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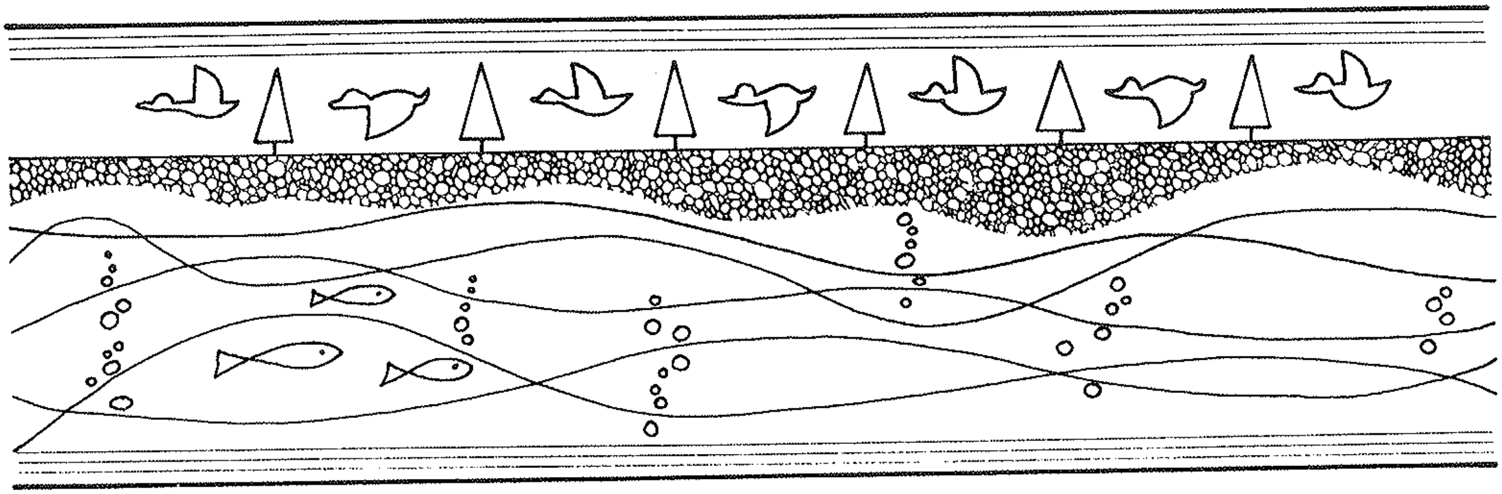

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The Spill Technology Newsletter was started with modest intentions in 1976 to provide a forum for the exchange of information on oil spill countermeasures and other related matters. We now have over 2,600 subscribers in over 40 countries.

To broaden the scope of this newsletter, and to provide more information on industry and foreign activities in the field of oil spill control and prevention, readers are encouraged to submit articles on their work and views in this area.

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INTRODUCTION

The first article, by Ken Meikle, describes the use of high pressure water to contain and divert oil. Readers may be interested to know that, in view of the success of the initial experiments, EPS is pursuing the application of this technology by constructing and testing experimental containment devices. As results become available they will be reported in this newsletter. The second article by Ian Buist and associates summarizes a study conducted to examine tanker spills in Arctic waters. The article reviews the problems and typical scenarios and suggests countermeasures for the envisaged spills.

Readers have, no doubt, noticed that the Spill Technology Newsletter fell behind schedule in the past few months. With the publication of the next issue, already in preparation, we will be up-to-date. The delay was a result of a number of factors, including reorganization of our unit. We again ask our readers to assist us in maintaining our schedule by providing news, articles, etc. We thank you for the past support and in advance, for the support we require to continue the Spill Technology Newsletter.

REPORTS AND PUBLICATIONS

- The Environmental Emergencies Technology Division has recently released four contractor's reports, the titles of which appear below. These reports are unedited and have not undergone rigorous technical review but will be distributed on a limited basis to transfer the results to people working in related fields. For copies of these reports contact: Publications Coordinator, Technology Services Branch, Environmental Protection Service, Ottawa, Ontario, K1A 1C8. (Phone 819-997-3405)

  "A Safety and Reliability Analysis of Arctic Petroleum Production and Transportation Systems - A Preliminary Study" (EE-44)

  "A Safety and Reliability Analysis of Arctic Petroleum Production and Transportation Systems - A Preliminary Study - Volume 2 - Appendices A&B" (EE-44a)

  "Gem Eng Lightweight Fireproof Boom: Oil Containment at OHMSETT" (EE-45)

  "Design of An Analytical System for The Detection and Monitoring of a Number of Hazardous Materials" (EE-46)

- The Environmental Protection Service has released three new publications on work done for the Environmental Emergencies Technology Division. These publications may be obtained upon request from: Publications Coordinator, Technology Services Branch, Environmental Protection Service, Ottawa, Ontario, K1A 1C8. (Phone 819-997-3405)

  The titles and abstracts are as follows:

Fate of Chemically Dispersed Oil in the Sea. A Report on Two Field Experiments. (EPS 4-EC-82-5)

PART 1: A Contained Oil Spill

Three litres of oil were spilled in each of two moored plastic enclosures (CEPEX enclosures) in Saanich Inlet, British Columbia. In one enclosure, Corexit 9527 was used to disperse a portion of the surface slick. The slick in the other enclosure was not chemically dispersed, but left as a control. Sampling of the enclosures was conducted over a 15 day period.

The oil dispersion was stable during the two week period of the experiment. The average droplet size was one micrometre or less, which is within the range required for a stable emulsion.

The dispersion of the oil resulted in a greatly increased rate of biodegradation. Within 15 days, microbial oxidation of the alkane component of the oil was completed. This rate is at least an order of magnitude higher than that for undispersed oil. Only 0.1% of the dispersed oil reached the sediments during the 15 day time period, and this oil was in an advanced state of bacterial decomposition. Loss of volatile components from dispersed oil was slower than from the surface slick. Evaporation from the water column took 10 to 15 days. In comparison, equivalent evaporation from the surface slick took from one to two days. No detectable photochemical oxidation of the dispersed oil or the surface slick occurred during the experiment.

PART 2: A Boomed Oil Spill

Three experimental oil spills of 200, 400 and 200 L were conducted in October 1978 at Royal Roads, British Columbia, a semi-protected coastal area. The surface slicks were restrained with a Bennett inshore oil boom. The spilled oil was chemically dispersed using Corexit 9527, applied as a 10% solution in seawater and sprayed from a sea truck. The dispersed oil was monitored fluorometrically for some hours. Surface oil and dispersed oil were sampled for chemical analysis.

The highest recorded concentration of dispersed oil was 1 ppm. After a short time (30 minutes) concentrations of 0.05 ppm were normal, decreasing to background within 5 hours. The concentrations were low compared to those expected for complete dispersion, which, as visual observation confirmed, was not achieved.

In contrast to predicted behaviour the dispersed oil did not mix deeper into the water column with the passage of time, in spite of the lack of a significant vertical density gradient in the seawater. This behaviour was attributed to the buoyancy of the dispersed oil droplets and the limited vertical turbulence in the coastal locale of the experiment.

The integrated quality of oil in the water column decreased more rapidly than either the mean oil concentration of the cloud or the maximum concentration, indicating that some of the dispersed oil was rising back to the surface. The surfacing of dispersed oil was confirmed visually during the experiment. The mixing action of the spray boat and breaker boards apparently created large oil droplets which did not form a stable dispersion.

Horizontal diffusion of the dispersed oil was initially more rapid than expected, but the rate of spreading did not increase with time as predicted. The results imply that the scale of diffusion was larger than the scale of turbulence, which again can be attributed to the locale of the experiment.

Evaporation of the most volatile components of the crude oil from the surface slick was rapid, with a loss of about 20% weight in two hours. Chemical dispersion of the oil apparently inhibited evaporation; gas chromatograms of the dispersed oil indicated that evaporative losses corresponded to those at the time of dispersal. No biodegradation or photooxidation of the surface or dispersed oil was observed, but none would be expected, given the short time period over which the samples were obtained.

A Review of Countermeasures for a Major Oil Spill from a Vessel in Arctic Waters (EPS 3- EC-83-2)

The existing capability to deal with a major tanker oil spill in the Arctic is presented. A particular emphasis is placed on the government's role and state of preparedness.

First, a review of the countermeasures utilized at past major tanker spills throughout the world is performed. This is followed by summaries of the northern environmental setting and the oil shipment operations that are proposed for the Arctic. A comparison between historical southern spills and those which could occur in the Arctic is then made.

Best-practicable oil spill control technologies for the North are identified through a group of hypothesized accident scenarios and response strategies. The government's present organizational structure, contingency plans and major equipment supplies for a northern oil spill response are reviewed, and the likely success of a government response to the hypothesized spills is discussed. Research and development of new equipment, equipment acquisitions and the planning activity needed to improve this capability are then recommended.

In general, it is felt that the government's ability to deal with an oil spill on open water in the Arctic is not too different from its capability in the south. However, a review of international responses to oil spills in offshore waters has revealed that these techniques are generally not very successful even in southern climates. The complete ice cover setting which exists in the Arctic for much of the year provides the best opportunity for a successful countermeasures operation. Oil spilled under these conditions would be contained and preserved by the ice. If adequate incendiary devices were available in the spring thaw, a high percentage of the released oil could be removed by burning. At present, methods are not available which can deal effectively with spills that occur in a partial ice cover situation.

Countermeasures operations in general could be improved if the damaged tanker were to be used as a work platform. Studies are required to determine the feasibility of this concept.

The Use of Satellite Data for Monitoring Oil Spills in Canada (EPS 3-EC-82-5)

The use of satellite data for the surveillance and monitoring of oil spills is examined. The sensors aboard the Landsat and NOAA series (TIROS-N and GOES) satellites are described. In addition, a review of future satellite systems is presented. The various operational parameters including areal coverage, spatial resolution and spectral response are presented and used to analyze the applicability of the satellites to oil spill detection. Methods for the acquisition and use of these satellite data in a spill emergency are detailed.

It is concluded that current satellite systems are not configured to provide operational oil spill monitoring. Orbits, sensor parameters and coincidence of timing with cloud conditions are such that the probability of succesfully imaging an oil spill at Canadian latitudes is low. If the parameters are such that spill detection is feasible, it may be possible to generate near-real time information. It is recommended that tests, both over real and experimental spills, be conducted to provide information and experience on the use of satellite data for oil spill detection.

THE USE OF HIGH-PRESSURE WATER FOR SPILL CONTAINMENT

Submitted by: K.M. Meikle
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INTRODUCTION

Work at the U.S. Environmental Protection Agency's (EPA) Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility at Leonardo, NJ, demonstrated that airjets and low-pressure waterjets move floating oil (Cohen, 1979; Smith, 1981). However, no information could be found on the use of high-pressure water for that purpose. EPS, very much aware of the limitations of existing technology in ice-infested Arctic waters and in wave conditions commonly experienced off Canadian coasts, decided to find out whether or not some of the problems could be overcome by using water at substantially higher pressure (an order of magnitude greater), and at a correspondingly lower volume. The basic approach is to use the effect induced by the jets to move the oil over the surface of the water instead of moving or stopping the underlying water to influence the floating oil.

Ocean Dynamics International Ltd. (ODI) of Langley, B.C., proposed a small scale test to demonstrate the performance and the effect of waves. Wood chips were to be used to simulate oil. However, this approach was abandonned in favor of an offer by the OHMSETT Interagency Technical Committee to investigate the use of high-pressure waterjets on oil slicks in their tank as an OHMSETT-funded project.

A test protocol was developed by Mason and Hanger - Silas Mason Co., Inc., the operating contractor for the OHMSETT facility, in consultation with Mr. Christie. A 7-phased series of 32 test runs was planned for the purpose of qualitatively assessing the sensitivity of high-pressure waterjet barriers to changes in the following parameters:

a) jet height above the slick surface (10-150 cm);
b) jet flare angle (15°, 25° and 40°);
c) pressure (11,032-17,237 kPa or 1,600-2,500 psi);
d) flow rate (221-140 L/min or 57-36 US gpm);
e) current speed (0-5 knots);
f) wave characteristics (calm; short, low, regular; and 0.6 m harbour chop).

Most of the assessments were to be made on the basis of a direct confrontation between the jet effect and the oil. However, the plan did include a few runs to assess capability. Time and cost constraints precluded a test program that would accurately establish the optimum combination of the several variables.

A design specification was prepared by ODI in consultation with the OHMSETT test engineer for a 6.1 m wide channel boomed off along one side of the tank and a three-jet manifold of 19 mm diameter steel pipe clamped to supports on the main towing bridge so that jet height could be varied. A pumping unit capable of producing at least 295 L/min at 27,579 kPa was specified.

The final project report was still in preparation at the time this paper was written. The results described were derived from the OHMSETT draft overview report and from personal observations.

A trailer-mounted diesel-driven Triplex pump of the type most commonly used by water-blasting contractors was rented. It was purported to have the required output capacity and was positioned on the main bridge as shown in Figure 1. The jet manifold and boomed-off channel are also shown. The only significant departure from the specification prepared by ODI was that pipe with an inside diameter of only 10 mm was used to make the manifold.

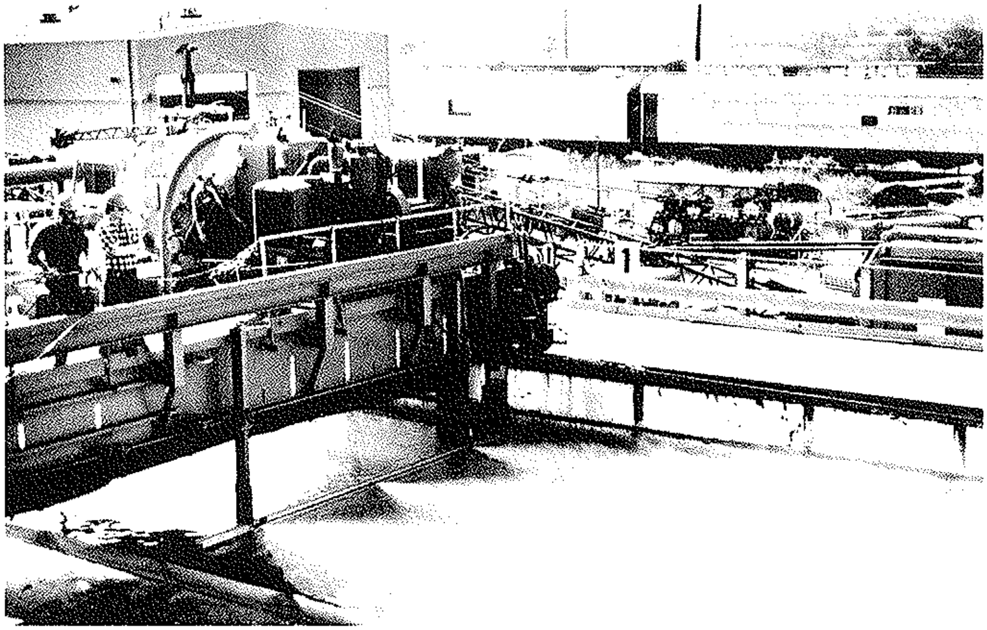

FIGURE 1 TEST ARRANGEMENT WITH SINGLE PUMP

It was soon found that the required flow and pressure combinations could not be developed and hence the jets could not perform as designed. Nevertheless, their ability to move oil was still quite impressive.

The procedure used to assess the result of a change of one of the variables was to lay a 2 mm slick of Circo X heavy oil within the channel. The jets were turned on and the rate at which the oil moved down the tank was recorded, as was the distance at which movement essentially ceased.

Figure 2 shows the swept area extending 18 m or so beyond the auxiliary bridge, a total movement of approximately 38 m. The limit of oil movement for these runs ranged from 45 to 60 m, substantially more than the predicted 17 m. The time taken for the oil to be swept the first 7.6 m ranged from 10 to 38 seconds, which translates into average speeds of 20 to 76 cm/s or 0.4 to 1.5 knots. The time to reach 30.5 m ranged from 1 min 48 s to

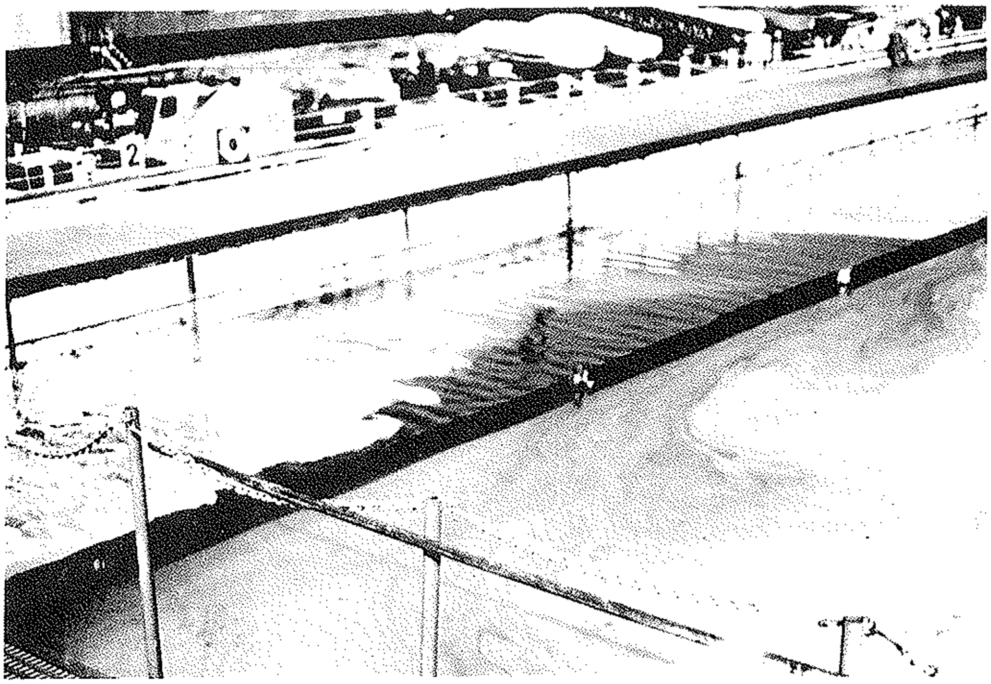

FIGURE 2 OIL MOVED APPROXIMATELY 38 m

3 min 49 s. The corresponding average speed of oil movement over the longer distance ranged from 13.3 to 28 cm/s or 0.25 to 0.5 knots.

To more closely achieve the desired jet flow rates, a second pump was placed on a truck and connected to the other end of the manifold. As shown in Figure 3, the number of jets was reduced to two and the width of the channel was reduced by about 1 m. The resulting interference between the boom and the end of the manifold raised the minimum height at which the jets could be set to about 280 mm.

The flow of air induced by the jets was such that a breeze could still be felt at the limit of the oil movement up to 60 m down the tank. A further indication of the large amount of air being drawn in was the presence of a waterspout behind and about midway between the jets at some settings.

To assess the ability of the jets to move oil against a current, the bridge was advanced at various speeds immediately after the jets were activated. Overrunning occurred at about 0.75 knots.

During the runs in wave conditions, the manifold had to be raised to about 1 m above the water, well above the optimum height, to avoid wave contact and possible damage to the bridge structure. To partially compensate for the loss of efficiency, the jets were depressed about 10° below the horizontal. Two wave conditions were used; 0.4 m regular waves spaced 7 m apart, and the 0.6 m harbour chop. Over-running occurred at about the same speed and to the same extent in waves as in calm conditions. This was true even in the harbour chop. It has been well established that conventional barriers are unable to hold oil at any speed under those conditions. The jets impacting the face of each

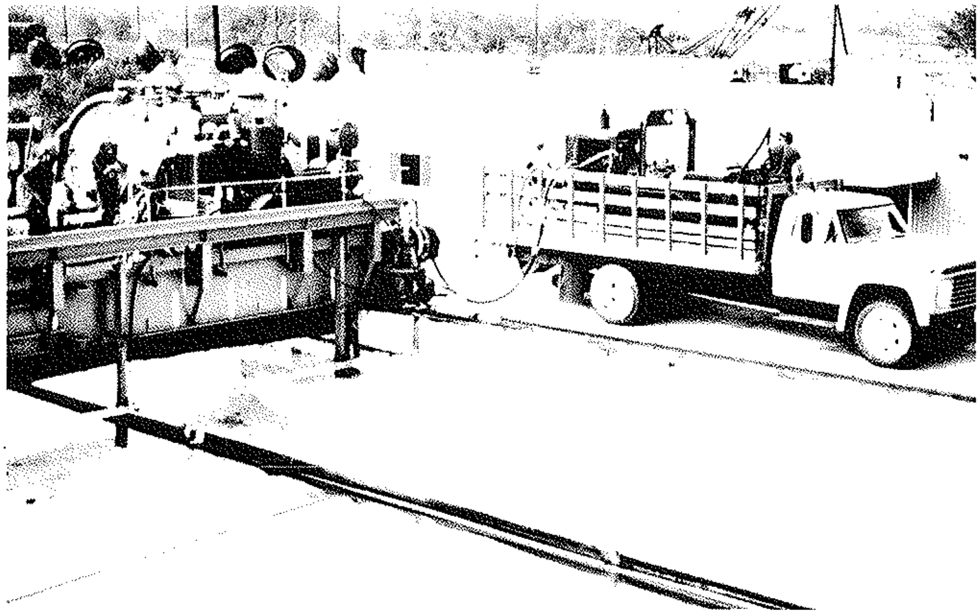

FIGURE 3 TWO-PUMP TEST SET-UP

oncoming wave created small whitecaps of very brief duration, but did not noticeably flatten the waves or reduce their height. Although each wave briefly interrupted the jet effect on the oil, the resulting pulses appeared to move the oil as well as the steady flow had done under calm conditions.

As a final test, the two jets were directed at an angle of about 45° to the direction of travel as shown in Figure 4. This left a strip of oil along the tank wall that was not contacted, but the rest was swept cleanly across the tank at speeds of advance of up to 1 knot even though the jets were still positioned well above their most effective height.

EXPERIMENTAL SYSTEM DESIGN

The OHMSETT tests clearly demonstrated that high-pressure water jets will effectively move oil on water even when power and orientation are less than ideal. Although the optimum values for the main parameter could not be precisely determined in the time available, they were quantified sufficiently for the design of an experimental barrier system. Accordingly, ODI was tasked to produce a specification for a diesel-driven power plant and two waterjet barriers, one for containing a slick and one for diverting or moving oil to a desired location.

The pump for an experimental system may have to deliver up to 2,600 L/min at a pressure of 7,200 kPa to achieve optimum performance from a barrier approximately 50 m long, the length chosen as the minimum that would permit a reasonable assessment of the operational potential of high-pressure waterjet barriers. That output requires a 500 horsepower unit, and the horizontal triplex-plunger type was chosen on the basis of its established reputation. If so desired, a pump of that capability can also deliver 87 L/min

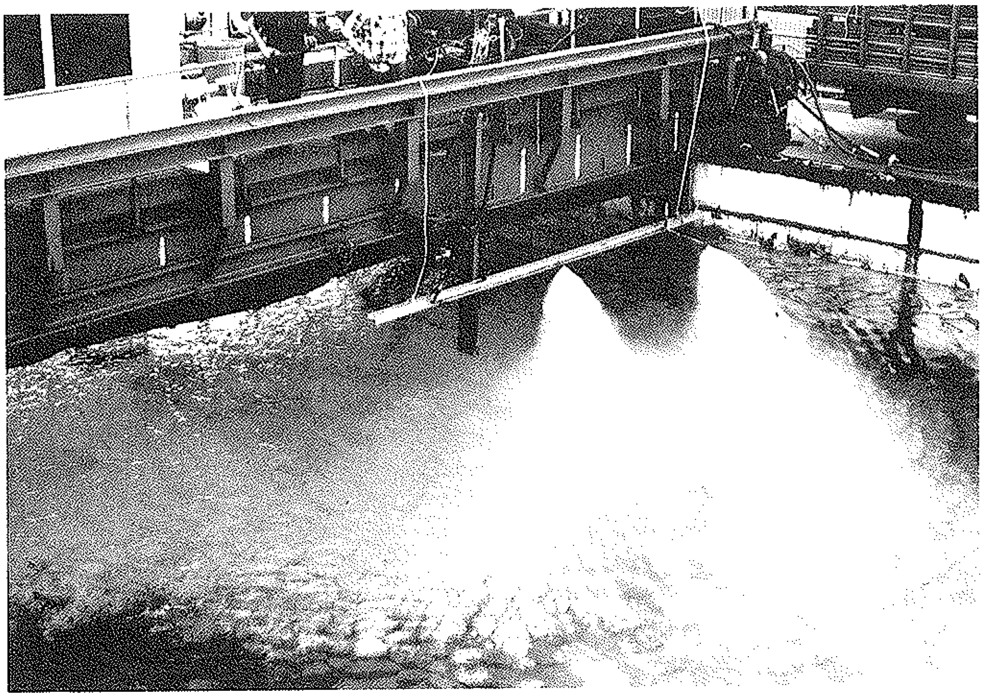

FIGURE 4 OIL DIVERSION TEST

at a pressure of 116,080 kPa, a feature that might well prove useful at a spill scene where cutting or cleaning operations are required.

An uprated 550 horsepower 8-cylinder G.M. Detroit diesel has been selected to drive the pump. It is equipped with spark arrestors, electric start, and an air-cooled exhaust system. The main pump, diesel engine, fuel tank, charging pump and the associated power take-offs and controls are mounted on a rugged steel skid that has oilfield-type rolled ends and lifting hooks. The assembly is 4,267 mm long, 2,134 mm wide, 1,676 mm high and weighs about 6,800 kg. It can therefore be transported by road or Hercules aircraft and operated from the working deck of a Sealander-type vessel, a barge, a supply ship, or from shore.

Two waterjet barriers have been designed, one for restraining floating oil and the other for moving it. Both have opposing pairs of jets arranged in series and mounted on a low, floating platform so that the jets are projected horizontally from origins not more than 30 cm above the surface of the water. One jet in each pair acts on the oil; the other provides the counteracting force that will be adjusted as necessary to advance the barrier or to effect a retreat. A pair of light, flexible hoses supported by buoyancy collars connects each pair of jets to the next pair of the series array. The jets emit a flat spray pattern with uniform droplet distribution and tapered edges.

The oil-restraining barrier jets will be uniformly spaced, about 2.4 m apart initially, pending determination of the optimum spacing during trials. The 15 m supply/tether lines from the pump will be supported by flotation collars and connected to the barrier at its mid-point to form a "T" as depicted in Figure 5. The jets will be directed inwards about 30° towards that intersection and their patterns will overlap to provide a continuous

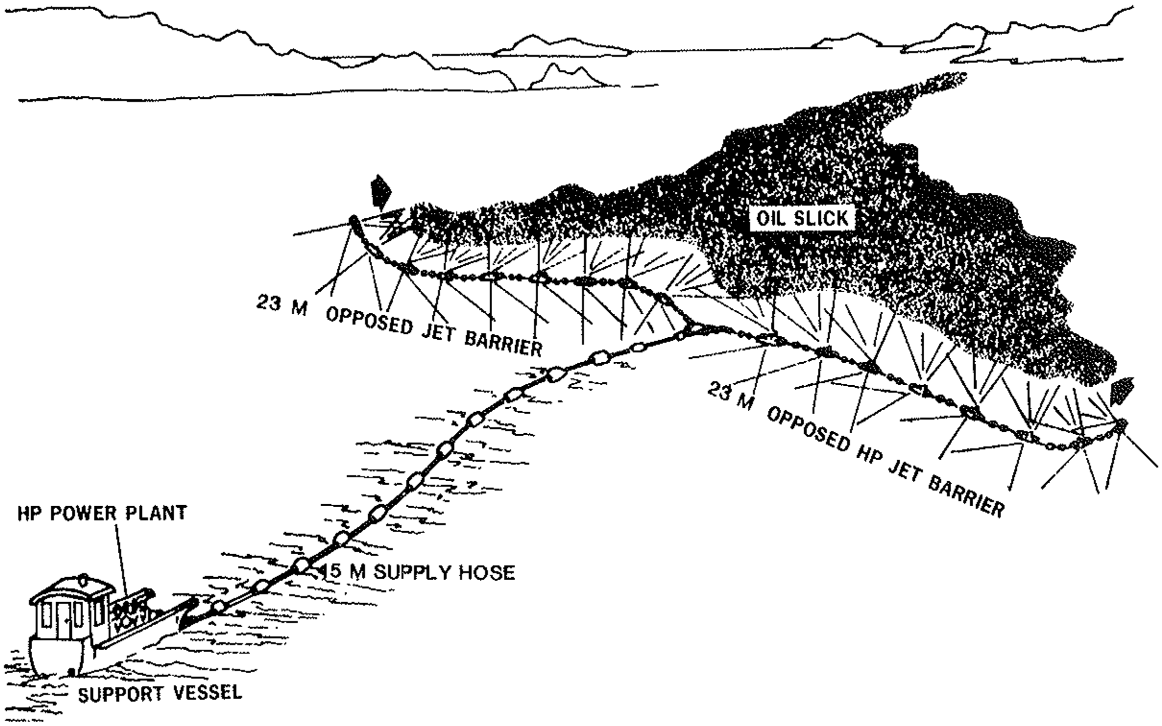

FIGURE 5 OPPOSED-JET BARRIER

barrier. This angling of the jets towards the middle of the barrier also makes it possible to position the barrier laterally by temporarily unbalancing the forces in the opposing arms of the "T". The operator at the pump output controls will thus be able to manoeuvre and shape the barrier without requiring the assistance of other watercraft.

The oil-moving barrier will be supplied/tethered from one end. Its jets, spaced about 4.8 m apart will emit a narrower spray pattern and will be directed so that the centreline of each spray will be at an angle of about 45° towards the tethered end.

EVALUATION PLAN

When this paper was written, a power package was ready for delivery to EPS and action had been initiated to have one of each type of barrier made up. Functional testing is scheduled to begin in the Vancouver area in July 1983. Public demonstrations (without oil) are planned once any "bugs" in the systems have been corrected. Quantified performance testing with oil at OHMSETT could follow by late September 1983, subject to the availability of that facility and the results of the initial functional tests. Other trials would follow until the potential for applying high-pressure waterjet technology to deal with spilled oil has been satisfactorily assessed. Operational evaluations by the Canadian Coast Guard or others would be included. Possible applications currently include:

a) containment for in situ burning with combustion enhancement achieved by the associated water injection and induced air supply;

b) sweeping oil from mud flats and marshes with minimal additional damage;
c) extricating oil from areas of broken ice;
d) conveying oil that is too viscous to pump.

CONCLUSION

The results of the work to date continue to indicate that at least some of the major deficiencies in current spill countermeasures capability might be overcome using high-pressure waterjet technology.

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Cohen, S.H. et al., "Design, Fabrication and Testing of the Air-Jet Oil Boom", U.S. Environmental Protection Agency Report No. EPA-600/7-79-143, (1979).

Smith, G.F. et al., "Summary of U.S. Environmental Protection Agency's OHMSETT Testing, 1974-1979", U.S. Environmental Protection Agency Report No. EPA-600/9-81-007, pp. 286-301, (1981).

BEHAVIOUR OF AND RESPONSE TO A MAJOR OIL SPILL FROM A TANKER IN ARCTIC WATERS

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INTRODUCTION

The search for energy reserves in the Arctic has experienced rapid growth since the 1970s. Oil has been found in the southern Beaufort Sea and reserves of natural gas have been found in the western high Arctic at Melville Island.

Exploratory drilling for oil in several parts of the Canadian Arctic is also actively being pursued. Shipment of these commercial resources could be accomplished by large Arctic Class vessels. The advent of year-round shipping in the North creates the potential for accidents and the release of hydrocarbons into the environment. Of primary concern is the transport of crude oils by tanker.

This paper presents a review of techniques available to respond to a major oil spill from a tanker in Canadian Arctic waters. The size of potential oil releases and the behaviour of the spilled oil in a range of Arctic environmental conditions are discussed. Also included is a survey of the applicability of conventional countermeasures to a northern tanker accident. The use of igniters to burn oil contained by a complete ice cover is analyzed, and potential on-board self-help spill control and cleanup techniques for proposed Arctic tankers are reviewed. Finally, conclusions are drawn regarding the state-of-the art, and recommended actions are presented.

ACCIDENT SCENARIOS

A recent study of the risk of oil spills from Arctic tankers travelling along the route indicated in Figure 1 concluded that the Arctic tankers would have a safety factor 120 to 160 times greater than that of a conventional tanker operating on a southern Canadian route (Bercha, 1981). Table 1 shows the distribution of projected Arctic tanker accidents.

Each of the accident types involves a crack or hole in a cargo tank. These breaches can occur above the waterline, at the waterline, in the side below the waterline, and in the bottom. For the purposes of this paper, cargo tank hole sizes of 5, 0.5 and 0.1 m^2 were considered. The 5 m^2 case represents a worst plausible case in the event of a severe impact or grounding, while the 0.5 and 0.1 m^2 cases represent the probable size of cracks in the cargo tank resulting from an accident. Figure 2 illustrates the location of the breach in the cargo tank and the fate of the oil as it leaks out.

The chosen hole sizes are small in comparison with those recorded for historical tanker accidents. Webb Institute (1974) has shown that about 60% of past conventional tanker collisions resulted in perforations greater than 4 m and that 40% were greater than 6 m (the distance between the inner and outer hulls of the proposed Arctic tankers). They were selected because of the strength of the proposed Arctic tankers and the existence of a double hull. A U.S. Coast Guard study (Card, 1975) indicates that a double bottom with

TABLE 1 ARCTIC TANKER ACCIDENT TYPES
(adapted from Bercha,1981)

Accident Type	Percent of Total
Collision	5.6
Explosion	0.04
Grounding	58.8
Iceberg Collision	0.3
Ramming	4.4
Structural Failure	32.4
TOTAL	100.0

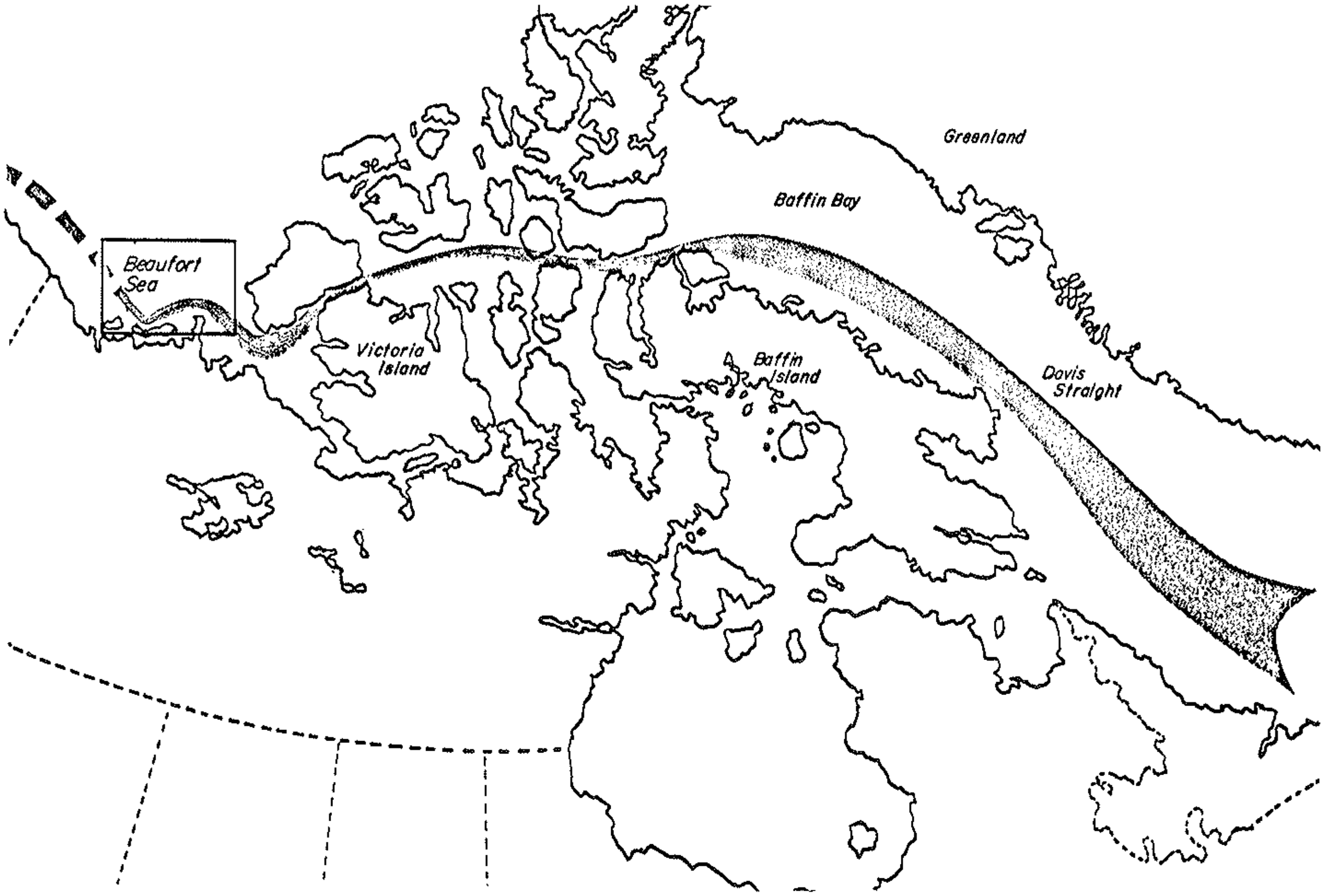


FIGURE 1 PROPOSED ARCTIC TANKER ROUTES

the depth of the one proposed for the Arctic tankers would reduce the number of oil spill-related grounding incidents by 90%.

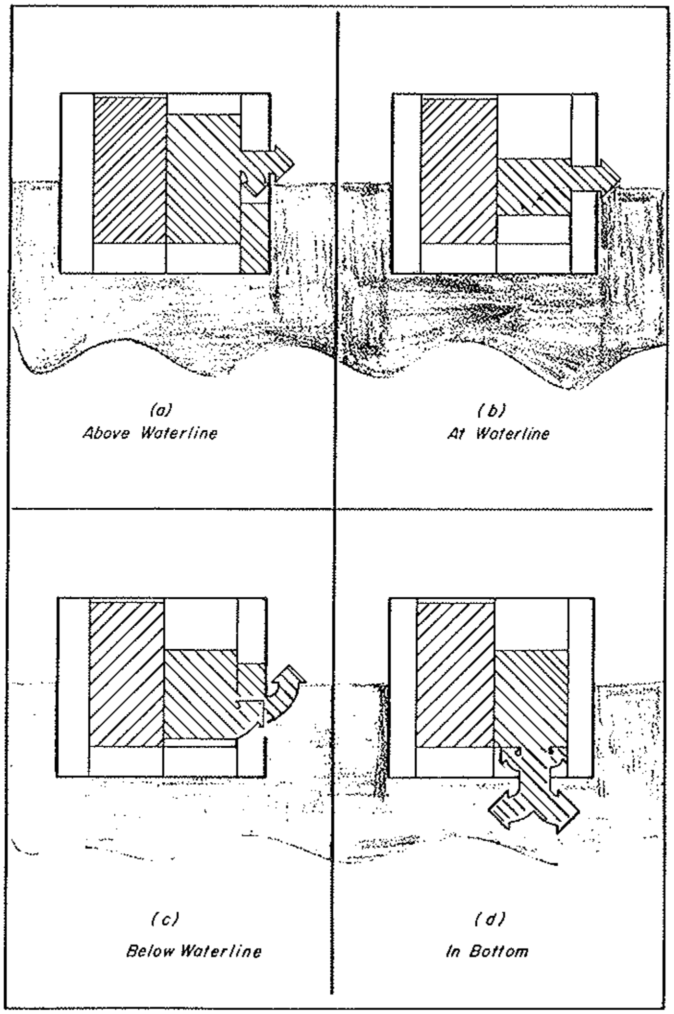


FIGURE 2 POSSIBLE TANK BREACH LOCATIONS AND FATE OF OIL WITH NO COUNTERMEASURES

Oil Outflow

The driving force for oil leakage from a holed tank can be characterized as having two distinct regimes: the pressure difference across the tank wall and the buoyancy of oil in water. The former predominates immediately after the holing of a tank; the latter predominates once the pressure difference across the hole drops below 0.01 P_{ATM} (Dodge et al., 1980). For holes in the tank side below the waterline (Figure 2), water will be ingested into the tank through the hole, driven by the difference in density of oil and water. The process can be viewed as a streamtube of water flowing into the tank, floating the oil up, and resulting in a streamtube of oil flowing out of the tank. The oil and water flows share the area of the hole, with the volumetric inflow of water equalling the volumetric outflow of oil. This process continues until the water levels reaches the top of the puncture.

For holes above the waterline in sealed tanks, air is ingested into the tank when the pressure difference drops to 0.01 P_{ATM}; the outflow continues as the ingested air increases the pressure in the ullage space (Figure 2). This continues until the level of the oil drops to the bottom of the puncture. For holes in the bottom, the outflow continues until the pressures are equal inside the tank at the puncture point.

In terms of total volume of oil lost, the worst case is a hole in the side of the cargo tank at the waterline. In this instance, the entire contents of the tank will be lost. Figure 3 shows the results for a waterline hole in a cargo tank of a 200,000 dwt tanker, and Figure 4 presents the oil outflow rate as a function of time. Much of the oil loss occurs in the first few minutes and hours after the accident occurs. The flowrate declines steadily with time until the water ingestion process starts. From this point on, the flowrate is constant until all the oil has escaped.

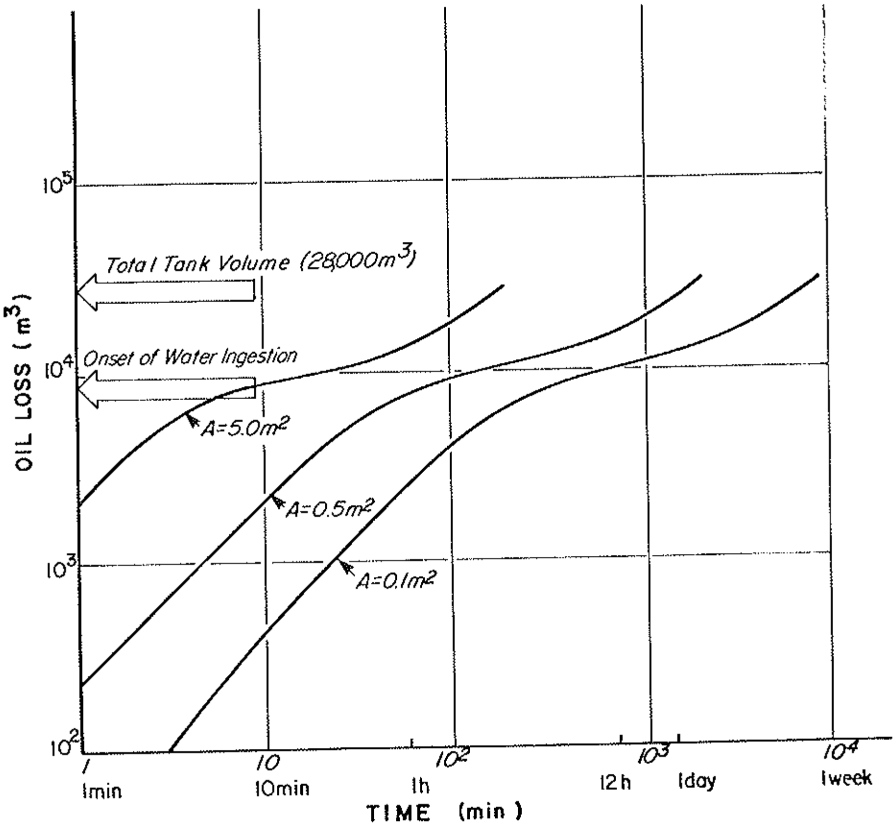


FIGURE 3 OIL RELEASE SCENARIOS FOR A 200,000 DWT TANKER WITH A HOLE AT THE WATERLINE (tank fully vented)

Figure 5 illustrates the oil loss characteristics of a puncture in a 200,000 dwt tanker 5 m above the waterline. As compared to the case of a hole at the waterline, the total volume of oil lost is considerably reduced since the process of water ingestion does not take place. A large diameter hole releases more oil than a smaller hole, as the oil drains to the bottom of the puncture. The characteristic rapid loss of oil from a large hole compared

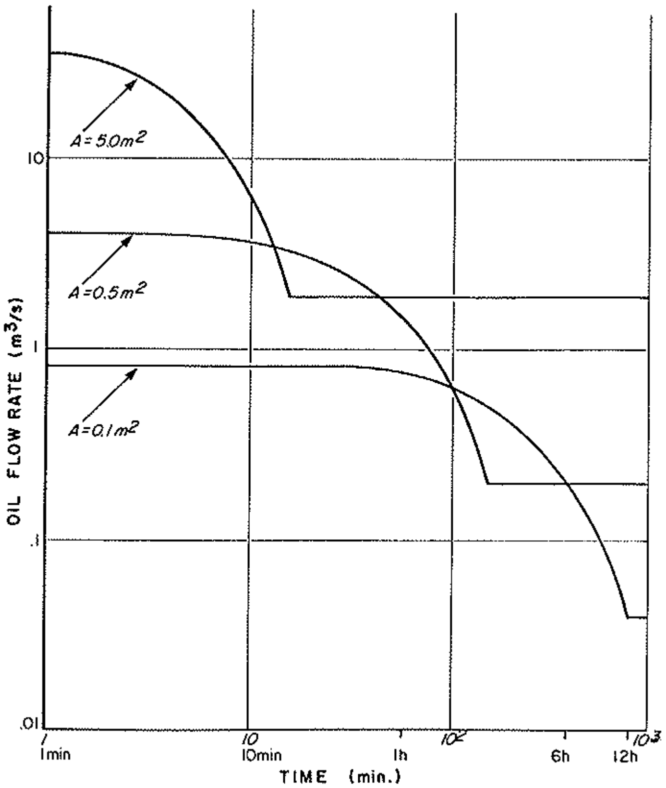


FIGURE 4 OIL OUTFLOW RATES FROM A 200,000 DWT TANKER WITH A HOLE AT THE WATERLINE (tank fully vented)

to the slower loss from smaller holes is evident. The effect of the distance of the hole from the waterline on the total oil volume lost is illustrated in Figure 6.

The trajectory of the oil released from a hole above the waterline can be calculated by comparing the oil discharge velocity with the acceleration of the oil stream due to gravity (Ashworth, 1982). The results of such an analysis (Figure 7) indicate that, providing the wing ballast tank is not flooded, the oil will be contained within the wing tank. The holding capacity of the wing tank (in excess of 24,000 m^3 below the waterline) is more than sufficient to hold the volume of oil released.

Figure 8 shows the effect of the depth of a hole below the waterline on the total volume of oil lost from the tank for a 200,000 dwt tanker. The initial outflow characteristics are almost identical to those of a hole at the waterline. The differences are that water ingestion commences sooner (due to the difference in oil and water density) and ends earlier (the water reaches the top of the hole sooner) in the case of a hole below the waterline. The decreasing volume of oil lost with increasing depth of the hole is due to the volume of oil contained in the tank between the equilibrium oil height and the top of the hole.

Also shown on Figure 8 is the holding capacity of the wing tank. If the cargo tank is punctured, the oil will first displace the water in the upper portion of the flooded wing

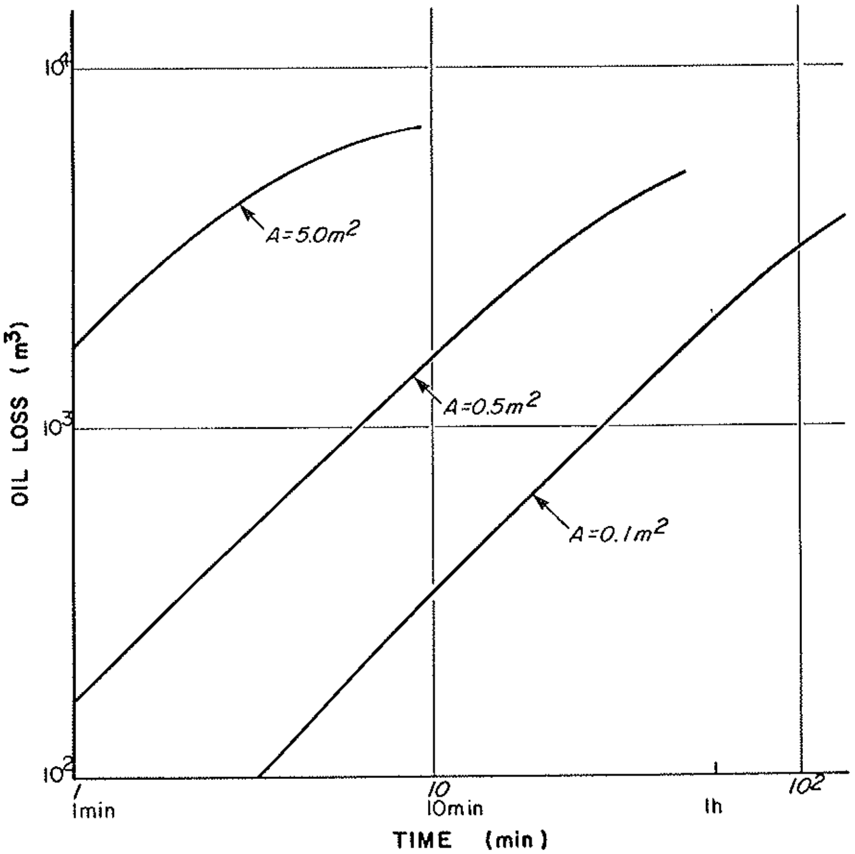


FIGURE 5 OIL RELEASE FROM A 200,000 DWT TANKER PUNCTURED 5 m ABOVE THE WATERLINE (tank fully vented)

tank. Once the level of oil in the wing tank reaches the level of the hole in the outer hull, it will begin to leak from there to the sea. Only for holes between the waterline and about 10 m depth will oil be released to sea.

A hole in the bottom of a cargo tank would release some 6,400 m^3 of oil. Based on the results of scale-model tests done for Dome Petroleum (Arctic Offshore Design Ltd., undated), 5,600 m^3 (87.5%) of this oil would be released to the sea and 800 m^3 would be retained in the double bottom. The initial outflow rates would essentially be identical to those for the case of a waterline puncture.

Environmental Conditions

The proposed route for the tankers through the Canadian Arctic from the Beaufort Sea to eastern markets is depicted in Figure 1. Since the tankers are to be designed for year-round use, a wide range of environmental conditions must be considered when evaluating oil spill countermeasures. In this study, four sets of environmental conditions have been specified and are delineated in Table 2.

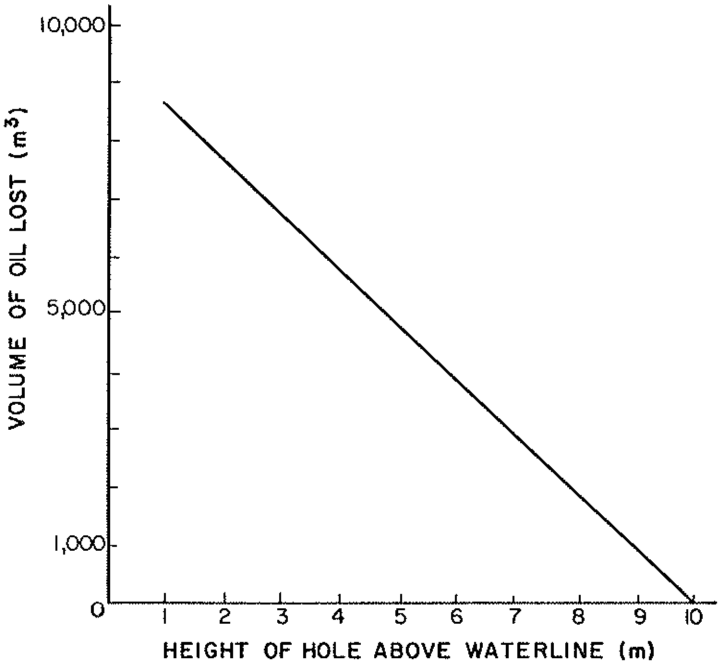


FIGURE 6 EFFECT OF HEIGHT OF HOLE ABOVE WATERLINE FOR A 200,000 DWT TANKER (A = 0.5 m^2, tank fully vented)

In calm, open water conditions, the major short-term processes dominating the behaviour of the oil will be spreading, advection and evaporation. Figure 9 illustrates the approximate spread of the oil released from 5, 0.5 and 0.1 m^2 holes at the waterline in a stationary 200,000 dwt Arctic tanker. (The spreading curves assume a crude oil with average spreading properties. They were derived using equations developed by Mackay et al. (1980). If the ship is considered to steam on, the spreading rates would be somewhat greater and would depend on the ship's speed.) Figure 10 shows the corresponding average slick thickness for each of the hole sizes. In the case of the nearly instantaneous release from a large hole, the initial condition is a very thick (40 mm) slick covering an area of some 0.5 km^2. After 48 hours, the slick area has increased to some 30 km^2, with an average thickness of 1 mm. At this time, 80 to 90% of the area consists of thin sheens 1 to 10 µm thick, and 10 to 20% consists of thick patches 1 to 10 mm thick (Mackay et al., 1980).

The slick(s) will move away from the release point at the speed of the current. After 24 hours exposure on the sea surface, up to 20% of the original volume will have evaporated. In the prevailing seas, no significant natural dispersion or emulsification takes place.

In rough, open water conditions, the oil spreading would be approximately the same as in the calm water case; however, the fate oil is dominated by the high sea state. Evaporation of the light oil components is enhanced, resulting in a loss of up to 30% of the initial oil volume in 24 hours. The processes of dispersion and emulsification are also important in these rough seas. After 24 hours, 20% of the oil is assumed to disperse naturally. During this period, the oil also forms increasing amounts of stable water-in-oil

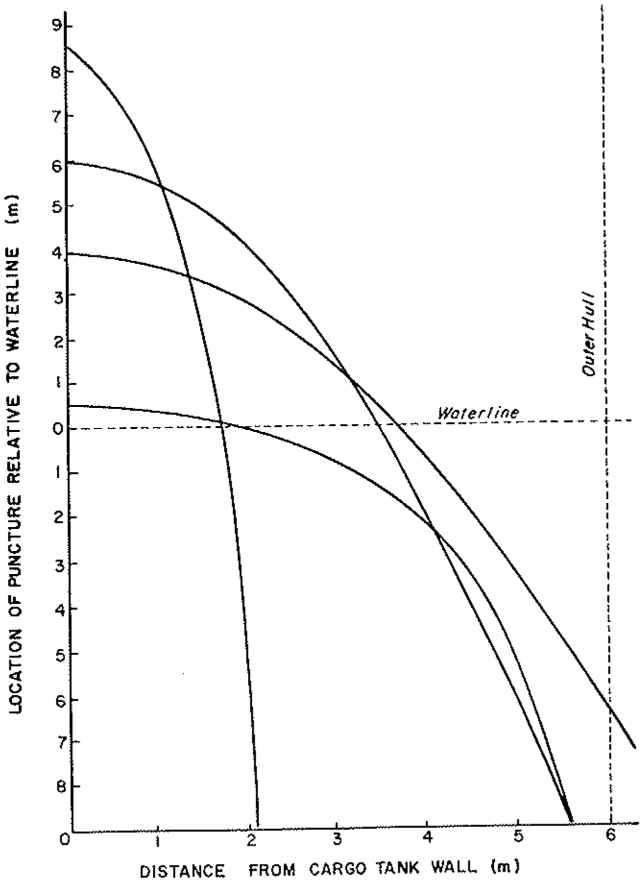


FIGURE 7 INITIAL TRAJECTORY OF ABOVE WATER PUNCTURES (200,000 dwt tanker, tank fully vented)

emulsion, and natural dispersion eventually ceases. The emulsion is extremely viscous and contains 60 to 80% water.

Oil spilled onto ice will spread due to gravity forces only (McMinn, 1974). The area the spill covers is dependent on the surface roughness of the ice. The maximum area covered by a 28,000 m^3 spill would be 1 km^2, with an average thickness of 3 cm. The oil would weather slowly due to the thick slick and cold temperatures. Blowing snow would eventually bury much of the oil.

Oil spilled in ice would leak into the ship's track as the tanker continues on. The average thickness of the oil along the track is shown in Figure 11. In the case of the 5 m^2 hole, all the oil would be contained in the track in thicknesses greater than 1 cm. The oil thickness drops below 1 mm after 24 km in the case of the 0.5 m^2 hole and after 56 km in the case of the 0.1 m^2 hole.

Oil spilled from the tanker beneath the ice will spread until it reaches its equilibrium thickness. In the absence of ridge keels, rubble fields and multi-year ice features, the oil coverage will range from a minimum of 0.025 m^3/m^2 (NORCOR, 1975) to a maximum of 0.1 m^3/m^2. The 28,000 m^3 spill with an average coverage of 0.06 m^3/m^2 results in the

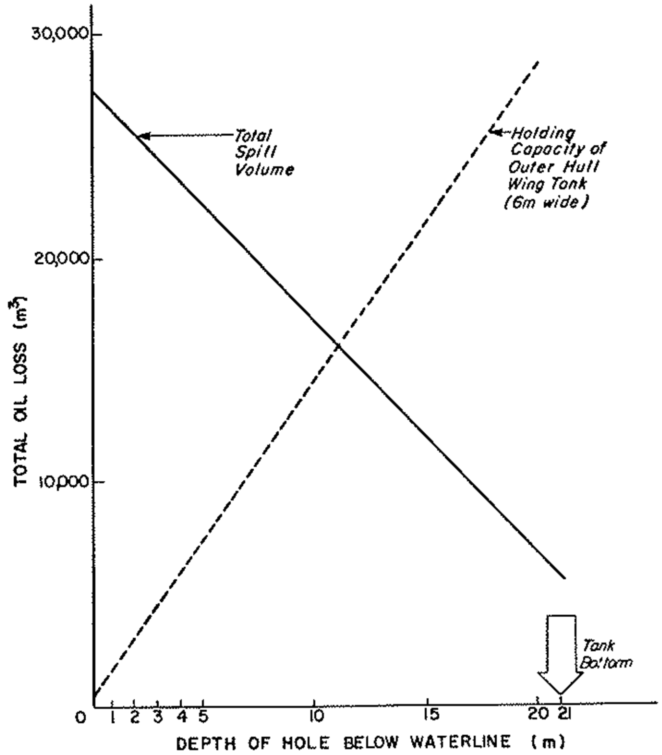


FIGURE 8 EFFECT OF HOLE POSITION BELOW WATERLINE (200,000 dwt tanker, $A = 0.5\ m^2$, tank fully vented)

TABLE 2 ENVIRONMENTAL CONDITIONS (adapted from Ross, 1982)

Type	Ice	Waves (m)	Currents (m/s)	Water Temp. (°C)	Air Temp. (°C)	Daylight (h)
Open Water - Calm	None	<1.5	<0.4	5	5	16-21
Open Water - Storm	Bergs	>3	>1	2	-20	6-9
Winter Ice	6/10 1st year 2 m thick, 4/10 multi-year 3 m thick, 1 ridge/km	None	0.05	-1	-30	10
Ice Floes	6/10 floes up to 5 km dia., 15-25 km/day drift	None	0.3	0	-10	24

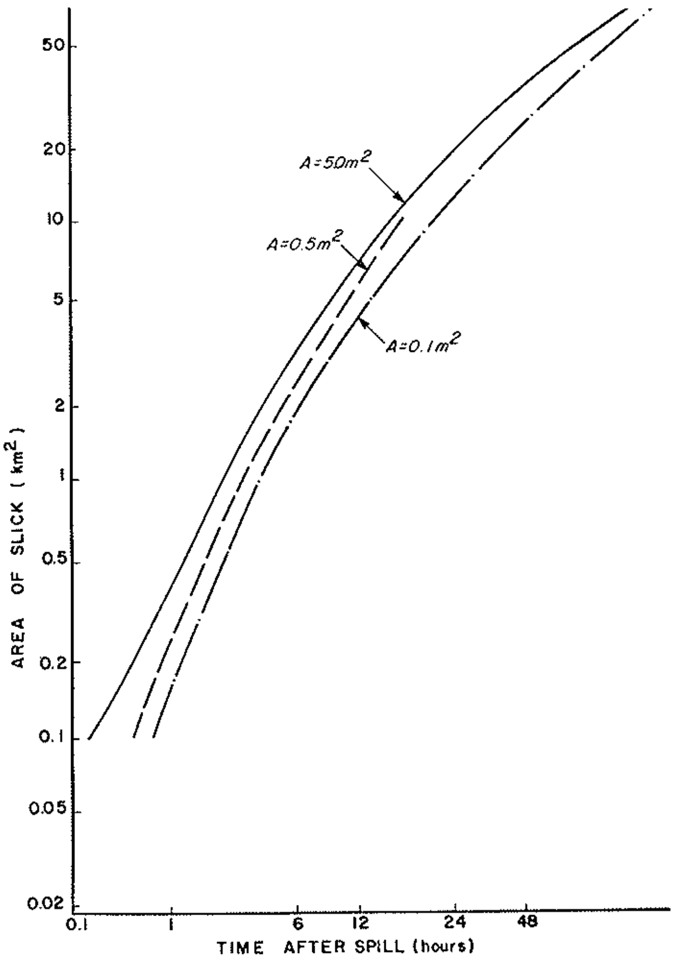


FIGURE 9 OIL SPREADING ON OPEN WATER FROM A HOLE AT THE WATERLINE (tank fully vented)

oiling of an area 0.5 km^2 in size. The oil will be encapsulated by the growing ice within a week and will not weather significantly.

Oil spilled on water amongst moving ice floes will spread as it would in the open water case. Evaporation will be the dominant weathering process and will result in the loss of 30% of the original oil volume after 48 hours. The oil will move away from the release point at a speed of 1 km/h and will be distributed amongst the ice floes. In the absence of waves and high currents, no oil will be carried beneath ice floes; however, oil slicks herded against floes will exceed 1 cm in thickness (Energetex, 1981).

REVIEW OF CONVENTIONAL LAND-BASED COUNTERMEASURES

The generally accepted strategies for dealing with an oil spill from a tanker utilize various combinations of the following basic procedures:

a) stopping the discharge;

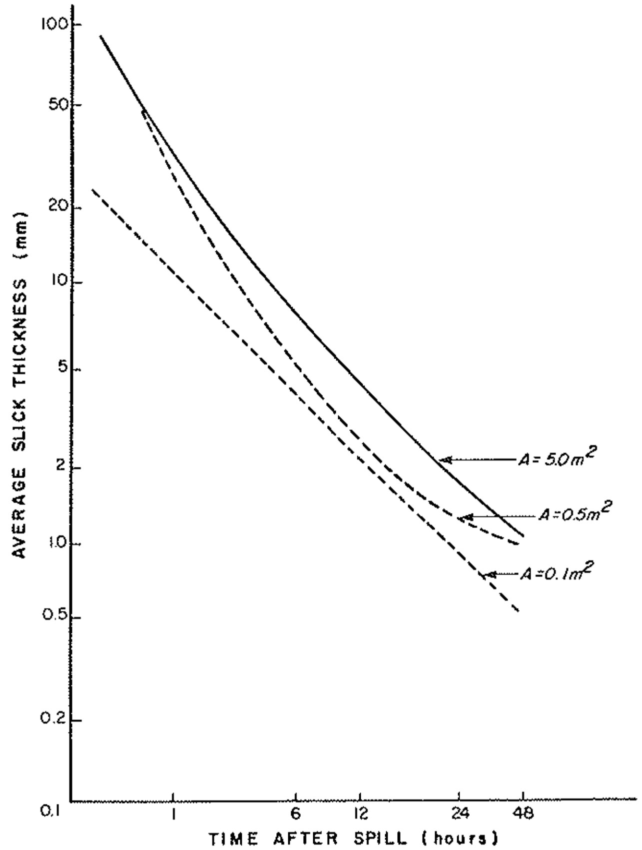


FIGURE 10 AVERAGE SLICK THICKNESS

b) containment of any released oil either on the open water or after shore contact;
c) mechanical removal of contained oil;
d) combustion of contained oil;
e) chemical dispersion of free-floating oil;
f) disposal of collected oil and oiled debris;
g) monitoring and surveillance of free-floating oil;
h) shoreline cleanup and restoration.

Specialized equipment and techniques have been developed for these operations based primarily on conditions more temperate than those experienced in the Arctic. Several programs have been underway in Canada and elsewhere to modify this equipment to meet the needs of the northern application, or to develop new technologies. A review of the present state-of-the-technology in each of the above control areas was the subject of the first of a series of reports on tanker spill countermeasures in the Arctic (Ross, 1982). The second and third reports dealt with the use of air-deployable igniters for spills in ice (Ross, 1983a) and on-board self-help countermeasures for Arctic tankers (Ross, 1983b).

The report on conventional land-based countermeasures systems provides a very detailed review and analysis of the problem. The following is a summary of its specific and general findings:

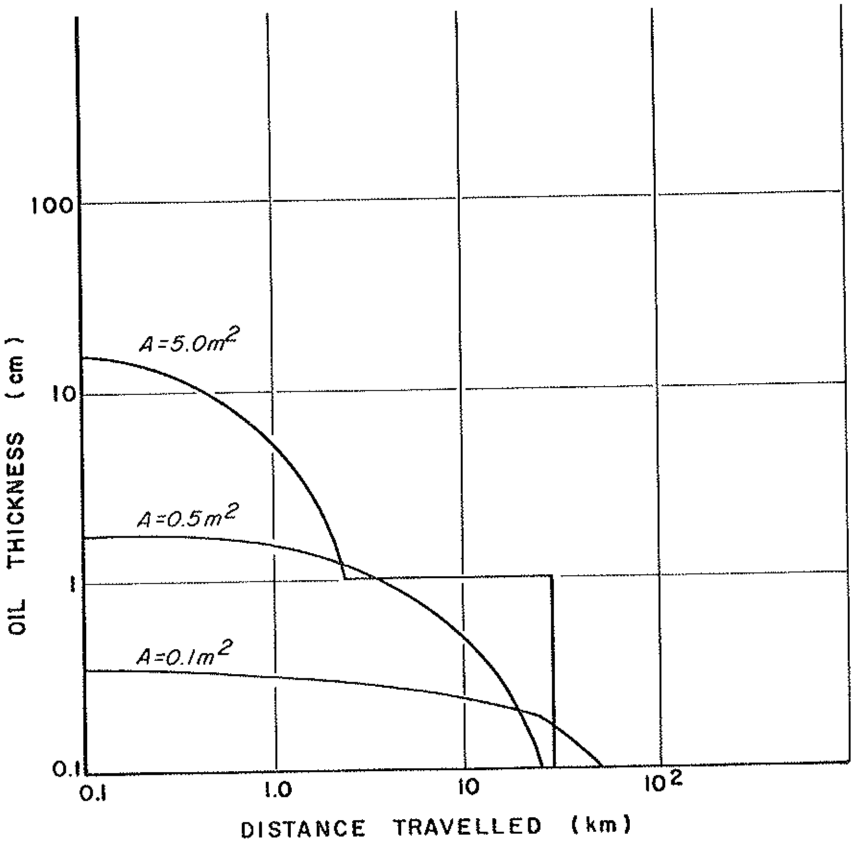


FIGURE 11 OIL THICKNESS IN BROKEN ICE TRACK (spill in ice; tanker continues at 10 km/h; hole at waterline; tank fully vented)

Specific

a) At present, high capacity skimmers are able to handle a maximum of about 150 m^3 of oil per hour. For a large tanker spill, recovery devices which could transfer upwards of 1,000 m^3/h would be needed for a manageable and efficient operation.

b) For existing dispersants to be effective in the North, they must be applied to the oil spill while it is still fresh, generally less than a day after the oil's release. Large aircraft (DC-6 type) and dispersant stockpiles (upwards of 2,500 m^3) would have to be permanently dedicated and manned at strategic locations along the tanker route to accomplish this. The considerable cost of doing this is deemed prohibitive.

c) A high percentage of the oil released from a tanker in a complete ice cover setting could be removed by burning during the spring thaw. Upwards of 20,000 air-deployable incendiary devices would be needed to ignite the oil from a large spill. A stockpile of such a large supply of igniters is not currently available.

d) No proven or tested technology exists which can efficiently remove oil from a partial ice cover setting.

e) In a rough, open water situation, little can be done at-source with present equipment to contain or collect oil released from a tanker accident.

General

The government's technological capability to clean up a major oil spill in the North is not too different from its southern capacity. For both cases, the capability depends strongly on the ocean's surface condition. Open water in the Arctic is often calmer than that in the south due to the North's shorter open water reaches. Containment and collection methods in ice-free situations may therefore be more successful in the North if they can be implemented rapidly. A partial ice cover in northern waters has the potential for mixed effects on an oil removal operation. It may contain the oil sufficiently to allow it to be burned or it may prevent any attempt to artificially contain and mechanically remove the oil. Oil released in a complete ice cover environment is naturally contained and preserved by the ice. The removal of a high percentage of this oil by burning is technically feasible. Under this ice condition, an oil removal operation in the Arctic will be much more effective than one mounted in the open waters of the south.

The above conclusions address the ability of available equipment to remove oil from the northern marine environment assuming that there is no restriction on transporting the equipment and manpower to the site. A northern oil spill cleanup operation, however, has obvious logistical and environmental difficulties which will hamper a countermeasure operation. First, there is a severe lack of local manpower available. Second, land-based transportation is nonexistent; the distances between major southern centres and northern air fields, and between the northern communities and possible spill sites are large. Third, the accommodation and servicing of large work forces in the North will be more difficult than in the southern regions of Canada. Finally, the Arctic climate can be much more severe than in the south. The technological ability to respond to a northern spill may be equivalent to a southern operation but these additional problems necessitate a much more complex support organization and planning structure.

AIR-DEPLOYABLE IGNITERS

As mentioned previously, one potentially effective technique for dealing with a major oil spill discharged under and into a complete ice cover is to use thousands of igniters to burn the oil when it appears in melt pools on the ice surface during the spring thaw. In order to determine the exact requirements for such an operation resulting from a tanker spill in the Arctic, a study of the numbers of igniters, their production, supply, and deployment was undertaken (Ross, 1983a). Two igniters were considered in the study: that developed by Energetex for Dome Petroleum (Energetex, 1982), and that developed by the Defence Research Establishment at Val Cartier (DREV) for Environment Canada (Meikle, 1981).

A large release of oil from a stationary tanker would require about 40 igniters per hectare of oiled ice for an effective burning operation. For a substantial discharge of oil from a moving tanker, about 15 igniters per hectare would be needed to burn the major oil pools. Therefore, based on the spill scenarios selected for the study, about 2,500 igniters would be needed to burn the oil from a large stationary tanker spill. Up to 30,000 igniters could be needed to ignite the oil from a large release of oil from a moving tanker. Three igniter requirement scenarios were investigated:

No. 1 - 2,500 required in 3 months;
No. 2 - 30,000 required for a stockpile to be ready in 5 years;
No. 3 - 30,000 required in 5 months.

The acquisiton of the necessary chemicals for the igniter production would likely take 2 to 3 months. Hardware items could have similar supply delays. Unless these raw items were stockpiled at the buyer's expense, production of igniters could only commence 2 to 3 months after an order was placed. Once the materials were on hand, the limiting steps in the production process would be the mixing and curing stages of the formulation process for solid rocket propellant. The specialized mixtures used in this process are small; therefore, significant time would be needed to produce large quantities of igniters (i.e., 30,000). Since the Dome igniter uses much less of this fuel, it could generally be produced at a higher rate than the DREV unit. Of the ten manufacturers surveyed, a maximum production of 6,000 units (Dome) per month was identified as possible once raw materials were on hand (3,000/month for the DREV). All of the potential manufacturers, except for one, would require that a pre-production run be funded anywhere from 3 to 12 months prior to the first full-scale production order.

The predicted cost of the igniters varied with the manufacturer and with the scenario. The Dome igniter would be generally less expensive to produce. Under the rushed demand of production scenario No. 1, the cost of the Dome igniter ranged from $65 to $67 per unit. The DREV igniter would cost between $72 and $113. For production scenario no. 2, the Dome version would cost between $40 and $65, and the DREV between $54 and $112. A similar cost breakdown for production scenario No. 3 could be expected. Only one potential manufacturer indicated a significant price reduction for higher production situations.

Because of the raw material supply delays and limited production rates, a short-term supply of even 2,500 igniters was found to not be possible. Igniters would therefore have to be stockpiled to handle any major spill which occurs late in the winter (i.e., up to 3 to 4 months prior to breakup). The 30,000 igniters needed for an oil release from a moving tanker could not be made by any one manufacturer even if it occurred very early in the year and 8 months were available to produce the units. The stockpiling of igniters would seem to be the only way to ensure that sufficient igniters are available for cleanup in the spring.

The Arctic settlements in the North considered suitable for land-based operations along the proposed shipping route are Frobisher Bay, Broughton Island, Cape Dyer, Clyde River, Pond Inlet, Nanisivik, Resolute Bay, Rea Point, Johnson Point, Inuvik, Cape Parry, McKinley Bay, and Tuktoyaktuk. The larger of these settlements would serve as intermediate links between the south and the small settlements near the spill site.

While land and sea shipment of igniters would pose no difficulties, both methods are relatively slow and seasonal; land access is available only to the southern Beaufort Sea area. Chartered cargo aircraft would be the only viable shipment mode for the expeditious movement of igniters from the south to northern spill sites.

The major drawback of a land-based helicopter operation would be the transit time to and from the spill site. The available flight time of suitable helicopters limits the time which could be used for the actual igniter deployment. The shipping lanes off Baffin Island are very far offshore; most helicopters do not have the range to fly a sortie to these locations. Depending on the accident location and the size of the spill, from one to more than five helicopters may be needed to deliver the igniters to the spill site during a spring operation.

Since the igniters would be dropped during the spring melt, the prevailing environmental conditions should not hamper the operation excessively. Sufficient daylight would be available at this time of the year (from 18 to 24 hours) and the probability of good flight conditions is high (70% to 80%).

ON-BOARD SELF-HELP COUNTERMEASURES

The effectiveness of any oil spill countermeasures operation is enhanced by a quick response. This is particularly true for tanker accidents in remote areas. With this in mind, a study was performed (Ross, 1983b) to investigate the feasibility of fighting a tanker spill using various techniques and equipment on board the tanker to greatly reduce or even eliminate the potential impacts of the spill.

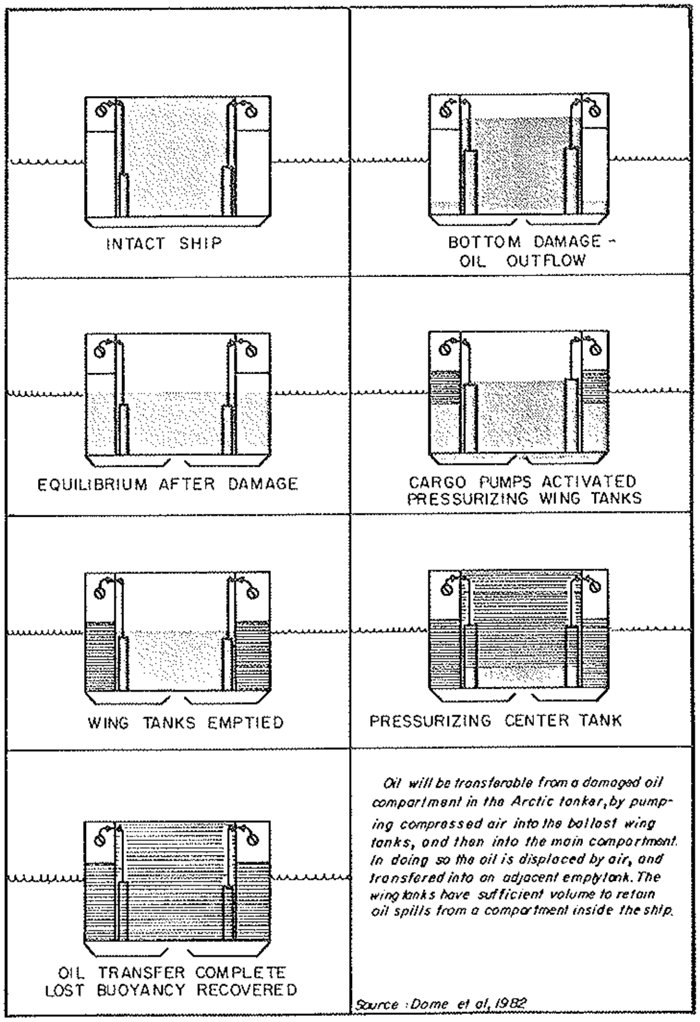
The unique design of the proposed Arctic Class tankers offers the possibility of equipping the vessel with novel systems for oil spill response. These systems can be placed in two categories: "inboard" countermeasures, to reduce oil losses from cargo tanks in the event of an accident, and "outboard" countermeasures, to deal with oil once it has escaped the confines of the tanker.

In-Board Countermeasures

Two previous studies (Arctic Offshore Design Ltd., undated; Aaegesen, 1982) have assessed the feasibility and efficiency of reducing oil loss by restricting the flow of air into the ullage space after the tank bottom is ruptured. Based on model studies (Arctic Offshore Design Ltd., undated), Dome Petroleum has proposed a scheme for the tankers to reduce oil outflow (Figure 12).

The principle by which restricted tank venting operates is as follows. When the damage occurs, the level of oil in the tank begins to drop, thus creating a partial vacuum in the ullage space. If the suction of air into the ullage space is restricted or not permitted, the total pressure head driving the oil outflow is reduced and thus the oil flowrate is reduced. The oil outflow ceases when the pressure difference across the hole is zero.

In the case of bottom damage, Table 3 indicates the reduction in outflow from the tank for the case of a fluid with negligible vapour pressure and an ideal gas in the ullage space. The process is assumed to be isothermal. With the tank vents closed instantaneously, only some 550 m^3, or less than 10% of the potential volume, will be released. Based on the Dome model tests, all this oil will be contained by the double bottom. If the vents are not closed instantaneously, more oil will escape. Table 3 also shows the effect of response time on volume of oil lost. Using a minimum delay of 7 min (Aaegesen, 1982), it can be seen that in the case of a 5 m^2 hole, the response would be ineffective. In the case of



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 doing so 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.

Source : Dome et al, 1982

FIGURE 12 PROPOSED ARCTIC TANKER SPILL CONTROL SYSTEM

0.5 m^2 hole, only half of the potential spill would be released; for a 0.1 m^2 hole, only a small amount would be released.

Figure 13 illustrates the effect of restricting tank venting on the outflow of oil from a 0.5 m^2 hole in the tank side at the waterline. For the case of the tank partially vented, i.e., kept at a constant partial vacuum by a relief valve (set at 8×10^4 N/m^2 or 12 psia in the example), the outflow is somewhat reduced.

The best reduction is achieved by having the vents closed. After 1 hour, 2,200 m^3 has been lost as opposed to 8,800 m^3 for the unvented tank; in total, 21,000 m^3 are lost as opposed to 29,000 m^3. Due to the process of water ingestion noted previously, restricted tank venting is not as effective in reducing the total amount of oil lost in the case of a hole in the side as it is for a hole in the bottom.

TABLE 3 EFFECT OF CLOSING TANK VENTS ON OIL LOSS FROM BOTTOM DAMAGE

Time to Close Vents (min)			Oil Lost	
5 m^2 hole	0.5 m^2 hole	0.1 m^2 hole	(m^3)	(% of potential)
0	0	0	550	8.6
0.4	4	21	1 970	30.8
0.9	8.6	43	3 020	47.2
1.3	13.4	67	3 880	60.6
1.9	19	93	4 660	72.8
2.4	24	121	5 510	86.1
3.1	31	152	6 260	97.8
3.8	38	190	6 400	100.0

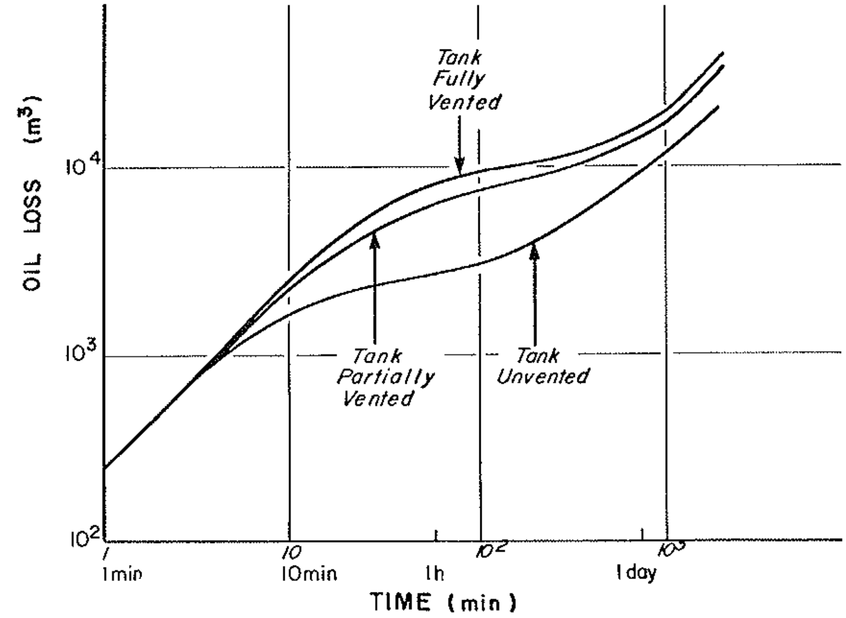


FIGURE 13 EFFECT OF TANK VENTING ON OIL LOSS FROM A 200,000 DWT TANKER WITH A 0.5 m^2 HOLE AT THE WATERLINE

Figure 14 illustrates the effect of tank venting on the loss of oil through a 0.5 m^2 hole in the tank side above the waterline. It can be seen that restricting the tank vents reduces the oil outflow rate, though the total volume lost is the same in all cases. Again, complete instantaneous sealing of the tank vents is the most effective.

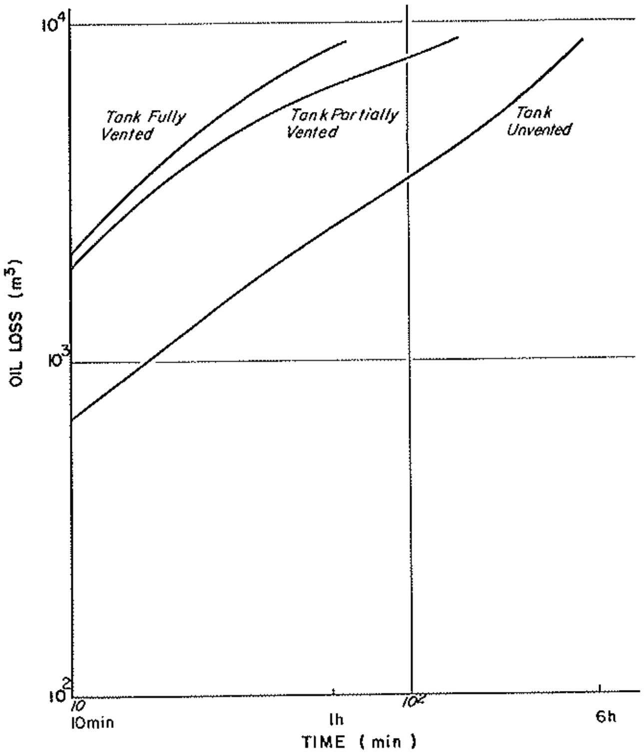


FIGURE 14 EFFECT OF TANK VENTING ON OIL LOSS FROM A 200,000 DWT TANKER WITH A 0.5 m^2 HOLE 1 m ABOVE THE WATERLINE

Pumps (installed or portable) on board a stricken tanker have two potential uses: pumping oil contained in bottom and wing tanks, and from damaged cargo tanks. The Arctic tanker has one major advantage over most conventional tankers: a large volume of unused ballast space. The 200,000 dwt version has about 155,000 m^3 of storage in the wing and bottom tanks alone. Even fully loaded, the loss of the buoyancy of two adjacent ballast tanks within the double hull would not affect the stability of the tanker (Dome et al., 1982). As such, the Arctic tankers need not wait for the arrival of a lightering vessel before commencing preventive emergency oil pumping.

In the event of bottom damage to an Arctic tanker, Dome has devised a system (Figure 12) for recovering the lost oil. This system combines restricted venting of the cargo tank to reduce oil flow out of the confines of the double hull, and the use of compressed air and deepwell cargo pumps to remove the oil to undamaged ballast tanks. This countermeasure will greatly reduce, if not eliminate, the oil lost due to bottom damage. The system, however, will not work in the case of a hole in the side of the ship. In this instance, the water ingested into the tank settles to the tank bottom to a level above the cargo pump suction.

Figure 15 shows the effect on total oil lost of emergency pumping from the cargo tank using a portable pump. In this instance, it is assumed that the hole is at the waterline, the pumping begins instantaneously, and the tank vents are wide open. It can be seen that, although relatively ineffective for the case of a large hole at the waterline, emergency pumping can be very effective in reducing the oil outflow from a tank with smaller holes.

Figure 16 shows the effect of response time on the effectiveness of pumping. Response time is not a factor in the case of a large hole since pumping alone is not a very effective control technique. It is interesting to note that response delays of up to an hour have only a minor effect on the efficiency of pumping for smaller holes. The price of delaying 1 hour in commencing pumping at 1,000 m^3/h is a decrease in the reduction of total oil outflow from 21,000 to 20,000 m^3 for a 0.1 m^2 hole and 12,000 to 11,000 m^3 for a 0.5 m^2 hole.

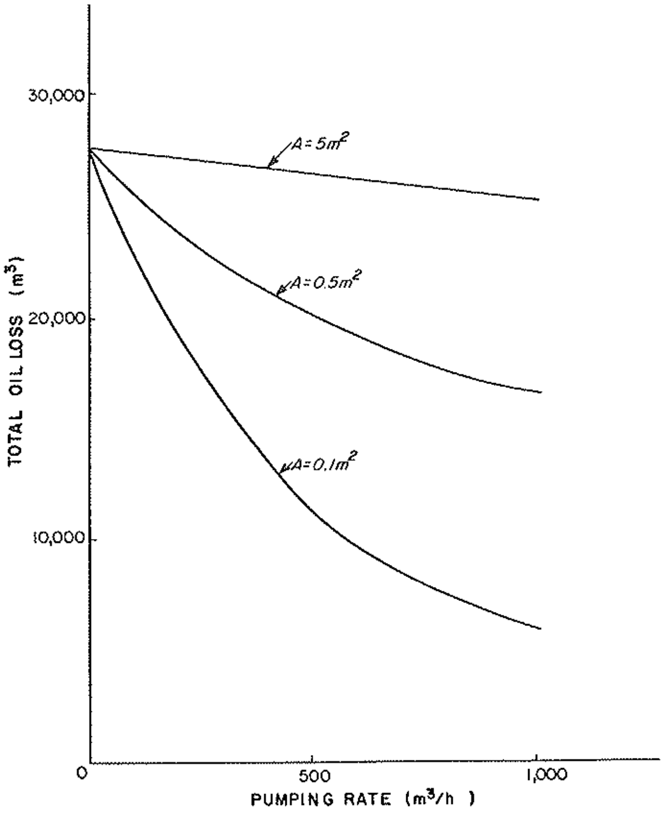


FIGURE 15 EFFECT OF EMERGENCY PUMPING (tank fully vented, hole at waterline)

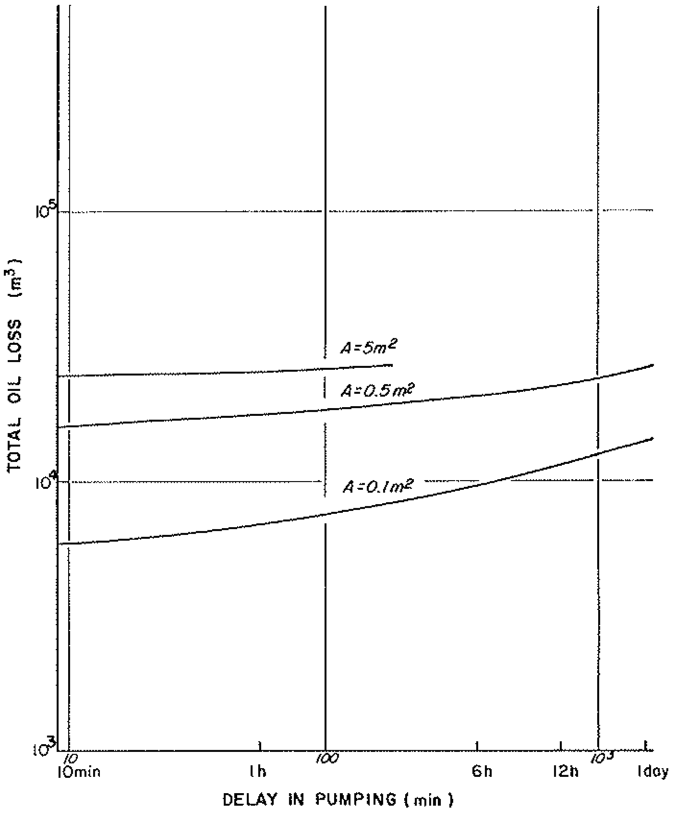


FIGURE 16 EFFECT OF RESPONSE ON EFFECTIVENESS OF EMERGENCY PUMPING (200,000 dwt tanker, hole at waterline, tank fully vented, pumping at 1,000 m^3/h)

In the event of a hole above or below the waterline, oil will be contained within the wing tanks of the vessel (Figure 2). In the case of a hole above the waterline, the vessel's ballast pumps may be able to recover this oil; however, this will not be the case for a hole beneath the waterline. In this instance, the oil will be floating on water inside the wing tank. The use of a portable pump will be required to remove this oil to a safe compartment. In addition, the use of a portable pump in this oil containment area will reduce the outflow of oil from holes less than 10 m below the waterline (Figures 2 and 8), as illustrated in Figure 17. The combination of the containment capacity of the wing tank plus pumping oil at 1,000 m^3/h from inside the wing tank results in considerable reductions in the volume of oil spilled. As before, the efficiency of pumping is greater for small holes than for larger ones.

Although pumping is an extremely effective countermeasure for small holes, it is limited for larger holes. In addition, the time required to deploy portable pumps in the affected tank(s) reduces the effectiveness. In order to significantly reduce the loss of oil, a system is required to quickly transfer large amounts of oil from the affected tank. One proposed concept that meets the above criterion is a semi-automatic dump valve in the cargo tank. This approach, depicted in Figure 18, consists of a large diameter pipe installed on the centreline bulkhead of each tank. The pipe, in this case 1 m diameter, leads from the cargo tank to the bottom ballast tank on the opposite side of the vessel. The pipe is fitted with an automatic one-way valve which is closed in normal operatons. The top of the pipe is located at the waterline to prevent it from being overtopped by water ingested into the tank. In the event of damage, the valve opens and oil begins to pour through the pipe from the tank to the undamaged ballast space. The efficiency of such a system in reducing oil losses from a hole at the waterline is shown in Figure 19. Even for large holes, the volume of oil prevented from entering the sea is considerable.

The use of a dump valve in the case of bottom damage would also be effective. If the tank vents are not sealed, the dump pipe will remove a portion of the oil that would normally be released. If the tank vents are shut, the dump valve will permit hydrostatic equilibrium to be reached sooner and continue to remove oil, building up a water cushion beneath the oil remaining in the affected tank.

The injection of gelling and solidifying agents into a damaged cargo tank is not an effective on-board self-help countermeasure (with the possible exception of the use of fast-acting chemicals to produce a plug) because of the large volumes of chemicals and lengthy mixing times required.

The injection of dispersants into a damaged cargo tank is not an effective on-board self-help countermeasure. The time required for mixing the dispersant and oil in relation to the oil loss rate is inadequate, and the large volume of dispersant required is prohibitive.

The installation of liners or bladders could significantly reduce oil outflow from a cargo tank but their applicability is dependent on tank design and washing procedures. Unless qualified divers with appropriate support facilities are to be stationed on an Arctic tanker, the use of plugs and patches to reduce oil loss from damaged cargo tanks is not considered an effective on-board self-help countermeasure.

Burning oil in cargo tanks is not an effective on-board self-help countermeasure for safety reasons and because of the low oil combustion rate in relation to the oil outflow. However, the use of in situ burning to dispose of oil spilled on, in, or under Arctic sea ice is a well-proven technique (NORCOR, 1975; Dickins and Buist, 1981), and shows good potential as a self-help countermeasure even on open water conditions. Field-proven, air-droppable oil slick igniters suitable for use on Arctic oil spills in ice conditions are commercially available (Meikle, 1981; Energetex, 1982). Table 4 shows the igniter requirements to deal with the various hole sizes, as well as the percentage of the volume

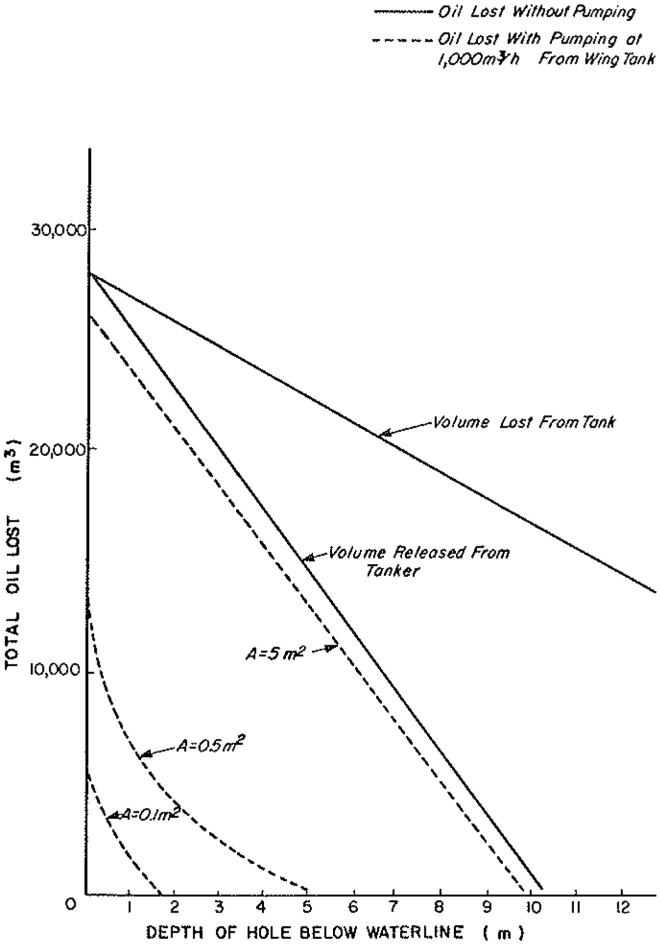


FIGURE 17 EFFICIENCY OF PUMPING FROM WING TANK (200,000 dwt tanker, tank fully vented)

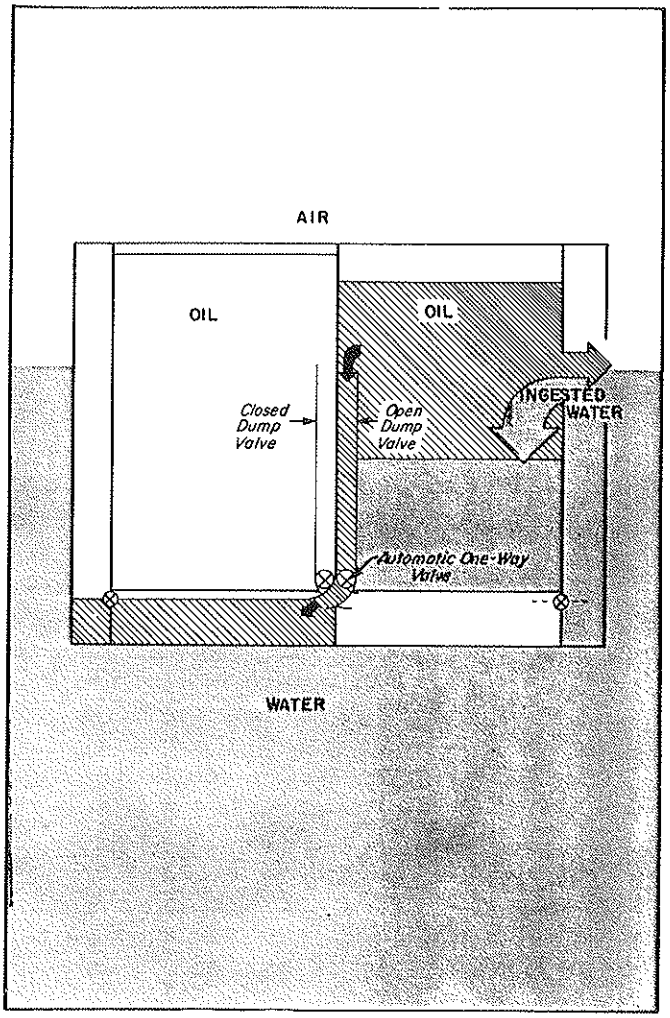


FIGURE 18 DUMP VALVE OPERATION

of spilled oil that lies within the area to be burned. The igniters could be dropped from a small helicopter (Bell 206B) in about 25 sorties or by a medium helicopter (Bell 212) in about 8 sorties (Ross, 1981b). The total time required to accomplish such an operation would depend on flying conditions, daylight, distance from the tanker to the oiled area, and oil pool size and separation. At an average igniter drop rate of 3/min, the actual deployment would require some 28 hours.

It is interesting to note that the number of igniters required almost doubles if the tanker continues on after the accident; the logistics of the igniter deployment operation become more complex. For the most efficient response to an oil spill on or in a complete ice cover, the tanker should remain stationary until the oil outflow ceases. Obviously,

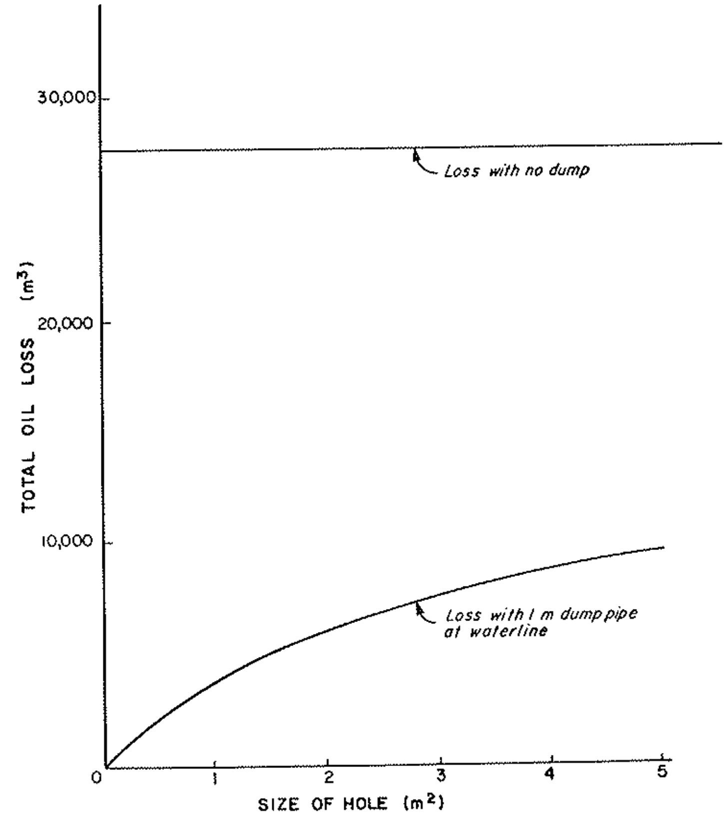


FIGURE 19 EFFECT OF DUMP VALVE (200,000 dwt tanker, tank fully vented, hole at waterline)

TABLE 4 IGNITER REQUIREMENTS FOR A TANKER SPILL IN BROKEN ICE TRACK

	Length of Oiled Track (km)				
Hole Size (m^2)	0.1 m^3/m^2 coverage	0.01 m^3/m^2 coverage	0.001 m^3/m^2 coverage	Burnable Thickness (% of total)	Approximate Number of Igniters
5	1	29	0	100	5,000
0.5	0	12	18	100	4,000
0.1	0	0	50	30	6,000

burning operations should not commence until the vessel has moved a safe distance from the spilled oil.

Even in the case of a spill on open water, in situ burning may be an alternative, though this is not yet a proven concept. There have been cases of tanker accidents where the oil accidentally caught fire and most of the spilled oil was consumed (e.g., Goodier and Siclari, 1981; Horn and Neal, 1981). The combustion process does not seem to be severely affected by regular waves such as a swell, although choppy seas may extinguish the fire (McAllister and Buist, 1981). They key to successful open water in situ combustion is to contain the oil at thicknesses much greater than 1 mm during the burning. An immediate response from the tanker increases the chances for effective open water burning since the slick is thick and the oil fresh; thus, potential combustion efficiency and flame spreading are enhanced.

One approach to containing the oil is to deploy a fireproof barrier around the slick. Although fireproof booms are available (e.g. Buist et al., 1983; Meikle, 1983), the same difficulties in deployment would be faced as noted for conventional containment booms. As such, the use of fireproof booms as an on-board self-help countermeasure is not recommended.

The second approach is simply to set the free-floating slick(s) on fire. This technique has been tried on past tanker spills, with varying success. For small slicks of weathered crude oil or bunker, the oil is difficult to ignite. Also, the combustion is not efficient and leaves behind large volumes of heavy, viscous residue that are difficult to deal with (Thompson et al., 1979). However, in cases where large, thick, slicks of fresh crude oil or light distilled product have ignited, the combustion is intense and much of the oil burns (Horn and Neal, 1981). This would be the case for a burning operation initiated from a holed Arctic tanker shortly after an accident.

Containment and recovery operations (except for small spills in sheltered waters) are not considered effective self-help countermeasures because of the difficulty in deploying equipment from the tanker and the length of time required to recover the oil using best available skimmer technology. The use of dispersants, except for small slicks on open water in the presence of waves, is also considered ineffective, only limited amounts of oil can be treated in the time available prior to increases in oil viscosity beyond the point below which dispersants could be effective. The use of gelling or solidifying agents on slicks is currently precluded because of the large volumes of chemicals required and the difficulties in applying them.

The following systems should be considered for installation on proposed Arctic tankers to reduce oil outflow in the event of an accident:

a) Restricted Tank Venting

- automatic system to seal all tank vents in the event of damage;
- vacuum relief valves on all tank deck vents set point below equilibrium ullage pressure for holed tanks with sealed vents;
- tank structure capable of withstanding partial vacuum;
- pressure sensor system to control inert gas topping up system.

b) Dump Valve

- large diameter pipe mounted on centreline bulkhead of each cargo tank leading to bottom ballast tank(s);
- semi-automatic valve controlled from bridge to be opened in the event of tank damage.

c) Emergency Pumps

- self-powered portable pumps capable of being inserted into cargo and wing-ballast tanks;
- 1,000 m^3/h capacity with hose and booster pump capable of discharging oil into any other tank on vessel or to another vessel;
- special airlock to permit insertion of pump into cargo tank under partial vacuum;
- portable, self-powered inert gas generator;
- oil monitoring system for wing-ballast tanks.

The potential spill reduction of such a system is illustrated in Figure 20.

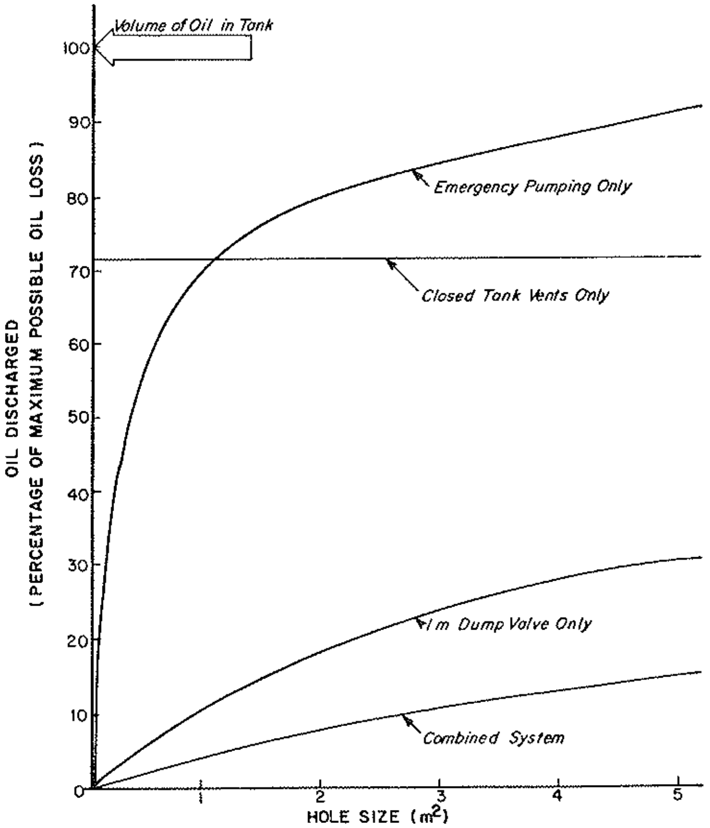


FIGURE 20 COMBINED EFFECTIVENESS OF IN-BOARD COUNTERMEASURES (200,000 dwt tanker, restricted tank venting, 1 m diameter dump valve, 1,000 m^3/h emergency pumping, hole at waterline)

The following equipment should be considered for placement on proposed Arctic tankers to respond to oil spills in a complete ice cover:

a) at least 5,000 air-droppable oil slick igniters and a helicopter; and
b) at least four satellite-tracked/radio direction finder buoys.

Consideration should be given to carrying the following equipment on-board Arctic tankers to respond to small oil spills:

a) Containment and Recovery

- small, 40 HP workboat;
- lightweight containment boom (1.5 shiplengths);
- small skimmer;
- pump and hose;
- small storage bladders;
- sorbents.

b) Dispersants

- 10 m^3 dispersant concentrate;
- either a helicopter spray bucket or vessel spray gear.

CONCLUSIONS

The application of conventional land-based oil spill countermeasures would be limited in dealing with oil released from a tanker accident in Canada's Arctic waters. Only in situ burning of oil spilled in complete ice cover conditions has the potential to efficiently remove significant amounts of oil. Twenty-five hundred air-deployable igniters would be required in the spring following an accident where the ship remained stationary during the oil release. Thirty thousand could be needed if the ship captain chose to steam ahead during the oil discharge.

It is unlikely that these igniters could be produced on a "demand" basis without a significant level of preproduction funding for the manufacturers. At best, between 3,000 and 6,000 igniters could be produced per month. The delivery of the igniters to strategic locations along the proposed tanker route could be accomplished by cargo aircraft. The deployment of the igniters at the spill site during spring thaw should be feasible but could be hindered by excessive helicopter transit times to and from the spill site.

The design of the proposed Arctic tankers offers the possibility of equipping the vessel with special systems for oil spill response. These systems can be placed in two categories: "in-board" countermeasures to reduce oil losses from cargo tanks in the event of an accident, and "out-board" countermeasures to deal with oil on water or ice.

The in-board countermeasures found to be potentially effective and worthy of further consideration are restricted tank venting, a special dump valve, and portable emergency pumps. The restricted tank venting operates by sealing all air vents of the damaged cargo tank, thereby allowing a partial vacuum to build up in the tank as oil leaks out. This slows and eventually stops the outflow of oil. A special dump valve mounted in each cargo tank could be opened in the event of damage to drain the tank contents to a safe compartment elsewhere in the tanker. Emergency pump systems could be used to reduce oil outflow from small leaks and would be necessary to recover oil floating in damaged cargo and wing tanks. The combination of these three in-board countermeasures has the potential to reduce the volume of oil lost from a breached cargo tank by 85 to 99% for the damage situations investigated.

Only one out-board countermeasure was found to be potentially effective for large spills, namely burning of crude oil spilled on or amongst ice. By carrying 5,000 igniters and a helicopter aboard the tanker, much of the spilled oil could be ignited and burned. Burning of crude oil on water could also be an effective countermeasure since the oil would be fresh and in thick slicks. Further research is required to evaluate this potential open water countermeasure.

In order to be able to have a capability to deal with small spills from the vessel, consideration should be given to placing on board the tanker a package of booms, a skimmer, a small workboat, pumps, small storage bladders, a small amount of dispersant, and helicopter- or vessel-mounted dispersant application equipment.

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