in May from a subsea blowout assumed to occur 200 days previously during late season drilling at the Kopanoar site. An area of relatively high oil contamination is surrounded by an area of relatively low contamination.*

area of relatively high oil contamination, and 360,000 barrels (15%) of more weathered oil in melt pools in the area where it has been exposed to open water in leads and polynyas at various times during the winter or stranded on the ice surface after rafting.

Throughout early June, melting transition zone ice would release oil to the water surface. During this period when fresh oil is being continually added to melt pool water through upward migration in remaining ice floes, concentrations of dissolved hydrocarbons in melt pools may reach several ppm in some areas. Approximately 24,000 barrels or 1% of the total volume of oil released during the blowout may be dissolved in melt pools. Most of the soluble low molecular weight petroleum hydrocarbons would probably evaporate from the surface of the melt pools. As the individual melt pools coalesce and large pieces of ice break away, the oil is assumed to begin reaching the surrounding water surface. Weathering would then occur at an accelerated rate due to the increased slick surface area, and winds would begin to dominate the movement of both broken ice and floating oil. Not all of the oil trapped in drifting ice floes is expected to be released during the spring break-up. Five percent of the total volume of oil lost during the hypothetical blowout (120,000 barrels) is assumed to penetrate the polar pack ice through interconnecting leads, and an additional 10% (240,000 barrels) is refrozen into transition zone ice at the onset of freeze-up. The former would be relatively unweathered oil, while the latter would likely be in the form of viscous lumps of debris-coated tar. Oil trapped in pack ice could travel westward throughout the year, and would probably only be released in significant amounts when polar ice extends into the transition zone. On the other hand, tarballs refrozen into transition zone ice at the end of the first summer could be released during the second summer at locations further west along the coast of Alaska.

It is assumed that strong northwesterly winds in the middle of June push broken ice and oil up against the landfast ice protecting the Mackenzie Delta (Figure 6.2-5). During this period, an additional 336,00 bar-

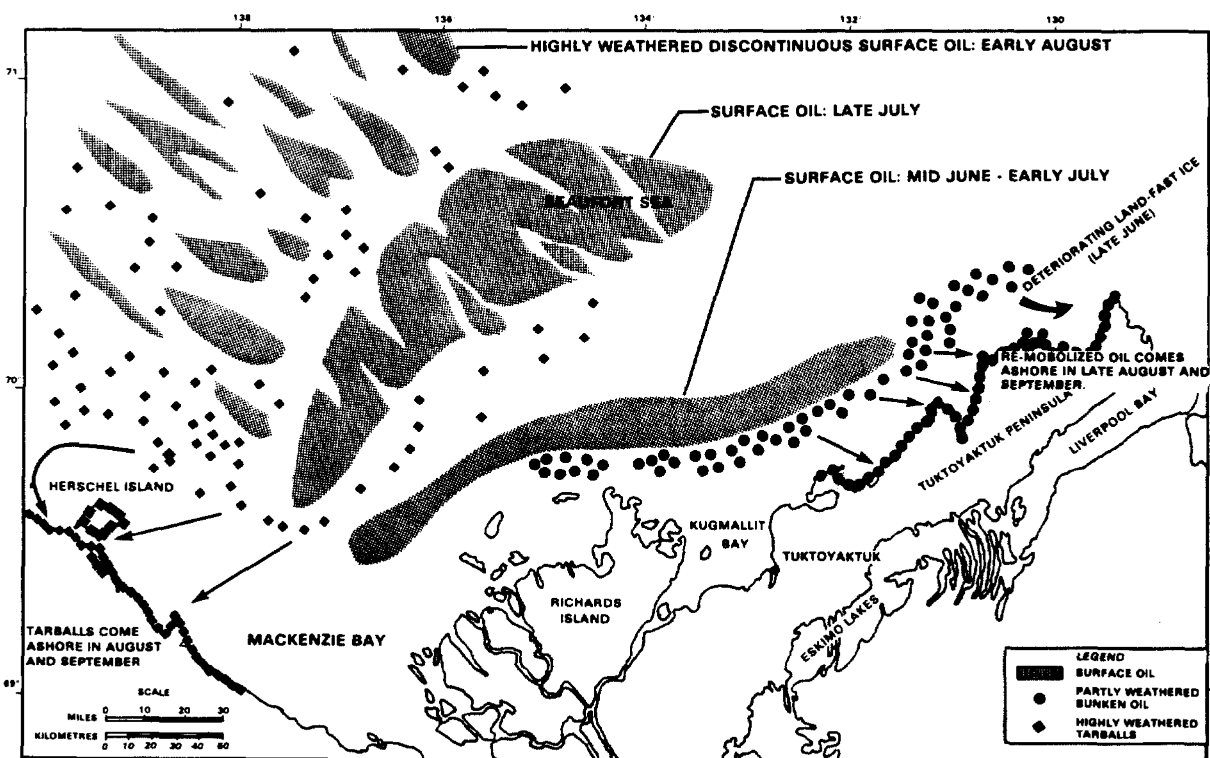


FIGURE 6.2-5 *Fate of oil during June to September following a subsea blowout assumed to occur in early winter at the Kopanoar site.*

rels (14%) of volatile hydrocarbons are assumed to evaporate from the floating oil slicks, while oil-contaminated broken ice and surface oil is also assumed to extend along the landfast ice zone from Ellice Island to McKinley Bay.

Heavier (denser than sea water) mousse "pancakes," released from the bottom of melt pools at the same time as floating oil, would slowly sink in the water column until the bouyancy compensation depth is reached and the increasing specific gravity of seawater prevents further sinking. As freshwater from melting ice and subsurface seawater mix under the influence of wind, some of this oil (i.e. that having a specific gravity less than the seawater-freshwater mixture) could rise to the surface and rejoin the surface slick. However, some of the submerged mousse may be swept by southeasterly currents under the outer (seaward) edge of the landfast ice where it is expected to encounter the eastward flowing Mackenzie River outflow.

A large proportion of the submerged oil could contact and incorporate river-transported sediment and gradually sink to the bottom (Duval *et al.*, 1978). Approximately 10% (240,000 barrels) of the oil released during the blowout is assumed to reach the sea floor due to this process. By early July, this oil is expected to settle to the ocean floor in 5 to 20 m water depths.

The sunken oil will likely be in the form of soft, sediment-coated lumps up to 1 to 3 cm in diameter. These lumps would not be immediately incorporated into bottom substrates, but rather remain free to drift along the bottom with prevailing currents, or to collect in shallow depressions and scour marks on the substrate. Concentrations of oil are expected to collect in isolated patches in bottom depressions. Some of this mousse may eventually be cast ashore during subsequent late summer storms.

During the first week of July, the prevailing winds and resultant surface currents are expected to transport much of the remaining surface oil away from the offshore Mackenzie Delta region. Together with small ice chunks, this oil is assumed to drift roughly northwest towards the southern limit of the polar pack north of Herschel Island. During the first and second weeks of July, a further 744,000 barrels (31% of the total volume of oil lost in the hypothetical blowout) are dispersed (oil-in-water emulsion) from the surface slicks by wind and wave action. Of this total, 288,000 barrels (12%) are assumed to be tarballs which are formed from mousse as the water component is gradually lost. Over the next 2 months, 96,000 barrels of tarballs come ashore along the coast from King Point to Barter island in northeast Alaska (Figure 6.2-5). These viscous oil masses are assumed to be stranded along the high water line and over several weeks harden into a debris-coated tarlike mass as more water reaches the surface of the water-in-oil emulsion and evaporates. Larger dispersed particles which are not in the form of mousse (114,000 barrels) are assumed to settle slowly and may be deposited along the margins of the Canadian Basin at depths ranging from 100 to 1,000 m. The remaining 342,000 barrels of finely dispersed oil particles may enter the westward flowing Beaufort Sea Gyre and are assumed to be transported out of the region.

6.2.3 BIOLOGICAL IMPACTS

The possible biological effects of a hypothetical winter subsea blowout on all levels of the food chain have been described in considerable detail in ESL (1982a). The following is a summary of the scenario, with primary emphasis being placed on the higher profile marine mammals and birds, which by and large could be expected to be most impacted by such an event, were it to occur.

The reader is again asked to bear in mind that this and subsequent biological assessments are based on many assumptions including the fact that no countermeasures steps are taken, which themselves would tend to contribute to a reduction in certain impacts.

Table 6.2-1 provides a summary of the nature and potential regional impacts of this hypothetical blowout on the marine resources of the southeastern Beaufort Sea.

The potential impacts of this event on the marine resources would generally be less severe prior to the onset of break-up, than during and following break-up, although MODERATE impacts on ringed seal, bearded seal and polar bear populations are considered possible, since a change in the distribution and abundance of these populations could persist for more than one generation. As indicated in Table 6.2-1, white whales and most species of birds would not be affected by this blowout prior to spring break-up, and only NEGLIGIBLE to MINOR impacts on lower trophic levels and fish are anticipated during the winter months.

During spring break-up and in the open water season, this hypothetical blowout would result in considerably more serious impacts than those expected as a result of the subsequent scenarios described in Sections 6.3.2 and 6.5.2. This is largely related to the timing of this event (ie. entire open water season is affected), the contamination of lead systems and polynyas, the amount of oil which is expected to reach coastal habitats, and the extensiveness of the shoreline contamination.

TABLE 6.2-1

THE NATURE AND POTENTIAL REGIONAL IMPACTS OF A HYPOTHETICAL SUBSEA WINTER BLOWOUT ON MARINE RESOURCES OF THE S.E. BEAUFORT SEA

Resource	Nature of Potential Impacts	Anticipated Degree of Regional Impact: Prior to Onset of Breakup	Anticipated Degree of Regional Impact: During and Following Breakup
Bowhead whale	S, C, F	Minor	Minor
White whale	S, C, F, M	None	Moderate
Ringed seal	H, S, C, F, M	Moderate	Moderate
Bearded seal	H, S, C, F, M	Moderate	Minor
Polar bear	S, C, F, M	Moderate	Moderate
Arctic fox	S, C, F	Negligible	Negligible
Red-throated loon	H, S, C, M, F	None	Moderate
Yellow-billed loon	H, S, C, M, F	None	Minor
Arctic loon	H, S, C, M, F	None	Moderate
Whistling Swan	H, S, C, M, F	None	Minor
Black brant	H, S, C, M, F	None	Major
White-fronted goose	H, S, C, M, F	None	Moderate
Snow goose	H, S, C, M, F	None	Minor
Scaup and Scoter	H, S, C, M, F	None	Moderate
Oldsquaw	H, S, C, M, F	None	Moderate
Common eider	H, S, C, M, F	Minor	Major
King eider	H, S, C, M, F	Minor	Moderate
Sandhill crane	H, S, C, M, F	None	Minor
Shorebirds	H, S, C, M, F	None	Minor to Moderate
Jaegers	S, C, M, F	None	Negligible
Glaucous gull	H, S, C, M, F	Minor	Moderate
Arctic tern	H, S, C, M, F	None	Moderate
Sabine's gull	H, S, C, M, F	None	Minor
Black guillemot	H, S, C, M, F	None	Major
Thick-billed murre	S, C, M, F	None	Negligible to Major
Fish	H, S, M, F	Minor	Minor to Moderate
Phytoplankton	S, M	Negligible	Minor to Moderate
Melt pool flora	S, M	None	Negligible to Minor
Zooplankton	S, M, F	Negligible to Minor	Minor
Ichthyoplankton	S, M, F	Negligible to Minor	Minor
Benthic fauna	H, S, M, F	Negligible	Minor to Moderate
Benthic microalgae	H, S, M	Negligible	Negligible
Epontic flora	H, S, M	Negligible to Minor	None
Epontic fauna	H, S, M	Minor	None
Terrestrial vegetation	H, S, M, C	None	Negligible to Moderate

[1]Nature of Potential Impact
- H = Habitat loss
- S = Sublethal effects
- M = Mortality
- C = Contamination (fouling)
- F = Reduced food availability

[2]See Section 6.1.2 for Impact Definitions
[3]Dependent on species and/or habitat affected

Source: ESL, 1982a

However, this blowout is not considered a "worst case" oil spill scenario for the Beaufort Sea region. More severe impacts on some resources would be expected if the period of oil release extended into late spring when oil is not likely to be encapsulated in the ice cover, thereby substantially increasing the risk of exposure of marine resources to water-soluble toxic hydrocarbons. Nevertheless, MAJOR impacts on at least three species of birds (common eider, black brant and black guillemot, and possibly thick-billed murres) are considered possible under the circumstances assumed to occur in this scenario, since the regional populations of these species may not return to their normal abundance and distribution within several generations. As indicated in Table 6.2-1, MODERATE impacts on white whales, Arctic and red-throated loons, white-fronted geese, scaup, oldsquaw, king eiders, scoters, glaucous gulls, Arctic terns, some shorebirds and fish, and depending on area, terrestrial vegetation, phytoplankton and benthic fauna are also considered possible as a result of this hypothetical blowout.

6.2.3.1 Possible Impacts on Marine Mammals

(a) Bowhead Whale

The western Arctic population of bowhead whales winter in the Bering Sea and undertake annual migrations to and from summer feeding grounds in the eastern Beaufort Sea and Amundsen Gulf (Volume 3A). Late migrating bowhead whales may occur in areas affected by oil released from the blowout during October as they move to the northwest toward their wintering grounds in the Bering Sea. However, few whales would likely contact oil at this time since most of the population has left the region by mid-October.

The probability that bowheads will contact oil during the spring migration is also expected to be remote since most travel through leads farther offshore than the predicted distribution of oil released and trapped under transition zone ice in the Beaufort Sea (Fraker, 1979; Braham *et al.*, 1980). The only whales that may occur in areas affected by oil are those that migrate later and possibly follow the nearshore lead; in most years, the number of affected individuals would probably be small.

Although the distribution of bowheads on their summer range apparently varies annually, they appear to initially occupy Amundsen Gulf and waters off the Bathurst Peninsula. During late July and August when the oil remaining on the surface is expected to move far offshore, contamination of some individuals may occur within summer feeding areas used by bowheads in some years (eg. 1981; LGL Ltd., unpubl. data). An unknown number of bowheads may contact the highly weathered slick, depending on their annual distribution, while other individuals would probably occur off the Tuktoyaktuk Peninsula and Mackenzie Delta where oil is expected to be dispersed throughout the water column.

During fall migration, most bowheads move gradually to the northwest within 40 km of the Yukon and Alaskan coasts, and therefore would probably not occur in areas affected by surface oil. However, they are likely to be present in waters containing dispersed and sedimented oil, as well as highly viscous and sinking tarballs. Bowheads may be affected by reduced food availability or ingestion of contaminated prey during the fall migration since the latter is characterized by extensive feeding activity.

The number of bowhead whales which may occur in areas affected by surface oil would depend on their distribution during the year of the event, although the majority of the regional population may encounter areas containing dispersed and sedimented oil. As indicated in Chapter 4, the detection and avoidance of surface or dispersed oil by cetaceans has not been documented. However, the oil spill case history literature suggests that some whales may in fact avoid oil-contaminated waters because oiled cetaceans have not been observed following spills (Duval *et al.*, 1981). Although the effects of dispersed oil on this species have not been documented, there is no evidence to suggest that this hypothetical event would result in mortality of bowheads. The potential sublethal effects of oil contact on whales include fouling of baleen plates, temporary eye irritation, and alteration of the physical and metabolic properties of the skin. Indirect effects may include contamination of prey and reduced food availability on the summer range and during fall migration. The potential long-term effects of this hypothetical blowout on bowheads are unknown, although direct mortality is considered unlikely. Consequently, the degree of potential impact on the regional bowhead population would probably be MINOR.

(b) White Whale

In most years, the majority of spring migrant white whales move through leads farther offshore than areas where oil is expected to be trapped and released during May and June. However, later migrants may contact surface oil since the nearshore lead system from the Mackenzie Delta to Atkinson Point could be contaminated with relatively unweathered crude at spring break-up. The number of whales which may be migrating eastward along this lead is not known, and would be highly dependent on prevailing ice conditions. In most years, however, the majority of the white whales are believed to travel along the aforementioned route far offshore (Fraker, 1977).

There is a concentrated westward migration of white whales from Amundsen Gulf to the Mackenzie estuary during late June and early July. This migration occurs along the landfast ice edge off the Tuktoyaktuk Peninsula, across northern Kugmallit Bay, and along the northeast and north coasts of Richards Island. At this time, a substantial portion of the regional white whale population would likely occur within some areas extensively contaminated with crude oil released during spring break-up.

When the landfast ice breaches during late June or early July, the whales move into concentration areas within the Mackenzie estuary, but they are unlikely to be affected by surface oil during their residence in the estuary, because the slick is not expected to reach these areas. Most white whales have left the estuary by late July and early August, although their distribution during August is not well documented. Some individuals may move along the Tuktoyaktuk Peninsula or offshore, and/or return to the estuary (Fraker and Fraker, 1981). Consequently, an unknown number of white whales may be present in areas affected by both the surface slick and dispersed oil during August. The majority of fall migrants are thought to travel far offshore near the edge of the pack ice, and therefore may also contact any oil remaining on the surface during their westward movements.

The total number of white whales that could contact oil released during this hypothetical blowout in the southeastern Beaufort Sea is unknown, but may be relatively high in view of the anticipated degree of contamination of the landfast ice edge where the whales concentrate before entering the estuary in late June and/or early July. In addition, smaller numbers of whales may contact surface or dispersed oil during spring migration, August, and fall migration. If whales along the landfast ice edge actively avoided the oil, they could be displaced from migration routes or concentration areas in the estuary during that year.

Sublethal effects of oil contact may include clogging of the blowhole, ingestion of oil through contaminated prey, suckling or respiratory surfaces, alteration of the metabolic and physiological character of the skin, and reduced food availability (Geraci and St. Aubin, 1980; ESL, 1982b). Mortality of cetaceans has not been reported following oil spills (Duval *et al.*, 1981), although it is not certain that mortality would not result under the circumstances assumed to occur in this hypothetical event, particularly in view of the anticipated degree of contamination (840,000 barrels) of waters adjacent to the landfast ice edge. In view of the large proportion of the regional population which may be affected during the relatively critical migration to the estuary, the degree of impact of the hypothetical subsea blowout on white whales could be MODERATE.

(c) Ringed Seal

The number of ringed seals (primarily subadults and non-breeding adults) that may be present within areas of the transition zone ice affected by the subsea blowout during winter and spring cannot be accurately estimated because of the marked year-to-year variability in the distribution and abundance of seals in this region (Stirling *et al.*, 1981a). However, approximately 15,000 ringed seals may winter in transition zone leads between Herschel Island and the west coast of Banks Island. Due to the abundance and mobility of ringed seals within the transition zone, and the discontinous coverage of oil over an area of 14,400 km^2 from early October until break-up, a substantial proportion of the population might occur in areas affected by oil during winter and spring, assuming this species is unable to detect and avoid petroleum hydrocarbons.

During late June, southeasterly currents are assumed to sweep some of the submerged mousse under the seaward edge of the landfast ice. Some of this oil may be retained by ice keels and other irregularities under the ice, and later swept out to sea. This process would coincide with the period when ringed seals are hauled-out on the landfast ice, although the main haul-out sites for this species are located in areas not expected to be affected by oil (eg. Cape Parry, Banks Island, Yukon coast; Stirling *et al.*, 1981a). Alliston (1980) reported mean densities of 0.51 hauled-out ringed seals/km^2 near McKinley Bay during icebreaking surveys conducted in June 1980. Alliston (1980) also indicated that seal densities were greater along the ice edge, and averaged 1.5 seals/km^2 along 4 km of ice edge in their study area. If these densities are representative of other coastal areas along the Tuktoyaktuk Peninsula, and mousse covered 140 km of ice edge and was swept 5 km under the landfast ice from Richards Island to McKinley Bay, approximately 600 to 1,000 seals may be present in the affected area. This is considered a minimum estimate because all hauled-out seals are not detected during such surveys, and seals beneath the ice are also not visible.

The best available data on ringed seal densities in open water were obtained during aerial surveys conducted in the summer of 1980 offshore of the Tuktoyaktuk Peninsula (Renaud and Davis, 1981). Average ringed seal densities were 0.003/km^2 on August 6-7, 0.416/km^2 on August 21-24, and 0.001/km^2 on September 3-4. (These are considered minimum estimates because no allowance was made for seals under the surface and because of the low detectability of seals in outer parts of transects.) Using these figures as minimum indices of ringed seal abundance in the open water season, and given the expected movement and extent of the surface slick (7,200 km^2), the number of seals which may contact the highly weathered oil during the open water season could range from a hundred to at least 3,000 to 5,000. (These are also considered minimum estimates since turnover rates are unknown; more seals could be affected if any large scale movements occurred.)

Seal mortality has been reported following some marine oil spills and not others (Duval *et al.*, 1981). The results of laboratory and field spill studies also indicate that oil exposure may lead to mortality of naturally stressed (e.g. diseased or parasitized) individuals, impairment of mobility, temporary eye and nostril irritation, reduced food availability, and physiological stress associated with ingestion of petroleum hydrocarbons. Although it is not known if seals would ingest contaminated food, studies conducted by Geraci and Smith (1976) suggest that seals are able to excrete accumulated petroleum hydrocarbons.

The degree of ringed seal mortality resulting from this hypothetical event would depend on the extent and duration of seal contamination, the general health of the affected individuals and the extent that the oil has weathered. Substantial numbers (e.g. several thousand) of subadults and non-breeding adults may occur in areas affected by relatively unweathered oil during winter and spring. Up to 1,000 seals may be affected by oil under the landfast ice during haul-out, and at least 3,000 to 5,000 individuals may be present in areas contaminated by the highly weathered surface slick during the open water season. In addition, other seals may encounter oil at the pack ice edge and a large proportion of the regional population may be exposed to dispersed oil. The anticipated degree of impact of the hypothetical subsea blowout on the regional ringed seal population would be considered MODERATE because a change in distribution and abundance of a portion of the population may occur over a period exceeding one generation. However, seal populations in the Beaufort Sea are believed to numerically recover from large (eg. 50%) natural fluctuations in only a few years, possibly due to large scale immigration (Stirling *et al.*, 1981a).

(d) Bearded Seal

During the winter, most bearded seals occur in shallow water areas within the transition zone or in nearshore pack ice areas (Eley and Lowry, 1978). Although individuals of this species are generally solitary, they may concentrate in open leads during winter. Pupping usually occurs on moving pack ice during late The winter density of bearded seals in the Beaufort Sea varies with ice conditions, but may be within the range from 0.012 to 0.040 seals/km^2 in active ice areas (Stirling *et al.*, 1975a). Using these densities as minimum estimates of bearded seal abundance in the transition zone, and the extent of discontinuous oil contamination in the transition zone at water depths less than 50 m (approximately 7,200 km^2), the minimum number of bearded seals which may contact the relatively unweathered oil during winter and spring may range from 80 to 300. The actual number of affected individuals would probably be higher because of the mobility of seals.

During the open water season, most areas in the southeast Beaufort Sea are unsuitable feeding habitat for bearded seals since they prefer the pack ice zone which is typically located north of the continental shelf. Consequently, few bearded seals are likely to contact the surface slick during the open water season. However, this species is relatively common during summer in some nearshore environments such as near Herschel Island, and some individuals may encounter dispersed and sedimented oil in these areas. In addition, oil sedimented in offshore and nearshore areas of the Beaufort Sea at depths from up to 50 m may result in a localized reduction of benthic and epibenthic food sources of bearded seals, as well as the potential for ingestion of oil-contaminated prey.

The effects of oil on bearded seals may include mortality (particularly naturally stressed individuals), reduced food availability, impaired mobility, clogging of nostrils, temporary eye irritation, behavioural effects (convulsions), or physiological dysfunctions associated with ingestion of petroleum hydrocarbons. The extent and significance of these potential effects would depend on several factors including the general health of individuals, the duration of exposure, degree of weathering of the oil and the status of the regional bearded seal population. The degree of impact of this hypothetical event on the regional bearded seal population could vary from MINOR in the open water season to MODERATE in the winter; moderate impacts could result during winter since potential effects of the blowout could result in a change in distribution and abundance of the local population that persists for more than one generation. However, like the ringed seal population, the Beaufort Sea bearded seal population was believed to have declined by 50% during the winter 1974-75 and recovered to 1974 levels within 4 years (Stirling *et al.*, 1981a).

(e) Polar Bear

During the winter and spring, polar bears in transition zone areas may directly contact oil present in leads, although it is not known if they would actually enter oil-contaminated waters. The number of bears which may be affected by oil at this time is unknown, but some individuals will probably contact oil given the abundance and mobility of this species in the transition zone, and the expected extent of discontinuous oil contamination (14,400 km^2) during the winter and spring.

Females and young-of-the-year cubs may occur in areas affected by oil during mid June when strong northwesterly winds are expected to transport broken ice and oil up against and under the landfast ice edge from the Mackenzie Delta to McKinley Bay. However, only small numbers of individuals would likely be affected since most females and young in this region are located off the west coast of Banks Island (Stirling *et al.*, 1981b).

Most polar bears in the Beaufort region move north with the retreating pack ice in summer, and consequently, contamination of bears during the open water season should be limited. As indicated in the previous section, all of the oil trapped in drifting ice floes during the winter is not expected to be released during the spring melt. An estimated 120,000 bbls of relatively unweathered oil is assumed to penetrate the pack ice, while approximately 240,000 bbls of highly viscous crude are expected to be refrozen into transition zone ice at freeze-up. As a result, bears on the pack ice may occur in areas affected by oil during the summer following the hypothetical event, while individuals foraging in the transition zone during the year(s) following the blowout may also occur in affected leads and polynyas. It is impossible to predict the total number of bears which may be exposed to oil since it would depend on several factors including the extent of lead contamination, the distribution and abundance of bears in affected areas, and the prevailing winds and current patterns.

Polar bears are highly dependant on fur for insulation (unlike ringed and bearded seals), and oil contact may alter the insulative qualities of the fur and cause thermoregulatory stress (Frisch *et al.*, 1974). Recent investigations have also demonstrated the extreme physiological sensitivity of this species to petroleum hydrocarbons ingested during grooming (Engelhardt, 1981). Mortality of bears that are heavily contaminated would probably occur in most cases, although ingestion of small amounts of oil may only result in physiological disorders. Polar bears may also accumulate petroleum hydrocarbons if they ingest oil-contaminated prey (Schweinsburg *et al.*, 1977) since ringed seals (their primary prey) have also been shown to accumulate hydrocarbons (Engelhardt *et al.*, 1977; Engelhardt, 1978).

If this hypothetical blowout caused a reduction in the survival of overwintering seals, additional indirect impacts on the polar bear population are also considered possible. For example, a 50% decline in the Beaufort Sea seal populations between 1974 and 1975 was accompanied by a 30% reduction in the polar bear population due to decreased survival and breeding success, and emmigration (Stirling, 1978).

The degree of impact of this hypothetical event on the regional polar bear population of the Beaufort Sea would be considered MODERATE because local populations could require more than one generation to recover as a result of the anticipated losses through mortality, persistent contamination of transition zone leads, and indirect effects associated with prey availability and ingestion of contaminated prey.

(f) Arctic Fox

Arctic foxes are unlikely to directly contact oil unless they scavenge on the carcasses of oiled seals on the landfast ice. Consequently, the number of individuals which may be affected by this event should be relatively small. Like polar bears, this species is probably highly dependent on the insulative properties of the fur for thermoregulation, and matting with oil could cause thermoregulatory stress or death. Acute toxic and sublethal effects associated with the ingestion of petroleum hydrocarbons by foxes are unknown, but could include some or all of the physiological disorders noted in other mammals (ESL, 1982b). Indirect effects of this event on the Beaufort Sea Arctic fox population could also include reduced prey availability (eg. ringed seal pups, carrion). Nevertheless, since only a small proportion of the regional population would be affected by the hypothetical subsea blowout, the anticipated degree of impact is considered NEGLIGIBLE.

6.2.3.2 Possible Impacts on Birds

The susceptibility of marine-associated birds to oil spills varies with the species and the circumstances surrounding the event, although it is generally agreed that even small amounts of oil can cause mortality due to the exceptional vulnerability of many bird species (Milne and Smiley, 1976). The degree of bird contamination and mortality as a result of past marine oil spills has been largely related to the number of birds contacting oil (a function of abundance and distribution of the birds), rather than the size of the spill and type of oil involved (Duval *et al.*, 1981). The biological effects of oil on marine birds have recently been discussed in detail by Duval *et al.* (1981), Brown (1981), and ESL, (1982b), and were summarized in Chapter 4. Those species considered most vulnerable to the particular event described in the present scenario are listed in Table 6.2-2.

Within the areas which are assumed to be affected by oil from this hypothetical blowout, the most biologically sensitive habitats for birds include the landfast ice edge, and the Herschel Island and Tuktoyaktuk Peninsula areas. Contamination of offshore leads for at least one spring season and the more chronic, long-term contamination of the coastal bays, lagoons and shorelines along the Yukon and Alaskan coasts and on the Tuktoyaktuk Peninsula would have the greatest impact on birds in this region. In addition, when oil reaches the ice surface in early May, a time when open water areas are relatively scarce and migrants are numerous, the dark patches of oil could appear similar to open water areas and attract some birds (Barry, 1970). Although large natural bird mortality has occurred during offshore migrations in heavy ice years (eg. 1964) in the Beaufort region, oil-related population declines may require a longer recovery period than natural decreases in the abundance of some species since nesting, moulting and brood-rearing habitats may be affected in addition to the spring staging areas. Oil which may be transported into backshore environments during storm surges may adversely affect the annual production of young and contaminate nest sites for several years.

As previously indicated in Table 6.2-1, most species of marine birds could be affected by this hypothetical oil spill. However, for the purposes of this summary, only the four species for which major impacts might be expected will be examined. The reader is referred to ESL (1982a) for further impact details on these and all other species which frequent the Beaufort region.

TABLE 6.2-2

BIRDS OF THE SOUTHEASTERN BEAUFORT SEA CONSIDERED VULNERABLE TO A WINTER SUBSEA BLOWOUT IN THE KOPANOAR FIELD

Species		Vulnerable Time			
Common Name	**Scientific Name**	**Spring Migration (May-June)**	**Nesting and brood-rearing (June-Sept)**	**Moulting (July-Aug)**	**Autumn Migration/ Staging (Aug-Oct)**
Red-throated loon	Gavia stellata	X	X		X
Yellow-billed loon	Gavia adamsii	X			X
Arctic loon	G. arctica	X	X		
Whistling swan	Olor columbianus			X	
Black brant	Branta bernicla		X	X	X
White-fronted goose	Anser albifrons			X	
Snow goose	Chen caerulescens		X	X	X
Greater scaup	Aythya marila			X	
Oldsquaw	Clangula hyemalis	X		X	X
King eider	Somateria spectabilis	X			X
Common eider	S. mollissima	X	X		X
Surf scoter	Melanitta perspicillata			X	
White-winged scoter	Melanitta deglandi			X	
Sandhill crane	Grus canadensis			X	
Shorebirds			X		
Jaegers	Stercorarius sp.		X		
Glaucous gull	Larus hyperboreus	X	X		
Sabine's gull	Xema sabini	X	X		
Arctic tern	Sterna paradisaea		X		
Thick-billed murre	Uria lomvia	X			X
Black Guillemot	Cepphus grylle	X	X	X	X

Source: (Barry, 1976)

(a) Black Brant

Four thousand black brant are estimated to nest along the Beaufort Sea coast from Demarcation Bay to Darnley Bay; of these, approximately 500 nest in coastal areas between Warren Point and Atkinson Point on the Tuktoyaktuk Peninsula (Figure 6.2-6). Brant also nest in the Phillips Bay -Stokes Point area on the Yukon coast, and probably as single pairs throughout the coastal Beaufort region (Searing *et al.*, 1975). Moulting areas for brant within the area affected by the blowout include habitats surrounding their nesting areas, Cape Dalhousie and Russell Inlet on the Tuktoyaktuk Peninsula, the Blow River delta and Beaufort Lagoon in Alaska. Major moulting areas for non-breeding birds occur outside the Canadian Beaufort region and therefore in areas not affected by this hypothetical event. However, major staging areas for brant occur in the littoral zones of two regions which may be affected by oil from the subsea blowout. During surveys conducted on September 8 and 9, 1980, Barry *et al.* (1981) observed 12,000 brant staging on tidal flats between Kay Point and Stokes Point, and 700 birds in McKinley Bay.

Brant are considered particularly vulnerable to marine oil spills because nest sites are often located at the edges of freshwater or tidal pools, often just above the high tide line (Bellrose, 1976). Adults, young-of-the-year and subadults are also vulnerable during the brood-rearing and moulting period (about early July until mid August) when they forage in the littoral zone.

The number of moulting and staging brant that may be affected by oil reaching coastal areas along the Tuktoyaktuk Peninsula and the Yukon coast may be greater than 10,000 to 15,000 birds in some years, based on the recent observations of Barry *et al.* (1981) and the fact that turnover rates are unknown (Koski, 1977b; Barry *et al.*, 1981). In addition, nesting areas for at least 700 brant may be contaminated with oil and rendered unuseable during subsequent seasons, resulting in continued contamination of birds, loss of habitat and reduced food availability. Since this combination of factors could result in a change in the distribution and abundance of brant that may not recover within several generations, the degree of impact of this event on the regional black

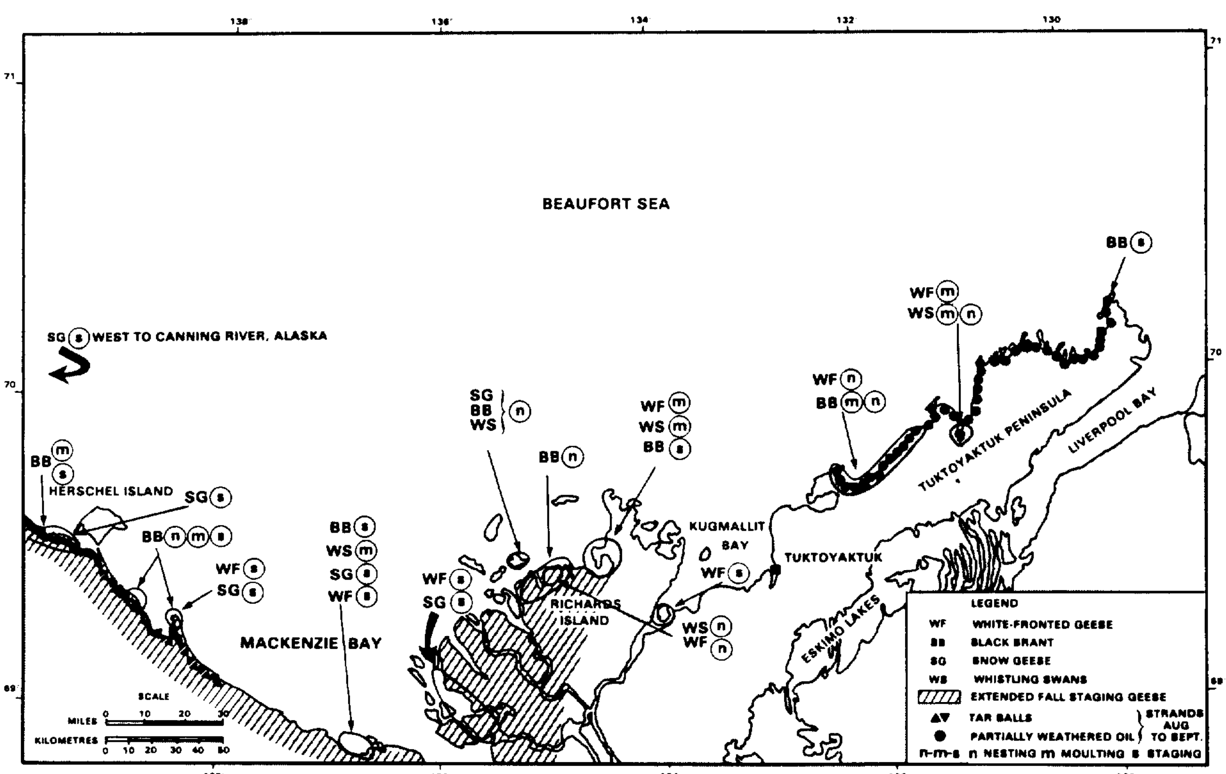


FIGURE 6.2-6 *Nesting moulting and staging areas for geese and whistling swans on the Tuktoyaktuk Peninsula, Mackenzie Delta and Yukon North Slope.*

brant population is considered MAJOR.

(b) Common Eiders

During mid to late May, thousands of eiders arrive and stage in the large polynya which develops west of Banks Island and within Amundsen Gulf. Barry *et al.* (1981) reported average densities of 1.1 common eiders/km^2 along the ice edge off Banks Island, 2.2/km^2 along the Amundsen Gulf ice edge, 15.8/km^2 off the Tuktoyaktuk Peninsula, and 9.0/km^2 along the ice edge from Tuktoyaktuk to Nuvorak Point. Peak reported densities were 39.6/km^2 near Baillie Islands and 34.8/km^2 near Cape Dalhousie. Searing *et al.* (1975) observed an estimated 75,000 spring staging common eiders in the latter area on May 21, 1974.

The number of spring migrants that may be affected by the hypothetical blowout include all those staging along the landfast ice edge from Shallow Bay to McKinley Bay. Common eiders would probably be affected in largest numbers. The minimum number of common eiders that may be affected could range from 20,000 to 30,000 given the densities recorded by Searing *et al.* (1975) and Barry *et al.* (1981), the potential for rapid turnover, and the probable extensiveness of the oil in areas frequented by staging birds. More extensive mortality would be anticipated if oil reached the Cape Dalhousie area or the Bathurst polynya.

Common eiders nest at least 3 known coastal nesting areas adjacent to the southeastern Beaufort Sea: Cape Parry in western Amundsen Gulf (50 plus nests; Ward, 1979), Nunaluk Spit on the Yukon coast (30 nests, Gollop *et al.*, 1974), and Phillips Island off the Tuktoyaktuk Peninsula (100 to 200 nests, J. Ward, pers. comm.).

Although the time that oil is expected to reach shorelines on the Tuktoyaktuk Peninsula and Yukon coast does not coincide with the nesting period of common eiders, females and their broods at the Phillips Island and Nunaluk Spit colonies could still be affected. In addition, nesting, moulting and brood-rearing habitat may remain contaminated during the subsequent nesting season(s). Some mortality of eiders from both colonies would probably occur during the year of the event, while recovery could be relatively slow because two generations could be affected and nesting habitats may be contaminated.

The fall migration of common eiders occurs westward over a broad offshore front from July (mostly males) until September (mostly females and young) (Searing *et al.*, 1975). Consequently, large numbers of fall migrants during the period of the actual blowout and in the following year may contact surface oil during the autumn migration in offshore areas.

In view of the probable mortality of spring migrants, and nesting females and young-of-the-year from the southeastern Beaufort Sea region, the degree of impact of this hypothetical event on the Beaufort Sea common eider population would be considered MAJOR. Other significant impacts of this hypothetical blowout on common eiders would be the potential loss of tens of thousands of spring migrants bound for nesting areas to the north and east of the Beaufort region. The potential impact on these populations could be MODERATE to MAJOR.

(c) Alcids (Black Guillemot and Thick-billed Murre)

A small nesting colony of black guillemots on Herschel Island was first observed in an abandoned building during 1958. Kuyt *et al.* (1976) subsequently reported 30 nests in 1973 and 10+ nests in 1974. The only other area in the Canadian Beaufort Sea where nesting black guillemots and thick-billed murres have been recorded is Cape Parry (Volume 3A; Section 4.2).

Black guillemots occupy the Herschel Island colony from approximately early June to early or mid September (Barry *et al.*, 1981), and fledging probably begins in late August (Divoky, 1978). Young are capable of sustained flight when they leave the nests, but are not attended by adults (Cairns, 1978). Adults moult and are flightless after the brood-rearing period.

Alcids are particularly vulnerable to oil contamination because they spend much of their time foraging on or below the water surface. There is a definite possibility that spring and/or fall migrant murres and guillemots may be affected by this event, although the routes and timing of their migrations to and from the eastern Beaufort Sea remain virtually unknown. Non-breeding birds are known to forage far offshore in the Beaufort Sea, and small numbers of both murres and guillemots may contact oil in these areas. Due to the exceptional vulnerability of alcids to oil, mortality of most individuals which become contaminated is anticipated.

Since oil is expected to strand along the Yukon and Alaskan coast during August and September, most if not all foraging adults, non-breeding subadults and young-of-the-year guillemots at the Herschel Island colony could contact surface and dispersed oil. The amount of oil stranded as tarballs at Herschel Island is expected to reach approximately 600 bbls/km of shoreline. The degree and type of impacts of past oil spills on alcid populations suggest that mortality would probably result in most cases where birds were oiled.

Since alcids are slow to mature, have a low reproductive potential and are long lived, the loss of the majority of breeding adult black guillemots from the Herschel Island colony could have a MAJOR impact on this population. Recovery of this colony would probably take more than 10 years, even if suitable nesting and foraging habitat was available in subsequent years. On the other hand, the degree of impact of this blowout on the thick-billed murres and black guillemots from the Cape Parry colony could be NEGLIGIBLE to MAJOR, depending on the number of foraging and migrant birds that contact oil in offshore areas.

The foregoing has summarized some of the more important projected implications of a subsea blowout during winter on higher profile marine species (mammals and birds frequenting the Beaufort area). For further details and particularly for information on the possible impacts to other species of biota, the reader is referred to ESL (1982a). As stated at the outset, these projections have been based on a variety of assumptions including the fact that no countermeasures have been employed, which should tend to reduce the possible impact. The following section (6.2.4) will examine the kinds of countermeasures strategies which could be employed. Although it is not reasonable to determine how much the possible impacts to marine life could be reduced by application of appropriate countermeasures, it is assumed that they will help to alleviate certain impacts.

6.2.4 COUNTERMEASURES STRATEGY

6.2.4.1 Summer - Open Water Conditions

In the event of a blowout, relief well drilling to stop the flow of oil would be the most important response. Relief well drilling is discussed in Volume 2.

Burning at the sea surface above the well blowout would be the first oil removal process. The ignition may occur unintentionally due to equipment operating on the rig or result when gas is fired as a safety precaution. Based on observations at the Mexican blowout, Ixtoc 1, about 35% of the discharging oil will be consumed in the fire (Ross *et al.*, 1979). Also, the Ixtoc 1 blowout indicated that if the discharging oil at the water's surface could be contained and concentrated by a fire-proof boom, the efficiency of oil burning could have been increased beyond 35%. Such a boom is now under development by the industry.

As a second line of defence, the Response Barge could be deployed and anchored downstream from the blowout. It would be used to deal with oil, and emulsion that had not been burned. Lengths of the Arctic boom would be fastened to either side of the barge's skimmer and moored or held at the other end by two vessels to form a V-configuration. Oil would then be recovered by the skimmer, pumped to storage, heat-treated if necessary, and burned.

As part of this secondary control system, additional containment and skimming equipment could be deployed close to the blowout site. In particular, the Vikoma Seapack could be positioned in a U-configuration to collect oil escaping past the barge system. The Framo skimmer could then be used to remove oil that had been contained and concentrated by the boom. Other conventional barriers could also be placed to intercept oil flowing beyond the other more primary defense mechanisms. Figure 6.2-7 shows one possible deployment scheme. In general, every attempt would be made to maximize the amount of oil collected near its source. As outlined in the introduction to this Chapter, every available means would be brought to bear on the problem, including equipment from regions other than the Beaufort Sea.

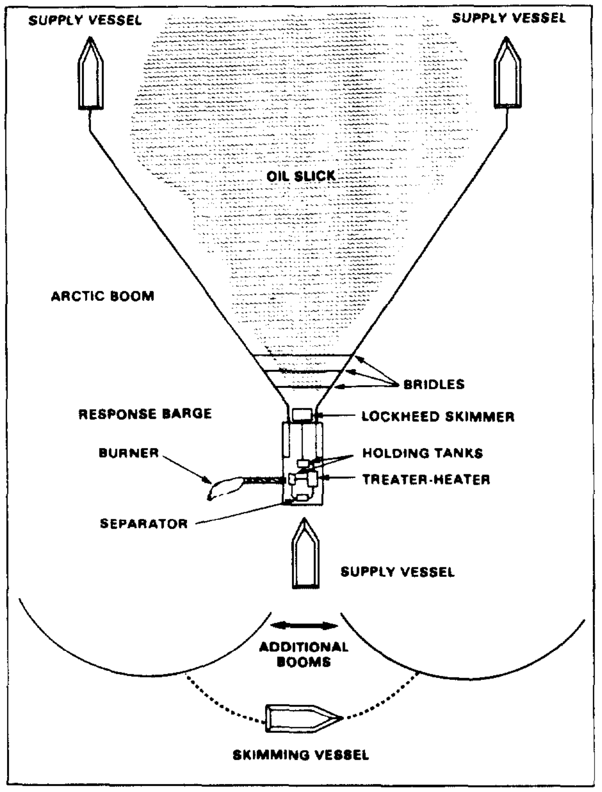


FIGURE 6.2-7 *One possible deployment scheme for the CO-OP response barge cleanup system (see Chapter 5) to be used as a second line of defence after ignition of the hypothetical subsea blowout at Kopanoar.*

With the exception of severe storms, most available containment and recovery equipment should be able to function effectively a high percentage (85%) of the time in the offshore producing region. (A significant wave height of 1.5 metres is only exceeded 10% of the time). Disposal of the collected oil or emulsion by burning could be accomplished using the burner system on the barge.

Any oil escaping the containment and recovery activities at the well site would be monitored and tracked. In addition to visual observations made from helicopters and fixed-wing aircraft, remote sensing equipment would be called upon to assist in tracking and charting the location of the slicks. These observations would be fed to the computer tracking program together with weather forecasts to predict the movement of the oil. These procedures would assist in efficiently allocating response equipment for chemical dispersion and shoreline protection.

The application of chemical dispersants would be considered in the event that oil was threatening sensitive areas. In the interests of preventing the oiling of birds and shorelines, a dispersant application program could be initiated. If large slicks began to move ashore, an intensive aerial application program could be initiated. The dispersing system used could be similar to that used successfully at the Mexican blowout, Ixtoc 1.

This would be carried out only after receiving government approval and guidance on the use of chemical dispersants in the area. Decisions on dispersant use would have to be made on a case-by-case basis during the spill.

In order to identify sensitive coastal areas and best allocate shoreline protection and cleanup equipment the "Shoreline Oil Spill Protection" manual would be used. According to the computer trajectories illustrated in Figures 6.2-1 to 6.2-3, the shoreline areas covered by Figures 6.2-8 and 6.2-9 would be oiled. The shoreline maps show where the sensitive areas are and the text explains where and how equipment should be used.

The model (Figure 6.2-3) indicates that, over the 60 day open water period, approximately 8,000 m^3 (50,000 bbl) of weathered oil (or emulsion) comes ashore, a small amount ten days after the accident, and a majority two weeks later. The manual indicates that the entire area is sensitive, with the area of Figure 6.2-9 given higher priority than that of Figure 6.2.8. The placement of nearshore booms between Kendall and Bird Islands, Kendall Island and the mainland, and Bird Island and the mainland could protect hundreds of kilometres of delta tundra. Booming of the outfalls of the Mackenzie could also be undertaken. This effort would require about 10,000 m of boom. The manual recommends that oil be diverted to the sand beaches of Garry and Bird Island for later recovery. The area of Map 8 would be difficult to deal with as the entire coastline is sensitive. Booming of the inlets with nearshore boom to protect inland waterways could be undertaken. This would require a further 10,000 m of boom that would be brought in from stockpiles in the south.

With the exception of the sand beach areas shown on Figure 6.2-9 only manual cleaning would be possible, however in some areas, e.g., cliffs and some tundra, no cleanup is recommended as the disturbance caused by the cleanup would cause further impact. Birds would be deterred from entering oiled areas by using helicopters and scare cannons.

Collected oil and oily debris could be disposed of using two methods, burning and landfill. The various incinerators described in Chapter 5 would be used to burn the collected oil. They could include: the helicopter portable burner, the air-portable pit incinerator, the air-curtain incinerator and the reciprocating kiln. If necessary, a number of the landfill disposal sites and temporary storage sites along the Beaufort Coast designated as appropriate by Environment Canada (R.M. Hardy and Associates Ltd., 1979) could be used. Shoreline restoration would be the final step of the cleanup.

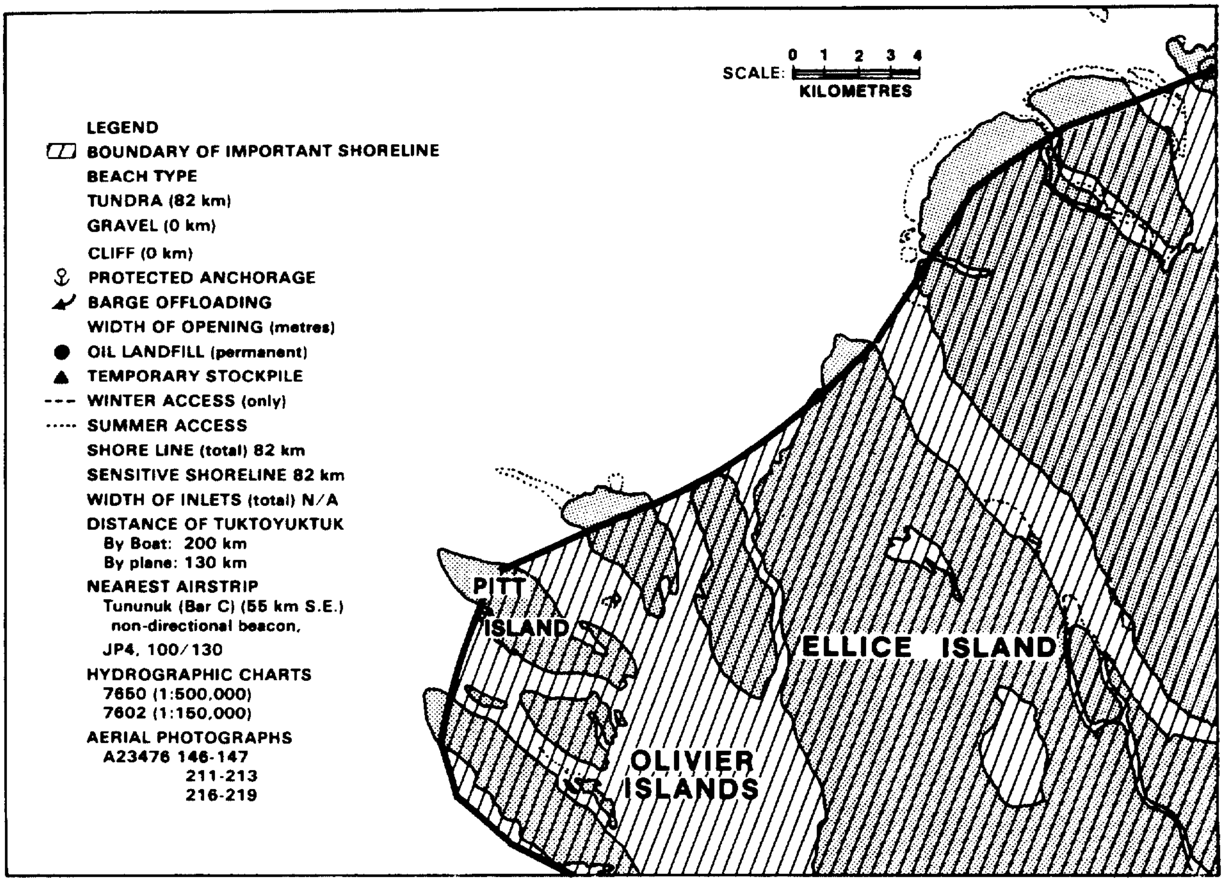
In summary, countermeasures are now available to substantially minimize the environmental impact of a subsea blowout occurring during conditions of open water. The comprehensive studies conducted to date pertaining to shoreline protection and oil disposal in the southern Beaufort Sea greatly contribute to this capability.

One other avenue of research will likely contribute to even further advancing the level of spill control possible. Research work might yield a dispersant that would prove to be effective on emulsions in cold water.

6.2.4.2 Winter - Ice Conditions

With the onset of winter and incorporation of released oil into the overpassing ice, an intensive effort would begin in order to develop the capability to deal with the oil that is expected to rise up to the surface in spring.

Tens of thousands of air-deployable igniters - perhaps as many as 100,000 - could be stockpiled at the Tuktoyaktuk base. Staging areas would then be selected for establishing fuel caches and for use as deployment bases.



Countermeasures

Offshore cleanup methods (including dispersants applied further than the 15-metre water contour) presently appear to be the only feasible method of protecting these shorelines. The entire coastal margin is sensitive to oil contamination. There appears to be no shoreline strategy for protecting or cleaning these shorelines because of their extent (112 kilometres) and inaccessibility by boat. Shallow (1 metre deep) water extends for 15 kilometres offshore. **Small scale manual cleanup** is recommended and could be facilitated by using helicopters. Because of the extent of the sensitive shoreline, it may be of little practical use during a large spill. **Bird scare devices** should be used to keep marine waterfowl away from oncoming slicks.

Access

Boat access in this region is nearly impossible due to the shallows fronting the mouth of the delta. Waters less than 1 metre deep occur 15 kilometres offshore. Deep water occurs in channels behind the river mouth, but access cannot be gained to offshore regions. Shore camps on the lowlying delta are not recommended because of the dangers of storm surges. Any cleanup or protection team working on these low delta plains must have the capability of evacuating on very short notice during the open water season.

Harbour

Safe anchorage at a depth of 1.8 metres is available at the south end of Pelly Island, 50 kilometres northeast. Anchorage near the spit at Pelly Island can be changed for protection from easterly or westerly winds.

Sensitivity

Residents of Inuvik and Tuktoyaktuk navigate the river channels to hunt geese on Ellice, Pitt and Olivier Islands in the spirng (June) and fall (August-September). Local people trap on Ellice Island for fox and muskrat. Some beluga whales are found in the shallow water (June-August), but the larger concentrations occur further south. Ellice and Olivier Islands are very important fall staging areas for geese (especially snow geese) from September to early October. All channels in the Mackenzie Delta are potential migration routes for anadromous fish. Movement into offshore coastal areas occurs at breakup (June-July), while spawning or movement back into the estuary occurs throughout the summer until early September. Anadromous species are able to utilize the outer Mackenzie delta after a freshwater environment becomes established in the fall.

FIGURE 6.2-8 *An extract from the Shoreline Oil Spill Protection Manual (Worbets, 1979). According to computer trajectories illustrated in Figures 6.2-1 to 6.2-3, the areas shown would be subject to oiling.*

A number of other steps could also be undertaken. Drillships along with ice-breaking supply vessels could be sent to anchorages for overwintering at points close to the expected oil-contaminated track. ARGOS buoys (see Chapter 5) could be released at regular intervals on the ice drifting over the blowout site to assist in monitoring the movement of oil via satellite throughout the winter. Oil appearing in cracks and leads could be ignited using air-deployable igniters.

The strategy would be to use drillships and shore facilities as bases of operation from which helicopters carrying igniters could be flown in spring to ignite the oil appearing on the melt pools. Feasibility studies of the operation indicate that 10 to 20 helicopters would be required to deploy igniters onto the oil released from the blowout (Ross, 1981).

The igniter approach is likely to be an effective means of burning off oil resulting from a winter blowout. Because oil encapsulated in ice remains in a fresh state, its combustion during spring is easily accomplished in more favorable weather.

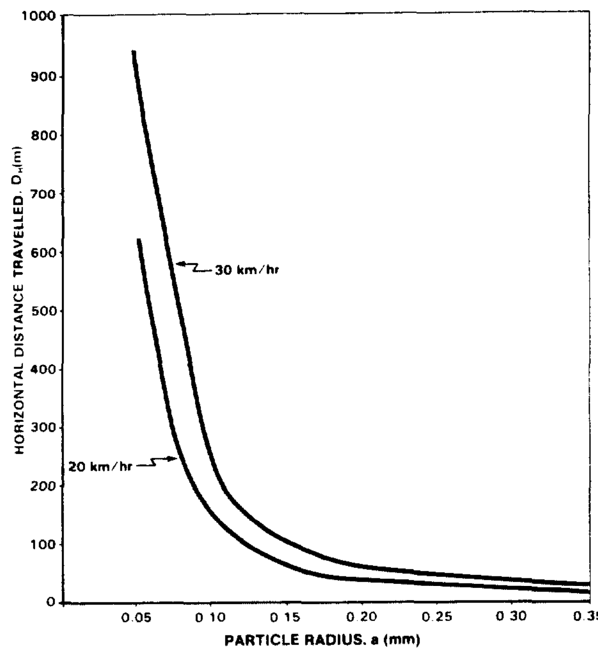


FIGURE 6.3-1 *Oil from an island blowout would be discharged into the atmosphere in the form of a mist and swept downwind. The oil would fall at various distances downwind depending on droplet radius and windspeed.*

6.3 SCENARIO #2: BLOWOUT ON A PRODUCTION ISLAND IN THE BEAUFORT SEA

6.3.1 ACCIDENT DESCRIPTION

In this scenario the gas and oil flow rates and general location of the well are assumed to be the same as for Scenario #1, but the incident occurs on a drilling/-production artificial island. A hypothetical blowout has occurred on a production island located at Kopanoar and it flows oil at a rate of 12,000 barrels a day for 60 days at which time a relief well has been drilled and the flow of oil stopped.

Summer

If the well should catch fire, 95% of the oil would burn. This would leave a net spillage rate of oil residue of 95 m^3/day (600 bbls/day). As the producing platform is located on an island, the oil is discharged from the derrick directly into the atmosphere. The oil, in the form of mist, is swept downwind until droplets fall to the surface (Figure 6.3-1). Oil falling on the island forms puddles on its generally impermeable surface; oil falling on the water spreads and moves under the influence of winds and currents.

Winter

In the winter the oil falls on ice and snow and spreads very slowly. If a smooth snow-covered ice sheet surrounds the island and the blowout persists for 200 days, the areal extent of the spill covers about 7 km^2. However, more likely, the island would be surrounded by rubble fields; thus the areal extent of the contamination is drastically reduced, and large, deep pools of oil are formed. Some of this oil finds its way through cracks and leads into the water, but this oil will be trapped by the rubble keels and frozen into the ice in a matter of days.

In the spring contaminated rubble melts more slowly than the rest of the ice sheet and the oil is retained. Eventually the oil is released into the water as break-up progresses.

6.3.2 OIL SPILL TRAJECTORIES

Based on the computer model trajectory analysis (Marko and Foster, 1981), during the summer months the oil that finds its way into open water is projected to move in a manner similar to that shown previously in Figures 6.2-1 to 6.2-3. However, the volumes of oil lost to the ocean are likely to be considerably lower, because the accident occurs on an island and particularly if the well is set on fire. If this hypothetical event were to take place during winter much of the oil released from the blowout would land on ice surrounding and attached to the island platform. If any of the ice were to move away, it would likely travel in a general westerly heading.

The following describes the possible fate of an oil spill emanating from a production island during summer, and its projected biological implications (6.3.3). It represents a summary of the more complete scenario available in the ESL (1982a) supporting document.

This hypothetical blowout is assumed to occur in August and continues for 60 days at a flow rate of 12,000 barrels per day. The fire which is also assumed to occur subsequent to the blowout consumes 95% of the escaping oil, thus reducing the amount of oil reaching the marine environment. The fire would also produce atmospheric emissions, including ash, which would be dispersed by prevailing winds. The impacts of these emissions on the marine environment would likely be negligible and are not discussed in the following scenario. The unburned oil fraction is expected to be in the form of a mist, and enter adjacent marine waters at a rate of about 600 barrels (95 m^3) per day. Most of the oil droplets which reach the water surface would likely coalesce to form discontinuous surface slicks which spread under the combined forces of wind and surface currents. Since the fire would burn most of the volatile, low molecular weight hydrocarbons, this surface oil would be very viscous. Thus weathering processes, which usually account for losses of volatile hydrocarbons from surface oil slicks, would play a very minor role in changing the physical and chemical character of the surface slick. It is also important to note that the concentration of soluble hydrocarbons beneath the slick would be negligible, because the majority of these compounds would be lost during combustion.

Discontinuous oil slicks are expected to be present over an area of approximately 600 km^2 after five days. The surface slick would be very viscous, favouring the formation of tar balls, many of which could subsequently sink and contaminate bottom sediments beneath the advancing slick. Six days after the hypothetical blowout, oil is assumed to reach the coasts of Pullen Island and North Head (Figure 6.3-2). Oil stranding on the shorelines will most likely be in the form of tar balls or large tarry lumps containing accumulated debris. Since this oil would be highly viscous, it probably would not penetrate into subsurface sediments, but would rather tend to accumulate in the high water driftwood line. During the second week of this scenario, most of the oil in

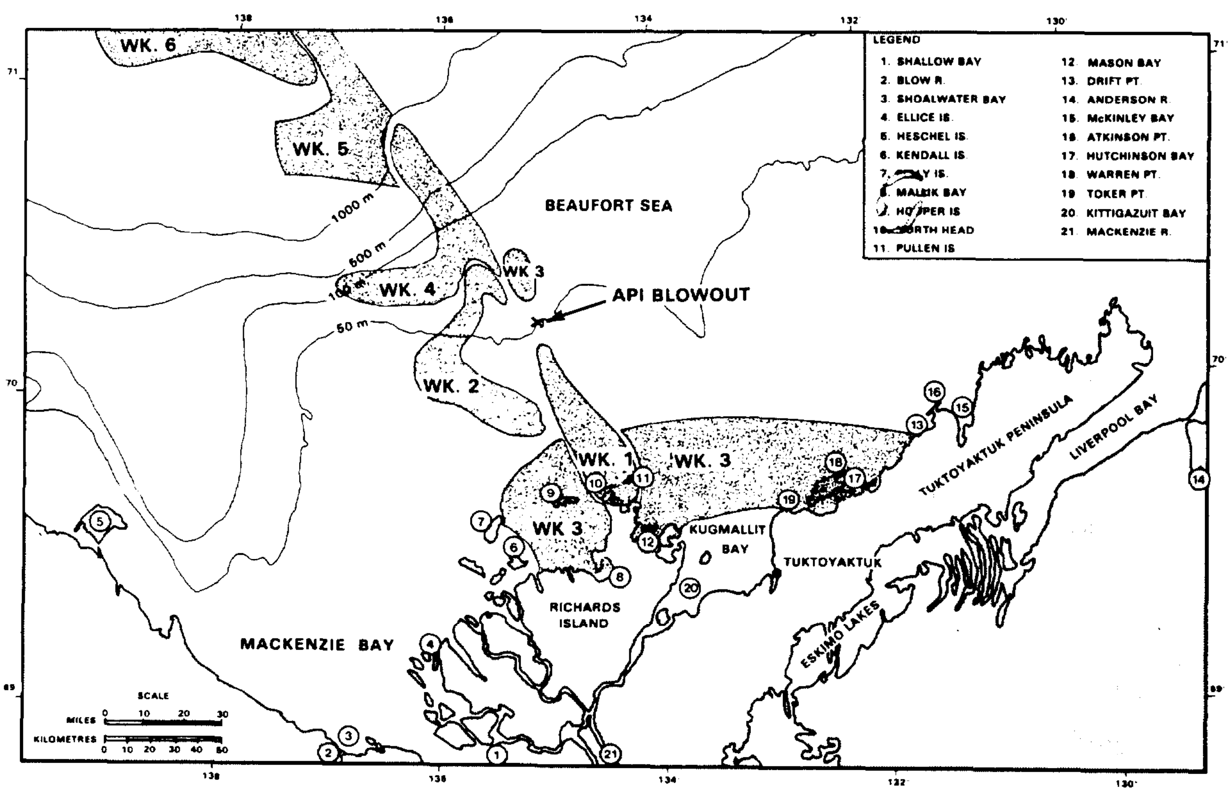


FIGURE 6.3-2 *Fate of oil spilled from an assumed oilwell blowout on an artificial production island at the Kopanoar site. Six days after the blowout in August, the oil is projected to reach the coasts of Pullen Island and North Head.*

coastal areas, and that still being released at the blowout site is expected to drift out to sea in a northwesterly direction driven by offshore winds. During the third week, strong onshore winds are again assumed to cause contamination of shorelines including Pelly, Hooper and Pullen islands, the coast of Richards Island from Middle Channel to Mason Bay, and the Tuktoyaktuk Peninsula from Toker Point to Drift Point (Figure 6.3-2). Assuming high coastal water levels, viscous oil and tarballs overwash the low barrier beaches and could be deposited in low lying backshore lagoon systems up to 500 m inland. These relatively low energy coastal environments are common in the Hutchinson Bay, Mallik Bay and northeast Richards Island areas (Woodward-Clyde Consultants, 1980), and oil stranded in these environments would likely persist for several years, weather slowly and probably sink into bottom sediments. Offshore winds which are assumed to prevail during the latter weeks of the hypothetical blowout are expected to carry the highly weathered oil remaining in coastal areas as well as that still being released from the well, into the advancing polar pack. Due to the high specific gravity of the oil, some of the surface slick would likely continue to sink as it was transported offshore.

Some of the oil droplets not burned during the hypothetical blowout may be dispersed throughout the upper layers of the water column rather than coalescing to form a discontinuous surface slick. This phenomenon would become increasingly important when high wind speeds cause rough seas (Fingas *et al.*, 1979), and during this event it has been assumed that 3% of all the oil lost may be dispersed. The dispersed oil would be subject to several processes including sedimentation, biodegradation, and transport by subsurface currents. In this scenario, two major fates of this dispersed oil are assumed to be possible. Firstly, the relatively high turbidity of the Mackenzie River and the specific gravity of the oil droplets will favour the sedimentation of this dispersed oil following adsorption to inorganic particles (Duval *et al.*, 1978). Although it is not possible to determine the volume of oil which could be deposited on the bottom due to this phenomenon, it is assumed that up to 70% of the dispersed oil is sedimented in shallow areas of North Point (Richards Island), particularly in Mallik and Mason bays, and in the lee of Pelly, Hooper and Pullen Island spits. Assuming that suspended sediment concentrations in Mackenzie Bay averaged 5 mg/L, and that 15,000 barrels of oil were dispersed in a 2,000 km^2 area, the deposition could amount to 1 g oil/m^2 of seabottom (Duval *et al.*, 1978). A second possibility would be the transport of the unsedimented fraction of oil to the north and then northeast along the Tuktoyaktuk Peninsula with the outflowing Mackenzie River and with subsurface currents. Assuming that the total volume of oil dispersed as a result of this blowout was about 21,000 barrels, and 70% sedimented within Mackenzie Bay itself, the remaining volume of unsedimented oil reaching the Tuktoyaktuk Peninsula may approach 6,500 barrels. Oil transported up the Tuktoyaktuk Peninsula could be deposited in shallow coastal areas perhaps as far north as Atkinson Point, but transport further north would be unlikely.

6.3.3 BIOLOGICAL IMPACTS

The possible biological effects of this hypothetical blowout from a production island on all levels of the food chain have been described in detail by ESL (1982a). The following is a summary of the scenario, with emphasis being placed on the higher profile marine mammals, birds and fish, which would most likely be impacted by this event, were it to occur. As with the previous and subsequent biological assessments, it is assumed that no countermeasures have been taken, although these would be expected to reduce certain impacts.

Table 6.3-1 provides a summary of the nature and potential regional impacts of this hypothetical blowout on the marine resources of the southeastern Beaufort Sea.

This blowout is not expected to result in any impacts on regional resources which would be considered major according to the definitions used, with the possible exception of alcids from the Cape Parry colonies. The potential degree of impact on birds from these colonies could range from NEGLIGIBLE to MAJOR, depending on the proportion of the colony contacting the oil slick during fall migration. MODERATE impacts on regional populations of white-fronted geese, black brant, glaucous gulls, some shorebird and nearshore fish species, and some benthic invertebrates could occur. These MODERATE regional impacts would be predicted due to the fact that for many species more than one generation could be affected by oil which persists in coastal environments.

6.3.3.1 Possible Impacts on Marine Mammals

(a) Bowhead Whale

During August and September, the western Arctic bowhead whale population is present on its summer feeding grounds in Amundsen Gulf and the southeastern Beaufort Sea. Based on the results of previous surveys (Volume 3A), the estimated number of bowheads which could occur within the 5,000 km^2 area affected by discontinuous oil slicks from the hypothetical blowout during the first 3 weeks of August might range from less than 10 to 300 or 400 whales. This represents about 0.5 to 18% of the regional population (Braham *et al.*, 1979). However, a greater number of bowheads could encounter areas

TABLE 6.3-1

THE NATURE AND POTENTIAL REGIONAL IMPACT OF A HYPOTHETICAL BLOWOUT AT A PRODUCTION ISLAND ON MARINE RESOURCES OF THE SOUTHEAST BEAUFORT SEA

Resource	Nature of Potential Impacts[1]	Anticipated Degree of Regional Impact[2]
Bowhead whale	S, C, F	Minor
White whale	S, C	Minor
Ringed seal	S, M, C, F	Minor
Bearded seal	H, S, M, C, F	Minor
Polar bear	S, M, C, F,	Minor
Arctic fox	S, C, F	Negligible
Loons	H, S, M, C, F	Minor
Whistling swan	H, S, M, C, F	Moderate
Black brant	H, S, M, C, F	Moderate
White-fronted goose	H, S, M, C, F	Moderate
Snow goose	H, S, M, C, F	Minor
Oldsquaw, scaup, scoter	H, S, M, C, F	Minor
Eiders	H, S, M, C, F	Negligible to Minor
Sandhill crane	H, S, M, C, F	Minor
Shorebirds	H, S, M, C, F	Minor to Moderate[3]
Jaegers	S, M, C	Negligible
Glaucous gull	H, S, M, C	Moderate
Arctic tern	H, S, M, C	Minor
Alcids	S, M, C, F	Negligible to Major[4]
Coastal anadromous fish	H, S, M, C, F	Moderate
Coastal marine fish	H, S, M, C, F	Minor
Phytoplankton	S, M	Negligible
Zooplankton	S, M	Negligible
Benthic invertebrates	H, S, M, C, F	Minor to Moderate[3]
Benthic microalgae	H, S, M	Negligible to Minor[3]
Terrestrial vegetation	H, S, M, C	Negligible to Minor[3]

[1]Nature of Potential Impacts
- H = Habitat loss
- S = Sublethal effects
- M = Mortality
- C = Contamination (fouling)
- F = Reduced food availability

[2]See Section 6.1.2 for Impact Definitions
[3]Dependent on species and/or habitat affected
[4]Dependent on number affected

Source: ESL, 1982a

affected by the oil if any large-scale movements of whales occur throughout the region.

During the fourth and subsequent weeks of this scenario, the remaining surface oil is expected to be transported offshore towards the northwest. A few bowheads may occur in offshore areas affected by oil during the fourth week following the event, although density estimates for the area are unavailable. The affected area probably occurs within the bowhead summer range used in some years, for example, 1981.

It is not known whether bowheads (or any cetaceans) can detect and avoid surface or dispersed oil, although mortality of cetaceans has not been reported following past marine oil spills. Assuming they do not avoid the oil, bowheads that occur in oil-contaminated waters may suffer from various sublethal effects, but mortality is considered unlikely. Sublethal effects may include fouling or damage of baleen feeding mechanisms, temporary eye irritation or ocular damage, alteration of physiological and metabolic properties of the skin, and reduced food availability or displacement from preferred feeding areas. The potential short and long-term impacts of these possible sublethal effects are not known, although the proportion of the regional bowhead population which could be affected would likely be small since only a relatively small volume of oil (i.e. 9,300 bbls) may be present in the form of discontinuous surface slicks. On the basis of the foregoing, the potential impact of this hypothetical blowout on the regional population of bowheads would be considered MINOR.

(b) White Whale

The Mackenzie stock of white whales numbers approximately 7,000 and concentrates in three well-defined areas in the Mackenzie estuary from late June-early July to early August (Figure 6.3-3). Widely dispersed individuals and groups are also found in both nearshore and offshore waters of the southeastern Beaufort and Amundsen Gulf from late spring to early fall (Volume 3A, Section 3.2).

Oil released from the hypothetical blowout is expected to remain largely in waters outside of the Mackenzie estuary, although in the third week of August, some oil may drift far enough south to enter white whale concentration areas in East Mackenzie Bay and Kugmallit Bay. However, very few white whales will be present within these areas at this time of year. The distribution and movements of whales after they leave the estuary remains poorly documented, although there is evidence that some individuals travel to offshore feeding areas near the edge of the pack ice, along Tuktoyaktuk Peninsula, and into Amundsen Gulf.

The number of individual white whales that could occur within the 5,000 km^2 area affected by oil during the first 3 weeks of this scenario is estimated to range from less than 10 to about 400. A greater number of whales could be exposed to oil if any extensive movements of animals across the slick trajectory occurred during this period.

Although there is limited information on white whale

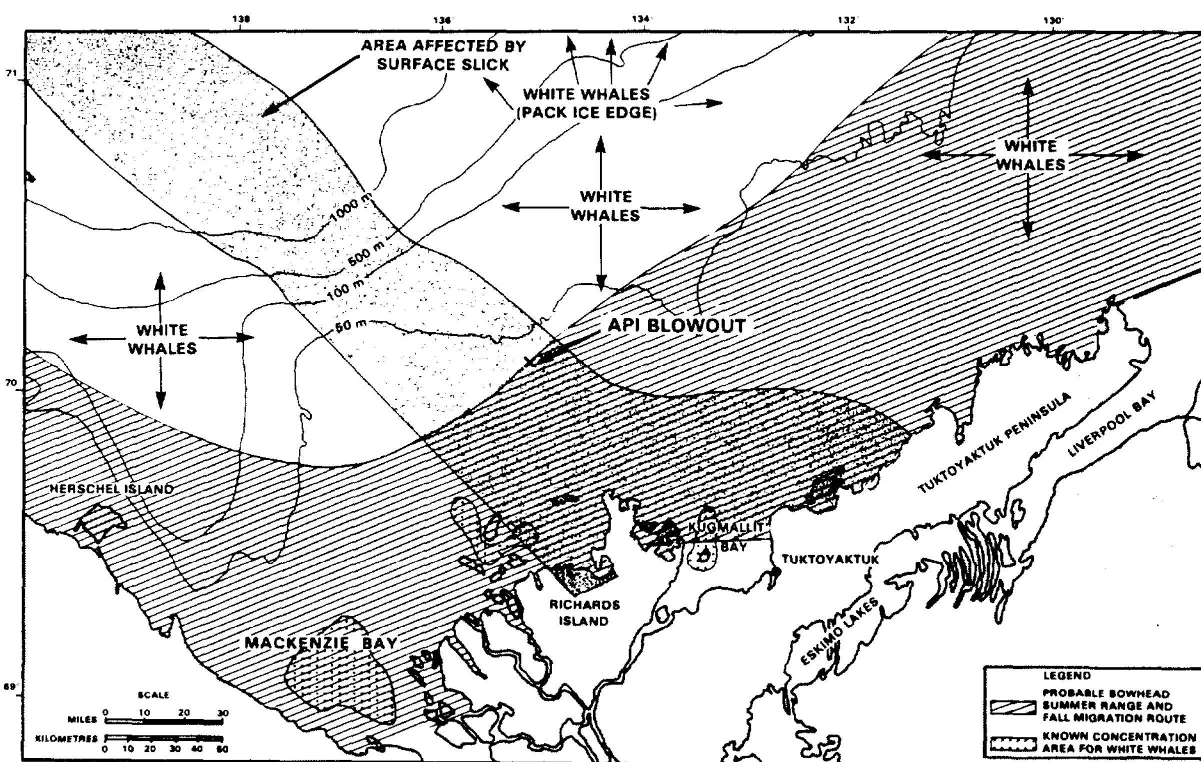


FIGURE 6.3-3 *Distribution of white whales during July to early August relative to the surface area affected by slicks from a hypothetical blowout in summer on an artificial production island at the Kopanoar site.*

abundance and distribution during late August and September, it is probable that the westward fall migration occurs in the offshore Beaufort during this period. Consequently, some individuals may occur in areas affected by surface oil when it moves offshore during the fourth through sixth weeks after the hypothetical blowout. It is not possible to predict the number of animals that may be affected because little is known regarding the timing and exact routes of the fall migrants. However, the 9,300 bbls of oil would be present as a discontinuous slick, and only a few whales could repeatedly or briefly contact oil.

Assuming that this species is unable to detect and avoid oil, the maximum number of white whales that may be exposed to surface or dispersed oil resulting from this blowout could be within the range from 400 to 550 individuals. Direct mortality is unlikely but potential sublethal effects, if they were to occur, would generally be similar to most of those anticipated for bowhead whales. In addition, if this species can detect and avoid oil, it is possible that the presence of surface slicks or dispersed oil may temporarily block or alter local or migratory movements of some individuals during fall. Nevertheless, only a small proportion of the Mackenzie stock of white whales would be expected to occur in or avoid areas affected by oil, and the overall impact of this hypothetical event on the regional population would probably be MINOR.

(c) Ringed Seal

Although ringed seals are the most abundant marine mammals in the Beaufort Sea, their distribution during August and September in the area of this hypothetical blowout is poorly documented. Renaud and Davis (1981) reported average ringed seal densities of 0.003/km^2 on August 6-7, 0.416/km^2 on August 21-24, and 0.001/km^2 on September 3-4, 1980 in waters off the Tuktoyaktuk Peninsula to the 50 m isobath. These surveys were conducted outside the area affected by oil from the hypothetical blowout, but the densities reported are probably reasonable indices of ringed seal abundance throughout the region at this time of year. Assuming a 5,000 km^2 area is affected by discontinuous slicks of viscous oil during the first three weeks of this scenario, from 5 to 2,500 ringed seals may occur in affected areas. As in the case of whales, larger number of individuals may be affected if extensive movements of seals occur throughout the area during August and September.

During the fourth and subsequent weeks following the blowout, surface oil is expected to be transported offshore towards the northwest. Although surveys have not been conducted in this area during September, ringed seal densities in the range reported by Renaud and Davis (1981) off Tuktoyaktuk Peninsula could also occur in these waters. If this were the case, several hundred ringed seals may also contact oil in offshore areas. In the latter part of September, oil from this hypothetical blowout would be expected to reach the edge of the advancing polar pack ice. Since this is known habitat of ringed seals in the late summer/fall, seals could similarly encounter viscous and highly weathered oil in this region.

A total of 3,000 to 4,000 ringed seals may occur in areas affected by oil from this hypothetical event. This represents 4.8 to 6.5% of the estimated 1978 ringed seal population in western Amundsen Gulf, the Canadian Beaufort Sea (to 160 km offshore) and the west coast of Banks Island (Stirling *et al.*, 1981a). If ringed seals contact the viscous surface oil, some mortality and several sublethal effects are considered possible (ESL, 1982b). However, it should be emphasized that the slick will be highly weathered, discontinuous, and total less than 10,000 bbls of oil. Heavy coating with oil may impair mobility and result in subsequent death due to exhaustion, while oil may also plug nostrils and cause suffocation. Ringed seals stressed by natural factors such as disease or poor nutritive condition may also be more susceptible to effects of oil exposure. This hypothetical blowout could also result in spatial or temporal displacement of ringed seals from possible feeding grounds and local reductions in prey availability.

Although some mortality of ringed seals could result from this hypothetical blowout, only a small proportion of the regional population is expected to be directly affected by oil. In addition, this population has shown an inherent ability to recover quickly from natural declines as a result of increased mortality, low productivity and emmigration (Stirling *et al.*, 1980). Therefore, the regional impact of this event on ringed seals would be considered MINOR.

(d) Bearded Seal

The bearded seal is widely distributed throughout relatively shallow waters (less than 100 m) of the Beaufort Sea region where it feeds on benthic and epibenthic organisms. There is little information regarding the abundance and distribution of this species in the southeastern Beaufort Sea during the open water period. However, most of the region is considered marginal feeding habitat for bearded seals during summer since they generally prefer shallow areas with associated pack ice.

The number of bearded seals that may contact oil released from this hypothetical blowout cannot be accurately predicted, although it should be low due to the limited suitability of the affected areas as summer range. Small numbers of bearded seals may be present in areas affected by surface slicks and dispersed oil during the first four weeks after the event. During the fifth and subsequent weeks, the region which is likely to be affected by oil occurs over water depths greater than those which are suitable bearded seal habitat, and few if any individuals would be affected.

The potential biological effects of oil on bearded seals are probably similar to those previously described for the ringed seal, although the former may be more susceptible to ingestion of oil-contaminated sediments and prey and bioaccumulation of petroleum hydrocarbons, since they feed on benthic species. Although some localized mortality of bearded seals could result from this hypothetical blowout, the wide distribution of this species in the region and its ability to recover rapidly from natural population declines (Stirling *et al.*, 1980) suggest that the degree of regional impact would probably be MINOR.

(e) Polar Bear

During the summer, polar bears in the eastern Beaufort Sea are generally found offshore on the polar pack ice, particularly along the floe edge where they prey on seals (Stirling *et al.*, 1981b). Consequently, polar bears would only encounter oil resulting from the hypothetical blowout in the latter part of September when highly weathered and viscous oil is expected to reach the floe edge. Bears could contact surface oil slicks since they regularly travel across the ice and traverse open water leads, or they may indirectly ingest petroleum hydrocarbons by feeding on oil-contaminated seals. The numbers of bears that may encounter oil in this area cannot be estimated because surveys have not been conducted at this time of year. However, since the oil would be confined to a restricted area along the ice edge, and the majority of the population occurs in the Banks Island and Amundsen Gulf areas, only a small proportion of the regional population of polar bears would likely be affected.

Studies conducted by Engelhardt (1981) demonstrated that exposure to oil can lead to thermoregulatory stress and mortality in polar bears. Three bears were exposed to a 1 cm slick of Midale crude for 15 to 50 minutes, causing the fur to become deeply coated with oil. Subsequent vigorous grooming activities by the bears spread the oil further and deeper into the fur. Although the insulative properties of the fur were reduced by the oil and this induced thermoregulatory stress, death of 2 of the 3 bears was attributed to ingestion of considerable quantities of oil while grooming over a period of at least four weeks after exposure. Depending on the degree of oil contamination, mortality of polar bears could also result from this hypothetical event. However, impacts on the regional population of polar bears would be considered MINOR because the number of bears affected would be small.

(f) Arctic Fox

During the open water season, Arctic foxes occur in terrestrial areas within their breeding range. Consequently, some individuals may occur in localized coastal and backshore areas contaminated with oil on outer Richards Island and along the Tuktoyaktuk Peninsula during August and September. However, these areas would be covered with snow later in the fall when Arctic foxes begin their seasonal migration onto the landfast ice, thereby reducing the potential for contamination through oil contact.

Foxes feeding on stranded carcasses of oiled seals or other prey may develop similar physiological dysfunctions resulting from the ingestion of petroleum hydrocarbons that have been reported with other mammals (ESL, 1982b). Some individuals may also experience thermoregulatory stress if their fur becomes oiled. Nevertheless, since the number of Arctic foxes which may be affected would be small in relation to the regional population, the potential impact of this event on the fox population would likely be NEGLIGIBLE.

6.3.3.2 Possible Impacts on Birds

The biological effects of oil on marine birds have recently been reviewed by Duval *et al.* (1981), Brown (1981), and ESL (1982b) and are summarized in Chapter 4. The susceptibility of marine-associated birds to marine oil spills varies among species and with the circumstances surrounding the event. Nevertheless, it is generally agreed that even small amounts of oil can lead to mortality due to the exceptional vulnerability of birds to petroleum hydrocarbons (Milne and Smiley, 1976). The species of birds which are considered most vulnerable to this oil spill resulting from the blowout, in view of both the timing and location of the hypothetical slick, and current knowledge of bird distribution, abundance and biology in the Beaufort region are indicated in Table 6.3-2.

Some coastal and backshore environments where tar balls and viscous oil are assumed to strand in this hypothetical scenario are considered particularly important habitat for some species of birds during certain periods in their life histories. For example, Pelly Island provides important nesting and brood-rearing habitat for whistling swans, glaucous gulls and brant from June through September, while snow geese, brant and whistling swans nest at the Kendall Island Migratory Bird Sanctuary during the same period. Harry and Swan channels are important nesting areas for whistling swans, white-fronted geese,

TABLE 6.3-2

BIRDS OF THE SOUTHEASTERN BEAUFORT SEA REGION CONSIDERED VULNERABLE TO A MARINE OIL SPILL RESULTING FROM A PRODUCTION ISLAND BLOWOUT

Species		Vulnerable Period		
Common Name	**Scientific Name**	**Nesting and Brood-rearing (June-Sept)**	**Moulting (July-Aug)**	**Autumn Migration/ Staging (Aug-Oct)**
Arctic loon	Gavia arctica	X		X
Red-throated loon	G. stellata	X		X
Yellow-billed loon	G. adamsii			X
Whistling swan	Olor columbianus		X	
Black brant	Branta bernicla	X	X	
White-fronted goose	Anser albifrons			X
Snow goose	Chen caerulescens			X
Greater scaup	Aythya marila		X	
Oldsquaw	Clangula hyemalis	X	X	X
King eider	Somateria mollissima			X
Common eider	S. spectabilis		X	X
White-winged scoter	Melanitta deglandi		X	
Surf scoter	M. perspicillata		X	
Sandhill crane	Grus canadensis	X	X	
Shorebirds		X		X
Glaucous gull	Larus hyperboreus	X		
Arctic tern	Sterna paradisaea	X		
Thick-billed murre	Uria lomvia			X
Black-guillemot	Cepphus grylle			X

Adapted from Barry, 1976

sandhill cranes and shorebirds, and coastal bays from Hutchison Bay to Atkinson Point provide nesting habitat for glaucous gulls, brant and white-fronted geese from June to September. These latter areas are also important moulting areas for oldsquaws, scaup and scoters during July and August (Barry, 1976).

It should be noted that the volume of oil projected to be stranded on shorelines in this hypothetical scenario is considerably less (3,600 bbls) than the volume stranded in a subsequent scenario (#4) (100,000 bbls), and the oil would be considerably more viscous due to the loss of volatile components in the accompanying fire. However, the length of shoreline affected by oil in the present scenario is considerably greater than that anticipated for Scenario #4. In general, the degree of bird mortality and contamination as a result of past marine oil spills has been largely related to the number of birds contacting oil (a function of bird abundance and distribution), rather than the size of the spill and type of oil lost (Duval *et al.*, 1981).

Consequently, the anticipated degree of impact of this event on bird populations may vary from impacts projected for Scenario #4 even though they occur at the same time of year and in the same general region.

As previously indicated in Table 6.3-1 most species of marine birds could be affected to some degree by this hypothetical spill. However, for this summary only those species for which moderate impacts might be expected will be examined. The reader is referred to ESL (1982a) for further impact details on these and other species of birds frequenting the region.

(a) Whistling Swan

An estimated 20,000 whistling swans summer between the west side of the Mackenzie Delta and the east side of the Anderson River delta (Bellrose, 1976). During the nesting period, this species is widely dispersed and tends to avoid marine areas, although Barry (1976) identified Harry Channel, Swan Channel and Kendall Island as important coastal nesting and brood rearing areas for whistling swans from June through September. During late August, pairs or small numbers of whistling swans moult along the north side of Shallow Bay, on Ellice Island, in Mallik Bay and along the Tuktoyaktuk Peninsula. Slaney (1975) reported approximately 1,000 moulting swans in the Mallik Bay area on outer Richards Island (Figure 6.3.4).

The number of moulting whistling swans that may contact oil from this hypothetical blowout during the year of the event may approach 1,000 individuals, while birds nesting in subsequent summers may also be affected if oil is present in backshore areas. Although the actual amount of oil reaching backshore nesting areas would probably be relatively small, the anticipated impacts of this event on the regional population are considered MODERATE because the local populations of whistling swans may be affected for more than one generation. Since this species also has a low reproductive potential, recovery could require a much longer period than other waterfowl species affected by the hypothetical blowout.

(b) Black Brant

Black brant may occur within some areas affected by the hypothetical blowout (Figure 6.3.4), although contamination would be limited to birds in areas where oil reaches the littoral zone and backshore environments since these species are essentially terrestrial (Volume 3A: Section 4.2).

Of the estimated 4,000 black brant that nest along the Beaufort Sea coast from Demarcation Bay to Darn-

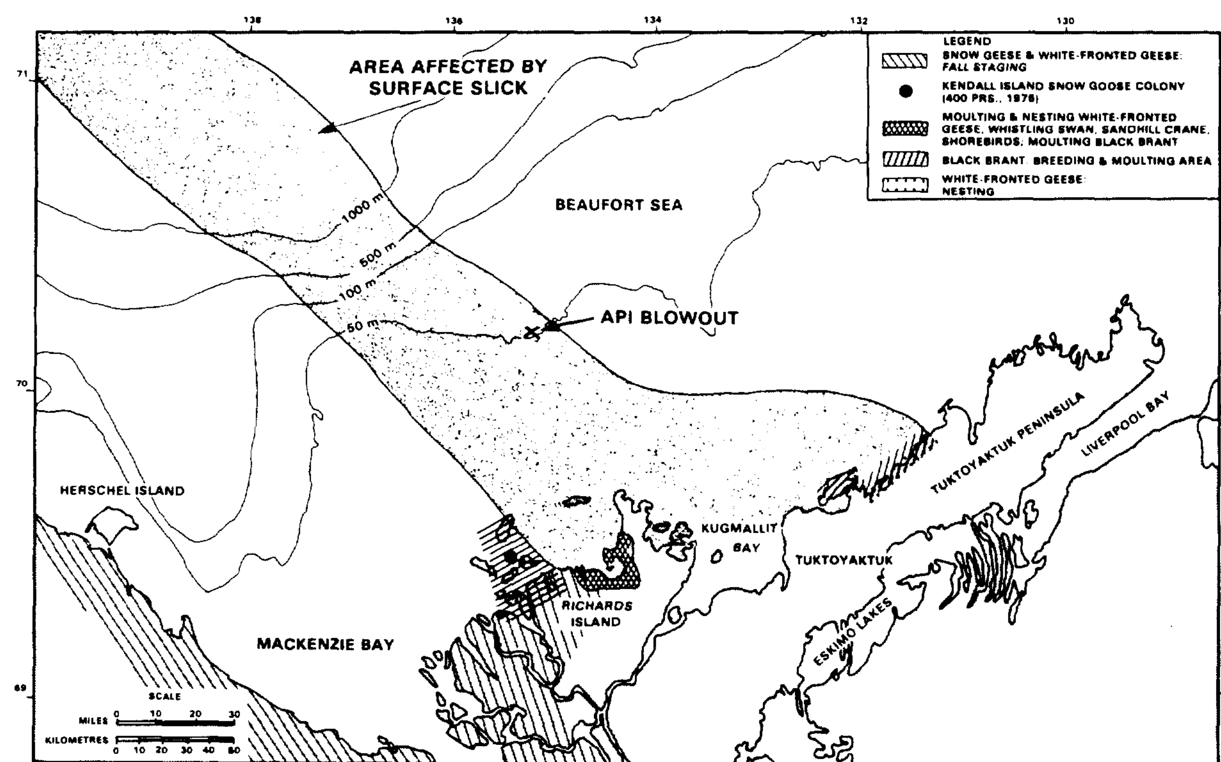


FIGURE 6.3-4 *Late summer distribution of geese, swans, cranes and shorebirds in the Mackenzie Delta and Tuktoyaktuk Peninsula area.*

ley Bay, about 500 nest on islands in the outer Mackenzie Delta and an additional 500 nest from Warren Point to Atkinson Point on the Tuktoyaktuk Peninsula. In addition, brant probably nest as single pairs throughout most coastal areas adjacent to the Beaufort Sea. Brant migrating through the Beaufort during August and September from nesting areas to the north and east may also occur in areas affected by oil during staging or migration.

Brant are considered vulnerable to marine oil spills because nest sites are often located at the edges of freshwater or tidal pools, often just above the high tide line (Bellrose, 1976). Adults, young-of-the-year and subadults are also vulnerable during the brood rearing period, from about early July until mid August, when they forage in the littoral zone. Major breeding and moulting areas for black brant in the southeastern Beaufort Sea are indicated on Figure 6.3-4. One of several of the more important fall staging areas for brant occurs in Mallik Bay on northern Richards Island.

The number of brant that may be affected by this hypothetical event is unknown, but probably at least 500 to 700 birds nest in areas which may be affected by oil. Although the nesting period does not coincide with the period when viscous oil blowout reaches the coast, some backshore nesting areas may be contaminated and rendered unsuitable for use in subsequent seasons. During the year of the event and in years to follow, moulting, brood rearing and staging brant at locations shown on Figure 6.3-4 may contact oil. Backshore moulting, brood-rearing and staging habitat for this species may be contaminated for an extended period, although the spatial extent of this contamination should be minimal because most of the oil would be in the form of tar balls and relatively small quantities are expected to reach shorelines and backshore environments. However, the anticipated degree of impact of this event on the regional black brant population would be considered MODERATE because this species is very dependent on marine areas and the local population may be affected over more than one generation.

(c) White-fronted Geese

The population of white-fronted geese that nest along the western arctic mainland from Demarcation Bay to Darnley Bay numbers approximately 40,000. Although white-fronted geese are not generally considered vulnerable to marine oil spills during the nesting period, Harry Channel, Swan Channel and areas from Hutchison Bay to Atkinson Point are important coastal nesting habitats for this species (Barry, 1976). Subadults moult at several coastal locations during July and August, and within the area affected by the hypothetical blowout, an estimated 4,000 white-fronts may moult on Richards Island. Adults with young arrive at the fall staging areas indicated on Figure 6.3-4 by mid to late August, and may remain as late as September. Major fall staging areas in the outer Mackenzie Delta include Shoalwater Bay, Shallow Bay, Kittigazuit Bay and Ellice Island. Total population estimates at these areas ranged from 12,500 to 25,000 between 1973 and 1976, although their distribution varies annually due to snow conditions.

The estimated 4,000 subadult white-fronts moulting on Richards Island may be affected by this hypothetical blowout, as well as nest sites and brood-rearing birds at Harry and Swan channels and along the Tuktoyaktuk Peninsula. The proportion of the local populations which may be affected during the year of the event, however, is likely to be relatively small since the oil would be primarily in the form of viscous tar balls and its coverage is expected to be somewhat discontinuous. Nesting habitats at Harry Channel and Swan Channel and from Hutchison Bay to Atkinson Point may be contaminated and rendered unsuitable for subsequent seasons, depending on the extent and location of oil in backshore areas. Fall staging birds may also be within coastal areas affected by the blowout, but total numbers would be small since the major fall staging areas are located elsewhere. Nevertheless, the anticipated degree of impact of this event on the regional white-fronted goose population would be considered MODERATE because a portion of the local population may be affected over more than one generation.

(d) Shorebirds

At least 27 species of shorebirds are known to nest in coastal areas adjacent to the Beaufort Sea (Volume 3A; Section 4.2). Shorebirds are particularly vulnerable to marine oil spills during August and September when the adults and/or juveniles of some species stage in the littoral zone. Since phalaropes are habitual swimmers, they are also vulnerable during foraging activities and migration. Barry (1976) reports that Harry and Swan channels are particularly important coastal nesting areas for shorebirds during the period from June until September (Figure 6.3-4). In addition, large numbers of staging shorebirds occur in littoral areas throughout the area affected by the hypothetical blowout, but are particularly numerous on the mudflats in Mallik Bay and on the west coast of North Point on Richards Island. Since the adults of most species leave the region before the young-of-the-year, the juvenile segment of the local populations are likely to be most seriously affected by the event.

Phalaropes, sanderlings and ruddy turnstones would probably require the longest recovery period following decreased population levels since they are considered the most vulnerable species to littoral zone disturbances. Semi-palmated sandpipers and Bairds' sandpipers are considered moderately vulnerable, while golden plovers and pectoral sandpipers are the least vulnerable shorebird species to littoral zone disturbances (Connors *et al.*, 1979).

Sediment deposition and natural wave and current action would probably remove much of the oil from ocean-side coastal marine areas within a year of the event. Consequently, uncontaminated staging habitat for shorebirds would likely be available in subsequent seasons. On the other hand, contamination of backshore nesting areas for some species, particularly near Harry and Swan channels, could render these habitats unusable during subsequent nesting seasons. The extent of the potential backshore contamination and the number of nesting shorebirds that may be affected during years following this hypothetical event are not known. Depending on species the degree of impact of this event on the regional populations of shorebirds would probably range from MINOR to MODERATE.

(e) Glaucous Gull

Glaucous gulls are thought to nest as single pairs throughout the coastal Beaufort region, and on at least three coastal colonies located within the area affected by this hypothetical blowout. Eleven of the 29 glaucous gull nesting colonies identified by Barry *et al.* (1981) in the Canadian Beaufort and Amundsen Gulf region are indicated on Figure 6.3-5.

Glaucous gulls are widely distributed throughout nearshore and offshore areas during the summer, but tend to occur in largest concentrations in the vicinity of the nesting colonies. Young-of-the-year at the colonies do not fledge until late August to mid September, and most glaucous gulls do not begin to leave the region until mid to late September.

Foraging gulls may contact the oil slick as it moves through offshore areas during August (Figure 6.3-5), but the number of individuals affected would be relatively small because this species is highly aerial and widely distributed. In addition, gulls are not generally considered vulnerable to marine oil spills. However, oil may contaminate the nesting colonies and cause mortality of (flightless) young-of-the-year

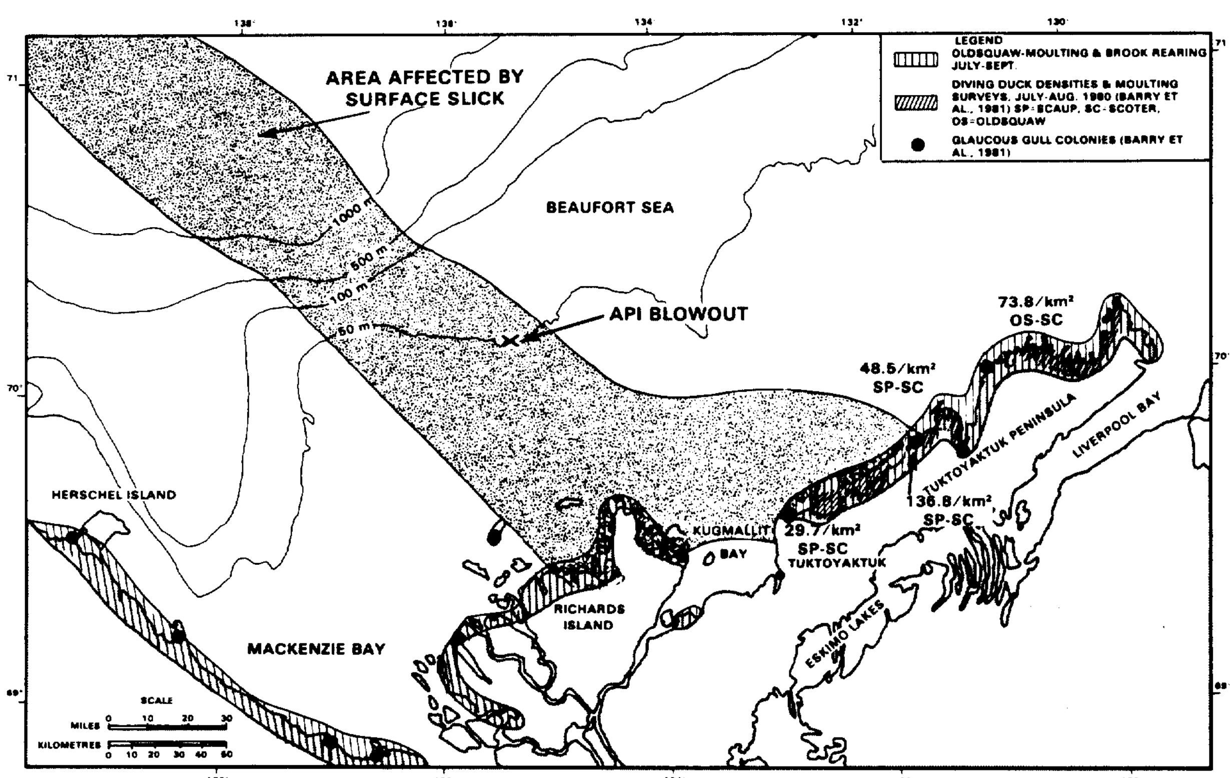


FIGURE 6.3-5 *Late summer distribution of diving ducks and glaucous gulls in the Mackenzie Delta and Tuktoyaktuk Peninsula.*

during the year of the event, and habitat loss during subsequent years. Cannibalism of young has also been observed at glaucous gull colonies that are disturbed (Barry *et al.,* 1981). The persistence of oil at the nesting sites would largely determine the rate of recovery at affected colonies. The total number of glaucous gulls which could be affected by this event would probably be within the range from 300 to 500 birds. Nevertheless, the potential impact of this hypothetical blowout on the regional glaucous gull population is considered MODERATE because the nesting colonies may be contaminated and this could affect nesting gulls for more than one generation.

6.3.3.3 Possible Biological Impacts to Fish

As indicated in Section 6.3.2, insignificant concentrations of dissolved hydrocarbons in the water column are expected following the hypothetical island blowout since the fire would combust virtually all low molecular weight hydrocarbons. Consequently, acute toxic effects of water-soluble petroleum hydrocarbons on fish are expected to be negligible throughout this incident. However, sublethal or chronic effects of sedimented oil on fish may occur in the low energy habitats where weathered oil is predicted to strand or settle, and where it may persist for several years while undergoing slow microbial degradation. In addition, dispersed oil may result in sublethal effects on some fish species in more offshore waters.

The lagoon areas of North Point between Mallik and Mason bays, of Pelly, Hooper and Pullen islands, and along the Tuktoyaktuk Peninsula between Toker Point and Drift Point, are all considered important rearing habitats for several anadromous fish species from the Mackenzie River system (Volume 3A, Section 3.4). These habitats are also important for certain marine species such as Pacific herring, Arctic cod and Arctic flounder. Most of these shallow coastal habitats are vacated by fish and freeze to the bottom in winter. At this time, deeper locations may become increasingly important and well populated by overwintering species, particularly Mallik and Mason bays which support winter populations of least and Arctic ciscos, inconnu, burbot and other species.

The types and magnitude of chronic or sublethal effects which may result from this hypothetical event are unknown, but could include temporary and localized reactions such as reduced feeding activity, altered metabolism or avoidance responses. Although these sublethal effects would usually be relatively short term, at this time of year they could affect the condition of fish or result in the use of sub-optimal wintering habitat. Either of these potential effects could locally reduce the survival of some populations. More visible physiological effects of petroleum hydrocarbons on fish could include tissue lesions, eye damage, reduced hatching success or developmental abnormalities. Among the most serious sublethal effects would be a disruption in critical behavioral responses such as the migration or reproductive behavior of anadromous populations concentrated in affected bays, lagoons and low energy backshore environments. The sublethal effects of petroleum hydrocarbons on fish are described in greater detail in a supporting document to this EIS (ESL, 1982b).

Ingestion of oil-contaminated prey and/or dispersed oil could also lead to accumulation of petroleum hydrocarbons in the tissues of some species including some fish stocks taken in the domestic fishery. Based on the foregoing, the potential regional impact of the hypothetical blowout on anadromous fish species which concentrate in brackish coastal and backshore environments could be considered MODERATE, while the degree of impact on marine species in coastal habitats would likely be MINOR.

The foregoing has summarized some of the more important projected implications of a blowout from a production island in the Beaufort Sea during summer on higher profile marine species including mammals, birds and fish which frequent the region. For further details, and particularly for information on the possible impacts to other species of biota, the reader is referred to ESL (1982a). As stated at the outset, these projections have been based on no countermeasures having been used, which would tend to reduce possible impacts.

Section 6.3.4 will briefly review the countermeasures strategies which could be employed.

6.3.4 COUNTERMEASURES STRATEGIES

The most important spill countermeasure would be to drill a relief well to stop the flow of oil as quickly as possible. This would be carried out as described in Volume 2..

It is likely that most of the oil residue would be confined to the island surface. Booms could also be deployed around the island to contain the oil. Skimmers and vacuum units could then be operated to remove the residue. If oil escapes this primary containment and recovery system, it could be recovered using the offshore systems on the Response Barge. Oil escaping these systems would be tracked with buoys and airbourne surveillance, the results of which would be used to plan shoreline protection activities should they be required. It would be expected that the volumes of oil coming ashore would be lower than was the case for the subsea blowout (Scenario #l).

Deployment of protective booms may prevent or minimize oil from reaching more sensitive habitats such as Mason Bay and Mallik Bay, while construction of protective berms could reduce the amount of oil reaching lagoon and backshore environments. In the event that oil did reach shoreline environments, there would be manual and/or mechanical removal of stranded oil from certain granular substrates. This action would reduce the potential long-term impacts since the viscous oil masses would tend to resist penetration into the sediments, and could therefore be recovered more readily than fresh or partially weathered crude.

In winter, oil on the ice could be recovered using vacuum units. Oil on the ice at a safe distance from the island could be burned *in situ*. Should the ice move, crews with igniters would be dispatched to burn larger concentrations of oil and place tracking buoys. In spring much of this oil could be removed by *in situ* burning.

To summarize, a blowout originating on a production island should prove to be amenable to an effective cleanup since most of the oil would likely be available for removal using burning or mechanical techniques.

6.4 SCENARIO #3: STORAGE FACILITY SPILL AT KOPANOAR IN THE BEAUFORT SEA

6.4.1 ACCIDENT DESCRIPTION

In this scenario 43,000 m^3 (270,000 bbl) of the 550,000 m^3 (3.5 million barrels) storage system's capacity is spilled. The location is the Kopanoar production island. The leak is assumed to persist for approximately four hours at a continuous rate of 180 m^3/min. (1,100 bbl/min.).

The oil spills onto the water and starts to spread. A small fraction of the oil also contaminates the shoreline of the island. During the summer, oil on open water will move with trajectories very similar to those depicted in Figure 6.5.1 (Section 6.5) for a tanker collision at Kopanoar. The oil quantities are the same.

If the spill occurs in winter, the ice around the island inhibits the movement of the oil, although open water areas and ships tracks are oiled. Eventually these areas fill and the oil spills onto and perhaps under the ice. If all the oil spills onto the ice, the areal extent of the contamination becomes about 3 km^2. The oil on the surface loses its light ends, but that beneath the ice retains its original composition until spring when it appears on the surface. During spring, the oiled ice melts and the residue enters the water.

6.4.2 COUNTERMEASURES STRATEGY

As was the case for the blowout in the open water season, containment barriers could immediately be deployed to retain oil. Large capacity vacuum units could be used to recover this oil. Should oil begin to move past the initial containment equipment and into the Beaufort Sea, the Response Barge and Arctic boom, as well as other oil spill barriers and mechanical recovery equipment, could be sent to the site and positioned to recover the escaping oil.

In the event that substantial quantities of oil escape, two other offshore responses would be considered. First, the fire-proof boom could be used to contain the oil for burning. A decision to burn would take into account any threat to personnel on the island. Second, aircraft carrying dispersants could be dispatched from Tuktoyaktuk to disperse slicks moving toward sensitive coastal areas. This operation would be supported by monitoring and surveillance activities.

Assuming that all the oil spilled escapes the island, the following shoreline protection and cleanup procedures could be undertaken. Based on the trajectory analysis, which would be similar to that illustrated in Figure 6.5-1, the shorelines most affected would be in Kugmallit Bay. The heaviest contamination would occur near North Point, in Kittigazuit Bay near Tuktoyaktuk and in Hutchinson Bay. The protection and cleanup of this area, comprising 500 km of shoreline, of which 264 km are designated sensitive by the Shoreline Protection Manual (Worbets, 1979), would be a major undertaking.

The most sensitive area, Tuktoyaktuk Harbour itself, could be protected by booms. Oil diverted to nearby sand beaches could be mechanically cleaned off. The next most sensitive area, the backshore zones south and west of Tuktoyaktuk to Naparotalik Spit could be protected by booming four inlets. The small inlet just east of Naparotalik Spit could be closed off using beach sand as a temporary berm. Manual cleanup would be required in this area due to the shallow nearshore zone and the poor bearing capacity of the shoreline. The other sensitive areas (Toker Point, Hutchison Bay, Bols Point, Kidluit Bay, Mason Bay and North Point) could be protected and cleaned up in the same way. In total 10,000 m of nearshore boom could be required. Collected oil could be disposed of by burning or, if necessary, by burial.

Should the spill occur in winter, vacuum units and pumps could be used to recover oil from pools on the ice. Once recovered, the oil could be stored and reclaimed or burned. Snow and ice dykes would also be used to contain flowing oil.

Oil on the ice beyond the production island could be burned *in situ* providing this was deemed safe. Oil that had frozen into the ice could be disposed of by *in situ* burning in the following spring.

6.5 SCENARIO #4: TANKER COLLISION IN THE BEAUFORT SEA

6.5.1 ACCIDENT DESCRIPTION

In this scenario it is assumed that a tanker in the Beaufort Sea is involved in a collision of such tremendous force as to tear a hole through both hulls on one side. This results in the discharge of 75% of the oil in two wing tanks or 43,000 m^3 (270,000 bbls) of crude oil in approximately four hours. In order to ensure the safety of the crew and vessel the master returns to the Kopanoar artificial island located approximately 32 km WSW.

6.5.2 OIL SPILL TRAJECTORIES

If the accident occurs during summer (in open water), in one day the slick spreads to cover an area of approximately 50 km^2. As the slick spreads the processes of horizontal diffusion and wave action break up the oil into patches surrounded by a thin sheen. At the same time the oil is weathering. The computer trajectory for this spill is shown in Figure 6.5-1 which also presents a summary of the amount of oil expected to be lost to dispersion, the amount of oil remaining on the sea, and the amount of oil on the shore as a function of time.

Should the spill occur during winter in an area of continuous ice, it is assumed that 80% of the oil is released into the vessel's track and dispersed and emulsified to some extent by the wash of the propeller. The remaining 20% is assumed to spread on and under the adjacent ice. This results in an oiled track approximately 50 m wide and 32 km long which would move in a westerly direction with the pack ice. In spring, the oil frozen in the ice would appear on the surface of the ice in melt pools. As the ice melts, this oil would be slowly released onto the water surface in the form of weathered patches surrounded by sheen.

Since the projected biological impacts of the summer scenario will be examined in Section 6.5.3, a more detailed discussion on the behavior and fate of this spill during summer follows.

The events to be described are based on the hypothetical collision occurring during open water on August 1 and on the trajectory analysis for the surface slick from this date to September 20, using physical data presented in Marko *et al.* (1981) and Marko and Foster (1981).

Initially, the spilled oil will spread horizontally over the water surface. In this scenario, the combined forces of gravity-induced spreading, winds and currents are expected to produce a slick covering a 270 km^2 area after 3 days. Beyond this time, movement of the oil mass will be primarily controlled by changing surface currents and wind patterns.

At the same time that the oil slick is moving, it will be gradually changing in physical and chemical composition as a result of various dispersion and weathering processes. The rate of weathering will be most rapid during the first few days after the spill when evaporation of volatile petroleum hydrocarbons and dissolution of most water-soluble components will occur. An immediate loss of the high volatility components of 1% due to dissolution, and 12% due to evaporation, was assumed. A further loss of 22% of the parcel volume was also assumed to occur over the next two days as a result of the evaporation of medium volatility petroleum hydrocarbons. This represents an assumed net loss of 35% (equivalent to 94,500 barrels) of the initial volume of oil spilled in the first 48 hours after the event. Depending on wind speed, a relatively large proportion of the oil may also be dispersed as an oil-in-water emulsion throughout the upper layers of the water column. At a wind speed of 30 kmh, approximately 10% of the surface oil slick could be dispersed into the water column per day (Audunson, 1980). The proportion of oil entering the water column would likely decrease to approximately 1% per day at a wind speed of 10 kmh, and increase to 38% at a wind speed of 60 kmh. Larger oil droplets which are dispersed into the water column may rise to the surface again if water turbulence decreases; these particles would then coalesce to reform part of the surface slick.

Oil present within the water column in either dissolved or dispersed forms may be subjected to a greater number of weathering and dispersion processes than surface slicks. In the present scenario, about 2,700 barrels are assumed to be dissolved and 73,500 barrels are assumed to be dispersed within the

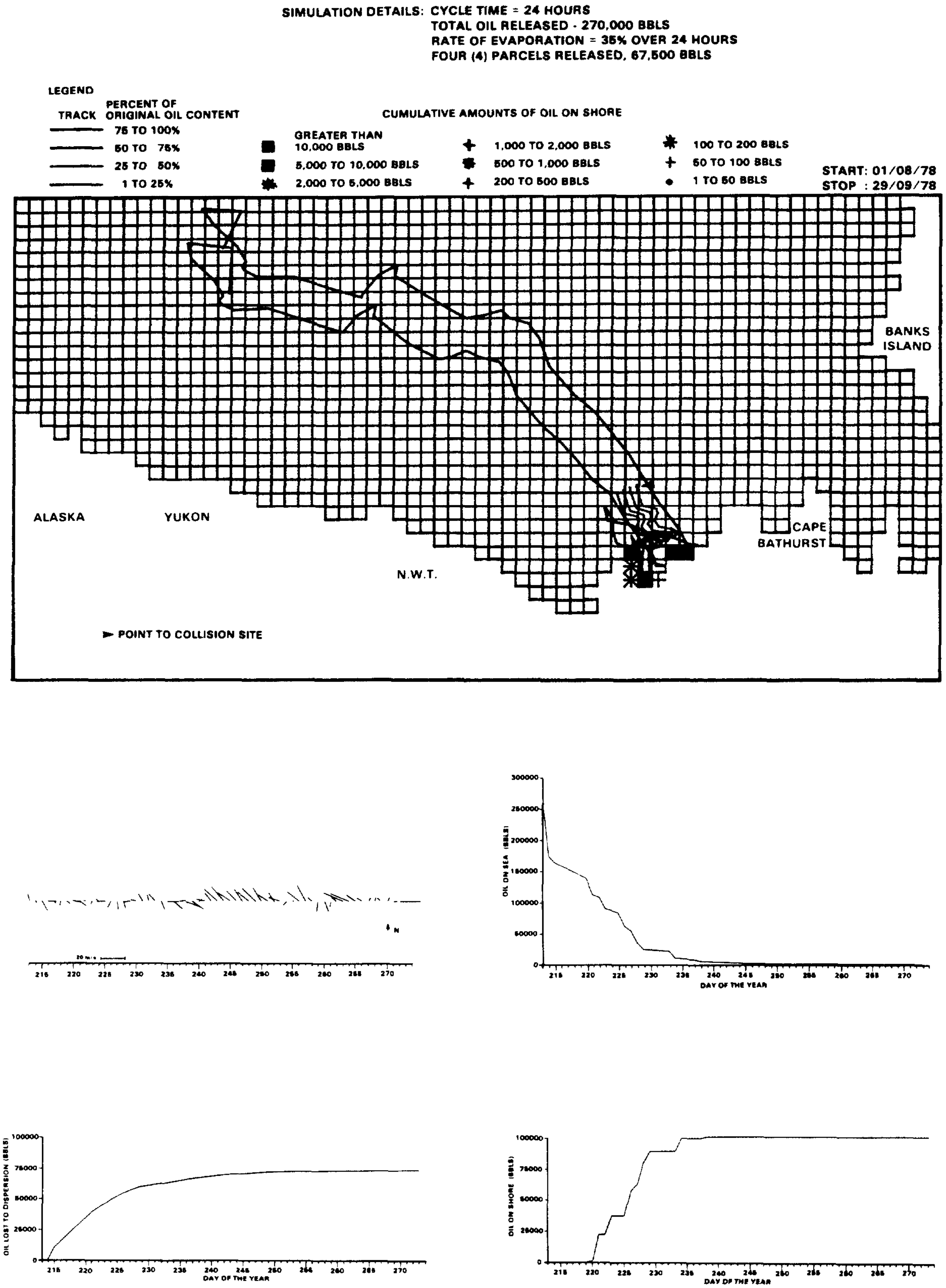


FIGURE 6.5-1 *Computer trajectories for oil spilled from an assumed tanker collision on August 1 in the Beaufort Sea. The graphs show the wind regime and the disposition of the oil vs time during the time interval encompassed by the trajectories.*

water column. Unlike evaporation, dissolution is long-term process which will continue throughout the duration of the total weathering process. This is due to the fact that oxidation and microbial degradation of the oil continuously produce compounds which are water soluble. The dissolved component will contain primarily low molecular weight aromatic and aliphatic hydrocarbons, with the former compounds being most responsible for the acute toxic effects of oil (Craddock, 1977). There have been very few field measurements of the concentration of dissolved oil beneath oil slicks, and therefore several assumptions are necessary to estimate the levels of dissolved oil which might result from this hypothetical spill. Craddock (1977) using laboratory data suggests that the maximum concentration of water-soluble constituents of crude oil in seawater ranges from 5 to 15 ppm. Data collected during the Ekofisk Bravo blowout in the North Sea indicate that concentrations of aromatic and aliphatic hydrocarbons 1 m beneath the slick were less than 2 ppm and 4 ppm, respectively (Law, 1977 unpubl. MS). Based on these reports and for purposes of this scenario, it has been assumed that during the first 12 hours after this hypothetical spill, concentrations of dissolved oil beneath the slick do not exceed 15 ppm.

Based on assumptions presented in ESL (1982a), concentrations of soluble hydrocarbons under the expanding slick are assumed to be less than 2.8 ppm 24 hours after this hypothetical spill. Concentrations of dissolved hydrocarbons beneath the slick would decrease rapidly after four days due to the breakup of the surface slick and ongoing weathering processes, and would likely not exceed 0.05 ppm for the duration of the event. Concentrations of dissolved petroleum hydrocarbons resulting from the continuous oxidation and microbial degradation processes described earlier would probably be less than 0.01 ppm in the upper 3 m of the water column.

During the latter half of the first week following the hypothetical collision, strong winds and waves are assumed to cause relatively large portions of the now partially weathered oil present on the surface to form a water-in-oil emulsion. The "mousse" (as such emulsions are called) is relatively stable on the water surface, and even mousse on the shoreline is expected to retain its liquid character until freeze-up. During the four week period following the hypothetical collision, approximately 37% (100,000 barrels) of the initial volume of oil spilled is assumed to strand on the shorelines of Kugmallit Bay. Since water-in-oil emulsions may contain from 70 to 80% water, the actual volume of oil and emulsified oil reaching coastlines could be as high as 180,000 barrels.

Based on oil spill trajectory analyses completed by Marko and Foster (1981), the shorelines of Pullen Island are expected be the first areas affected by surface oil and mousse after this hypothetical spill (Figure 6.5-2). Eroding tundra cliffs on the northwest coast of Pullen Island, sand beaches and lagoons behind low lying barrier beaches on the southeast shore would be particularly sensitive to oil (Woodward-Clyde Consultants, 1980). Oil and relatively unweathered mousse would tend to penetrate these substrates, contaminating both surface and subsurface sediments. In low energy environments such as lagoons, this oil could persist for several years since this degree of oil persistence has been reported following several spills in temperate and tropical latitudes (Duval *et al.*, 1981). On the other hand, oil in high energy or eroding shorelines, such as those along the northwest coast of Pullen Island, may re-enter the sea during storms which erode these areas in subsequent weeks and years. This could recontaminate areas which were previously cleaned by natural tidal and wave action.

The North Head area has a very irregular coastline configuration and a variety of shoreline types, including high slumping tundra cliffs with narrow sand beaches, wide barrier sandflats fronting low lying backshore lagoons, and low, peat tundra shores (Woodward-Clyde Consultants, 1980). Emulsified oil may contaminate these coastal environments during the second week of the scenario. In this area, occasional strong northwest winds throughout the remainder of the open water period could result in contamination of low relief backshores and lagoons.

The third week after the collision, the surface slick is assumed to be driven by strong winds into Kittigazuit Bay (Figure 6.5.2). Exposed sand bars and intertidal mudflats with marsh vegetation in this bay are assumed to be extensively contaminated with oil.

By Week 4, some oil is expected to strand on shorelines from Kittigazuit Bay to Toker Point. The low relief backshore lagoon systems, which are common in this portion of the Beaufort Sea coast, may eventually receive most of this weathered oil. Predominantly northwest winds, which are assumed to occur in this scenario, would produce high water, which in turn may carry some oil and oiled debris over the barrier beaches, and into low energy areas.

During the fifth and subsequent weeks after the tanker collision, all remaining surface oil would be transported by the prevailing winds to the northwest (Figure 6.5-2). As indicated earlier, the relatively high wind speeds during this period (up to 18 m/s) would emulsify much of the remaining oil, and by the end of the eighth week, only about 2,000 barrels of highly weathered crude would be present on the surface. The oil dispersed in this three week period would probably also be transported to the NNW by

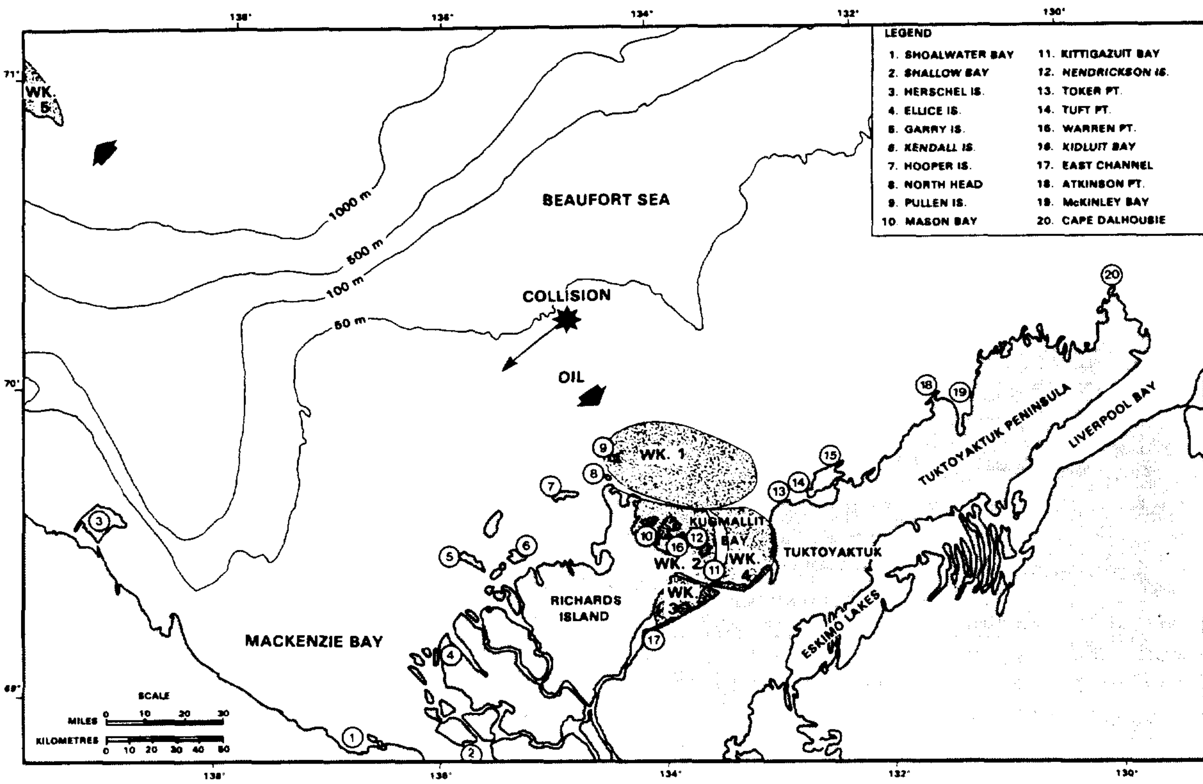


FIGURE 6.5-2 *Fate of oil spilled as a result of a hypothetical tanker collision in summer in the Beaufort Sea (see trajectories in Figure 6.5-1).*

the Beaufort Gyre and should eventually sink in deep waters.

A relatively large proportion of oil spilled as a result of this hypothetical event would be dispersed in the upper layers of the water column. Once the oil was dispersed in the water column, other weathering processes such as dissolution, sedimentation and biodegradation would be accelerated due to the large increase in the surface area of oil relative to its volume. The movement and subsequent fate of the dispersed oil will likely differ substantially from that of the oil which remains on the surface, primarily due to the more dominant influence of subsurface currents and the discharge of the Mackenzie River.

For this scenario, three possible fates of this dispersed oil are assumed to be probable. Firstly, the high turbidity of the Mackenzie River discharge will favour the sedimentation of much of this dispersed oil following adsorption to clay and other inorganic particles. This phenomenon could result in the deposition of weathered crude over the shallow substrates of Kugmallit Bay. Some of this oil could be reintroduced to the water column during periods of strong onshore (NW) winds later in the open water season, resulting in recontamination of some coastal areas of Richards Island and the Tuktoyaktuk Peninsula. Some dispersed oil will also sink and become entrained within the subsurface return ("upstream") flow of saline water which is associated with normal estuarine circulation patterns. Although it is not possible to determine the extent of the "upstream" transport of this oil, some deposition of oil in the shallow habitats from Kittigazuit Bay to the mouth of East Channel (Mackenzie River) is assumed to occur for this scenario. Assuming that suspended sediment concentrations in Kugmallit Bay during this period averaged 5 mg/L, and that 32,000 barrels of oil were dispersed in an area of 3,000 km^2 (approximate area of Kugmallit Bay), the volume of oil which may be sedimented in areas less than 5 m deep could reach 8,300 barrels (Duval *et al.*, 1978) This is approximately equivalent to the deposition of 0.4 g oil/m^2 on the bottom of Kugmallit Bay. The third and final possible fate of dispersed oil in this region would be the transport of the unsedimented fraction with the outflowing waters of the Mackenzie River.

This oil will be carried in the upper 3 to 6 m of the freshwater plume generally to the north and then northeast along the Tuktoyaktuk Peninsula. Oil could then tend to be deposited in coastal areas and embayments as it moved up the coast. The total amount of dispersed oil which may be transported to this region from Mackenzie Bay is not known, but may approach 24,000 barrels. Most oil transported up the Tuktoyaktuk Peninsula would probably be deposited in coastal areas west of Warren Point, although some oil is assumed to be carried as far as McKinley Bay with the freshwater plume of the Mackenzie River. This deposited oil would be highly weathered and would likely be in the form of tar balls.

6.5.3 BIOLOGICAL IMPACTS

The possible biological effects of this hypothetical tanker accident involving the loss of 270,000 barrels of crude oil on all levels of the food chain have been described in considerable detail in ESL (1982a). The following summary, as with those for Scenarios 1 and 2, addresses possible impacts related to the higher profile marine mammals, birds and fish. For further information on these and other members of the food chain which could possibly be affected, should such a spill occur, the reader is referred to ESL (1982a).

It should be re-emphasized that these statements of potential impact assume that no mitigative measures were employed during this spill. Offshore oil containment booms and recovery systems would be deployed when and where possible, while oil could be burned in areas where the slick was sufficiently thick and relatively unweathered. In addition, shoreline restoration programs would be undertaken where they are considered necessary and practical, particularly in low-energy environments where oil could penetrate and persist in granular substrates.

Table 6.5-1 provides a summary of the nature and potential regional impacts of this hypothetical tanker accident on all the marine resources of the southeastern Beaufort Sea.

This event is unlikely to result in any impacts on regional resources which would be considered major using the definitions provided in Section 6.1.2, with the possible exception of alcids from the Cape Parry colonies. The potential degree of impact on birds from these colonies could range from NEGLIGIBLE to MAJOR depending on the proportion of the colony contacting the oil slick during fall migration. Moderate impacts on regional populations of ringed seals, some diving ducks, white-fronted geese, black brant, glaucous gulls, some shorebird and nearshore fish species, and some benthic invertebrates could occur (Table 6.5-1). In the case of birds, and to a lesser extent fish, the degree of potential impact would be highly dependent on the amount of oil reaching coastal habitats and its subsequent persistence in these areas, since the potential for effects of stranded oil on more than one generation of these species (rather than direct mortality) is often the primary factor affecting the moderate (versus minor) degree of anticipated impact. The degree of potential impact of this event on benthic invertebrates in these same nearshore environments would also be dependent on the amount of oil which reaches the substrate, as well as the time required for recolonization of oil-contaminated or newly-deposited sediments.

6.5.3.1 Possible Impacts on Marine Mammals

(a) Bowhead Whale

The western Arctic population of bowhead whales migrates annually between wintering areas in the Bering Sea and summer feeding grounds in the eastern Beaufort Sea and Amundsen Gulf. Surveys have indicated that from mid August to early September in some years, significant concentrations of bowheads may feed in waters offshore of the Mackenzie Delta and Tuktoyaktuk Peninsula to at least the 50 m isobath. Data from other years suggest that summer feeding areas extend well offshore from Herschel Island east to Franklin Bay by Cape Parry.

The hypothetical tanker collision (August 1) and spill occurs in a water depth of approximately 50 m, and after 4 days the slick is expected to cover an area of about 420 km^2. By the end of the first week, the oil, now partially weathered and in a discontinuous slick, will have moved southeast to the entrance of Kugmallit Bay. The total surface area affected by the slick during this period could be as much as 2,000 km^2, although it should be emphasized that the oil coverage would be discontinuous and many uncontaminated open water areas would be present within the contaminated zone. The number of bowheads which may be present in the vicinity of the slick during the first week can be predicted from abundance data obtained from aerial surveys conducted during early August of 1978-80. Bowhead densities in this area appear to be highly variable from year to year, ranging from an estimated 0.00045/km^2 in 1978 and 1979 to 0.028 to 0.055/km^2 in 1980 (Fraker *et al.*, 1981). Assuming that a 2,000 km^2 area is affected by discontinuous oil slicks, the number of bowheads which could contact oil during the first week may approach 200 to 300 individuals or between 8 and 13% of the estimated western Arctic bowhead stock. However, this also assumes that individuals cannot detect and avoid oil.

TABLE 6.5-1

THE NATURE AND POTENTIAL REGIONAL IMPACT OF A HYPOTHETICAL OIL SPILL RESULTING FROM A TANKER COLLISION ON MARINE RESOURCES OF THE SOUTHEAST BEAUFORT SEA

Resource	Nature of Potential Impacts[1]	Anticipated Degree of Regional Impact[2]
Bowhead whale	S, C, F	Minor
White whale	S, C	Minor
Ringed seal	H, S, M, C, F	Moderate
Bearded seal	H, S, M, C, F	Minor
Polar bear	H, S, M, C, F	Minor
Arctic fox	S, C, F	Negligible
Loons	H, S, M, C, F	Negligible to Minor
Whistling swan	H, S, M, C, F	Minor
Canada Goose	H, S, M, C, F	Minor
Black brant	H, S, M, C, F	Moderate
White-fronted goose	H, S, M, C, F	Moderate
Snow goose	H, S, M, C, F	Minor
Oldsquaw, scaup, scoter	H, S, M, C, F	Moderate
Eiders	H, S, M, C, F	Negligible to Minor
Sandhill crane	H, S, M, C, F	Minor
Shorebirds	H, S, M, C, F	Minor to Moderate[3]
Jaegers	S, M, C	Negligible
Glaucous Gull	H, S, M, C	Moderate
Arctic tern	H, S, M, C	Minor
Alcids	S, M, C, F	Negligible to Major[4]
Offshore marine fish	H, S, M, C, F	Negligible to Minor[3]
Nearshore marine and anadromous fish	H, S, M, C, F	Negligible to Moderate[3]
Phytoplankton	S, M	Negligible
Zooplankton	S, M	Negligible
Benthic invertebrates	H, S, M, C, F	Minor to Moderate[3]
Benthic microalgae	H, S, M	Negligible
Terrestrial vegetation	H, S, M, C	Negligible to Minor[3]

[1]Nature of Potential Impacts
- H = Habitat loss
- S = Sublethal effects
- M = Mortality
- C = Contamination (fouling)
- F = Reduced food availability

[2]See Section 6.1.2 for Impact Definitions
[3]Dependent on species and/or habitat affected

Source: ESL, 1982a

In the second, third and fourth weeks following the hypothetical spill, most of the oil is predicted to travel further into Kugmallit Bay. Few bowheads are expected to be in the vicinity of the oil at this time since they generally do not travel far into the Bay. However, an estimated 24,000 barrels of dispersed oil may be transported up the coast of Tuktoyaktuk Peninsula during this period, with some dispersed oil possibly travelling as far as McKinley Bay. Based on available data (Volume 3A), the number of bowheads which could contact the dispersed oil in this area would probably not exceed 100 to 150 animals.

After the fourth week following the tanker collision, the remaining oil is expected to be transported by wind to the northwest. This period (early September) coincides with the beginning of the fall migration of bowheads out of the Beaufort Sea. Although the fall migration routes in Canadian waters are poorly documented, most whales off Alaska follow a corridor within 40 km of the mainland through waters 20 to 60 m deep. It is possible that a small number of fall migrants may also contact the remaining slick as it passes north of Richards Island in late August-early September. Since this period coincides with the beginning of the fall migration, the number of whales that could be affected in this area would probably be low. As the remaining oil continues to travel northwest to offshore areas in subsequent weeks, the chance of bowheads contacting oil becomes more remote.

It is not known if cetaceans can detect and subsequently avoid surface oil. However, mortality or contamination of whales has not been documented in the oil spill case history literature (Duval *et al.*, 1981), suggesting that whales may avoid oil-contaminated waters. There is no reason to expect that this hypothetical collision and oil spill would result in mortality of bowheads, although those individuals contacting the slick in Mackenzie Bay and near Herschel Island may suffer the following potential sublethal effects if they are unable to avoid the oil: fouling of baleen feeding mechanisms or damage of the structural integrity of same, temporary eye irritation, and damage and alteration of physiological and metabolic properties of the skin. The potential biological effects of oil on whales are discussed in more detail in ESL (1982b). The potential short and long-term implications of these possible sublethal effects on the bowhead population are not known, although mortality is unlikely and only a relatively small proportion of the regional bowhead population would be exposed to either surface or dispersed oil. Consequently, the anticipated degree of regional impact of this hypothetical event on the bowhead whale population would be considered MINOR.

(b) White Whale

The Beaufort Sea stock of white whales is migratory, and travels between the winter range in the Bering Sea and summer range in the eastern Beaufort Sea. Most white whales from this population concentrate in three areas of the Mackenzie estuary from late June-early July until early August (Figure 6.5-3). Approximately 7,000 whales may be present in the estuary at peak periods. The abundance of whales and the timing of their arrival in each concentration area varies from year to year as a result of annual changes in the pattern and timing of the break up of the landfast ice across Kugmallit Bay.

White whales generally begin to leave the estuary in mid July and most have left by the end of the first week in August. Little is known regarding the movements of whales once they have left the estuary. There is some evidence to suggest that they probably disperse to feed in offshore areas near the edge of the pack ice, along Tuktoyaktuk Peninsula, and/or in Amundsen Gulf. The whales leave the Beaufort Sea during late August and September, possibly travelling offshore near the edge of the pack ice (see Volume 3A; Section 3.2).

At the time of the hypothetical tanker collision, most white whales will have already left the Mackenzie estuary. As the slick moves towards Kugmallit Bay during the first week (August 1-8), some white whales may be in areas affected by the oil. Offshore surveys in the vicinity of Issungnak artificial island conducted during late July-early August in 1978-80, have indicated white whale densities ranging from 0.002 to 0.117/km^2 with a mean of 0.044/km^2 (Fraker and Fraker, 1981). Assuming the oil slick discontinuously affects an area over 2,000 km^2 during the first week, a minimum of about 100 to 300 whales could contact oil. During the second week, the slick is expected to move further into Kugmallit Bay, and could be present in the white whale concentration area surrounding Hendrickson Island. However, most whales have usually left Kugmallit Bay by this time. Less than 200 whales are usually present in this area by the second week of August, although approximately 500 whales were observed on August 10, 1976 (Fraker and Fraker, 1979).

Very few (if any) white whales will occur in areas which are expected to be affected by oil during the third and fourth weeks following the spill when the slick is transported further into Kugmallit Bay. However, some dispersed oil is also expected to travel up the Tuktoyaktuk Peninsula during this period, with most oil eventually sinking in shallow areas or stranding as tar balls on the shoreline west of Warren Point. Small groups of white whales are frequently observed feeding along the coast of the Tuktoyaktuk Peninsula during the latter half of August, although their abundance in this area does not appear to be particularly high. Renaud and Davis (1981) observed a group of about 100 whales moving west near Tuft Point on the Tuktoyaktuk Peninsula during an August 21-24, 1980 survey, while Fraker and Fraker (1981) recorded 123 individuals off the Peninsula on August 12, 1980.

As the remaining oil moves offshore during the fifth

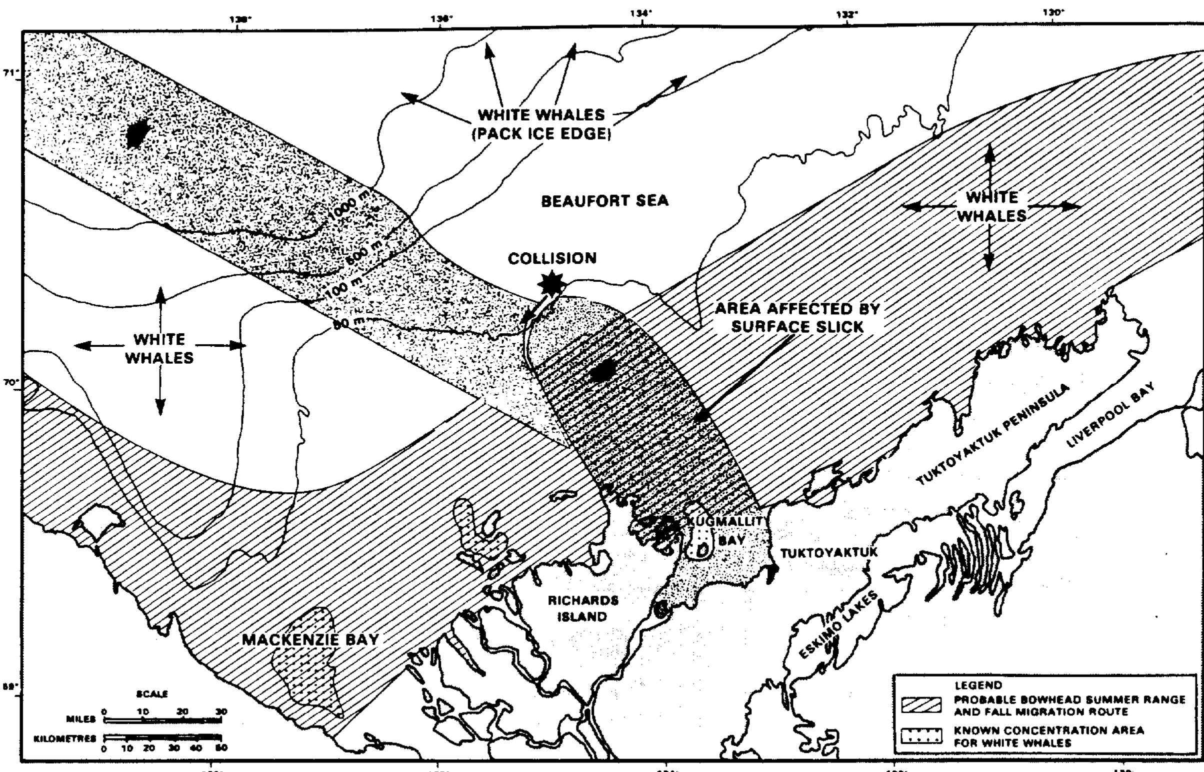


FIGURE 6.5-3 *Late summer distribution of bowhead and white whales relative to the area affected by surface slicks from an oil spill from a hypothetical tanker collision in summer (see trajectories in Figure 6.5-1).*

and subsequent weeks, it may cross the path of an unknown number of white whales during their fall migration out of the Beaufort Sea. However, by this time the oil would be highly weathered and present as a very discontinuous slick, and it is unlikely that many whales would more than briefly contact the oil.

Although it is difficult to accurately predict the numbers of white whales which could contact oil released after this hypothetical tanker collision, in an average year approximately 200 to 300 whales may be affected. In a worst case situation, as many as 700 to 800 whales could be exposed to the oil. These predictions assume that white whales are unable to detect and avoid surface oil slicks, which may or may not be the case.

It is doubtful that direct mortality would result if white whales did contact oil and potential sublethal impacts, if they were to occur, would generally be similar to those described for bowhead whales. The long-term impacts of these potential sublethal effects of oil on the whales are not known. However, since mortality is not anticipated and only a small proportion of the Beaufort population of white whales would likely contact oil, the degree of potential regional impact is considered MINOR.

(c) Ringed Seal

The ringed seal is the most abundant and widespread species of marine mammal in the Beaufort Sea. In 1978, the ringed seal population in western Amundsen Gulf, the Canadian Beaufort Sea (to 160 km offshore) and the west coast of Banks Island was estimated at 61,000 (Stirling *et al.*, 1981a). Ringed seals are relatively solitary and do not undertake long migrations, although there is some evidence of a westward migration of subadults just prior to freeze-up in the southern Beaufort Sea.

Based on the best data available (Renaud and Davis, 1981), a number of ringed seals, ranging from a few to about 1,000 seals could be present in the 2,000 km^2 oil-affected area during the first week. This is considered a minimum estimate because many seals may have been under the ice during the aforementioned surveys, and because movements of seals in and out of the area have not been investigated.

Ringed seal densities in Kugmallit Bay have not been documented, and this is the expected location of most of the oil during the second to fourth weeks of this scenario. However, it is likely that no more than a few hundred seals would encounter oil in this area. Dispersed oil is also expected to travel up the Tuktoyaktuk Peninsula, possibly as far east as McKinley Bay, while after late August, the remaining surface oil is assumed to be transported into offshore areas to the northwest. Significant numbers of ringed seals, perhaps in the hundreds, may contact oil in both of these areas.

As with other marine mammals, it is not known if ringed seals can detect and avoid oil. Both sublethal and lethal effects as described in Chapter 4 may be expected if some individuals are contaminated with oil. The amount of seal mortality would depend on the duration of exposure to the oil and the physiological state of each affected individual. Although some mortality would be expected if animals were heavily contaminated, recovery of the local ringed seal population would probably occur fairly rapidly. Recovery from natural population declines through immigration has occurred in the past over a period of about 4 years (Stirling *et al.*, 1980). Based on the foregoing assessment, the potential degree of impact of this event on the regional population of ringed seals would be considered MODERATE.

(d) Bearded Seal

The number of bearded seals that may contact oil from this hypothetical spill is not known, but should be relatively low given their widespread distribution during the open water period. Small numbers of bearded seals would probably be present in the vicinity of the oil slick during the first 4 weeks following the spill. However, as the slick moved northwest during the fifth week, it would drift over waters greater than 100 m deep which are generally not used by bearded seals.

Bearded seals exposed to oil may experience sublethal or lethal effects similar to those for other seals (Chapter 4). Since bearded seals feed on benthic invertebrates, potential indirect impacts may also result from any local reduction in the abundance of benthic fauna or ingestion of oil-contaminated prey. Geraci and Smith (1976) found that captive ringed seals fed 5 ml of crude oil/day for 5 days showed no major changes in blood chemistry or obvious behavioural effects. However, the amount of ingested oil that bearded seals could tolerate when feeding in oil-contaminated habitats is unknown.

Any mortality of bearded seals resulting from this hypothetical oil spill would likely only involve a few individuals at localized areas. Due to the wide distribution of this species in the region and its apparent ability to recover from natural population declines through immigration (Stirling *et al.*, 1980), no significant long-term impacts of this spill on the regional population would be expected. Consequently, the potential degree of impact of this event on the regional bearded seal population is considered MINOR.

(e) Polar Bear

During the open water season, polar bears in the eastern Beaufort Sea occur on the polar pack ice, particularly along the floe edge where they prey on seals (Stirling *et al.*, 1981b). Consequently, polar bears would only encounter oil lost in this hypothetical spill in the latter part of September when highly weathered and viscous oil is expected to reach the floe edge. Bears could contact surface oil since they regularly traverse the sea-ice and open water leads. They may also be indirectly affected through ingestion of petroleum hydrocarbons if feeding on oil-contaminated seals (Engelhardt, 1978). The number of bears that may occur in areas affected by the spill cannot be estimated because surveys of bears on the pack ice at this time of year have not been conducted. However, since the oil would be confined to a restricted area along the ice edge, only a small proportion of the regional population of polar bears should be affected. Based on this, the anticipated degree of impact on the regional polar bear population is considered MINOR because the number of bears which could be affected would be small.

(f) Arctic Fox

During the open water season, Arctic foxes occur in terrestrial areas within their breeding range. Consequently, some individuals may be contaminated with oil present in shoreline and backshore environments of Kugmallit Bay and outer Richards Island during August and September. However, these areas would be snow-covered later in the fall when foxes from coastal areas begin their seasonal migration onto the landfast ice, reducing the potential for contamination through contact with buried oil.

Foxes feeding on carcasses of oiled seals or other prey may develop physiological dysfunctions resulting from the ingestion of petroleum hydrocarbons that have been reported with other mammals (ESL, 1982b). Some individuals may also experience thermoregulatory stress if their fur becomes oiled. Nevertheless, since the number of foxes which may be affected would be small in relation to the size of the local and regional populations, the anticipated degree of impact of this hypothetical spill on the regional Arctic fox populations is considered NEGLIGIBLE.

6.5.3.2 Possible Impacts on Birds

The biological effects of oil on marine birds have been recently discussed in detail by Duval *et al.* (1981), Brown (1981) and ESL (1982b) and were summarized in Chapter 4. The susceptability of marine-associated birds to oil spills varies with species and the circumstances surrounding the event, particularly the season of the spill and the types of habitats contaminated. Nevertheless, it is generally agreed that even small amounts of oil can lead to mortality due to the exceptional vulnerability of birds to petroleum hydrocarbons (Milne and Smiley, 1976). The degree of bird mortality and contamination as a result of past marine oil spills has been largely related to the number of birds contacting oil (a function of abundance and distribution of the birds), rather than the size of the spill and type of oil lost (Duval *et al.*, 1981).

Given the time and location of this hypothetical event, and current knowledge regarding the distribution, abundance and biology of birds in the Beaufort Sea region (Volume 3A; Section 4.2), the species considered to be most vulnerable are listed in Table 6.5-2

Coastal areas affected by surface oil released following the hypothetical tanker collision support local nesting populations of oldsquaws, dabbling ducks, brant, glaucous gulls, Arctic terns, shorebirds, and sandhill cranes. These areas also represent foraging, staging, moulting and/or brood-rearing habitats during August and September for several species including diving ducks, gulls, loons, brant, snow geese, white-fronted geese, Canada geese, sandhill cranes and whistling swans. In addition, a proportion of the dispersed oil transported to the northeast along the coast of the Tuktoyaktuk Peninsula may be sedimented or form tar balls which are subsequently deposited in shallow bays and coastal lagoons. Many of these areas provide moulting habitat for oldsquaws, scaup and scoters during July and August.

TABLE 6.5-2

BIRDS CONSIDERED VULNERABLE TO A HYPOTHETICAL TANKER COLLISION AND OIL SPILL IN THE SOUTHEAST BEAUFORT SEA

Species		Vulnerable Period		
Common Name	Scientific Name	Nesting and Brood-rearing (June-Sept)	Moulting (July-Aug)	Autumn Migration/ Staging (Aug-Oct)
Arctic loon	Gavia arctica	X		X
Red-throated loon	G. stellata	X		X
Yellow-billed loon	G. adamsii			X
Whistling swan	Olor columbianus		X	
Canada goose	Branta canadensis		X	
Black brant	B. bernicla	X	X	
White-fronted goose	Anser albifrons			X
Snow goose	Chen caerulescens			X
Greater scaup	Aythya marila		X	
Oldsquaw	Clangula hyemalis	X	X	X
King eider	Somateria mollissima			X
Common eider	S. spectabilis		X	X
White-winged scoter	Melanitta deglandi		X	
Surf scoter	M. perspicillata		X	
Sandhill crane	Grus canadensis	X	X	
Shorebirds		X		X
Glaucous gull	Larus hyperboreus	X		
Arctic tern	Sterna paradisaea	X		
Thick-billed murre	Uria lomvia			X
Black guillemot	Cepphus grylle			X

Adapted from Barry, 1976

and nesting and brood-rearing habitat for brant and glaucous gulls from June through September. The spatial and temporal extent of habitat contamination would depend on the extent and success of the clean-up operation, and the prevailing wind and current patterns during and after the event. The following sections summarize the possible implications for bird species for which the more significant, or moderate impacts might be expected, should the event occur.

(a) Black Brant

An estimated 500 black brant nest on islands in the outer Mackenzie Delta, while widely dispersed pairs probably also nest in most coastal areas throughout the Beaufort Sea region (Figure 6.5-4). This species is particularly vulnerable to oil spills because nests are often located just above the high tide line or in coastal meadows, and because adults, young and non-breeding birds feed in the littoral zone during the brood-rearing period which extends from early July to mid-August. Koski (1977b) reported that in August 1976, brant were concentrated in Kittigazuit Bay, an area which is expected to be extensively contaminated as a result of this hypothetical event. CWS (1972) reported 700 brant moulting at McKinley Bay, although recent surveys have indicated few individuals in this area (Volume 3A; Section 4.3). Brant moulting in McKinley Bay may be affected by tarballs and sedimented oil, and may suffer localized mortality, sublethal stress, or reduced weight gain as a result of a local reduction in food availability. Brant migrating through the Beaufort during August and September from nesting areas to the north and east may also moult and/or stage in the Beaufort Sea region, although most major moulting areas occur outside the Canadian Beaufort and therefore not in areas affected by oil.

The total number of brant which may be affected by this hypothetical oil spill would be relatively small at this time of year (eg. 100 to 300) since some brant begin to leave for fall staging areas elsewhere by mid August. Nesting, moulting and brood-rearing areas located in low energy backshore environments in Kugmallit Bay and along the Tuktoyaktuk Peninsula could remain contaminated with oil for several years following the spill, and this may result in long-term exposure of the local brant population to weathered

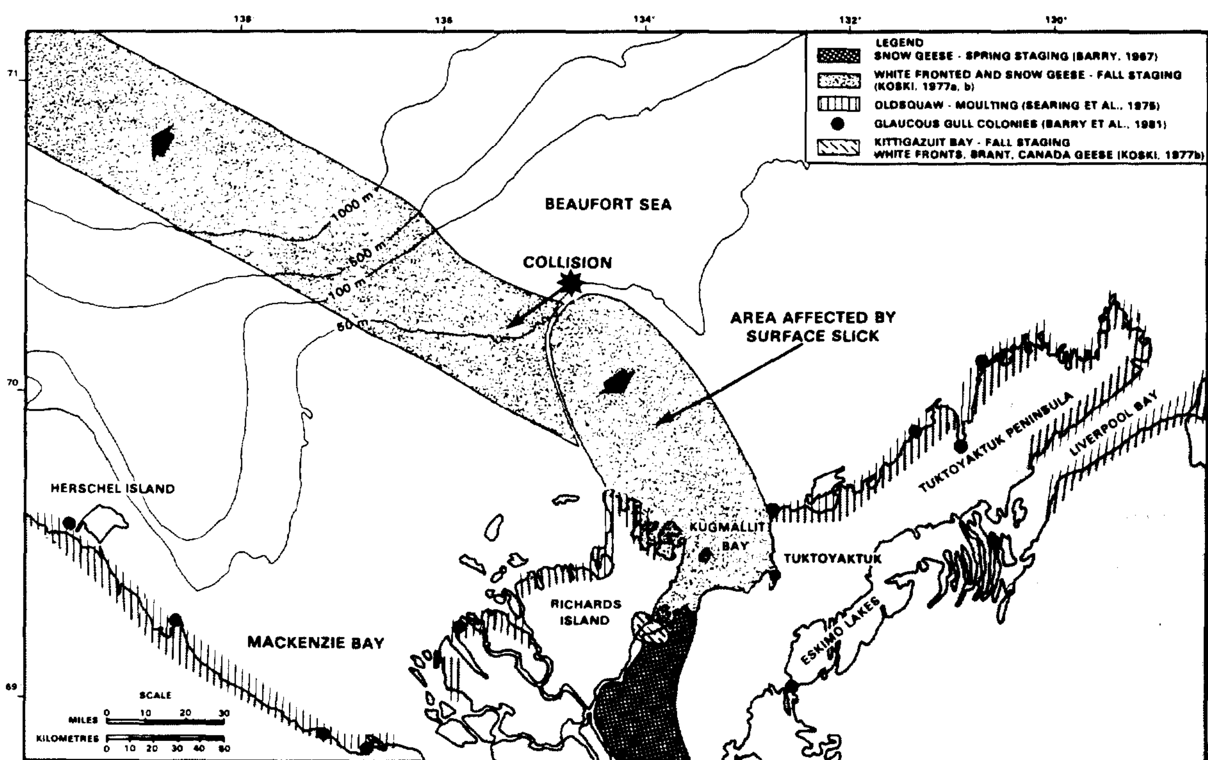


FIGURE 6.5-4 *Late summer distribution of geese, diving ducks, and glaucous gulls in the Mackenzie Delta and Tuktoyaktuk Peninsula relative to the area affected by surface slicks from a hypothetical tanker collision in summer in the Beaufort Sea (see trajectories in Figure 6.5-1).*

oil, as well as less than normal food availability. The anticipated degree of impact of this event on the regional brant population would be considered MODERATE due to the high vulnerability of this species to oil, and potential for more than one generation to be affected.

(b) White-Fronted Geese

The Mackenzie Delta is a major fall staging area for white-fronted geese from nesting habitats on the Alaskan North Slope and the Anderson River area (Figure 6.5-4). Major concentration areas in the outer Mackenzie Delta include Shoalwater Bay, cShallow Bay, Kittigazuit Bay and Ellice Island. Total population estimates for these staging areas ranged from 12,500 to 25,000 between 1973 to 1976, although the distribution of white-fronted geese in these areas varies markedly between years depending on snow conditions. Consequently, the number of white-fronted geese that stage in Kittigazuit Bay during September, and therefore may occur within the area affected by the spill, could range from a few hundred to several thousand birds. The extent of mortality would also depend on the amount and persistance of oil in backshore terrestrial areas. In addition, a localized reduction in food supplies could result in decreased nutritional reserves being acquired on the staging areas. Due to the relatively large proportion of the regional population of white-fronted geese that could be directly or indirectly affected by this hypothetical event, the potential degree of impact may be considered MODERATE.

(c) Oldsquaws, Scoters and Scaup

During July, August and September, several species of diving ducks are known to moult and/or rear their broods in coastal bays, lagoons and barrier islands along the Beaufort Sea coast. The local populations are particularly vulnerable to marine oil spills during this period because young-of-the-year are present, and the adults and subadults are flightless for about 2 to 3 weeks. The annual variability in the number of moulting and brood-rearing birds in coastal areas makes it difficult to predict the number of birds which may be affected by this spill (Volume 3A; Section 4.2). Many yearling and adult male oldsquaws moult along the coast during July and August, while females move to the coast with their young in late August and early September (Figure 6.5-4). Male and non-nesting female scoters are abundant at several coastal moulting locations in the Beaufort region from late June to late August. Greater scaup are also abundant at some coastal locations during the moulting period, although most scaup that moult in coastal areas of the Beaufort Sea region occur along the Tuktoyaktuk Peninsula and in Liverpool Bay, and therefore outside of the area which is expected to be affected by surface oil.

The maximum densities of moulting oldsquaw, scaup and scoters recorded by Barry *et al.* (1981) near Tuktoyaktuk during surveys in July and August 1980 were 4.4/km^2 (end of July), 31.6/km^2 (mid August), and 8.7/km^2 (mid July), respectively. Similarly, the maximum densities of these three species recorded in Kugmallit Bay ranged from less than 0.1/km^2 to 0.9/km^2 during the same surveys. The populations of moulting ducks in these areas are not considered large in contrast to those in Liverpool Bay, Herschel Island and in parts of the Tuktoyaktuk Peninsula.

The number of diving ducks that may contact the surface slick as it moves through its projected trajectory is not known, but it is probable that the oil may result in considerable mortality within local populations. Female and young-of-the-year oldsquaws, male and non-nesting female scoters, and greater scaup would likely be most seriously affected at this time of year. Contamination of localized nesting and moulting habitat in coastal areas could also cause continued oiling and/or displacement of an unknown number of birds for one or more years after this hypothetical accident.

Diving ducks have a relatively high reproductive potential, and recovery of the local populations should occur fairly rapidly (possibly within 5 years) once the affected coastal nesting and moulting habitats were available in subsequent years. However, the overall recovery period would be highly dependent on several factors such as the quantity and persistance of oil in nearshore and backshore environments. Waves, currents and tidal flushing would probably remove oil from nearshore areas within 1 to 2 years, while the low energy backshore lagoon systems may remain contaminated for several years, both in the areas affected by the surface slick and along the Tuktoyaktuk Peninsula where dispersed oil is expected to be transported. The potential degree of impact of this hypothetical oil spill on the regional population of diving ducks is considered MODERATE since a change in the abundance or distribution of these populations could persist over one or more generations.

(d) Glaucous Gulls

Glaucous gulls probably nest as single pairs throughout the coastal Beaufort Sea region, and at colonies on at least 6 barrier islands along the Yukon coast and 8 offshore islands in the Mackenzie Delta (Figure 6.5-4). The largest documented colony in the Delta had 85 pairs of glaucous gulls. Barry (1976) reported that Kidluit Bay and the areas along the Tuktoyaktuk Peninsula from Hutchinson Bay to Atkinson Point were important nesting and brood-rearing habitats for glaucous gulls from June through September. Glaucous gulls are widely distributed throughout nearshore and offshore areas during the summer, but tend to occur in largest concentrations in the vicinity of the colonies. The young-of-the-year do not fledge until late August - mid September, and most glaucous gulls do not begin to leave the region until mid to late September.

The number of glaucous gulls that may occur within offshore areas affected by the slick would probably be relatively low since this species is highly aerial and widely distributed. However, as the oil approached and contaminated North Point and Kugmallit Bay during mid to late August, the probability of gulls contacting the slick would increase since they are concentrated near shorelines and within at least two colonies. Mortality of breeding birds and young-of-the-year may occur at these colonies, with losses from this hypothetical event potentially totalling about 100 to 300 birds. Young-of-the-year birds would not have fledged by the time the oil reaches the colony at Kidluit Bay. The glaucous gull colonies along the Tuktoyaktuk Peninsula could also be affected by stranded tar balls during the year(s) following the hypothetical event.

In the event of considerable mortality of either young-of-the-year or breeding adults, the rate of recovery of the local population would be highly dependent on the quantity and persistance of oil in the nesting habitats. In summary, the potential degree of impact of this hypothetical event on the regional population of glaucous gulls would likely be MODERATE.

(e) Alcids

Alcids are considered to be extremely vulnerable to marine oil spills because they are highly aquatic and have a low reproductive potential (ESL, 1982b). Thick-billed murres and black guillemots from the Cape Parry colonies may occur in areas affected by the slick during their fall migration in September. Although little is known regarding the fall migration routes and patterns, most alcids probably migrate through offshore areas. Mortality of individuals contacting oil is anticipated due to the exceptional vulnerability of these species to oil. Consequently, the potential degree of impact of this spill on the regional alcid populations could be NEGLIGIBLE to MAJOR depending on the number of fall migrants that actually contact the surface slick which intersects their probable fall migration route.

6.5.3.3 Possible Impacts on Fish

For this discussion of the potential effects of this hypothetical oil spill on fish, it is advantageous to divide the total area contacted by the oil slick into four zones (Figure 6.5-5), since each zone has a relatively homogeneous fish habitat and each would be exposed to different dissolved oil concentrations. Zone 1 is the offshore habitat extending shoreward from the collision site in about 75 m of water to approximately the 10 m isobath. Zone 2 includes the complex lagoon systems behind sandbars and the intertidal mudflats which are expected to be contaminated between Day 5 and Day 30 in the hypothetical spill. Zone 3 is the nearshore area also affected by oil between Day 5 and Day 30, but is located slightly seaward of the shore to a depth of about 10 m. Zone 4 extends from the nearshore waters to offshore waters at depths greater than 1,000 m, and is affected by discontinuous weathered oil slicks after 30 days.

(a) Potential Effects on Fish in Zone 1

Fish present in the surface waters of this area are expected to include anadromous species from the Mackenzie River (mainly Arctic and least ciscos, and boreal smelt), as well as pelagic marine species such as Arctic cod and Pacific herring. Young-of-the-year Arctic cod may be particulary abundant in this zone, but like other species are probably unevenly distributed and generally dispersed. A more detailed discussion of the distribution and life history of fish species found in this region is provided in Volume 3A, Section 3.4.

Concentrations of dissolved hydrocarbons in the upper 3 m of the water column in Zone 1 are expected to decrease from less than 15 ppm to 0.3 ppm in the 4 day period as the oil slick passes through the area. These concentrations are within the range where acute lethal effects have been demonstrated in laboratory investigations, particularly on the larval stages of some species (ESL, 1982b). Limited fish mortality could occur in this zone over the 4 day exposure period, although the case histories of past spills suggest that extensive mortality would be unlikely (Duval *et al.*, 1981).

Although the distribution, abundance and potential avoidance responses of fish in this zone are not well documented, available information does not suggest that any critical populations or concentrations of fish would be affected by this hypothetical event. In addition, no long-term habitat changes would be expected to result from the spill in this zone.

(b) Potential Effects on Fish in Zone 2

This zone includes several bays which support con-

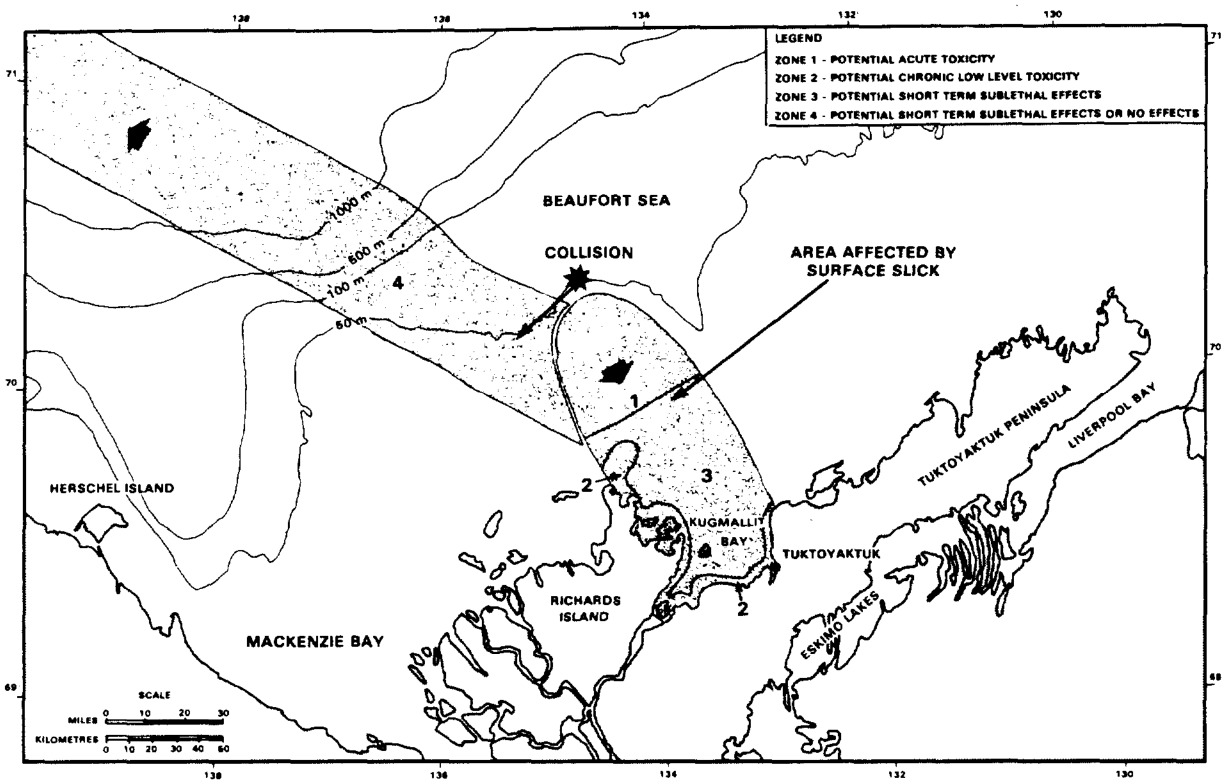


FIGURE 6.5-5 *Zones of different potential effects on fish within the area affected by surface slicks from a hypothetical tanker spill in summer in the Beaufort Sea (see trajectories in Figure 6.5-1).*

centrations of a few marine species such as Pacific herring which are abundant along the east side of North Point, as well as brackish water environments of the Mackenzie River including Kugmallit Bay. Throughout the summer, populations of anadromous species such as least and Arctic ciscos, boreal smelt, whitefish and inconnu are generally restricted to these brackish areas at depths less than 5 m. Backshore lagoons also support these species and may be contaminated if waves and storm surges transport oil over the low barrier beaches.

Dissolved hydrocarbon concentrations in this zone are not expected to exceed 0.05 ppm, and these levels are unlikely to result in acute toxic effects on even the more sensitive fish species or life history stages. However, once the oil becomes stranded in shoreline areas and penetrates granular substrates, or is transported into the low-energy lagoon environments, fish species in these habitats may be chronically exposed to low hydrocarbon levels. Oil may persist for years in environments with a high oil retention capacity (Duval *et al.*, 1981), but fish would only be exposed to the traces of oil during the summer months. The repeated chronic exposure of fish to low levels of hydrocarbons could result in a range of sublethal effects such as developmental abnormalities, tainting and behavioral modifications, although direct mortality is considered unlikely. The greatest potential for these and other sublethal effects (ESL, 1982b) would likely occur in relatively confined embayments where the oil may be deposited or accumulate and then slowly weather.

(c) Potential Effects on Fish in Zone 3

This zone generally supports the same fish species as Zone 2. However, this area is located seaward of the bays and lagoons, and fish in these waters are likely more mobile and less concentrated. As in Zone 2, acute toxic effects would not be expected at the predicted dissolved hydrocarbon concentrations. Due to the increased circulation in waters away from beaches, bays and lagoons, chronic release of dissolved hydrocarbons in the months following oil contamination would likely have less effects on fish in this region than in Zone 2. Long-term impacts of this hypothetical spill on fish in Zone 3 are therefore expected to be very unlikely.

(d) Potential Effects of Fish in Zone 4

As the remainder of the weathered oil slick is transported seaward during Week 5, dissolved hydrocarbon concentrations in the water column would probably be appoaching background levels. Fish present in this zone would be primarily pelagic marine species, as well as a decreasing proportion of some anadromous species as water depth and distance from shore increase. Due to the brief exposure times and very low concentrations of dissolved hydrocarbons, no lethal effects on fish would be anticipated, and there is no evidence which suggests that even sublethal effects would occur under such conditions.

(e) Regional Significance

Since fish populations are not confined and are expected to be well dispersed in the area where the highest concentrations of dissolved hydrocarbons would be expected as a result of this hypothetical spill, and since the volume of water contaminated is small in a regional context, any potential acute lethal and sublethal effects on Arctic cod, Pacific herring, least and Arctic ciscos, boreal smelt and other species would not be expected to change the integrity of the regional populations of these species. Since the affected populations would likely return to their former abundance and distribution within one generation, the impacts of this hypothetical spill on species present in offshore areas would be considered NEGLIGIBLE to MINOR according to the definitions used for this assessment.

Longer term impacts of the spill on the primarily anadromous species using nearshore lagoon habitats could occur if oil was transported into these areas. Although the nature and magnitude of these potential impacts of chronic oil exposure are less clearly documented, they would generally be considered MINOR since the amount of oil remaining in such areas should be small in relation to the available habitat of this type. However, MODERATE impacts are possible in some low energy habitats where long-term persistence of stranded oil could result in change in distribution, abundance or habitat use by fish that extends over more than one generation.

6.5.4 COUNTERMEASURES STRATEGY

To effectively respond to an open water spill of this type, immediate steps would be taken to control the source of the oil. This would be accomplished by pumping oil from the damaged tanks to sound ballast tanks. Oil would be contained and recovered offshore using every available piece of equipment including the Response Barge (Chapter 5).

At the same time, oil slicks moving towards sensitive areas could be sprayed with dispersants while the oil was still relatively fresh, subject to being approved by the Federal Government. The application of approved chemical dispersants in offshore areas near the hypothetical collision site would minimize the quantity of surface oil entering Kugmallit Bay. Although this countermeasure could result in some impacts on pelagic and benthic resources in offshore areas, the overall impact of the hypothetical event on coastal habitats and resources (particularly birds) could be reduced to minor for some species. A second countermeasure would involve the deployment of protective booms to prevent or minimize oil (depending on weather and speed of deployment) from reaching more sensitive areas such as Kittigazuit Bay and would also decrease the potential impacts of this event, while construction of protective berms on barrier spits and low-lying frontal beaches would reduce the amount of oil reaching lagoons and backshore environments.

In summary, an offshore tanker collision resulting in a large unconfined release of oil over a period of hours would pose a difficult cleanup problem in open water conditions. The mechanical equipment now available could be expected to deal with a certain amount of the oil offshore, however, the remainder would have to be dealt with using dispersants and shoreline cleanup techniques. Research into different techniques to deal with such spills, including stockpiling equipment on tankers, is required and will be undertaken.

In contrast, the response to a similar release of oil during the winter months should be considerably more effective, since the oil would be confined by the surrounding ice. Oil could be burned *in situ*, safety permitting, or tracked using radio and satellite buoys. Due to the existance of large pools of oil in a small area the great majority of the oil could be burned during the following spring.

6.6 SCENARIO #5: TANKER FIRE AND EXPLOSION IN AMUNDSEN GULF

6.6.1 ACCIDENT DESCRIPTION

In this scenario, which takes place south of Banks Island in Amundsen Gulf (Figure 6.6-1) during August, the tanker's main inert gas system and the backup system are assumed to fail, allowing combustible vapours and air to mix. A spark ignites the vapour in one cargo tank, and this sets off a chain reaction that causes all the cargo tanks to explode and burn. As a result of the explosions the cargo tanks are holed. The intense heat of the flames burns approximately 30% of the oil. The rest loses some of

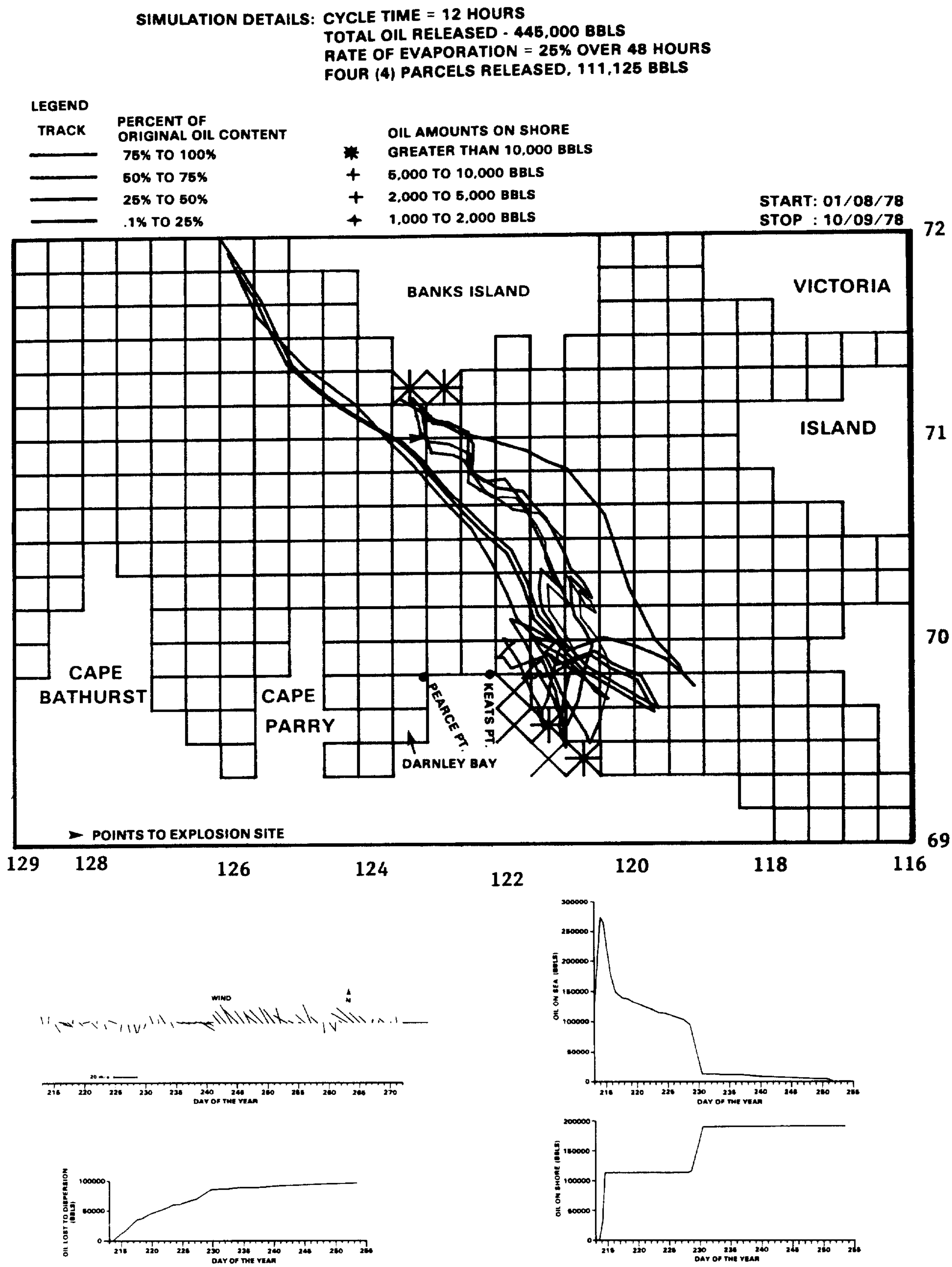


FIGURE 6.6-1 *Computer trajectories for oil spilled from an assumed tanker explosion in Amundsen Gulf on August 1, 1978. The graphs show the wind regime and the disposition of the oil vs time during the time interval encompassed by the trajectories, from August 1 to September 10.*

its light ends and 70,000 m^3 (445,000 bbls) of the remainder leak out over a period of two days. Eventually the tanker sinks and any oil remaining in the cargo tanks is released and gradually rises up through the water column.

If the accident occurs in the open water season the oil spreads over the water surface and undergoes the various weathering processes described in Chapter 3.

The computer trajectory for this spill is shown in Figure 6.6-1, along with estimates of the amount of oil expected to remain on the sea, the amount reaching shore, and the amount lost to dispersion as a function of time. As illustrated in the trajectory analysis, roughly one half of the oil lost is projected to reach the mainland shores east of Darnley Bay within twenty-four hours.

If the incident occurs in ice conditions the oil rises and collects under the ice. If the ice is stationary, as is probably the case, and there is a current, the contaminated area becomes roughly elliptical in shape and covers an area of 3.3 km^2 for first year ice and 0.3 km^2 for multi-year ice. For higher currents, the contaminated area becomes larger. This oil rises to the surface in spring, weathers and eventually is released into the water.

6.6.2 COUNTERMEASURES STRATEGIES

A large percentage of the oil from this spill is projected to reach the shore. The strategy for dealing with the oil is largely one of shoreline protection, cleanup and restoration. A large-scale equipment depot would be set up at Pearce Point (east of Darnley Bay), with equipment flown in from the Tuktoyaktuk base. A second base could be set up at Tysoe Point if required. The equipment to be used and measures to be employed would be determined with the assistance of a shoreline cleanup manual.

The impacted mainland shoreline is generally composed of low-lying sand and pebble barrier beaches and lagoons. As the seaward access to the shoreline is good, barges with the necessary cleanup and disposal equipment on board could be used, supported by smaller craft to deploy booms and skimmers. Booms could be placed to protect some of the areas, particularly Pearce Point Harbour, Keats Point and the Roscoe River outflow. *In situ* burning methods would be attempted in nearshore areas, provided that there was no risk of starting a tundra fire. The cleanup would be a labour intensive manual operation. Collected oil and oiled debris would be disposed of by incineration.

The shoreline area impacted on Banks Island consists of both rocky beaches backed by high cliffs and low sand beaches backed by lagoons. It would be possible to manually and mechanically clean the sand beaches but access to and cleaning of the rocky areas would be very difficult if not impossible, therefore, they would be left to cleanse naturally.

In winter following the accident, ignition of the oil would be attempted. Oil trapped under marine ice would be tracked with ARGOS buoys (See Chapter 5) and burned *in situ* the following spring. In spite of the loss of light ends in the initial fire, ignition of the oil would still be possible and most could be burned.

6.7 SCENARIO #6: TANKER GROUNDING IN NORTHERN PRINCE OF WALES STRAIT

6.7.1 ACCIDENT DESCRIPTION

In this scenario, a tanker grounding is assumed to occur during August in the northern end of Prince of Wales Strait (Figure 6.7-1). The grounding results in an oil spill where the volumes, flowrates and circumstances are similar to those described previously for Scenario #4. Seventy five percent of the oil in two wing tanks, or 43,000 m^2 (270,000 bbls) of crude oil is discharged in about four hours. After being refloated the tanker heads south toward Amundsen Gulf rather than continuing through southwestern Viscount Melville Sound where multi-year ice floes could be encountered.

The computer trajectory for the open water spill is shown in Figure 6.7-1 and includes estimates of the amount of oil expected to be on the sea, the amount predicted to reach the shore and the amount lost to dispersion as a function of time. Virtually all the oil is projected to come ashore in the first two days.

6.7.2 COUNTERMEASURES STRATEGY

The first response to a grounding is to transfer oil from the affected tanks to other tanks and ballast space on the vessel. The spill countermeasures strategy involves removing concentrated pockets of oil in small coves and bays. A large staging depot would be established at Johnson Point on Banks Island, and all available containment barriers, skimmers and portable burners flown there. This equipment could be deployed in the areas where it would be of most use.

The delta areas near Peel Point on Victoria Island

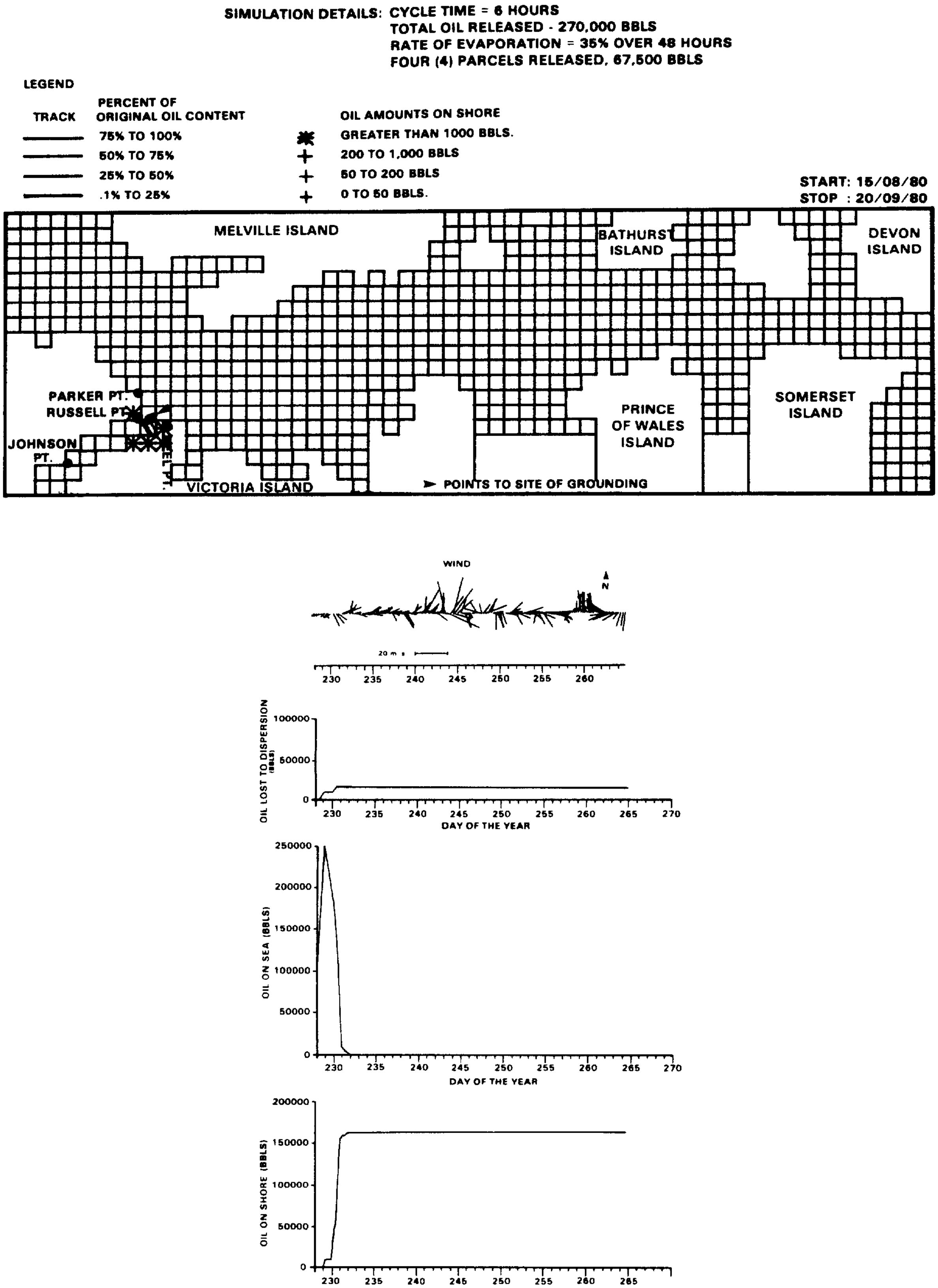


FIGURE 6.7-1 *Computer trajectories for oil spilled from an assumed tanker grounding at the north end of Prince of Wales Strait. The graphs show that very little of the oil is dispersed; almost all of it ends up on the shores. The trajectories cover the time interval August 15 to September 20; open water is assumed.*

and Parker and Passage Points on Banks Island could be protected by booming, to prevent recontamination by refloated oil. Much of the shore and nearshore areas are ice infested thus the coastline would be protected and oil could not become stranded. Should oil wash ashore or over the barrier beaches into lagoons manual cleaning could be carried out.

In situ combustion could be used to remove oil concentrated against nearshore ice. Precautions would be taken to ensure that tundra was not set on fire.

To summarize, manual, mechanical and *in situ* combustion methods could be used to remove oil during the summer months. It may be necessary to return to the site in subsequent years to continue the cleanup.

The development of a shoreline protection and cleanup manual and possibly the stockpiling of equipment on the tanker would assist in providing a better, more efficient response. These are the topics of future research programs described in Volume 7 of the EIS.

6.8 SCENARIO #7: TANKER COLLISION IN VISCOUNT MELVILLE SOUND

6.8.1 ACCIDENT DESCRIPTION

This scenario describes a tanker collision occurring during August in Viscount Mellville Sound that results in a spill. The volumes, flowrates and circumstances are similar to those described previously for Scenario #4. Seventy five percent of the oil in two wing tanks, or 43,000 m^3 (270,000 bbls) of crude oil is discharged in approximately four hours. After the accident the tanker heads away from the spill site to avoid the danger of fire but may remain in the vicinity in order to assist with countermeasures activities.

The computer trajectory for the open water spill is shown in Figure 6.8-1 which also presents an estimate of the amount of oil on the sea, the amount of oil projected to reach the shore, and the amount of oil lost to dispersion as a function of time.

In the location of the hypothetical collision, there is seldom open water, and if there is, its duration is usually less than 40 days. Open water generally exists in the short summer along the northern portion of Viscount Melville Sound (see Section 1.1 in Volume 3B), consequently the open water computer trajectory depicted in Figure 6.8-1 is generally unrealistic in that the movement of the oil slick would be impeded by sea ice in various concentrations.

6.8.2 COUNTERMEASURES STRATEGY

The first countermeasure is to control the source of the oil, by pumping any oil remaining in the affected tanks to other tanks. Concurrently, tracker buoys and airborne monitoring would be carried out to track the major slicks.

There are two spill responses that could be used to clean up an oil spill in Viscount Melville Sound during the open water season. These are aerially-applied chemical dispersants and the deployment of nearshore booms and skimmers. Collected oil would be disposed of using shore-based portable incinerators, burners and if necessary by burial.

Information on the expected trajectory of the oil would be used to determine appropriate areas for deploying equipment and personnel. For example, in this scenario it is predicted that Bathurst Island would be impacted 18 days following the collision (Figure 6.8-1). Both mechanical equipment as well as dispersants could be transported to Rae Point and Resolute and readied for use.

Due to the length of time oil would remain on the water, its spread during that interval, and the location of the spill, it is unlikely that offshore *in situ* combustion techniques would be successful unless ice concentrations were high enough to inhibit the rapid spreading of the oil so that it remained thick enough to burn.

The shorelines that are predicted to be oiled (Bathurst and Lowther islands) are generally low-lying sand, pebble and cobble beaches. The shore area is ice covered for all but a few weeks in summer and even then ice can be present in the nearshore zone. Both Allison Inlet and Dyke Ackland Bay on Bathurst Island could be protected by 3,000 m of boom to prevent oil from moving inland. As the other areas impacted are not generally exposed to high waves and there is no tundra near, the shoreline oil could be burned *in situ* against the shore and the nearshore ice. Any oil stranded on sensitive beaches could be manually cleaned up. The recovered oil could be disposed of in air portable incinerators and kilns.

In summary, although a response to this spill can be made using existing equipment, the effectiveness of the response could be increased with equipment and/or dispersants stockpiled on the tanker. This will be a subject of future studies and is briefly addressed in Volume 7.

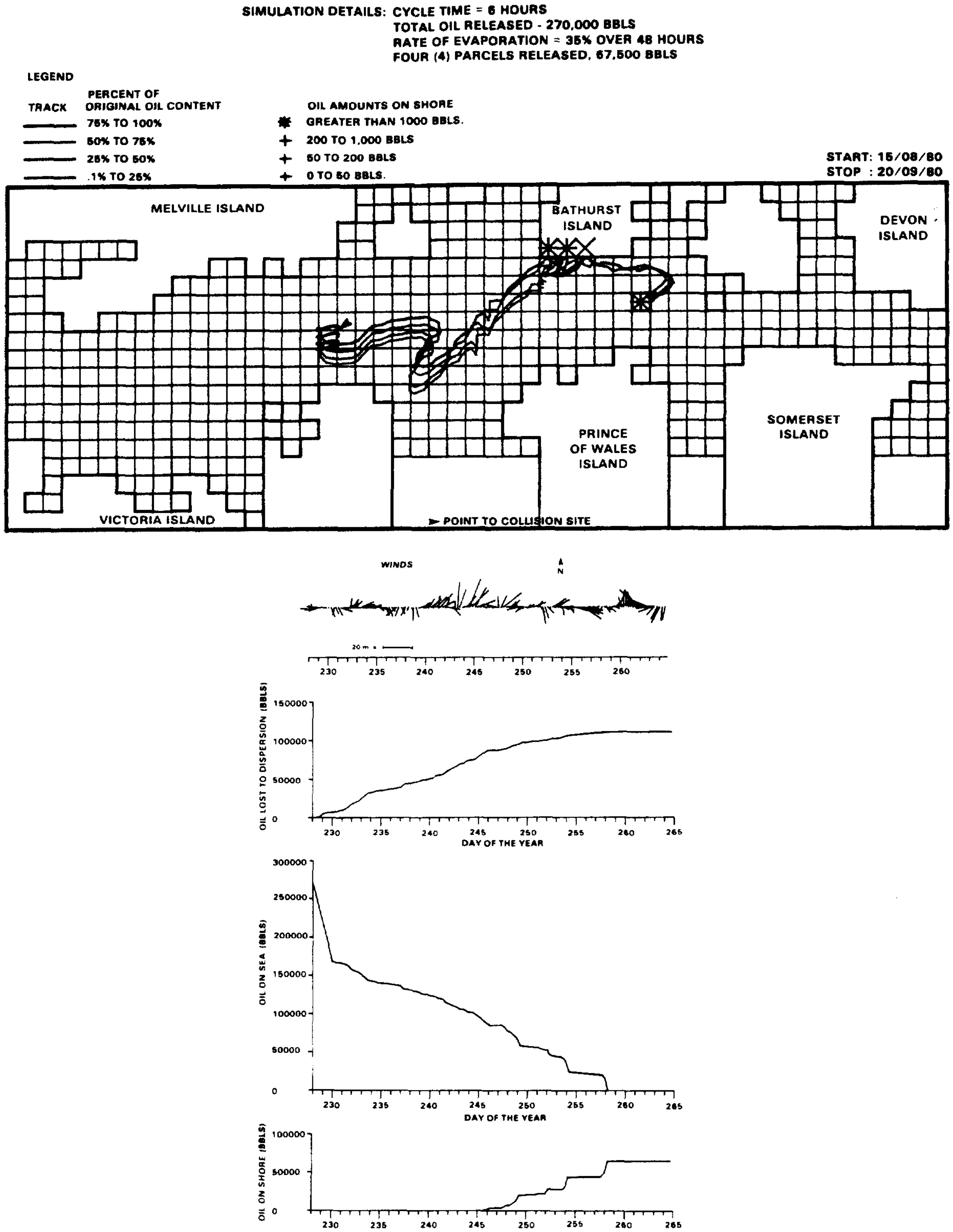


FIGURE 6.8-1 *Computer trajectories for oil spilled from an assumed tanker collision in Viscount Melville Sound on August 15, 1980. The graphs show the wind regime at the time and the disposition of the oil during the time interval encompassed by the trajectories, from August 15 to September 20. Open water is assumed, athough this represents a less likely situation, which tends to promote spreading of the oil.*

During the winter months, the primary response would be *in situ* burning of the oil. The tanker would have been breaking landfast ice before the collision and the spilled oil would likely be discharged both on top and under the ice and in the ship's track filled with broken ice. Much of the oil could be burned *in situ* once the tanker had left the collision site. The remaining oil under the ice could be more easily incinerated in the following spring and early summer before breakup when most of it would rise to the surface. Tracker buoys would be deployed to ensure identification of this ice.

6.9 SCENARIO #8: TANKER COLLISION IN LANCASTER SOUND OFF BRODEUR PENINSULA

6.9.1 ACCIDENT DESCRIPTION

In this scenario it is assumed that a tanker in Lancaster Sound is involved in a collision of such tremendous force as to tear a hole through both hulls on one side. This results in the discharge of 75% of the oil in two wing tanks or 43,000 m^3 (270,000 bbls) of crude oil in approximately four hours.

6.9.2 OIL SPILL TRAJECTORIES

The following scenario, which will be described in considerable detail because of the great interest in the Lancaster Sound region, is assumed to occur during August or September. Two possible trajectories, based on different environmental conditions, are presented in Figure 6.9-1 and 6.9-2. These trajectories also include estimates of the amount of oil expected to remain at sea, the amount projected to reach the shore, and the amount lost to dispersion as a function of time. The physical data used for the computer trajectory analyses were collected between August and September, 1978 and are presented in Marko *et al.*, 1981.

The fate of oil released from a subsea blowout in Lancaster Sound has been previously described by Milne and Smiley (1978). Since the present scenario is assumed to occur at the same time of year (August-September), much of the information provided by these authors may be used to supplement slick trajectory analyses presented by Marko and Foster (1981). In Marko and Foster's analysis, the major factors governing the movement of the oil slick were assumed to be winds and surface currents.

The trajectory analysis completed for this event indicates that a relatively high proportion of the released oil (46%) may strand in shoreline areas during the 22 day period following the accident (Figure 6.9-3). However, due to the low oil retention potential of many of the shorelines within Lancaster Sound (Owens, 1977), together with the relatively high wave energy in the region, it is assumed that much of the oil stranded on shorelines re-enters the marine environment within several hours or days after initial contact.

Heavy seas and a strong northwesterly wind prevailing at the time of the accident are expected to accelerate the initial spreading of oil released from the tanker. The oil leakage from damaged compartments continues for 48 hours, and at the end of this period, a slick 35 km long and 4 km wide extends away from the ship in a generally southeast direction. During this first 48 hours, the concentrations of dissolved hydrocarbons under the slick may be relatively high, ranging from 10 to 15 ppm (based on assumptions in Milne and Smiley, 1978 and ESL, 1982a). These concentrations would be expected to decrease rapidly as the more volatile components of the remaining surface oil evaporate and oil present in the water column is diluted due to horizontal and vertical mixing processes. After 48 hours, mean dissolved oil concentrations beneath the expanding slick are assumed to be less than 0.1 ppm.

During the first 2 days after this event, evaporation from the slick results in the loss of 84,800 barrels of oil or 31.4% of the original amount released (Marko and Foster, 1981). Loss of these more volatile fractions increases the density and viscosity of the oil so that by the morning of the third day, the specific gravity of the remaining oil is approaching that of seawater. At this time, the leading edge of the slick is approaching Cape Charles Yorke (Figure 6.9-3), and most of the oil is in the form of long windrows containing slightly emulsified and relatively viscous oil.

By 18:00 hr on the third day, approximately 40,000 barrels of oil (18.2%) strand along a 47 km section of coastline from Cape Joy to a point 30 km east of Cape Charles Yorke. Waves are assumed to cast this oil along the high water mark of the pebble-cobble beaches, where it is subsequently stranded during the receding tide. The degree of contamination varies from 6 barrels/km at Cape Joy, to 2,000 barrels/km along the west facing coast of Baffin Island just south of Cape Charles Yorke.

During the evening of Day 3, the wind speed decreases and its direction changes slightly (Marko and Foster, 1981). The relative calm prevailing over the next 2 days causes much of the emulsified oil in the upper portions of the water column to resurface

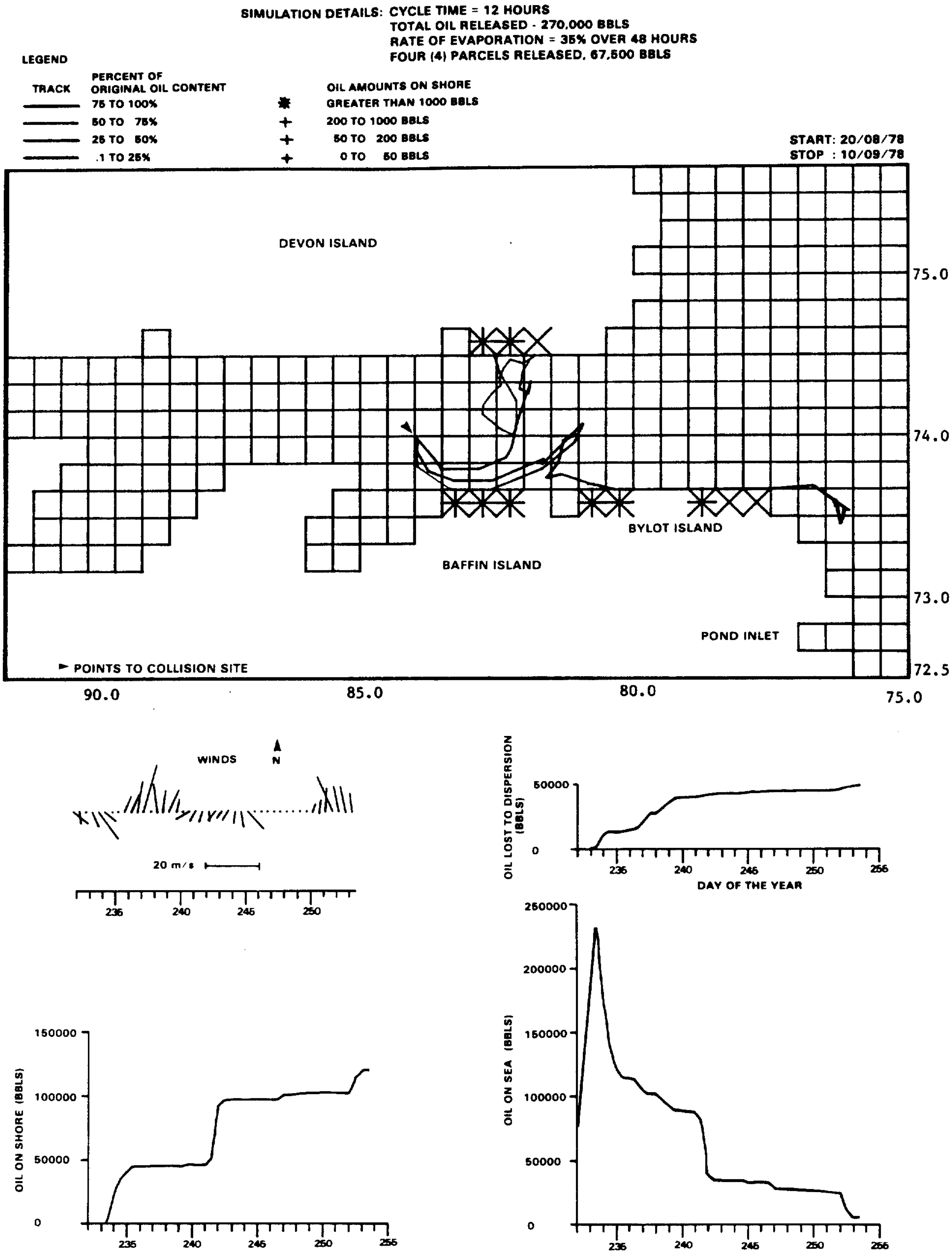


FIGURE 6.9-1 *Computer trajectories for oil spilled from a hypothetical tanker collision in Lancaster Sound on August 20, 1978. The trajectories show that oil strikes both the north and south shores. The graphs show the wind regime and the disposition of the oil during the time interval encompassed by the trajectories, from August 20 to September 9.*

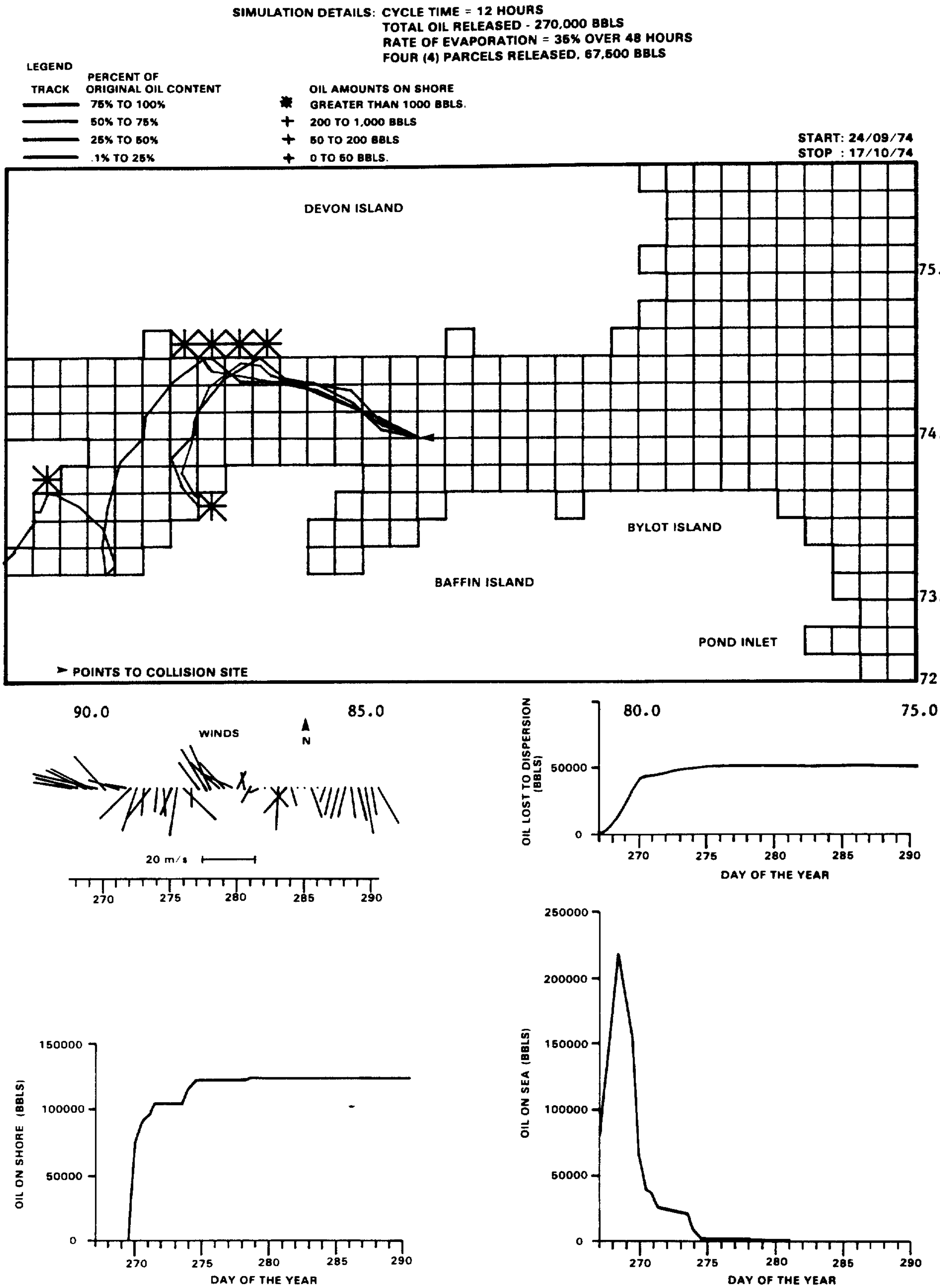


FIGURE 6.9-2 *Computer trajectories for oil spilled from a hypothetical tanker collision in Lancaster Sound. The collision location is identical to that shown in Figure 6.9-1, however, the computer trajectories use winds from September 24 to October 17 in 1978 and the collision is assumed to have occurred September 24.*

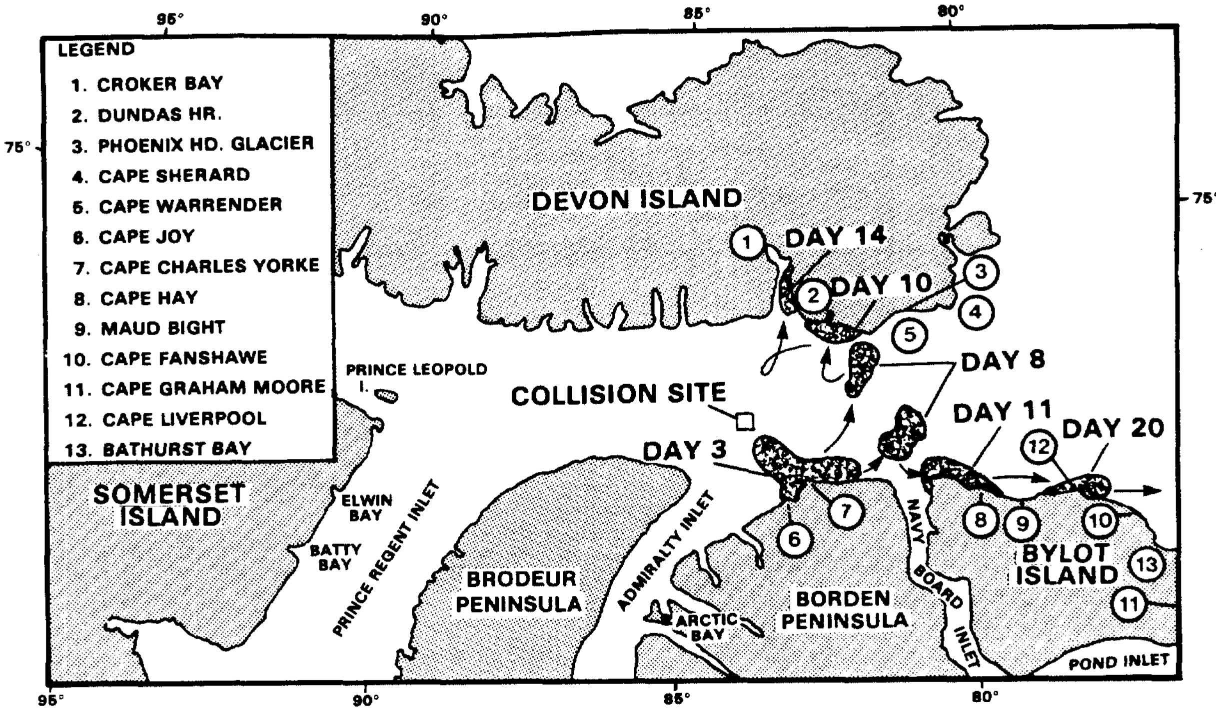


FIGURE 6.9-3 *Distribution of surface oil released after a hypothetical tanker collision in Lancaster Sound assumed to occur on August 20 (see Figure 6.9-1 for trajectories).*

as the oil mass moves slowly east and northeast away from the coast. The area of the slick increases to over 400 km² by the end of Day 5, when south-southwest winds begin to increase in intensity. At this point in the scenario, half of the oil begins to move north towards the southeastern shores of Devon Island, while the remainder is carried farther east towards the coast of Bylot Island. These two oil masses remain away from coastal environments of Lancaster Sound for the next 5 days.

On Day 10, oil moving north reaches the coast of Devon Island near Cape Warrender, and is then gradually transported west along the coast by prevailing currents and winds. At this point in the scenario, the oil is assumed to be in the form of a water-in-oil emulsion (mousse) due to the high mixing energy which prevails between Day 5 and Day 10. This oil comes ashore at low tide and is gradually stranded on the sloping beaches in this region.

During the next 2 days, a total of about 21,300 barrels of oil (8%) are deposited along the coast from Cape Warrender to the western shores of Dundas Harbour. The degree of contamination over the 400 km of affected shoreline is estimated to vary from 20 to 600 barrels of oil/km. Approximately 5 km east of the abandoned settlement of Dundas Harbour, a small tongue of the Cunningham Glacier reaches the shoreline of Devon Island and extends into Lancaster Sound. Relatively strong wave action during the morning of Day 11 strands emulsified oil across the edge of this glacier, and some mousse is assumed to work its way into crevices, to be leached out as the edge of the glacier breaks away.

Several days of weak variable north winds cause much of the surface oil in this northern portion of the slick to move offshore of Devon Island. Wave energy during this period is relatively low and only a small fraction (less than 10%) of the oil present on the surface is dispersed in the upper layers of the water column. Most of the oil remaining at this time is either near or on the surface in the form of small pancakes 10 to 20 cm in diameter. Although the weathered oil is still relatively liquid, only slowly forming sheens are visible around the edges of the floating oil masses.

Two weeks after the hypothetical tanker collision, this part of the slick is transported west and north (Figure 6.9-3), penetrates into Croker Bay, and contaminates its eastern shore. Low marshy areas near the mouth of Croker Bay are covered by mousse arriving at high tide under the influence of strong westerly winds and high waves. Some of this oil is stranded in backshore wetlands where it is assumed to persist throughout the winter. The base of an extended region of steep talus slope further inland within Croker Bay is also contaminated with oil. This relatively low energy shoreline is assumed to retain much of the stranded mousse in crevices and depressions over the subsequent winter. During late season freeze-thaw cycles, much of the oil in this part of Croker Bay is covered over by fresh rock debris falling from the cliff face at the top of the slope. In total, about 8,450 barrels of oil (3%) are stranded along 20 km of the shoreline in Croker Bay over a 3 day period, after which virtually no floating oil remains in this area.

On Day 11, the southern portions of the slick sweep across the entrance of Navy Board Inlet and reach the northwest coast of Bylot Island just south of Wollaston Island. Partly sunken and emulsified oil is transported eastward along 55 km of coastline by surface currents and northerly winds, and reaches as far as the western end of Maud Bight. However, in the small bay 1 km west of the Cape Hay murre colony, a peculiarity in the offshore currents results in a clockwise back eddy within the bay (L. Patterson, pers. comm.). Several thousand barrels of floating mousse are assumed to be trapped within this relatively protected bay for several weeks. In total, approximately 31,000 barrels of oil (11%) are stranded along 55 km of the northwest coast of Bylot Island during the period from Day 11 to Day 15 (Marko and Foster, 1981).

Westerly winds beginning on Day 14 transport the remaining surface oil across Maud Bight, and on Day 20, much of this oil is stranded near the lowland coast of Cape Liverpool on northeast Bylot Island (Figure 6.9-3). By this time, the remaining oil is in the form of a viscous mousse which tends to resist further weathering. About 15,200 barrels of oil (5%) are deposited along the 40 km of generallying low-lying shoreline from east of Maud Bight to Cape Fanshawe on the northeast coast of Bylot Island. High waves originating from late summer storms over Baffin Bay are assumed to result in the deposition of much of this emulsified oil in the upper intertidal zone and backshore environments.

After Day 20, strong southerly winds cause the remaining 7,000 barrels of surface oil to drift westward into the open waters of Baffin Bay where it eventually sinks. As indicated earlier, much of the oil stranded on shorelines during this 22 day scenario is also assumed to re-enter the marine environment of Lancaster Sound. In low energy coastal regions such as the upper reaches of Dundas Harbour and Croker Bay, tidal action produces surface sheens for several days after the oil initially comes ashore. In higher energy environments such as Cape Hay and Cape Warrender, oil stranded on rocks and ledges is assumed to rapidly re-enter the marine environment as both surface slicks and dispersed particulate oil. Most of the oil which does not re-enter Lancaster Sound is in the form of a viscous mousse stranded in the upper intertidal zone and in some lowlying backshore environments. As temperatures decrease, this oil eventually freezes and remains in the region throughout the winter.

6.9.3 BIOLOGICAL IMPACTS

Lancaster Sound was selected as the site for a hypothetical major oil spill because of the considerable significance of this area in terms of its biological productivity. The dates and location of this scenario were selected on the basis of the best available physical data (Marko *et al.*, 1981). Therefore, it must be pointed out that should the event have occurred at other times of the year or in other locations, the projected impacts would naturally differ, being generally higher earlier on in the spring, and lower during winter.

The possible biological effects of this hypothetical tanker accident are described in considerable detail in LGL (1982). The following is a summary of the scenario, with primary emphasis being placed on the higher profile marine mammals and birds. Impacts on the benthic and intertidal community are also discussed as major impacts are projected to occur to these biota. For further details, the reader is encouraged to consult LGL (1982).

In this scenario 270,000 bbls of oil are spilled offshore in eastern Lancaster Sound in late August. Over the following three weeks the slick affects an offshore area of about 6,000 km^2, and eventually oil contaminates about 200 km of shoreline and 220 km^2 of nearshore seabed. Table 6.9-1 summarizes the projected effects on the fauna of Lancaster Sound.

Although it is not possible to predict what proportion of the fauna of nearshore and littoral areas will be affected by this hypothetical event, the proportion could be high. Recovery would probably be slow and the overall impact on these organisms could be MAJOR. However, walruses and bearded seals, the only mammals dependent on littoral and benthic organisms in Lancaster Sound, are not abundant there. Oldsquaws, king and common eiders also eat littoral and benthic organisms, but do not feed in the areas affected in fall and do not always use the areas affected in very large numbers in spring. Thus, impacts of the loss of littoral or benthic fauna on higher trophic levels is expected to be MINOR.

With the exception of the possibility of fouling the fur of polar bears, impacts on marine mammals are predicted to be NEGLIGIBLE or MINOR. Impacts are considered MODERATE for polar bears because of both the probability that they could die if badly oiled, and the fact that polar bears are a hunted species highly valued by the local Inuit. However, it is

TABLE 6.9-1

THE NATURE AND DEGREE OF POTENTIAL IMPACTS OF OIL RELEASED AFTER A HYPOTHETICAL TANKER COLLISION AT 74°N 84°W IN LANCASTER SOUND ON AUGUST 20, 1978

Resource	Nature of Potential Impact[1]	Anticipated Degree of Regional Impact[2]
BIRDS		
Red-throated loon	C, M, S[1]	Moderate
Northern fulmar	C, M, S	Moderate to Major[3]
Geese	C, M, S	Negligible
Oldsquaw	C, M, S, F	Minor
Eiders	C, M, S, F	Minor to Moderate[3]
Shorebirds	C, M, S, F, H	Negligible to Minor[3]
Glaucous gull	C, M, S	Minor to Moderate[3]
Ivory gull	C, M, S	Negligible to Minor[3]
Black-legged kittiwake	C, M, S, F	Major
Other gulls and Arctic tern	C, M, S	Negligible
Thick-billed murre	C, M, S	Major
Dovekie	C, M, S	Negligible
Black guillemot	C, M, S	Minor to Moderate[3]
MAMMALS		
White whale	F, S	Negligible to Minor[3]
Narwhal	S	Negligible
Bowhead	S, C	Negligible
Walrus	F, C, S	Minor
Harp Seal	C, S	Negligible to Minor[3]
Ringed seal	C, S	Negligible to Minor[3]
Bearded seal	F, C, S	Minor
Polar bear	C, M, S	Minor to Moderate[3]
FISH		
Arctic cod	S, C, M	Negligible to Moderate[3]
Other fish	S, C, M	Negligible to minor[3]
LOWER TROPHIC LEVELS		
Benthos and intertidal	H, C, S, M	Major
Phytoplankton	S, M	Negligible
Zooplankton	S, M	Negligible
Ichthyoplankton	S, M	Minor

[1]Nature of potential impacts
- H = habitat loss
- C = contamination (fouling)
- S = sublethal effects
- M = mortality
- F = reduced food availability

[2]See Section 6.1.2 for impact definitions

[3]Level of impact depends on number of individuals affected. See text.

Source: LGL, 1982

likely that these impacts could be mitigated by chasing bears away from oiled areas.

Birds are the group that will be most affected by oil. MAJOR impacts could be expected on thick-billed murres and black-legged kittiwakes and could occur to northern fulmars. The primary reason for the projected major impacts on murres and kittiwakes is that the oil slick is expected to cover a large area adjacent to Cape Hay where about 140,000 pairs of murres and 20,000 pairs of kittiwakes nest. Only if a large proportion of the slick was prevented from arriving at Cape Hay could impacts on these species be significantly reduced. The countermeasure most likely to be effective is the use of chemical dispersants. Dispersants applied in large amounts near the source of the spill could reduce the amount of oil on the surface of the water. This would reduce the size of the slick and the amount of oil that would reach the Cape Hay seabird colony, which in turn would reduce the impact on thick-billed murres and black-legged kittiwakes near the colony. It could also reduce the effects on other bird species. Effect of the dispersant itself, if applied at the site of the spill, would be minor. Birds would not be concentrated in offshore areas and dilution of the dispersant would be rapid.

6.9.3.1 Possible Impacts on Marine Mammals

(a) White Whale

Several thousand white whales pass through Lancaster Sound in June and July en route to central Arctic summering areas (Volume 3B). These animals begin their return migration in mid September. The main movement usually occurs after September 10 and most animals follow the coast of Devon Island.

Oil that moved toward Devon Island is projected to almost entirely strand on the shore by September 3. Thus, few or no white whales would be expected to contact the oil slick and the greatest potential for impacts comes from possible effects on food organisms. Croker Bay is believed to be an important feeding area during fall migration (Koski and Davis, 1979) and the oil is projected to impinge on large numbers of potential food organisms in this bay. Although no precise estimate of the proportion of the food supply affected can be made, it is possible that Croker Bay could not be used by the usual numbers of migrating white whales in the year of the oil spill. However, subsequent years would not likely be affected. It is also possible that white whales would ingest oil. Effects of ingestion are unknown. However, seals are able to detoxify small amounts of oil (Geraci and Smith, 1976) and the same is probably true of white whales. Thus, the overall impact on white whales would probably be NEGLIGIBLE or MINOR. If the scenario had taken place in late September, during migration, Croker Bay would probably not have been used as a feeding area and migrating whales would have been subject to toxic effects of the oil. However, no mortality would be expected and impacts would still be MINOR.

(b) Narwhal

An estimated 20,000 narwhals entered Lancaster Sound in June and July 1976 (Volume 3B) and similar numbers may enter the sound each year. However, most spend the summer in adjacent fiords and inlets and return migration does not occur until late September. Thus, few narwhals would be directly affected by oil. Narwhal migration from Lancaster Sound is rapid and there are no known feeding concentrations in the area affected by the oil slick (Koski and Davis, 1979, 1980). Thus, impacts on narwhals from this particular scenario are expected to be NEGLIGIBLE. If the scenario had taken place during migration, narwhals would probably have still suffered only MINOR impacts from sublethal effects of the oil.

(c) Bowhead Whale

Like narwhals, bowheads occur primarily in bays adjacent to southern Lancaster Sound during the period when the oil slick is present (Volume 3B). However, there have been sightings of bowheads off northern Bylot Island in late August (Koski and Davis, 1980) and some individuals could contact the slick. The main impacts on such individuals would be sublethal in nature and there is a potential for a somewhat reduced feeding efficiency if the baleen plates became fouled. However, mortality is considered unlikely and the overall impact would be MINOR.

(d) Ringed Seal and Harp Seal

Fairly large numbers (several thousand) of both these species are likely to be in the area of oil contamination (Volume 3B). However, effects on both individuals and populations are difficult to predict. Seals that surface through the slick may experience eye irritation but the slick will not be continuous and affected animals may be able to move to clean waters. Neither harp nor ringed seals rely on their fur for insulation and, thus, surface oiling is unlikely to affect their ability to maintain body temperature (Oritsland, 1975; Kooyman *et al.*, 1977).

Seals may ingest oil on food organisms during the spill but large scale death of the food organisms of these two seal species is not likely. Ingestion of moderate amounts of oil over a short period by seals has also been shown to have no longlasting effects (Geraci and Smith, 1976; Englehardt *et al.*, 1977). Since ringed and harp seals are not very sensitive to short term exposure to oil, and the oil does not remain in one location for lengthy periods in this scenario, overall impacts are likely to be MINOR or NEGLIGIBLE.

(e) Bearded Seal and Walrus

Lancaster Sound is not a major concentration area for bearded seals or walruses and relatively small numbers of each species would be affected by oil from this scenario. Physical impacts would be similar to those described above for ringed and harp seals and would be NEGLIGIBLE. Of greater importance than direct effects are the effects of oil on the benthic organisms, which form the major portion of the diet of both walruses and bearded seals. As indicated in Section 6.9.3.3, a relatively large proportion of benthic organisms in parts of Lancaster Sound could be killed by the oil and recovery could be slow. A reduction in food availability could cause decreases in numbers of bearded seals and walruses using parts of eastern Lancaster Sound over several years. However, in terms of regional populations, this potential decrease would be a MINOR impact.

(f) Polar Bear

Polar bears in eastern Lancaster Sound are part of the same population that also ranges over the Barrow Strait-Prince Regent Inlet-Jones Sound area. About 1,000 bears were estimated to be in eastern Lancaster Sound in 1979 but some of these bears may move into Baffin Bay on floating ice or retreat to the west as the ice melts in Lancaster Sound. However, some bears, particularly females and subadults, retreat to land areas during summer and others, primarily adult males, may remain on pack ice in Lancaster Sound (Schweinsburg *et al.*, 1980).

The bays along the south coast and especially the southwest coast of Devon Island, as well as the northern Borden Peninsula and northern Bylot Island are known to be summer sanctuaries for polar bears. Bears from these areas may travel along the shore and may move out into Lancaster Sound on pan ice. Observations of polar bears reported by Johnson *et al.* (1976a) suggest that a minimum of 10 polar bears were in offshore areas affected by the oil slick from this scenario in late August 1976. Bears that actually became oiled to a significant degree could die (Englehardt, 1981).

It is not possible to estimate the actual number of bears that might be affected by this scenario. However, the impacts would be expected to be MINOR to MODERATE. This assessment is based on the potential for affecting a moderate number of bears, because the oil is present on summer sanctuary shorelines and the fact that the bears affected, particularly those on northern Baffin and Bylot islands, are probably part of the population hunted by Inuit from Arctic Bay and Pond Inlet. However, impacts could be mitigated readily by patrolling shorelines and chasing bears away from oiled areas. Alternatively, bears could be tranquilized and removed to unaffected areas.

6.9.3.2 Possible Impacts on Birds

The susceptibility of marine-associated birds to oil spills varies with the species and the circumstances surrounding the event, although it is generally agreed that even small amounts of oil can cause mortality due to the exceptional vulnerability of many bird species (Milne and Smiley, 1976). As indicated in previous scenarios, the degree of bird contamination and mortality as a result of past marine oil spills has been largely related to the number of birds contacting oil (a function of abundance and distribution of the birds), rather than the size of the spill and type of oil involved (Duval *et al.*, 1981). The biological effects of oil on marine birds have recently been discussed in detail by Duval *et al.* (1981), Brown (1981), and ESL (1982b), and were summarized in Chapter 4.

The bird species considered to be most susceptible to oiling are those that dive for food and spend much time resting on the water. In Lancaster Sound these are primarily thick-billed murres, black guillemots and dovekies. Species that feed on the wing, such as gulls and fulmars, are generally considered to be less susceptible to becoming oiled (Clark, 1973; Croxall, 1977). Nevertheless, the circumstances of this scenario are such that large numbers of the latter species could also be oiled.

The number of birds which could be affected by this oil spill, were it to occur, would naturally vary from year-to-year, between seasons and from one site to another. Most of the estimates for the number of birds which could be present in various areas are based on data from only one year. Numbers in other years could be higher or lower, although the available evidence suggests that the areas of highest density are constant from year-to-year (Johnston *et al.*, 1976b; McLaren and Renaud, 1979) and colony locations are certainly constant.

Estimates of numbers of birds in coastal areas (up to

TABLE 6.9-2

ESTIMATED NUMBERS OF SEABIRDS THAT COULD BE AFFECTED BY OIL FROM A HYPOTHETICAL SPILL AT 74°N, 84°W IN LANCASTER SOUND ON AUGUST 20, 1978

Species	Devon I.[1]	Coast Borden Pen.[1]	Bylot I.	Offshore[4]
Northern fulmar	15,000	300	(2600)[2]	38,700
Glaucous gull	750	100	(100)[2]	200
Black-legged kittiwake	300	4000	40,000+[3]	4500
Thick-billed murre	0	0	325,000[3]	4,800
Dovekie	0	0	(0)[2]	7,500
Black guillemot	20	20	(0)[2]	330

1 Estimated numbers within 1.4 km of the coast in 1976 at approximately the time of arrival of the slick. Based on Johnson et al. (1976b).
2 Minimum estimates since the portion of the coast adjacent to Cape Hay was not surveyed. Based on Johnson et al. (1976b) and McLaren and Renaud (1979).
3 Estimated numbers at the Cape Hay colony. Thick-billed murre estimate includes subadults (Gaston, 1980), kittiwake estimate does not (Nettleship, 1980)
4 Estimated peak numbers found in the offshore area affected by oil (approximately 6,000 km^2) between August 20 and September 13, 1976. Based on Johnson et al. (1976b).

1.4 km from the coast) presented below were calculated by methods given in McLaren and Renaud (1979) and based on densities of birds obtained from aerial surveys conducted by LGL Ltd. for Norlands Petroleums Ltd. in 1976 and Petro-Canada in 1978. For northern Bylot Island, where data from both 1976 and 1978 were available, the higher estimate was used.

The area beyond 1.4 km from the coast that is affected by the slick at some time in the scenario is about 6,000 km^2. Estimates of the numbers of birds that might be in this area were based on Johnson *et al.* (1976b) who estimated the number of each species in about 9,000 km^2 of offshore Lancaster Sound. The estimates presented in Table 6.9-2 are simply 67% of Johnson *et al.'s* maximum estimate for the period August 20 to September 13. Johnson *et al.'s* (1976b) surveys did not encompass the entire area affected by the slick in this scenario, but they did cover a large proportion of the area. It is not unreasonable to extrapolate their numbers to a relatively small portion of Lancaster Sound adjacent to their study area.

The numbers of birds estimated by these methods are minima, not only because they are based on aerial surveys, during which all birds present are not detected, but also because they are estimates of numbers of birds present at one moment in time. No estimates of turnover times, that is, numbers of birds arriving and leaving a particular area per unit time, are available. Turnover times could significantly influence the numbers of individuals affected. If the residence time of the slick was long in relation to turnover time, far more birds could be affected than if it was short. In the former case, numerous new birds would arrive in the area while the slick was present.

In the following assessments of possible effects of oil on key species, the effects on individuals are differentiated from those on populations. Individuals of some species may be susceptible to oiling because they are present at the time of the spill. However, unless a fairly large proportion of the regional population occurs in the area of the spill, that population is not considered to be vulnerable. For example, dovekies, because they frequently rest on the water and dive for food, are susceptible to oiling. However, only a small proportion of the nesting population is likely to be in Lancaster Sound at the time of this scenario, so the population is not considered to be vulnerable.

In the assessment of effects of the scenario, numbers of birds that could become oiled are emphasized over effects of ingestion or effects on reproductive systems, because there is insufficient information to assess the effects of physiological impacts on populations.

(a) Red-Throated Loon

The coast from Croker Bay to Dundas Harbour that is projected to be affected by oil is the only area in eastern Lancaster Sound where red-throated loons occur regularly. Loons in this area most likely nest in the adjacent lowlands and fly to the ocean to forage. In late August, red-throated loons will still be foraging for their chicks and most of the individuals that nest in the lowlands adjacent to Croker Bay and Dundas Harbour could be killed. The chicks of adults that were killed would also die. Impacts on the regional population of red-throated loons could be MODERATE since a substantial number of loons could be killed. Nevertheless, recruitment from other areas would probably serve to repopulate the Croker Bay-Dundas Harbour area within one generation.

(b) Northern Fulmar

Table 6.9-2 shows the estimated numbers of fulmars in areas affected by oil from this scenario. These figures are based primarily on aerial surveys conducted in 1976 (Johnson *et al.*, 1976b) and the offshore estimate is the maximum estimate, which occurred late in the period August 15 to September 13. Nevertheless, large numbers of fulmars (that is, 21,000 on August 17) occurred offshore throughout the period. Aerial surveys in 1978 covered mainly areas east of the slick track but showed that fulmar distribution was similar to that observed in 1976, although numbers offshore were somewhat lower in 1978 (McLaren and Renaud 1979).

Fulmars are cnsidered to be only moderately susceptible to oil fouling because of their habit of feeding on the wing. However, fulmars in the eastern Lancaster Sound area often sit on the water while resting, and occasionally while feeding. In western Lancaster Sound up to 72% of fulmars observed by Nettleship and Gaston (1978) during aerial surveys were sitting on the water (Table 6.9-3). Birds sitting on the water are much more susceptible to fouling than those feeding on the wing.

TABLE 6.9-3

PROPORTION OF SEABIRDS OBSERVED SITTING ON THE WATER DURING AERIAL SURVEYS IN WESTERN LANCASTER SOUND AND BARROW STRAIT DURING AUGUST AND EARLY SEPTEMBER.[1]

Species	Percent on water	
	Coastal surveys	Offshore surveys
Northern fulmar	46-72	20-70
Black-legged kittiwake	0-92	9-56
Thick-billed murre	16-100	18-100
Black guillemot	37-100	0-100

[1]Data from Nettleship and Gaston (1978).

One cannot estimate how many fulmars might actually land in the oil slick. However, using Nettleship and Gaston's observations of 72% sitting on the water and assuming that all of these become oiled, about 39,000 birds or 15% of the regional breeding population could be killed. However, the slick is not continuous and this is probably an unrealistic prediction. In addition, the breeding status of fulmars in the affected area is unknown. About 40% of the fulmars at Prince Leopold Island colony are non-breeding subadults (Nettleship and Gaston, 1978) and presumably the proportion of subadults at other colonies is similar. Impact on the regional population would be much greater if mainly breeding adults were affected, rather than if mainly non-breeding subadult birds were affected, since natural mortality rates are higher for subadult birds than for adults, and fulmars continue to breed for many years once they reach maturity.

Fulmar young do not fledge until mid September (Nettleship and Gaston, 1978). Thus, there is the potential for the growth rate of chicks to be slowed by ingestion of oil-contaminated food brought to the nest by adults (Butler and Lukasiewicz, 1979; Peakall *et al.*, 1980). Since the latest fledging chicks do not leave the cliffs until early October, when ice is forming on the marine channels, slower growth that resulted in still later fledging could well affect survival. In addition, any chicks whose parents had succumbed to oiling would die.

The overall impact on fulmars from this scenario cannot be predicted accurately because of unknowns associated with numbers of birds actually oiled, numbers that die as a result of oiling, and the breeding status of the potentially affected birds. However, impacts would likely be at least MODERATE and could be MAJOR. In the worst but unlikely case, 15% of the breeding population of Lancaster Sound fulmars could be killed. Because of the low intrinsic rate of increase in fulmars, this loss would be considered a MAJOR impact.

(c) Black-legged Kittiwake

Black-legged kittiwakes are the most abundant gull species in Lancaster Sound and they tend to be widely distributed, especially in coastal areas, in late summer. Table 6.9-2 suggests that over 50,000 kittiwakes could be in the area affected by oil.

The largest proportion of these are breeding birds from the Cape Hay colony. Fledging of young kittiwakes begins about August 25 and continues through September. Thus, large numbers of adults are likely to still be feeding young when the oil slick arrives off the Cape Hay colony about August 30.

Kittiwakes are less susceptible to fouling by oil than are murres because they often feed on the wing. However, Nettleship and Gaston (1978) reported a maximum of 56% of kittiwakes sitting on the water in offshore areas of western Lancaster Sound (Table 6.9-3), and large flocks often sit on the waters off southeast Devon Island. Thus, kittiwakes in offshore areas would be susceptible to oiling, although it is not possible to estimate how many might be affected.

Impacts on kittiwakes from this particular scenario are likely to be MAJOR, primarily because the oil comes to shore adjacent to the Cape Hay colony. Large numbers of kittiwakes forage in waters near the colony and rest on the water near the colony (L. Patterson, pers. comm.). The latter birds particularly, are very likely to become oiled and would likely die. Whether the oil will have significant effects on the food supply in the immediate area is not known but the foraging range of kittiwakes is probably sufficiently long that impacts on food supply would be minor.

Overall, the impact from this scenario on the kittiwake population in Parry Channel would probably be MAJOR. Many adults could be killed near the Cape Hay colony and several generations would be required to recover this loss.

(d) Thick-billed Murre

Murres from the colonies at both Prince Leopold Island (86,000 pairs plus about 27,500 non-breeding immatures) and near Cape Hay (140,000 pairs plus about 45,000 immatures; Gaston, 1980) could be affected by this scenario. Murre chicks leave the cliffs in late August while still flightless and swim to the east in the direction of wintering areas (Volume 3B). Adult/chick pairs believed to have been from Prince Leopold Island were observed north of the Borden Peninsula on September 13, 1978. Nesting was late in 1978 and, in a normal year, flightless murres could be expected in this area about three weeks earlier, that is, at a time when the oil slick from this scenario would be travelling north of the Borden Peninsula.

The slick from this scenario could conceivably affect nearly all the murres from the Cape Hay colony. Adult murres tend to remain close to their colonies in August, and relatively small numbers occur in offshore areas or coastal areas away from the colonies. The slick is projected to arrive off northwest Bylot Island on about August 30. In a normal nesting year this is about the middle of the fledging period (Tuck, 1961). At this time many adult/chick pairs are likely to remain on the sea near the colony, some adults will still be feeding young, and large numbers of adults and subadults are likely to be on the water in the vicinity of the colony (Tuck, 1961; Nettleship and Gaston, 1978). All of these birds could be contaminated by oil. Because portions of the slick remain on the water in the bay adjacent to the colony, there is an even greater potential for large numbers of murres to become oiled.

After murres leave the Cape Hay colony they undertake a swimming migration. The precise routes followed are not known but adult chick pairs have been seen north of Bylot Island during the period September 9 to 30 (McLaren and Renaud, 1979). These birds are presumably being carried by currents and most would probably stay ahead of the oil slick. Nevertheless, it is possible that some swimming murres that escaped contamination near the colony could be oiled as the slick moved eastward.

Impacts on thick-billed murres in this scenario could be MAJOR. There is the potential for mortality of over 50% of the regional (Parry Channel) population including large numbers of breeding adults. Murres have a very low intrinsic rate of increase (doubling of the population of the closely related common murre is estimated to required 50 years; Leslie, 1966) and murres are very susceptible to becoming oiled. The impact would likely be centred on the Cape Hay colony but could also involve an unknown number of murres from Prince Leopold Island.

The foregoing has highlighted those species of birds most likely to be significantly impacted by an oil spill in Lancaster Sound during August of any given year, were one to occur. Much of the predicted impact stems from the fact that the slick is projected, in this case, to cover a large area adjacent to the Cape Hay bird colony. To minimize impacts from this or some other oil spill in the region, the countermeasures to be employed would have to stress the use of those actions aimed at reducing the chances of oil approaching bird concentration areas. The use of "effective" oil dispersants would undoubtedly be high on the list.

6.9.3.3 Benthic and Intertidal Biota

An oil spill of the type described in this scenario could contaminate approximately 202 km of the 380 km of shoreline found in the eastern Lancaster Sound region (from Croker Bay to Cape Sherard in the north and Cape Joy to Cape Graham Moore in the south). Although oil concentrations under the slick would decrease rapidly in offshore waters, concentrations in nearshore waters could be high because of wave action and interactions with suspended sediments, especially in the presence of heavy seas (Cabioch *et al.*, 1978). These high concentrations in the nearshore zone would tend to counteract the assumed early loss of the toxic fractions. Therefore, all of the shallow water (less than 25 m) seabed and intertidal zone found on potentially contaminated shorelines has the potential for interacting with the oil. The 25 m contour is usually found approximately

0.9 to 1.5 km from the shore. The total area of the seabed that could be affected by the oil might be on the order of 220 km^2.

There could be mass mortality of amphipods along shorelines that are impinged upon by the slick. However, the high mobility of these animals would likely enable adults to recolonize affected areas rather quickly (Notini, 1980). These animals probably have a two year life cycle (Foy, 1978) and for this reason, population recovery may be on the order of one to two years.

Mortality of benthic animals in shallow water along shorelines impacted by the slick may be expected (Duval *et al.,* 1981). Effects on the benthos would depend on the amount of oil that reaches the sea bottom, which in turn is a function of shoreline morphology, sedimentation regime, current, tides and weather. It is not possible to determine the proportion of the stranded oil that could become incorporated into bottom sediments.

In this hypothetical scenario, most of the oil stranded on shorelines is released to the marine environment. If one tenth of this oil becomes incorporated into nearshore bottom sediments to a depth of 1 cm, resulting oil concentrations may be on the order of 960 ppm. Sediment hydrocarbon concentrations of this magnitude may not be unrealistic. After the AMOCO CADIZ spill Boucher (1980) found up to 300 ppm of aromatics and aliphatics alone at his offshore station in 19 m of water. Concentrations of this magnitude may be sufficient to cause mortaility of benthic animals (Roesijadi and Anderson, 1979; Augenfeld, 1980).

Full recovery of the affected areas may be rather slow since the productivity of many Arctic benthic animals is low (Curtis, 1977; Petersen, 1978) as are growth rates (Andrews, 1972). For specific highly impacted areas, full recovery may take more than 10 years. Because a relatively high proportion of the oil released by the hypothetical spill strands on shorelines, impact on intertidal amphipods may be MAJOR over a period of one to two years. Much of the stranded oil is hypothesized to re-enter the marine system. If heavy wave action on this exposed coastline causes one tenth of this stranded oil to become incorporated into bottom sediments, impact on the nearshore benthos may be MAJOR.

6.9.4 COUNTERMEASURES STRATEGIES

In the case of the hypothetical tanker accident in Lancaster Sound, the first countermeasures response is to control the source of oil by pumping the remaining oil out of the affected tankers.

The second countermeasures response is to disperse as much of the oil as possible in deep water, once government permission for the use of dispersants was obtained. Dispersal of the oil into deep water, using aerial spraying techniques would minimize expected biological impacts which are expected to be major on some seabird species, particularly murres from the Cape Hay colony.

A major equipment depot would likely be located at Pond Inlet. Countermeasure equipment in the form of containment barriers, skimmers, portable incinerators and igniters could then be sent to sensitive areas threatened by oil slicks. Aerial spraying of chemical dispersants would continue offshore.

This first trajectory predicts the oiling of some 400 km of shoreline with approximately 20,000 m^3 (125,000 bbls) of oil. The heaviest contamination threat is on the north coast of the Borden Peninsula on Baffin Island and the south coast of Devon Island.

The area threatened by oil on the Borden Peninsula is predominantly one of gravel beaches backed by low eroding cliffs. Only the area between Cape Joy and Cape Charles York contains a small lagoon system that could be protected by booming or diking. The rest of the area would be cleaned by wave action.

The north coast of Bylot Island is predominantly of hummocky rock foreland interspersed with low-lying deltas and barrier beach-lagoon systems. Booms could be placed to protect these lower areas since the oil is not predicted to arrive there for a week. The Cape Hay, Maud Bight-Cape Liverpool areas and Bathurst Bay could be sealed off. Manual cleanup could take place in these areas while the exposed rocky coast would be cleaned by wave action.

The oiled shores along the south coast of Devon Island are similar and the protection and cleanup could proceed in the same manner. Dundas Harbour could be used as a basecamp.

The second trajectory (Figure 6.9-2) predicts oiling of the south west coast of Devon Island, the Brodeur Peninsula and the west coast of Somerset Island.

This part of Devon Island has steep rocky beaches backed by high cliffs. Numerous inlets headed by deltas are found along this shore which extend many kilometres inland. Due to the inaccessability of the coasts of this area by fixed wing aircraft, any cleanup operations would be supported by boats and helicopters. The deltas could be protected by booming and cleaned by manual means. The majority of the exposed coast would be left to be cleaned by waves and tides. Thick pools of oil in the inlets could be removed by mechanical techniques and *in situ* combustion.

The affected northwest coast of the Brodeur Peninsula on Baffin Island is characterized by gravel beaches backed by high rock cliffs. These areas would be best left to be cleaned by waves and tides. Further south, several long inlets contain deltas (Jackson Inlet, Port Bowen, and Port Neill) which could be protected by booming. The east coast of Somerset Island expected to be oiled has gravel beaches and high rock cliffs. The delta areas of Elwin Bay and Batty Bay could be protected and cleaned. In any event, cleanup of oil onshore would be conducted in as thorough and complete a manner as possible.

Should such an accident occur in winter in Lancaster Sound, countermeasures similar to those described for Scenario #7 in winter could be applied - namely *in situ* burning of the oil. The difference would be that in Lancaster Sound the sea ice will not generally be landfast and will be drifting eastward toward Baffin Bay (see Section 1.1 in Volume 3B). No shoreline contamination is expected. The oil contained in and under the sea ice could be relocated in the spring by tracking buoys placed on ice floes, then it could be burned *in situ*.

6.10 SCENARIO #9: TANKER FIRE AND EXPLOSION IN BAFFIN BAY

6.10.1 ACCIDENT DESCRIPTION

This scenario describes a tanker fire and explosion that occurs in Baffin Bay during August or September. The details of the accident are similar to those described for Scenario #5. The tanker cargo tanks catch fire, and are holed. Thirty percent of the cargo is burned up; the rest loses some of its light ends, and 70,000 m^3 (445,000 bbls) of the remaining oil leaks out over a period of two days. Eventually the tanker sinks and any remaining oil is released and rises up through the water column to the surface.

The computer trajectories for this spill are shown in Figures 6.10-1, 6.10-2 and 6.10-3, and include estimates of the amounts of oil on the sea, the amount reaching shore, and the amount lost to dispersion, as a function of time. Three trajectories are included to demonstrate the variability in oil slick movement due to different environmental conditions. In the first trajectory (Figure 6.10-1) all the oil remains at sea during the 20 day computer run. In the second and third trajectories, some oil moves west to reach the shores of Devon Island and/or Ellesmere Island.

For this scenario no biological assessment was undertaken at this time. However, many of the environmental implications of a major spill in the Baffin Bay region would be similar to those described previously in Scenario #8 describing a hypothetical tanker accident in Lancaster Sound. For other projections of the kinds of impacts that could be expected for an oil spill in Baffin Bay, the reader is referred to Petro-Canada (1979), which presents an initial environmental evaluation for proposed drilling in offshore Baffin Bay.

6.10.2 COUNTERMEASURES STRATEGY

Since much of the oil is projected to hit coastal shorelines in two of the three trajectories, the primary response effort would be focussed on a shoreline protection, cleanup and restoration operation. A staging area would be set up at the closest settlement with a runway; in this case Grise Fiord. During the period prior to the oil coming ashore, containment, removal and disposal units would be readied.

The areas predicted to be oiled on Devon Island are characterized by raised gravel beaches backed by rock cliffs or low-lying land. Due to the exposed nature of these beaches they would be cleaned naturally by wave action. In some areas, such as Bethune Inlet, Dundas Harbour and backshore lagoons, efforts could be made to protect them by booming or by the construction of temporary dikes and berms.

At present too little is known of the eastern coastline of Ellesmere Island to determine appropriate protection, cleanup and restoration activities. The lack of knowledge of the applicability of countermeasures for these coastal areas has been identified as an area for further study in Volume 7. The end result of this future work will be a shoreline protection cleanup and restoration manual for the entire tanker route.

In ice, the viscous oil could be burned *in situ*. tracking buoys could be placed in the affected area to monitor the movement of the oiled ice. *In situ* burning could take place in spring if necessary.

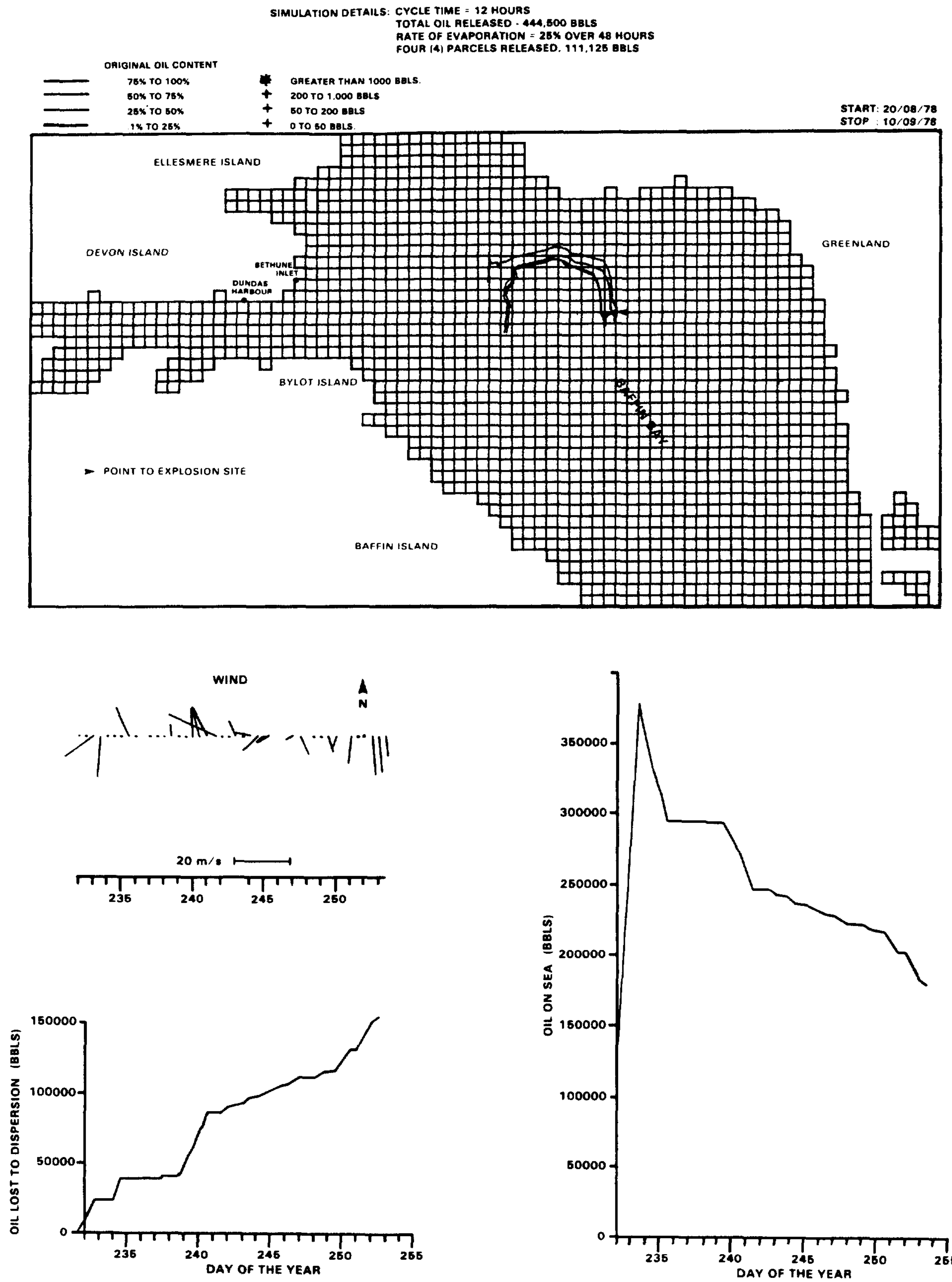


FIGURE 6.10-1 *Computer trajectories for oil spilled from a hypothetical tanker explosion in Baffin Bay assumed to have occurred on August 20, 1978. The wind regime, and graphs showing the disposition of the oil, cover the time interval August 20 to September 10 during which no oil impinges on shores.*

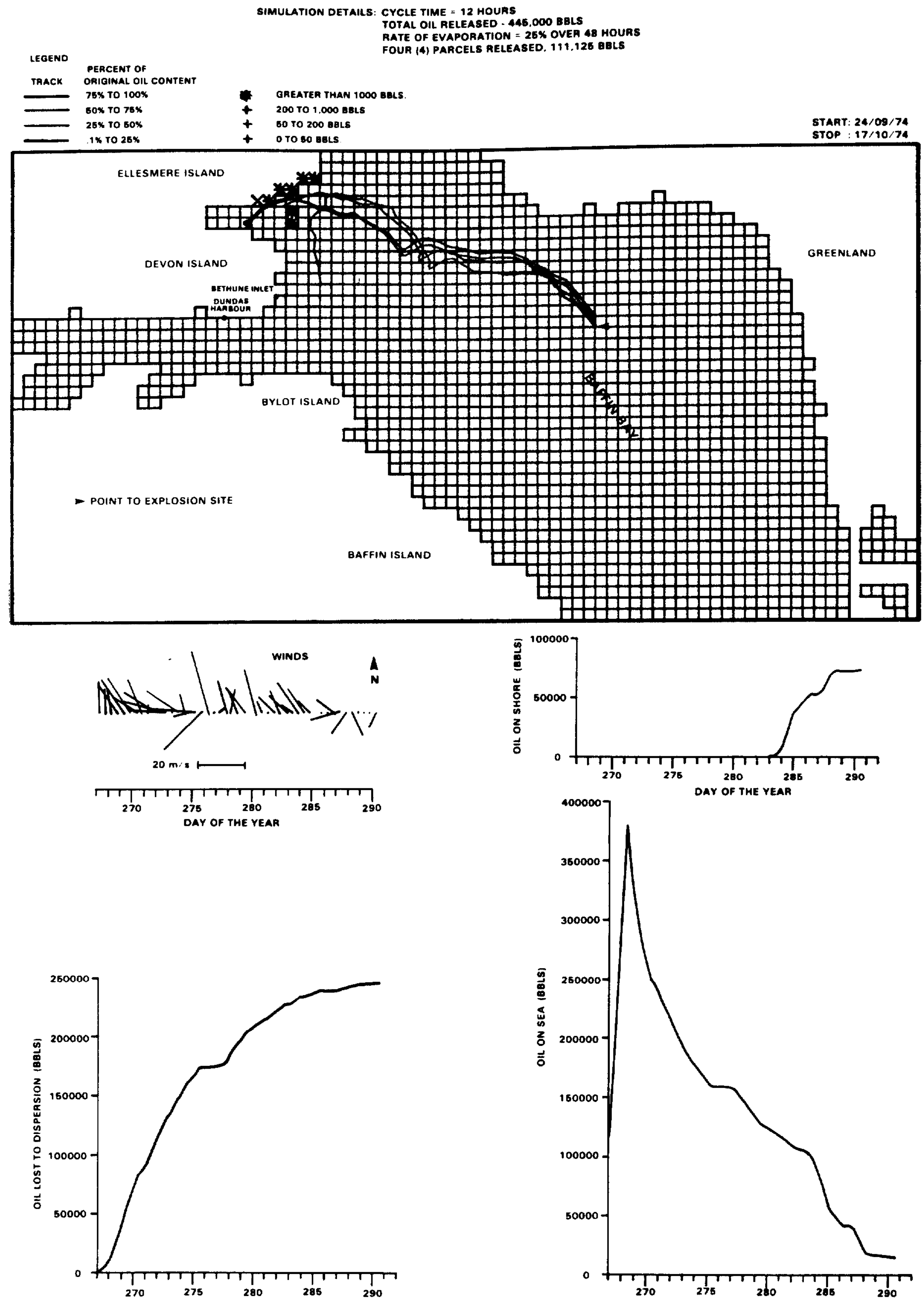


FIGURE 6.10-2 *Computer trajectories for oil spilled from a hypothetical tanker explosion in Baffin Bay assumed to have occurred on September 24, 1974 (same location as in Figure 6.10-1). The graphs show the wind regime and the disposition of the oil over the time interval September 24 to October 17, during which a substantial quantity of oil is projected to reach the shore.*

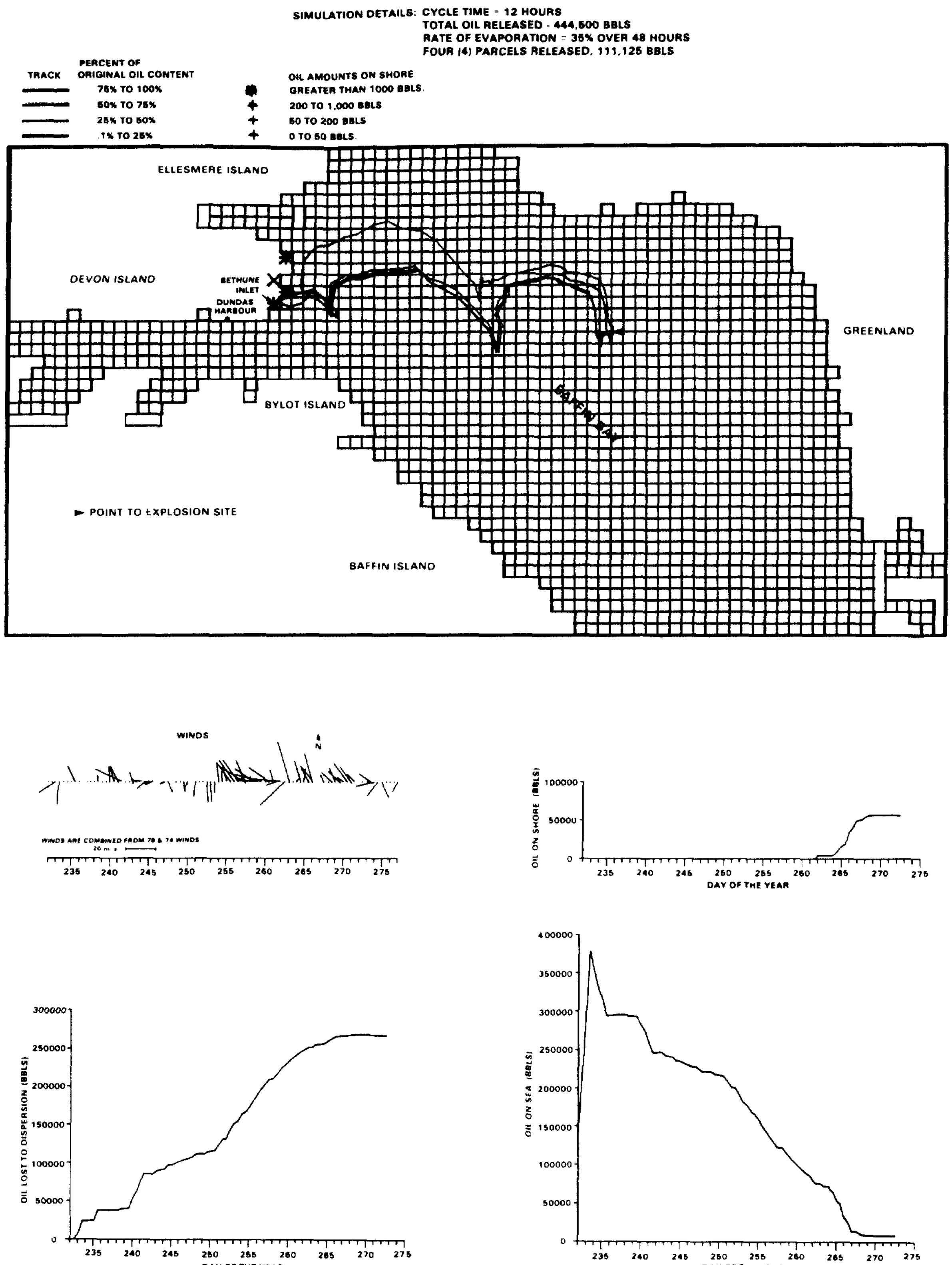


FIGURE 6.10-3 *Computer trajectories for oil spilled from a hypothetical tanker explosion in Baffin Bay assumed to have occurred in mid August (same location as in Figure 6.10-1). The wind regime was made up from a sequence including winds during the interval August 20 to September 10, 1978, and from the interval September 24 to October 17, 1974. The graphs show the disposition of the oil during these combined time intervals and indicate that some oil is projected to reach the shore.*

6.11 SCENARIO #10: TANKER COLLISION IN DAVIS STRAIT

6.11.1 ACCIDENT DESCRIPTION

This scenario describes a tanker collision in Davis Strait (Figure 6.11-1) resulting in a spill. The volumes, flowrates and circumstances are as described previously for Scenarios 4 and 5. Namely, 75% of the oil in two wing tanks, or 43.000 m^3 (270,000 bbls) of crude oil is discharged in approximately four hours.

Three computer trajectories for an open water spill are shown in Figures 6.11-1, 6.11-2, and 6.11-3 along with estimates of amount of oil lost to dispersion, and the amount remaining on the sea as a function of time. The three trajectories are presented to show the variability in slick movement and fate under different environmental conditions.

For this scenario, no biological assessment was undertaken at this time. Scenario #8 (Section 6.9) describes a hypothetical tanker accident occurring in Lancaster Sound, and provides the reader with a projection of the kinds of impacts which could be anticipated in this somewhat similar but more "sensitive" area. For other projections of the kinds of impacts that could be expected from an oil spill in Davis Strait, the reader is referred to the EARP Panel report on eastern Arctic offshore drilling in Davis Strait (FEARO, 1978), the proponents' EIS related to that project (Imperial Oil *et al.*, 1978) and the very recent Petro-Canada initial environment evaluation for drilling in the offshore Labrador area (Petro-Canada, 1982).

6.11.2 COUNTERMEASURES STRATEGY

The primary countermeasure is to control the source by pumping oil out of the affected tanks. The first two trajectories (Figures 6.11-1 and 6.11-2) predict that the oil remains far offshore and dissipates naturally. In these instances the response would be to monitor the slicks and stockpile dispersants and shoreline equipment to deal with oil should it approach sensitive areas.

Figure 6.11-3 projects the possibility of some oil coming ashore near Pangnirtung on Baffin Island. The shoreline in this high rocky coastal area would be best left alone as the waves and tides will naturally cleanse the shoreline of stranded oil. Attempts could be made to protect more sensitive areas such as Pangnirtung through the use of booms, although it is recognized that the considerable tides and currents would make this difficult. On the other hand, high energy environments such as those typical of this area will assist in removing oil from the shores relatively quickly. Any recovered oil would be disposed of by incineration.

During periods of ice cover, *in situ* burning of the oil could be undertaken as described for winter countermeasures in Scenarios #7 and #8. Buoys could be deployed to track oiled ice if it appeared to be moving away from the spill site.

It is also remotely possible that this scenario could result in some oil reaching the coast of Labrador north of 60° latitude. The coastal area of interest is characterized by low and moderately steep rock shores and cliffs. (Petro-Canada, 1982). This type of coast is difficult to clean manually or mechanically and is best left to be cleaned by the action of waves and tides. The area has been classified as one where little or no long-term persistence of oil would be expected. (Fenco and Slaney, 1978). Since the area is some distance from the hypothesized accident site the oil could take at least one month to reach it, and would arrive in the form of a heavily weathered residue or emulsion. In winter the landfast ice would prevent any shoreline contamination.

The response to a spill threatening the North Coast of Labrador would entail monitoring the oil movement and protecting and cleaning up any sensitive coastal areas. Frobisher Bay would most likely be used as the major support base and response headquarters for an accident in the Davis Strait region and other smaller centres would be used as appropriate.

SIMULATION DETAILS: CYCLE TIME = 12 HOURS
TOTAL OIL RELEASED - 270,000 BBLS
RATE OF EVAPORATION = 35% APPLIES INSTANTLY
FOUR (4) PARCELS RELEASED, 67,500 - 35% = 43,875 BBLS

START: 20/08/78
STOP : 10/09/78

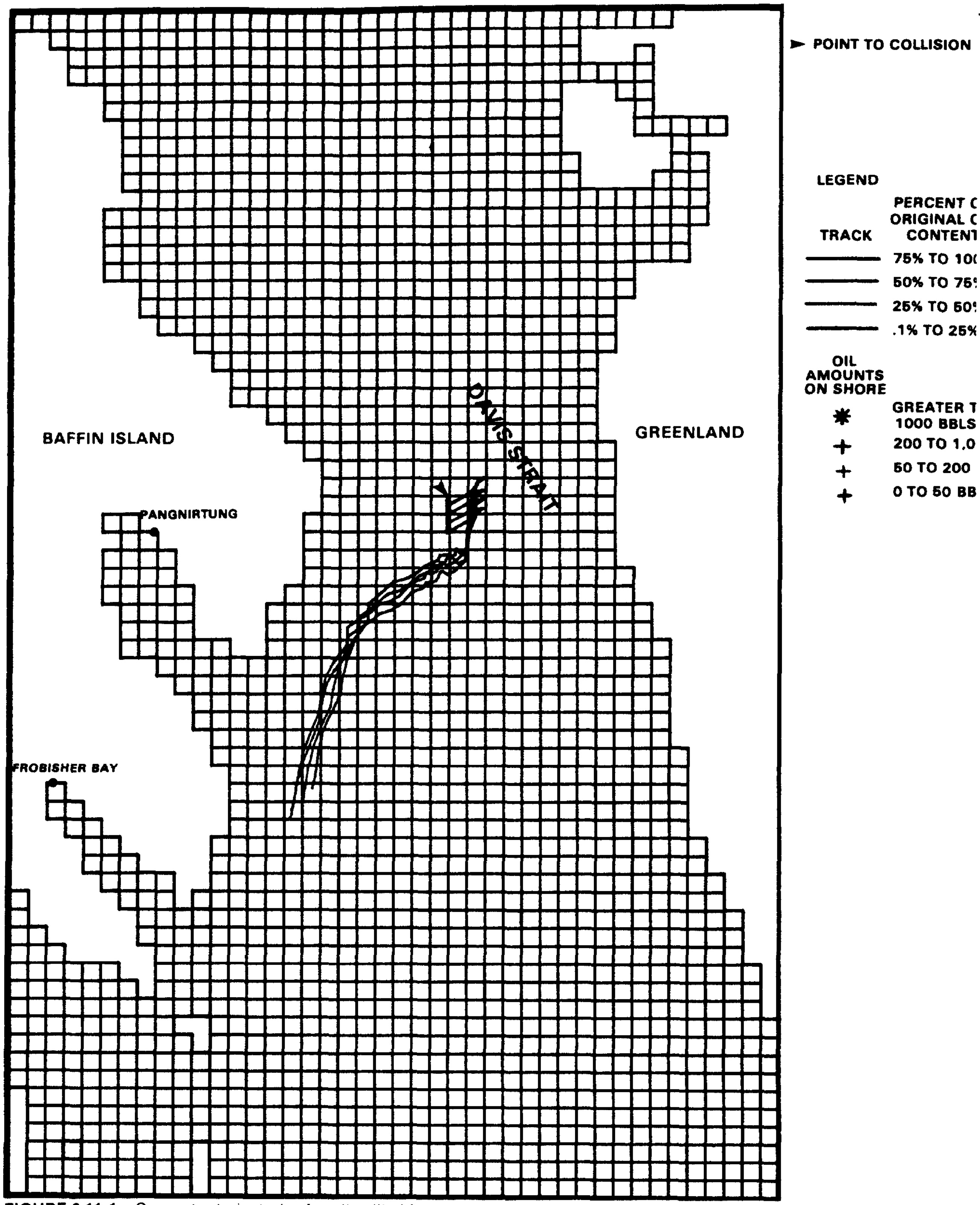


FIGURE 6.11-1 *Computer trajectories for oil spilled from a hypothetical tanker collision in Davis Strait assumed to have occurred on August 20, 1978. The wind regime, and graphs showing the disposition of the oil, cover the time interval August 20 to September 10 during which no oil impinges on shores.*

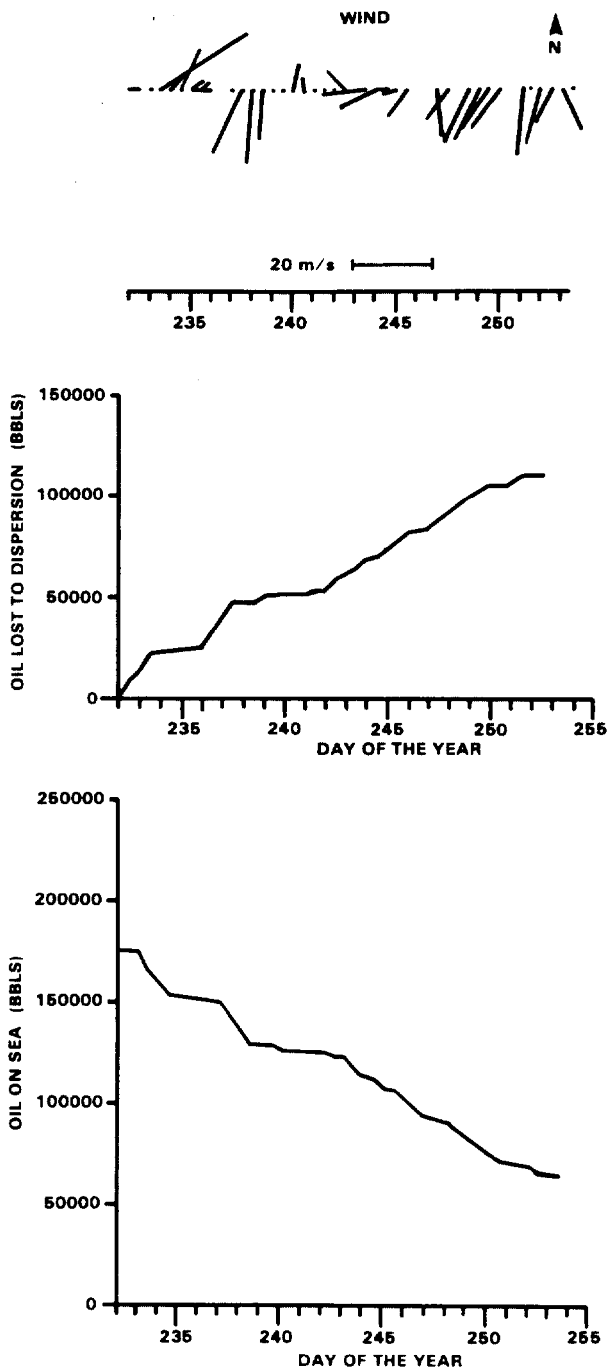


Figure 6.11-1 Continued

TOTAL OIL RELEASED - 270,000 BBLS
RATE OF EVAPORATION = 35% APPLIES INSTANTLY
FOUR (4) PARCELS RELEASED, 67,500 - 35% = 43,875 BBLS

START: 24/09/74
STOP : 17/10/74

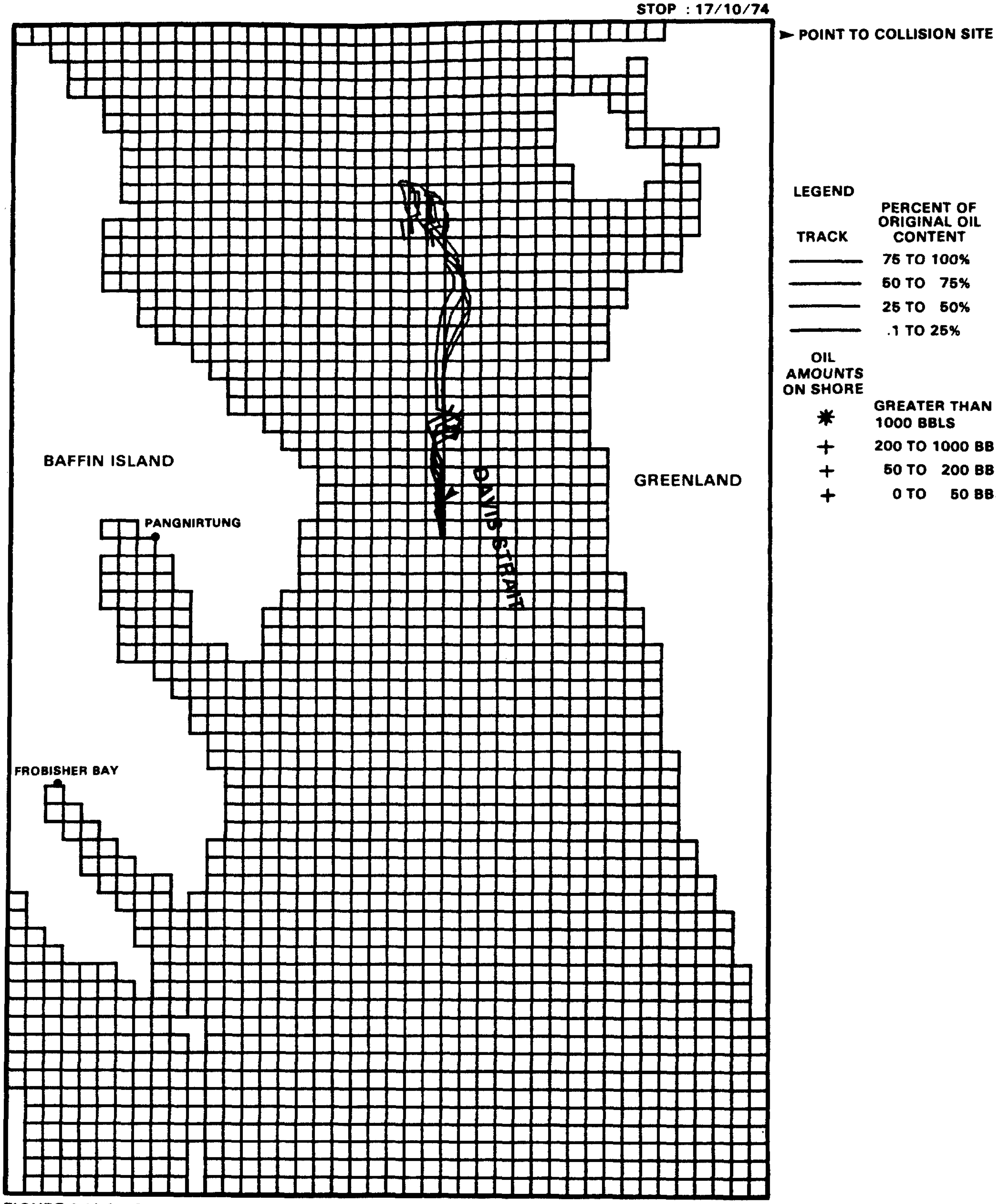


FIGURE 6.11-2 *Computer trajectories for oil spilled from a hypothetical tanker collision in Davis Strait assumed to have occurred on September 9, 1974 (same location as in Figure 6.11-1). The wind regime, and graphs showing the disposition of the oil, cover the time interval September 24 to October 17 during which no oil impinges on shores.*

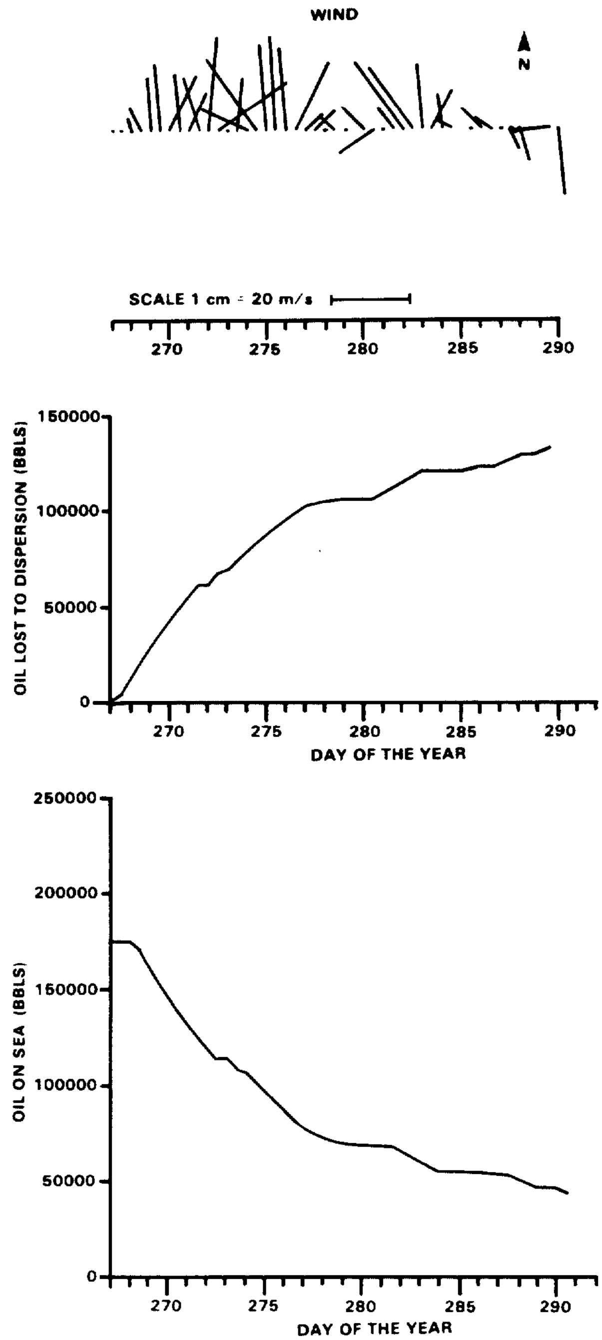


Figure 6.11-2 Continued

SIMULATION DETAILS: CYCLE TIME = 12 HOURS
TOTAL OIL RELEASED - 270,000 BBLS
RATE OF EVAPORATION = 35% APPLIES INSTANTLY
FOUR (4) PARCELS RELEASED, 67,500 - 35% = 43,875 BBLS

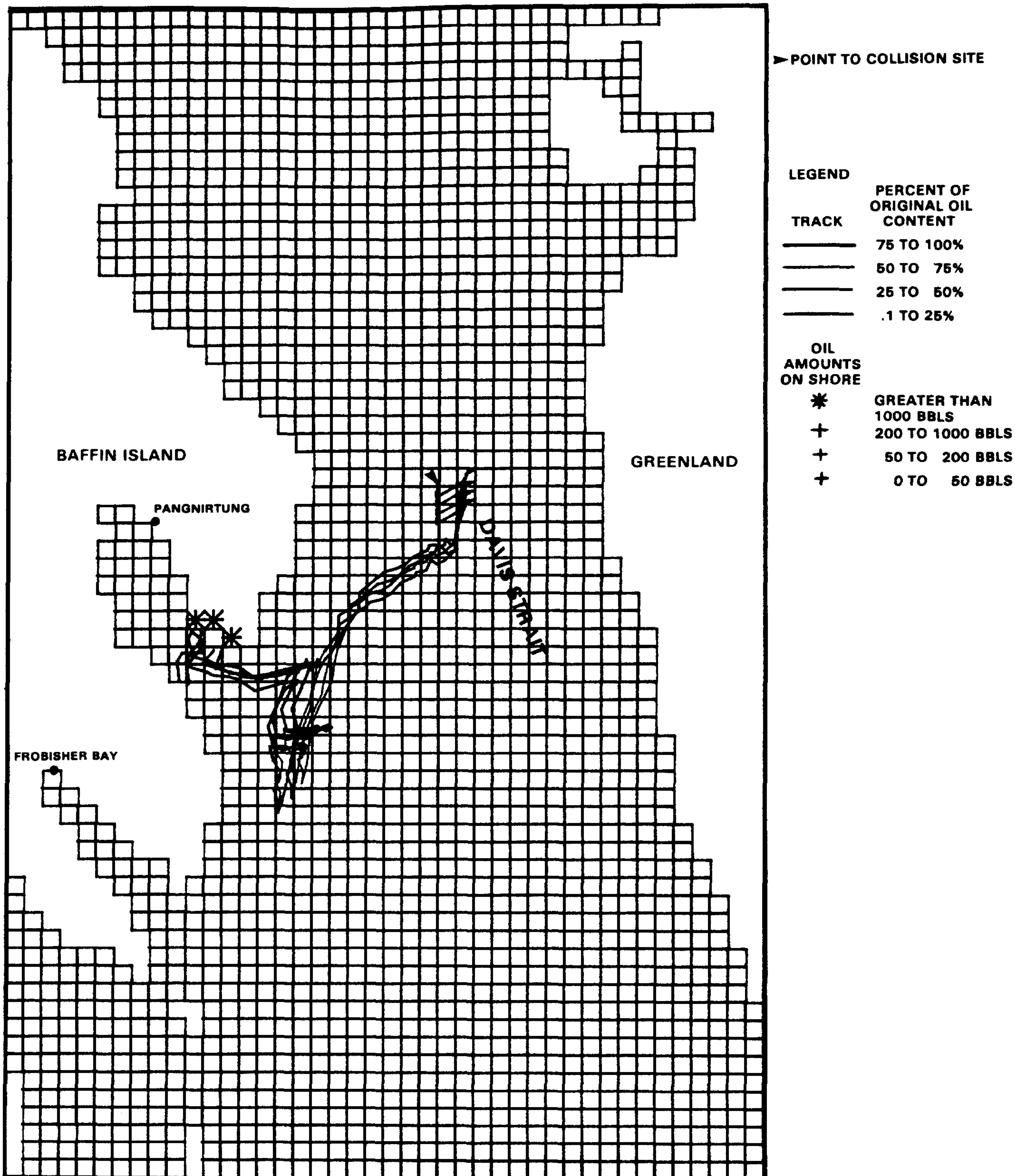


FIGURE 6.11-3 *Computer trajectories for oil spilled from a hypothetical tanker collision in Davis Strait assumed to have occurred in mid August (same location as in Figure 6.11-1). The wind regime was made up from a sequence including winds during the interval August 20 to September 10, 1978, and from the interval September 24 and October 17, 1974. The graphs show the disposition of the oil during these combined time intervals and indicate that some oil could impinge on shores near Pangnirtung, Baffin Island.*

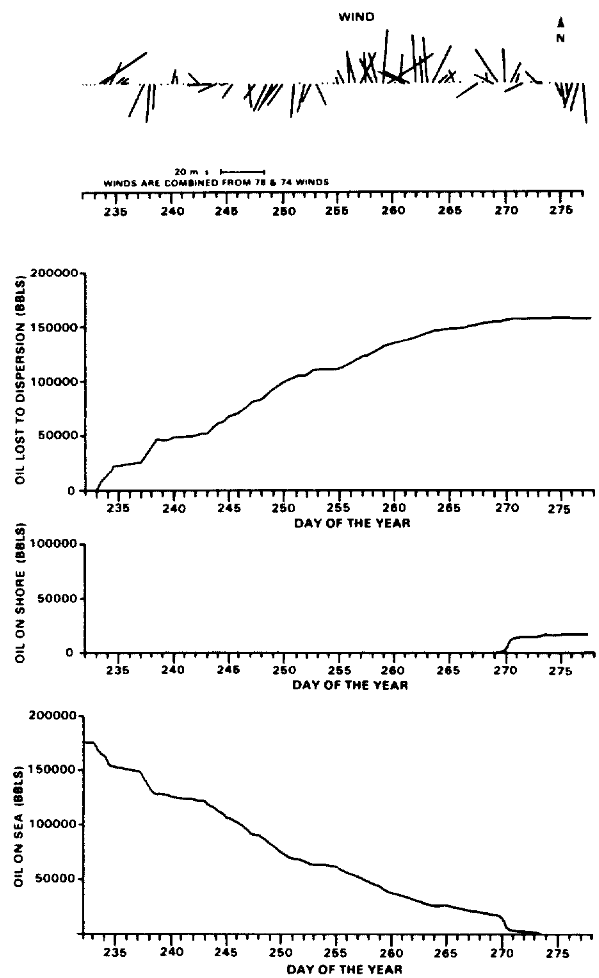


Figure 6.11-3 Continued

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6.13.3 Personal Communications

J. Ward. Dome Petroleum Limited, Calgary.

L. Patterson. LGL Ltd., Toronto.

CHAPTER 7

OIL SPILLS FROM PIPELINES

Chapter 6 examined the possible fate and effects of a series of hypothetical marine oil spills. This chapter describes similarly hypothetical spill scenarios related to pipelines located offshore and on land.

A detailed description of the proposed production facilities and associated pipelines is presented in Volume 2. Based on this information it is evident that subsea and overland pipelines will play an integral part in the development of the Beaufort Sea-Mackenzie Delta hydrocarbon resources.

The following will briefly review 5 oil spill scenarios related to pipelines, and describe the kinds of countermeasures strategies which could be employed to minimize potential impacts. Section 7.3 of this chapter briefly examines the kinds of environmental impacts which could result from oil spills being released onto the land or into fresh waters.

7.1 SPILL PREVENTION

Chapter 2 reviews the circumstances which have been known to cause oil leaks or spills from offshore pipelines. United States Geological Survey pipeline failure data for the Gulf of Mexico during the period 1967 to 1975 show that most pipeline breaks are caused by ships' anchors being dragged over the submerged, often buried line. Other mishaps have been due to the existence of loose flanges and riser failures. Although large spills have occurred, spill volumes have been generally estimated at less than 5 m^3 per event.

For both offshore and onshore pipelines, systems have been devised for continuous monitoring and recording of flow through the lines (Volume 2). The leak detection system will form an integral part of the control system and have the capability to detect and identify the location of a leak which is in the order of 0.5% of pipeline flow. Upon detection of a leak or suspected leak, an alarm will indicate the line section with the problem and the operator will, if necessary, shut down the line and isolate the section in question by closing the appropriate remote controlled valves. Even if a leak continued at a rate below the detectability limits over a prolonged period, particularly under ice, cleanup would still be possible, but the extent of contamination would be more widespread.

Other safety features included in the design and construction of offshore and onshore pipeline systems are addressed in Volume 2.

7.2 SCENARIOS AND COUNTERMEASURES STRATEGIES

To demonstrate the potential oil spillage that could result from pipeline ruptures or leaks, five scenarios have been postulated for which countermeasures strategies have been examined. These are:

1) rupture of a subsea pipeline containing "dead" crude oil,

2) corrosion leak in a subsea pipe line,

3) rupture of a subsea infield pipeline containing "live" crude,

4) rupture of a major overland pipeline,

5) corrosion leak in a major pipeline crossing the Mackenzie River at Fort Simpson.

7.2.1 SCENARIO #1 - RUPTURE OF A SUBSEA PIPELINE IN 25 METRES OF WATER

7.2.1.1 Accident Description

In this scenario, a 760 mm subsea pipeline containing crude oil that has been processed to removed associated gas (dead crude) ruptures while flowing at a rate of 95,000 m^3/day.

During summer, the rupture would initially discharge approximately 160 m^3 of oil assuming that a 2.5 minute time lapse occurs from time of detection to when the valves are fully closed. To minimize the amount of oil lost after shutdown, reversible pumps to evacuate the remaining oil in the line could be used. The quantity of oil that would be lost through displacement, assuming it takes 10 days before back-suction can be applied, would be approximately 560 m^3. The total quantity of oil lost under these particular conditions would approach 720 m^3. Once released at the seafloor, the oil would rise to the surface and spread, advect and weather as described in Chapter 3.

Should this same incident occur during the winter while the ice cover is moving, the oil would again rise but will quickly become encapsulated in the growing ice sheet. The 160 m^3 of oil initially spilled would cover an under-ice area of approximately 0.01 km^2. Based on an average ice movement of 2.5 km/day, the remaining oil forms a track about 25 kilometres long by 10 metres wide for a period of about ten days. In spring, oil appears in melt pools.

7.2.1.2 Countermeasures Strategy

During summer, once the failure is detected, the first response would be the deployment of offshore containment boom and skimming equipment downstream from the oil leak. The initial oil release would be tracked and should it threaten a shoreline, the use of further booming to protect the coast would be required. Onshore cleanup activities would be used if it were determined that this would further reduce possible environmental impacts.

During periods of ice cover, the ice passing over the discharge point would be tracked using Argos buoys. Igniters would be used in spring to burn oil appearing in melt pools. This would not be a major incident since less than 1,000 m^3 of oil is released.

7.2.2 SCENARIO #2: CORROSION LEAK OF A SUBSEA PIPELINE

7.2.2.1 Accident Description

A leak develops in a section of 760 mm pipeline buried beneath the sea bottom. Oil is flowing through the line at a rate of 95,000 m^3/day with a minimum leak detection limit of 0.5% of flow. Assuming the leak discharges at a rate just below this detection limit, the flow continues for 24 hours before a mass balance check spots the oil loss and the pipeline is shut down. The maximum volume of oil released is approximately 475 m^3.

Due to line pressure, the oil exits with sufficient force to penetrate the overlying sediment and enter the water column. From that point, it behaves as described in the previous scenario with the exception that the oil pools against the under-ice surface of stationary landfast ice as opposed to moving pack ice.

7.2.2.2 Countermeasures Strategy

The countermeasures employed under these circumstances would be similar to those described for Scenario #1. Containment booms and skimming devices would be used during open water periods to retain and retrieve as much of the oil as possible. In winter, no action would be required as the oil would become encapsulated in stationary landfast ice. During spring when the oil would rise to the surface of the ice sheet through brine channels, the oil would be burned away using igniters, and the residue picked up manually.

7.2.3 SCENARIO #3: RUPTURE OF A SUBSEA INFIELD GATHERING LINE

7.2.3.1 Accident Description

In this scenario, a 219 mm subsea pipeline is gathering oil with gas in solution (live crude) and transporting it from a production island to another offshore island where the crude will be processed prior to shipment to market. The gas is present at a gas-to-oil ratio (G.O.R.) of 140:1 and the oil content of the mixture is flowing at a rate of 4,000 m^3/day. The line ruptures in 25 metres of water.

Assuming a response time of 2.5 minutes to close the valves, approximately 7 m^3 of oil plus associated gas will have escaped. Due to the sudden pressure drop in the line, oil and gas will escape very rapidly until the pressure of the water column is equal to that in the line. The energy resulting from this "mini-blowout" breaks the oil into small droplets at the point of rupture which rise in the resulting plume.

If this hypothetical failure were to occur during summer, the gas in solution would dissipate into the atmosphere, leaving the majority of the oil on the water surface. Some oil would be dispersed as it rose through the 25 metre deep water column. Should this incident occur during winter under newly forming ice, less than 1 m in thickness, the gas would fracture the ice cover and vent into the atmosphere. The oil droplets would rise and become encapsulated into the under-ice surface.

Should the pipeline rupture happen under thicker ice, the gas would spread and fill the under-ice undulations. The oil would collect in pools under the ice and possibly under pools of gas. In either case, encapsulation of oil and gas would quickly follow. In spring, oil trapped as discrete droplets will appear on the surface as the ice ablates. Pools of oil frozen into the ice will ultimately surface in the spring through the processes of brine channel migration and ablation.

7.2.3.2 Countermeasures Strategy

The steps taken to control an open water release from a gathering line would involve a series of activities. Containment and recovery would be initiated as soon as possible downstream from the spill point. Monitoring and tracking of the slick would proceed at the same time. Should the oil move towards sensitive shoreline areas, protection by further booming and skimming would be undertaken. Oil washing ashore would be removed along with oily debris and disposed of using burning techniques and/or burial at approved locations. Oil rising to the surface in spring from a winter-time accident would be dealt with by *in situ* burning. The amount of oil released is small, thus precluding the need for extensive countermeasures.

7.2.4 SCENARIO #4: RUPTURE OF A MAJOR OVERLAND PIPELINE

7.2.4.1 Accident Description

In this scenario, a 1067 mm pipeline is transporting oil to Edmonton from a pipeline terminal located on Richards Island. Maximum flow rates of 218,000 m^3/day are projected when the line approaches peak throughput. The pipeline is assumed to rupture in an elevated portion of the line over permafrost terrain.

The quantity of oil that would escape from a pipeline rupture is dependent on flow rate: valve spacing; hydrostatic head differential; and response time to detect the leak, close the adjacent valves and isolate the ruptured section of the line. At a peak throughput rate of 238,000 m^3/day, assuming the valves are spaced at 24 km intervals and can be closed within 5 minutes after the leak is detected, approximately 500 m^3 will have escaped from the pipeline. In addition, oil could continue to drain from the line after shutdown and this will vary depending on the location of the break. If 40% drained from the line before sealing procedures could be implemented, an additional 8,100 m^3 could flow from the line. Although this could occur, the proposed pipeline system would be designed such that the maximum spill from a pipeline rupture would not likely exceed 8,000 m^3 (see Volume 2). In environmentally sensitive areas, closer spacing of remotely controlled valves would reduce this quantity even further.

In summer, the oil penetrates the active or insulating layer above the permafrost while in winter the oil penetrates the snow but does not enter the soil due to its frozen condition. Evaporation takes place in either case resulting in the loss of the lighter fractions, albeit more slowly in winter.

7.2.4.2 Countermeasures Strategy

If the accident occurred during summer, trenching and berming would be initiated and the confined oil would be pumped into temporary storage bladders as soon as possible for reinjection into the pipeline.

In areas where shallow bodies of water are near the rupture, consideration would be given to directing the oil to a small pond where it could be subsequently skimmed off into temporary holding tanks.

In sensitive tundra areas, fencing off the area around the spill would prevent intrusion of large animals. Sampling would be undertaken to determine the advisability of fertilization with nitrogen and phosphorus and reseeding. Impacted areas would then be treated and monitored through the recovery period. Once regeneration of the tundra has taken place, the fencing would be removed.

Should the oil be released during the winter, consideration would be given to using *in situ* burning methods. This activity would be complemented by manual recovery of any residual material. If *in situ* combustion of the oil is deemed inadvisable, clean-up of concentrations of oil would be undertaken using mechanized equipment. Recovered oil and debris would be removed along the pipeline right-of-way to approved disposal sites. If required, a similar revegetation program to that previously described would be initiated in fenced-off oiled areas. The area affected would be small and would not impact the regional biological system.

7.2.5 SCENARIO #5: CORROSION LEAK IN A MAJOR PIPELINE AT A MAJOR RIVER CROSSING

7.2.5.1 Accident Description

On this occasion a leak caused by corrosion of the 1067 mm pipeline is hypothesized to occur at a point on the Mackenzie River directly upstream of Fort Simpson. For a leak equalling 0.25 % of the flow rate, 544 m^3 of oil would escape into the river over a 24 hour period. Pipeline systems with computer based leak detection systems operating in Canada today are able to detect minor leaks and shut the system down before 50 to 100 cubic metres have escaped.

In summer, the oil surfaces and drifts downstream to collect in bays and back eddies along the shore. These areas would be identified from video records of the river banks related to the flow of the surface waters in the river. In winter, the oil impacts the under-ice surface and moves slowly downstream filling undulations as it proceeds.

7.2.5.2 Countermeasures Strategy

During summer, using Fort Simpson as a base of operations, mechanical containment and recovery equipment would be deployed to remove concentrations of oil. Barges would be used as working platforms. The collected oil would be burned; and impacted shorelines would be cleaned, using manual techniques.

In winter, attempts would be made to divert and collect oil travelling downstream. Slots would be cut in the ice angled toward shore for this purpose. Oil rising up into these trenches would collect in pools at the river bank and be removed by skimming and pumping. Disposal of oil through *in situ* combustion at the slot ends could also be accomplished, as this is a proven technique.

7.3 GENERAL ENVIRONMENTAL IMPLICATIONS OF TERRESTRIAL AND FRESHWATER OIL SPILLS

The following briefly reviews some of the general environmental implications which may result in the unlikely event that oil is accidentally spilled from the pipeline into a terrestrial northern area or into a freshwater lake or stream.

7.3.1 TERRESTRIAL IMPACTS

If oil were spilled onto land, for example, the tundra or boreal forest regions of the north, direct impacts could be expected mainly upon vegetation contacted by the oil.

The effects of experimental crude oil spills on forest vegetation of the Mackenzie Valley are described by MacKay *et al.* (1974), Hutchinson and Hellebust (1974), Hutchinson *et al.* (1974, 1976), and Hutchinson and Freedman (1978). The latter report summarizes terrestrial studies of the effects of crude oil spills on a mature black spruce-white birch forest and a 30 to 40 year old burned area of black spruce near Norman Wells, N.W.T.

Spray spills at an intensity of 9.1 litres per square metre caused the death of all plant tissue contacted by the oil. Lichens and mosses were killed quickly and completely. Up to four years lag time occurred between the time of the spill and the death of some black spruce stems. Spills in winter were less damaging than equivalent spills in summer, and point spills were far less damaging per unit of oil than spray spills. Regrowth shoots of some species developed within a few weeks. Other species survived for a number of years as underground rhizomes before resprouting. Limited seedling establishment of vascular plants was noted in the fourth growing season after the spill. No black spruce regeneration was noted during the six years of monitoring.

MacKay *et al.* (1974) report the effects of a 1972 point spill of crude oil near Norman Wells. They found that vegetation was affected to varying degrees by the oil spill. Mature black spruce trees were not significantly affected while some of the smaller conifers and deciduous species were injured or killed. Nearly all of the mosses and lichens on the surface were dead within several days in areas covered by surface oil Subsurface oil did not affect mosses and lichens.

The impacts of oil spills on terrestrial vegetation would naturally be limited to the areas contacted or covered by oil. In the event a given area became significantly inundated by an oil spill, measures would be taken to limit the spread of the oil (if required) and to "close off" the area such that terrestrial mammals in particular would be restricted from coming in contact with it. Berms or trenching could be employed to limit the spread of oil, and temporary fencing (e.g. snowfencing) could be used to isolate the area until such time as cleanup could be effected or the area restored to a satisfactory state.

7.3.2 FRESHWATER IMPACTS

The types of biological impacts which could be anticipated as a result of oil contacting birds and furbearing mammals in the marine environment were reviewed in Chapter 4 and represent a summary of a comprehensive report on the subject (Duval *et al.*, 1981). Possible impacts for these classes of animals in a freshwater, or for that matter, in a land-based situation would be similar, and are therefore not discussed further here. This discussion will focus on the freshwater fish and lower trophic levels found in lakes and streams.

A general treatment of the impact of petroleum products on freshwater aquatic organisms in temperate regions (McKee, 1956) indicates that oil may: interfere with respiration facilities of aquatic organisms; coat and destroy primary producer organisms; coat and destroy benthic organisms, and thus the food sources of higher trophic levels; coat spawning habitat of fish; be ingested by fish and other aquatic organisms and thus taint flesh or cause mortality through toxic effects; or may de-oxygenate water resulting in indirect fish mortality.

The de-oxygenating effect would be more probable with a natural gas product but more recent studies have shown, in fact, that this type of impact is improbable (Welch *et al.*, 1979).

Data describing the composition and possible toxicity to aquatic organisms of specific oils from present offshore locations are not yet available. However, limited tests of the toxicity of selected types of oil from Norman Wells and from the Atkinson Point discovery on marine invertebrates were conducted by Percy and Mullin (1975). The only comparable works on freshwater organisms conducted in the region of the corridor are those of Brunskill *et al.* (1973), Roeder *et al.* (1975), Snow and Brunskill (1975), Snow and Rosenberg (1975a, 1975b, 1975c), and Snow *et al.* (1975), who visited sites of several spills, conducted controlled spills, and experimented with oil-soaked artificial substrates. These authors recorded the following effects of crude oil spills on the zoobenthos:

- Increases in abundance of selected taxa accompanied by reductions in species diversity and total standing crop;

- Temporary elimination of some components of the community from localized areas;

- Shifts in community structure displaying slow recovery rates;

- Reduction in abundance of organisms.

In contrast to the early work by McKee (1956), these authors found that algae production on oil-soaked artificial substrates appeared to be inhibited by high sediment levels and was stimulated by oil contamination. Brunskill *et al.* (1973) reported that oil soaked artificial substrates in clear streams produced a luxuriant growth of algae as compared to controls but that this did not occur in the heavy sediments of the Liard and East Channel of the Mackenzie River. It is suggested that current speed, silt loading, and reduced light penetration combine to limit algae production in these areas. Studies by Dickman (1971) on the effects of crude oil on primary production support the conclusion that oil tends to enhance primary production except under conditions of high turbidity where light penetration is reduced. This tendency toward eutrophication has been attributed to increased total dissolved nitrogen released from oil by nitrogen fixing microorganisms.

Other data, presented by Brunskill *et al.* (1973), indicate that the recovery rate of lower trophic levels from the effects of oil spills is considerably slower than recovery from sediment related community alterations. Snow *et al.* (1975) report, however, that northern streams appear to have a "self-cleaning capacity" which shortens the recovery period considerably in comparison to the recovery of zoobenthos from coastal marine spills. Snow *et al.* (1975) were unable to find extractable oil in a small stream in the Yukon Territory one year after an experimental spill of Norman Wells crude. A review of information on the toxicity and effects of crude oil on algae is contained in the introduction to Roeder *et al.* (1975)

McCart (1981) lists several factors which will tend to reduce the impact of oil spills in flowing water including:

- Rapid dilution of the spill will occur once it reaches the large discharge of the Mackenzie River;

- The lighter fractions known to be most toxic will evaporate quickly;

- The high sediment loads characteristic of the river during the open water period may remove oil by encouraging settlement;

- The major potential effects during the open water season will not involve the whole water column but will concentrate in quiet water areas where cleanup is relatively easing using conventional techniques;

- The self-cleaning capacity of streams will reduce the duration of any impacts.

McCart goes on to add that spills in lakes and under ice will likely produce greater effects on aquatic fauna than open water spills in streams. Studies by Snow and Rosenberg (1975a, 1975b) show clearly that spills entering Arctic lakes may cause effects throughout the water column and may reduce winter oxygen levels. These impacts are likely to be most difficult to contain during spring breakup, when conventional cleanup techniques are ineffective (McCart, 1981).

There are no data describing the sensitivities of common fish species in the Mackenzie River system to crude oil exposure. The available information on other species suggests that the sensitivity of eggs, juveniles, and adults to light oil fractions is relatively high but may vary considerably among species.

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CHAPTER 8

MINOR OIL SPILLS

A minor oil spill is generally one where a small volume of oil is discharged, and causes little environmental damage.

During offshore production operations, as shown in Chapter 2, minor spills account for only a small percentage of the volume of oil spilled. However they do account for, by far, the greatest number of spills, which if not cleaned up could result in chronically high levels of pollution in confined areas such as harbours. Typical examples of minor spills include tank farm spills of refined products, hose breaks during supply operations, tipping over of a drum of lubricating oil and the spillage of slops oil during transfer operations.

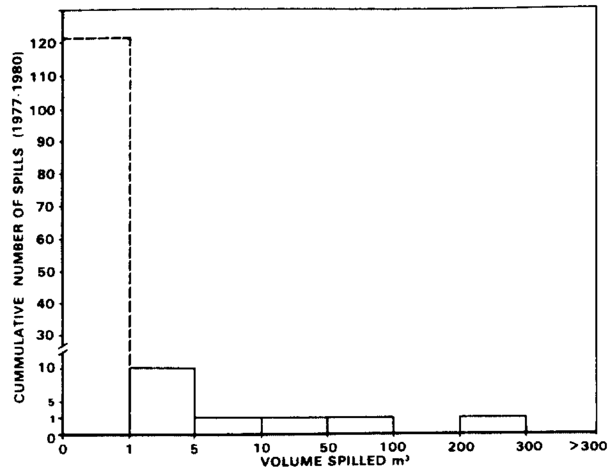

FIGURE 8.1-1 *Spill size distribution during Beaufort Sea drilling operations 1977-80 (Source; Dome Petroleum Limited Spill Response Team). This distribution is similar to that in other areas where offshore drilling is taking place.*

8.1 MINOR SPILLS DURING BEAUFORT SEA DRILLING OPERATIONS

Minor spills of oil and like materials have occurred during exploratory drilling operations in the Beaufort Sea. Table 8.1-1 shows a breakdown of the number and size distribution of spills by year, that have occurred since 1977 as reported by Dome's spill response team. Also shown is the percentage of oil spilled that was cleaned up. During the last three years over 95% of the oil spilled has been cleaned up.

TABLE 8.1-1

SUMMARY OF SPILLS 1977-1981

Year	1977	1978	1979	1980	1981
Number of ocean spills	3	2	1	32	9
Number of harbour spills	4	3	12	44	42
Number of land spills	0	0	9	20	12
Total number of spills	7	5	22	96	63
Percentage less than 1m³	100%	60%	90.5%	95.8%	87.3%
Total volume spilled*	.82m³	291 m³	33.4 m³	81.3 m³	790 m³**
Percentage recovered*	50%	1%	95%	95%	95%

*Note volumes and amount recovered are approximate values.
**of this total 763 m³ resulted from the Camp Farewell spill caused by vandals.

The distribution of spill size shown in Figure 8.1-1, is quite similar, to that in other areas of the world where offshore drilling is taking place (see Chapter 2). The largest number of spills were small having volumes less than 1 m³.

8.2 PREVENTION

The prevention of minor spills is closely linked with training of personnel, particularly those responsible for fueling and oil transfer operations. Care must be taken in the making and breaking of hose connections, the opening and closing of valves and in monitoring the level of tanks being filled. Personnel responsible for these operations are required to remain on site and be alert during the transfer of oil products so that should a leak occur the source can be isolated and the spillage of further oil prevented.

In addition, to prevent the spread of spilled oil, tank farms and individual storage tanks will be surrounded by dikes of sufficient strength and size to contain 110% of the volume of the largest tank plus 10% of the aggregate storage volume. The entire enclosed area, including the dike walls will be constructed of, or lined with, impervious materials.

With proper care and attention the frequency, volume and impact of minor spills will be reduced.

8.3 RESPONSE STRATEGIES

8.3.1 SPILLS ON LAND

The response to minor land spills involves preventing the spread of the oil using trenching and berming techniques. Pools of surface oil will be directly pumped to storage containers or sorbent materials will be applied to absorb the oil. If necessary, surface soils could be removed for disposal or cleaning. In the case of a spill on tundra only manual cleanup techniques would be used. Every effort would be made to minimize surface disturbance. The affected area could be isolated to prevent wildlife from entering the oil. Fertilizers could be applied to encourage microbial degradation of the oil.

8.3.2 SPILLS ON WATER

For minor spills occurring in harbours, lakes, and slow rivers, booms could be deployed around the spill to contain it and skimmers deployed to recover the oil. Sorbent materials could be used to remove any sheens. For unconfined slicks the Oil Mop unit mounted on a Sea Truck could be used to recover the oil (see Chapter 5). In the event of a minor spill into a swift flowing river, booms could be deployed to divert the oil into calm areas where recovery operations would take place. Manual shoreline cleanup techniques would be used to remove oil where necessary.

8.3.3 SPILLS IN ICE

Minor spills occurring on ice could be cleaned up by pumping pools of oil into drums, scraping up contaminated snow for disposal and the application of sorbent materials. If appropriate, the oil could be burned *in situ*. For spills in or under ice, trenching techniques could be used to recover as much oil as feasible. The following spring the oil that appears on the surface in melt pools could be removed by skimming, pumping, the application of sorbents and *in situ* combustion.

8.3.4 DISPOSAL

Any recovered oil could be either recycled, burned in utility boilers or in a ship's heat recovery system, flared using a portable burner, or used for dust control on nearby roads. Oiled sorbent materials would be disposed of by incineration.

8.4 SUMMARY

Minor spills have occurred frequently and have been cleaned up by the Oil Spill Response Team. The techniques used to clean up minor spills are well known and the equipment is simple and has proven effective, even for minor spills in ice. The recovered oil is, to the greatest extent possible, recycled or burned to recover its heating value.

CHAPTER 9

OTHER ACCIDENTAL SPILLS

This chapter deals briefly with gas well blowouts and spills of hazardous substances that may occur during the production of oil from the Beaufort region.

9.1 GAS WELL BLOWOUTS

Gas well blowouts are serious accidents in terms of the safety of personnel and equipment but due to the gaseous nature of the spill they do not usually present an environmental pollution problem. The exception to this is blowout of sour gas containing H_2S (hydrogen sulfide).

No zones have yet been discovered in the Beaufort region that contain sour gas. A blowout from a sour gas well would be immediately set on fire to oxidize hydrogen sulfide to the much less dangerous compound sulphur dioxide (SO_2) and thus protect human life. As is the case with any blowout, steps, including drilling relief wells, would be taken to stop the flow.

9.2 SPILLS OF HAZARDOUS MATERIALS

For production activities in the Beaufort, the range of substances required for normal well development and production operations that may be considered hazardous (Cottrell, 1980) include: completion fluids containing zinc bromide ($ZnBr_2$), hydrochloric acid (HCl), surfactants, oxygen scavengers, corrosion inhibitors, anti-scale compounds, demulsifiers and emulsion breakers. Small quantities of other chemicals would be required for support bases, such as chlorine and sodium hydroxide. In addition, radioactive well logging tools and tritiated water for waterflood injection studies may be used.

9.3 SPILL PREVENTION

All hazardous substances for use in the Beaufort Sea production scheme will be handled and transported in strict accordance with the Transportation of Dangerous Goods Act and regulations set out by the Department of Transport. They will be stored on site in approved containers suitably separated and surrounded by impervious dikes of the required size (Plate 9.3-1).

9.4 SPILL RESPONSE

The detection and reporting of a spill of a hazardous substance will be the same as for a spill of petroleum. The control procedures for a hazardous material spill depend on the nature of the chemical involved. Each of the hazardous products used in the Beaufort Region will have a product safety data sheet listing the product name, components, emergency phone numbers, physical data, hazards, fire-fighting techniques, personnel safety and spill cleanup procedures. These data sheets will form an integral part of the Hazardous Substances Spill Contingency Plan for Production and Transportation. In addition to the data sheets, information on the substance and cleanup strategies could be obtained from onsite representatives of the supplier and through the CHEMTREC (Chemical Transportation Emergency Center, Washington, D.C.) 24-hour hotline, the TEAP (Transportation Emergency Assistance Plan -Canadian Chemical Producers Association) Regional Control Centre 24-hour hotlines, or NATES (National Analysis of Trends in Emergency Systems - EPS) hotline or online computer through the regional EPS office.

Once the type of spill and the material(s) involved have been identified the following countermeasures are available for use (Smith, 1981):

- Containment and Recovery. This option could be applied to spills of liquids on land (using trenching techniques, pumps and possibly sorbents) and to spills on water for liquids that have densities less than that of water and are immiscible in water (using booms or barriers and pumps and possibly skimmers or sorbents, or both).

- Neutralization. This option could be used to deal with land spills of certain chemicals, primarily acids and bases. An example would be the neutralization of HCl by the application of lime or soda ash.

- Dilution. This option could be used to deal with spills of gases, such as chlorine leaks, and spills of water soluble liquids such as acids and bases to reduce their concentration for safety reasons. Dilution of liquids should only be attempted if they are rendered harmless (e.g. by neutralizing acids) or if containment and recovery is not possible.

- Scraping. This technique would be primarily used for the recovery of spilled solid materials and the removal of contaminated soils, snow or ice. Manual and mechanical means would be used to place the recovered material into suitable storage containers for recycling or disposal.

- Disposal. The ultimate disposal of recovered hazardous material would depend on its characteristics. The applicable disposal techniques would be determined by a qualified hazardous wastes contractor. If required the wastes would be containerized and transported to appropriate approved disposal facilities in the south.

9.5 SUMMARY

Even though the quantities of the hazardous materials involved in the production scheme are quite small, the proponents will have in place contingency plans, equipment and personnel to safely and effectively deal with any spillage of such materials.

9.6 REFERENCES

Cottrell, T.J., 1980. The Administration and Regulation of Hazardous Waste, Environmental Council of Alberta, Edmonton.

Smith, A.J., 1981. Managing Hazardous Substances Accidents, McGraw-Hill, Toronto.

PLATE 9.3-1 *All hazardous substances for use in the Beaufort Sea will be handled and transported in strict accordance with applicable acts and regulations. They will be stored on site in approved containers suitably separated and surrounded by appropriate dikes as shown here at Tuktoyaktuk.*

CONCLUSION

The proposed oil production and transportation development is a massive one involving the use and movement of much material and equipment and the delivery of billions of barrels of crude oil in an Arctic environment.

By studying and analyzing the causes and consequences of oil spills from similar developments in more temperate, but not less forgiving environments, the proponents have learned from the mistakes of others and will put into place safety systems to ensure that accidents and their consequences are minimized.

But this is not enough. Millions of dollars of research and development into the fate and behaviour of oil in Arctic waters have culminated in oil spill countermeasures systems tailor-made for the Arctic environment. This equipment is now stockpiled in the Beaufort Region and is ready, supported by a trained and dedicated team, to respond to any spill arising from the present exploration efforts. It is a commitment of the proponents that these efforts in both research and development and response capability will continue to improve.

This commitment is already evident in the research and development work completed thus far for production and transportation. Studies of tanker spills and risk analyses have been undertaken that have resulted in the design of features for Arctic tankers that will vastly reduce the risks of both operational and accidental spills. Historical analyses of past production accidents have also been completed to achieve the same goal for production facilities and pipelines. As well, the first steps toward identifying contingency planning needs, such as type, location and numbers of response equipment through computer forecasting techniques, and the completion of shoreline protection and cleanup and manuals, are evident in this volume.

No spill, no matter how small, will be ignored. It is the firm belief of the proponents that if a spill should occur in the Arctic that it will be cleaned up better than anywhere else in the world because of their state of preparedness.