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Oil Spill Countermeasures for the Beaufort Sea: Appendix

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Technical Report 31b

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OIL SPILL COUNTERMEASURES FOR THE SOUTHERN BEAUFORT SEA: APPENDIX

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FOREWORD

The findings of the Environmental Protection Service's portion of the Beaufort Sea Project (Oil Spill Countermeasures) are presented in two volumes - Technical Reports 31a and 31b. Technical Report 31a contains the summary information. Technical Report 31b contains the details of the information presented in 31a and should be regarded as the appendix to that report. The abstract pertinent to the combined report is as follows:

This report discusses the feasibilities of controlling and cleaning up an oil spill in the Beaufort Sea as a result of an exploratory well blowout. It is likely that, in waters with up to 10% ice concentrations, currently available oil spill countermeasures equipment and techniques could be employed in sea conditions up to Beaufort 3. No equipment is available for use in higher sea conditions. If the blowout were to occur in the landfast ice zone, oil that would accumulate at the under-ice surface during winter could be incinerated in place when the oil migrates to the ice surface in the springtime. No viable techniques or proven countermeasures equipment are available for use in the seasonal pack, shear zone and the polar pack zone. The cleanup and restoration of oil contaminated shorelines would be limited to sand beaches and to a lesser extent, shingle beaches, which together comprise 37% of the Beaufort Sea shoreline. Remote sensing of oil spills, although untried in the arctic environment, would be limited to periods of good visibility. In general, the logistical base required to support an effective oil spill countermeasures operation is not available in the areas adjoining the Beaufort Sea.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 DETECTION AND MONITORING

1.1 Radio Frequencies

1.1.1 Passive Methods

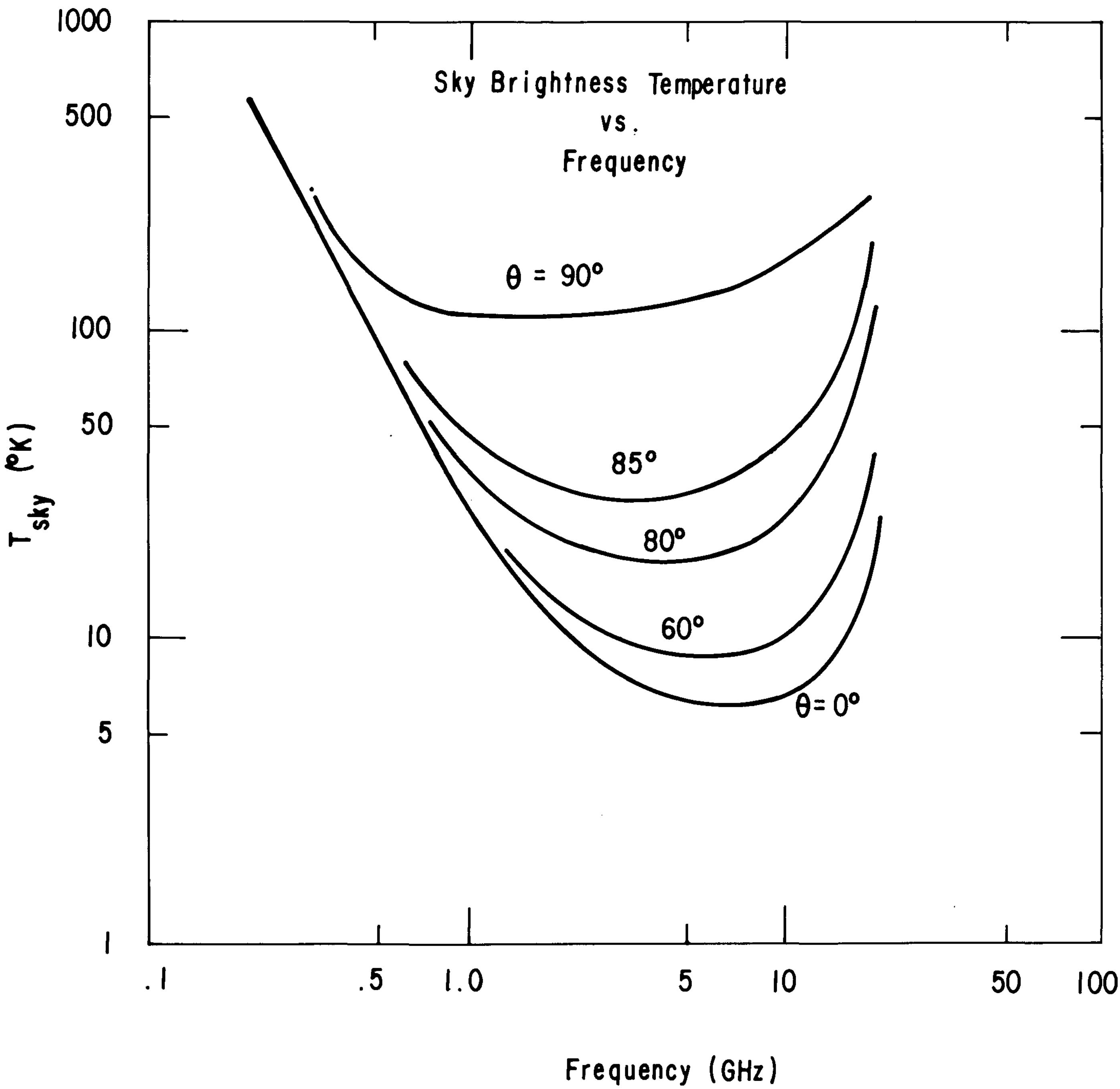
The radiation measured by a microwave radiometer comes from several different sources. The directly emitted blackbody radiation of the object or objects in the field of view usually contributes most of the signal energy. The sensor output then is related to the properties of the emitting medium. Other unwanted components of the received energy, such as man made noise, radiation from the sky, the sun, or from nearby natural objects may be reflected from the source into the mainfield of view, or into antenna "sidelobes". Furthermore, the medium between the source and the radiometer receiver may attenuate by absorption or scattering the original source signal, or radiate itself and add to the total received signal at the radiometer. These additional sources of radiation must be included in an analysis of sensors as the frequency range and field of view parameters of the instruments are often limited by the characteristics of the background signal.

The sum of galactic, solar and natural terrestrial radiation, expressed as the effective blackbody temperature for an equivalent radiation power at the receiver is shown in Figure 1.1.1, using the data or Penzias (1968) and Paris (1971). At frequencies of 200 MHz and lower, extraterrestrial sources become significantly strong and care must be taken to avoid specular reflections into the main field of view or strong sidelobes from these sources. At the higher frequencies shown in Figure 1.1.1 significant attenuation in the atmosphere, especially in heavy cloud or rain is important, and in specific frequency ranges large effects due to spectral resonances in atmospheric gases occur; for example, the water vapour absorption near 22 GHz, and the strong molecular oxygen absorption at approximately 60 GHz. At higher frequencies, many absorption bands from condensation and atmospheric gases occur.

The transmission of radiation from ground level vertically through the earth's atmosphere is shown in Figure 1.1.2 in the presence ice and water clouds (Moore, 1970).

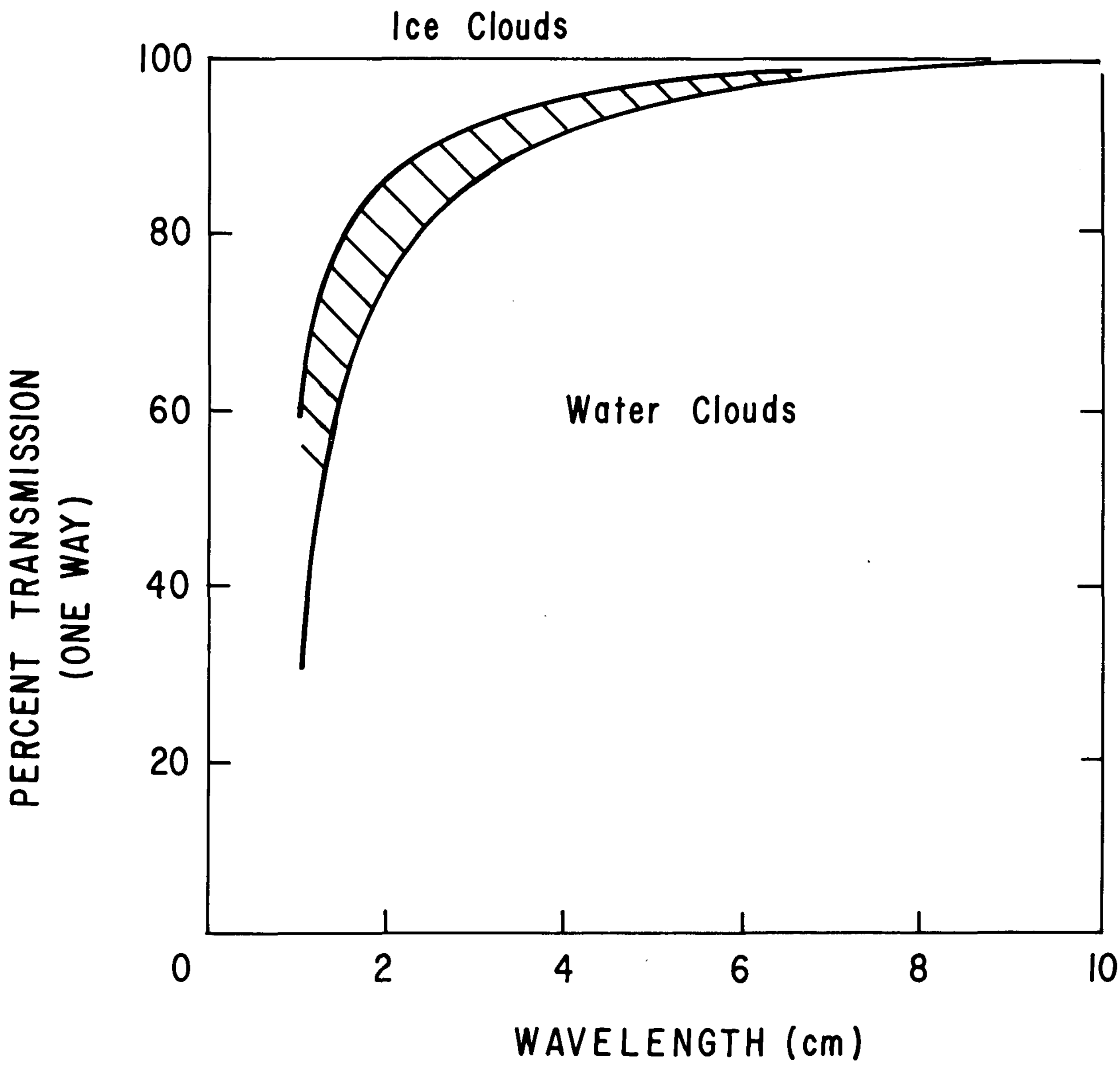
No significant attenuation occurs over this path for radiation wavelengths greater than about 10 cm ($f \leq 3$ GHz). For shorter wavelengths, especially below 3 cm (≥ 10 GHz), severe attenuation may be encountered due to water droplets in clouds. The attenuation in ice clouds is less severe.

For remote sensing programs, instruments are generally required to be portable and operational from fixed wing light aircraft, or helicopters. Such requirements also set restrictions on the frequency range available for use, primarily due to the antenna configurations and size for effective spatial resolution on the ground. The ground resolution of a microwave antenna is given approximately by the product of the radiation wavelength and the altitude of the antenna above the ground divided by the linear dimensions of the antenna. Thus, at 3 GHz, for example, an antenna 1 meter wide at an altitude of 100 meters has a ground resolution of about 10 m. Finer spatial resolution can be obtained at shorter wavelengths and with larger antennas. However, for the applications of Arctic airborne remote sensing, due to size and weight



The total sky brightness temperature incident upon the ice surface due to atmospheric, galactic and cosmic sources. Angle of incidence is the parameter.

FIG. 1.1.1



THE TRANSMISSION OF RADIATION THROUGH EARTH'S ATMOSPHERE

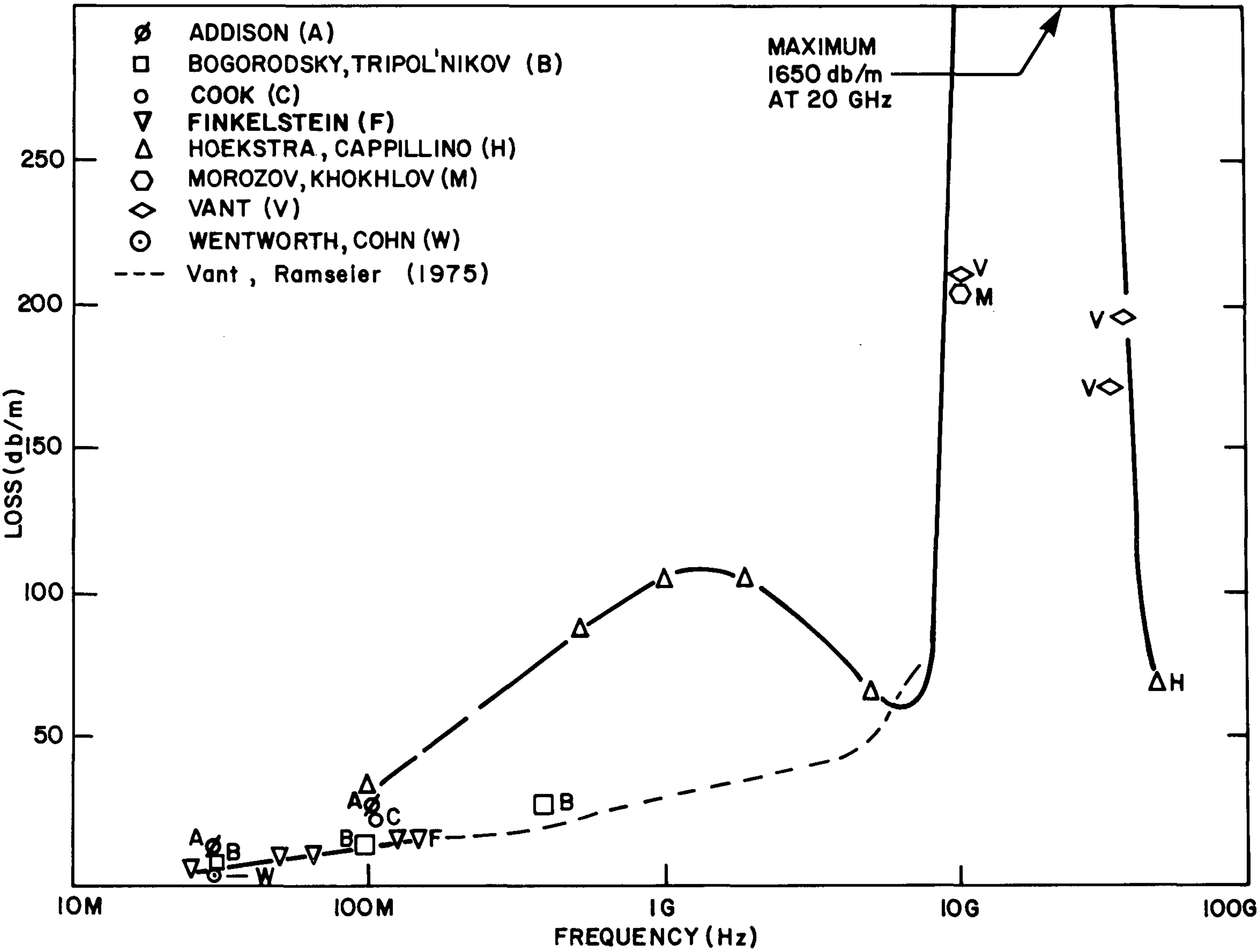
FIG. 1.1.2

restrictions, all weather microwave radiometers must be utilized to obtain information regarding the average properties of the source at the expense of obtaining high resolution data.

Restrictions on useable frequencies and modes of operation for passive microwave remote sensing are set by the physical properties of the source itself, in this instance mixtures of oil, sea water, sea ice and snow. Sea ice is known to consist of a mixture of pure ice and included brine cells and air bubbles. During the freezing process, brine, derived from sea water, becomes trapped in long, slender, primarily vertical pockets or cells within the ice. The relative concentration of brine and precipitated salts within these cells is a sensitive function of the ice salinity and temperature profile (Assur, 1958). Consequently, the dielectric coefficient of brine in the ice can be as large as (the complex number) 80+j110 indicating strong absorption of radio frequency energy. For comparison, pure ice with a dielectric constant of 3.5+j0 is comparatively transparent to microwave energy.

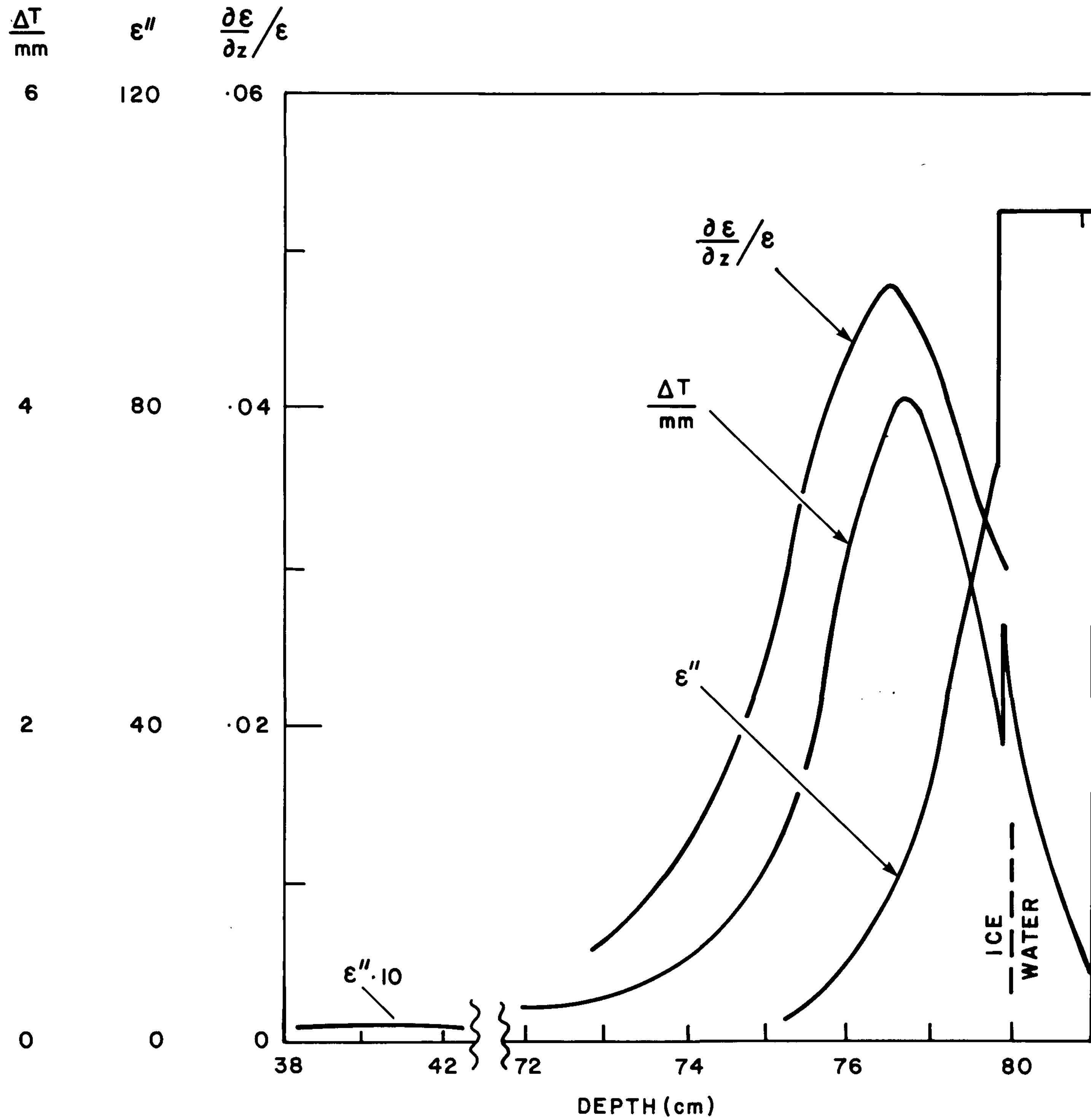
Several investigators have measured large absorption coefficients (Finkel'skteyn et.-al., 1970; Ramseier et.-al., 1974) and a summary of absorption of ice is shown in Figure 1.1.3. The preferential orientation of brine cells in the ice imparts a distinct anisotropy to the electrical properties, and causes absorption to be different for different orientations of the radiation electric vector. For maximum penetration into and emission from sea ice, there is therefore a preferred direction of view and polarization. Minimum absorption occurs for the electric vector aligned perpendicular to the major axis of the brine cells. Robar and Wood (1974b) have modelled the UHF emission from sea ice and indicated that at these frequencies most of the radiation emitted from a sea ice layer originates near the bottom of the ice. In this region, a large gradient in dielectric permittivity exists due to the warm temperature near the water and the consequent large concentration of brine in the ice structure. The profiles of the imaginary part of the ice-brine mixture permittivity, representing dielectric loss, the gradient of this permittivity and the computed brightness temperature contribution per millimeter of ice thickness are shown in Figure 1.1.4 for the model of Robar and Wood. The ice thickness is set at 80 cm and a linear temperature gradient through the ice to -10°C at the surface is assumed. To correspond with salinity measurements taken on first year sea ice in Hudson's Bay (Robar and Wood, 1974b) the salinity profile exhibits a maximum at the top and bottom surfaces of the ice sheet, and a salinity increase in the center to represent non-uniformity in the salinity profiles which may be caused for example by rafted ice. The important feature of this calculation is that the contributions to brightness temperature from salinity maxima at the top of the ice and interior to the ice are insignificant compared to the contribution from the bottom salinity maximum where a boundary region exists between the properties of ice and those of sea water.

The emission and propagation features of sea ice are important both in selecting operating frequencies and polarizations, and in understanding the physical basis for any microwave or UHF measurement of oil under, within, or on top of sea ice. In particular, the following facts are now known: for radiation frequencies where the wavelength is comparable to the linear dimensions of the brine cells, or the air pockets left



SUMMARY OF RADIOWAVE ABSORPTION IN SEA ICE

FIG. 1.1.3



DIELECTRIC PROPERTIES OF SEA ICE NEAR THE LOWER WATER BOUNDARY.

FIG. 1.1.4

when brine drains out, large absorption and scattering effects occur which prevent significant penetration of this radiation through ice. Thus at frequencies above a few GHz, radiometers and radars can measure only the near surface of sea ice. Propagation is less attenuated for waves with electric vectors perpendicular to the brine cells, thus vertical rather than off-nadir propagation directions are preferred. The ability of radars or radiometers to detect the bottom surface of sea ice depends on a steep gradient in ice dielectric properties occurring near the bottom surface.

There is a tendency for oil residing at the water-ice interface to migrate into the brine channels within the ice sheet, and the rate at which this process occurs depends upon numerous parameters (Beaufort Sea Technical Report No. 27, 1975). However, in this context, the important effect of this displacement of water by oil within the brine channels is to replace the high permittivity salt water with low permittivity oil (dielectric constant approximately 2.0 + j0). The consequence of this is to reduce the permittivity of the ice mixture and change the gradient in dielectric constant at the ice water interface. Confirmation of the dielectric properties of sea ice has been made from AIDJEX tests from 100 MHz up to 12 GHz (Ramseier, 1975, private communication). However, no measurements at the site of an oil spill have yet been performed. In fact, to this point in time, measurements of oil under ice have not been made by ice penetrating radars or radiometers. Thus, observation of the expected modification of sea ice dielectric properties due to the presence of oil are not available. As the efficacy of spill detection by RF techniques is closely related to such modification of electrical properties, it is desirable to obtain a confirmation of these effects through experimental measurements.

Since the bottom salinity gradient is expected to be most important to the radiation properties of sea ice, once oil becomes frozen into the ice and a substantial amount of new sea ice has grown below the oil, little effect is anticipated upon UHF or microwave properties of the ice emission. These concepts were tested with computer calculations of the radiation brightness temperature expected from a freezing layer of sea ice using the ice model from Robar and Wood (1974b) based on the theory of Stogryn (1970) and the earlier modelling of Pelletier and Adey (1973).

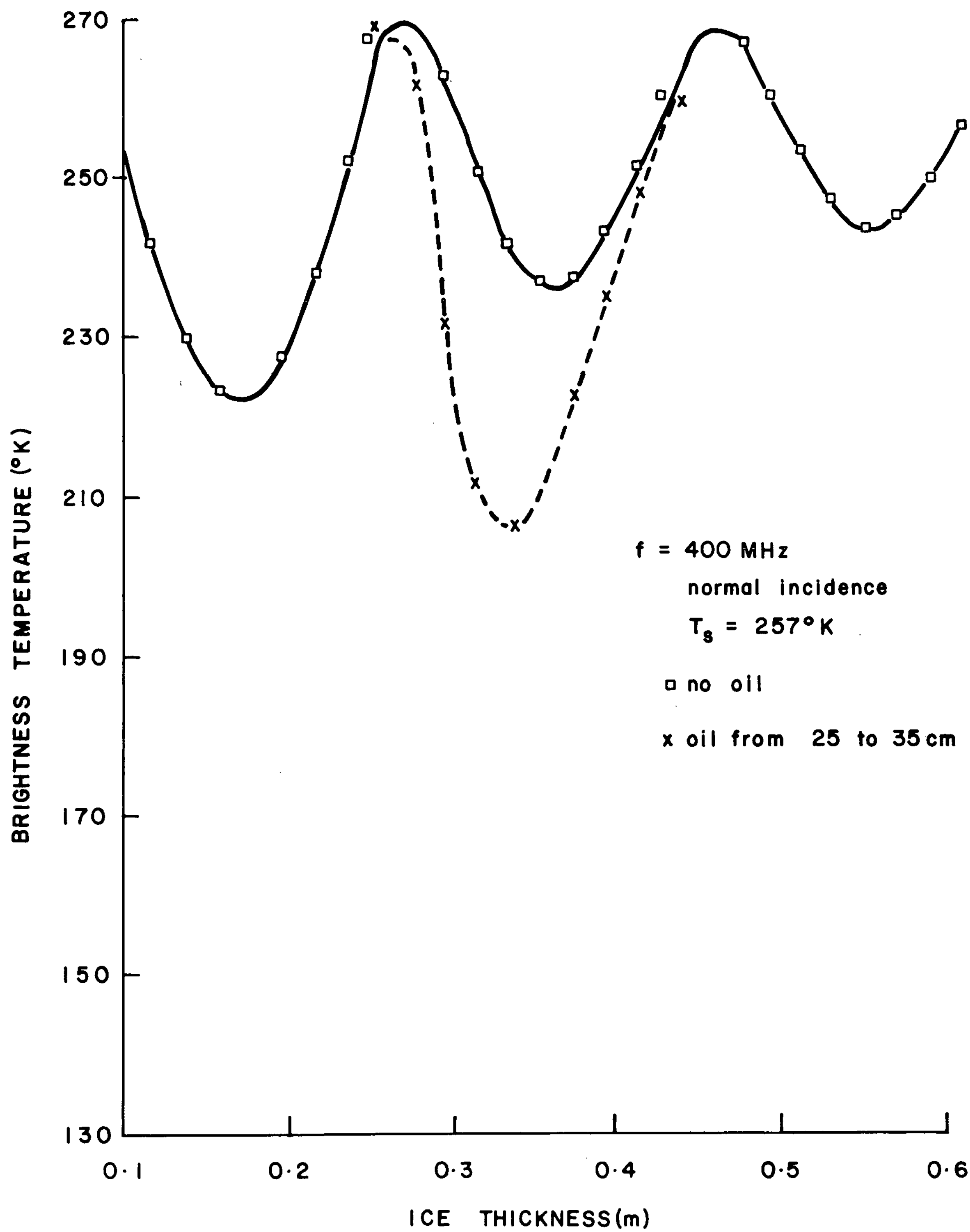
For frequencies of 400 MHz and 1200 MHz, the sea ice brightness temperature was calculated for a radiometer viewing perpendicular to the ice surface. Two different spill states were assumed in the calculation. Firstly, the brightness temperature was calculated for normal ice growth in the absence of oil. Secondly, it was assumed that an oil spill occurred under 25 cm of new sea ice followed by continued growth to a thickness of 62 cm. In the latter model the oil was assumed to extend from 25 cm to 35 cm through the ice, being frozen in the ice structure by ice growth. A linear decrease due to the replacement of brine by oil in total ice salinity was assumed to begin at 25 cm with a minimum salinity near 30 cm, approximating total exclusion of salt water at this depth. By 35 cm the bulk salinity had again increased linearly to that assumed for pure sea ice. This modification of ice salinity represents migration of oil into brine cells both above and below the principal oil layer. The results of these calculations are shown in Figures 1.1.5 and 1.1.6, where the typical predicted brightness temperature variation with increasing ice thickness is evident. These predicted variations of signal with natural sea ice, due to wave interference effects at the top and bottom boundaries of the ice have been reported from measurements by Basharinov <u>et. al.</u> (1971).

Two significant observations can be made from the foregoing simulation. Firstly, the change in brightness temperature in the presence of oil is between 30 Kelvins at 400 MHz and 100 Kelvins at 1200 MHz. With state of the art radiometers having resolutions and accuracies of $\lesssim$.5 Kelvins and $\lesssim$5 Kelvins respectively, such emissivity changes would be observable soon after a spill occurred. Observable changes in brightness temperature are predicted for oil penetration into the bottom 1 cm of the ice sheet, displacing 20% of the brine in the growing ice. These values of brightness temperature changes do assume that the effect of the oil is spread over the entire field of view of the radiometer. For cases where this is not true, the changes in the brightness temperature would approximately correspond to the fractional spill area in the main antenna beam. Secondly, it is noted that as the oil layer becomes frozen farther into the bulk of the ice, only very small changes in the composite signal are predicted. For example, when the oil is 15 cm from the bottom of the ice, changes $\simeq$ .2 Kelvins at 1200 MHz are predicted. Such temperature offsets would not be sufficient to identify the presence of oil in the ice by radiometric techniques.

For oil on the surface of smooth ice, different spreading characteristics are observed (Chen, 1972; Glaeser and Vance, 1971). For arctic temperatures, these investigators found that oil did not necessarily spread to a thin layer when spilled onto the surface of ice. In some cases oil was absorbed into the surface. This absorption is particularly strong on multiyear ice where brine drainage has occurred during melt seasons leaving cavities in the ice. The volume fraction of these cavities is significantly large, as Glaeser and Vance (1971) observed absorption of oil in ice during the summer to an extent of 25 percent of the ice volume involved. However, it seems quite likely that some oil will collect on the surface of water within melt ponds during the melt season (Beaufort Sea Technical Report No. 27).

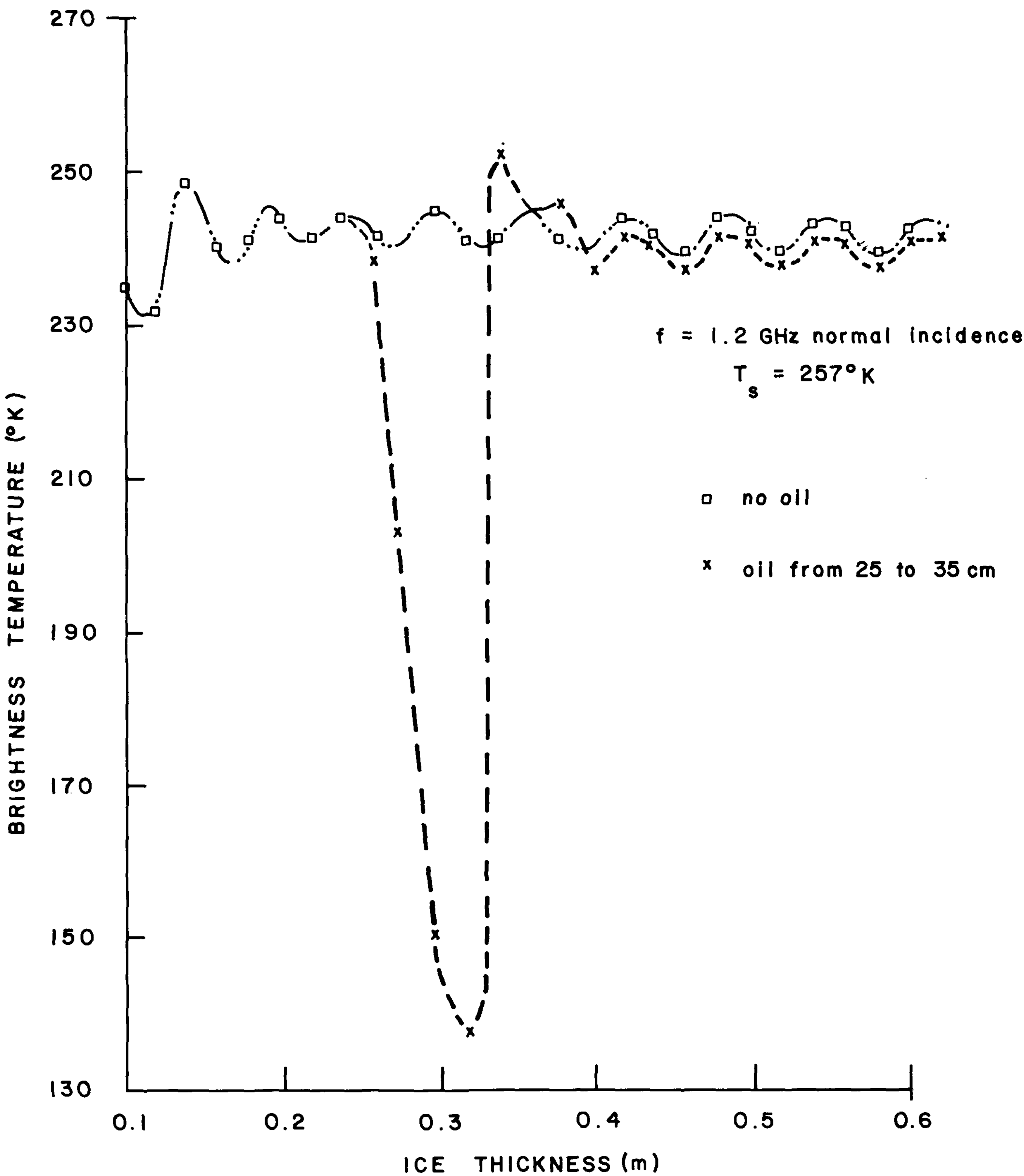
Whether oil spilled on the surface of ice can be detected and measured with radio techniques depend again upon the electrical properties of the oil and the ice.

Under normal arctic conditions where the temperature of the surface of the ice is less than -8 to -10^{o}C, the volume fraction of brine in the ice is small and the dielectric properties near the surface are approximately those of pure ice, ie. permittivity $\simeq$ (ice) $\simeq$ 3.3 + j < 0.02. Since the permittivity of crude oil is approximately ε (oil) $\simeq$ 2.0 + j0, and that of air is ε (air) $\simeq$ 1.0 + j0, the oil will act as an impedance matching medium between the air and the ice for radiation propagating from the ice surface. Furthermore, due to its small dielectric loss, the oil does not absorb any significant amount of microwave energy and mainly through interference effects will its presence modify the natural radiation emitted and reflected by the ice. Coincidentally, the dielectric properties of oil at microwave frequencies are



The Predicted Brightness Temperature Change with Ice Growth at 400 MHz with and without the Presence of Oil

FIG. 1.1.5



The Predicted Brightness Temperature Change with Ice Growth at 1200 MHz with or without the Presence of Oil.

FIG. 1.1.6

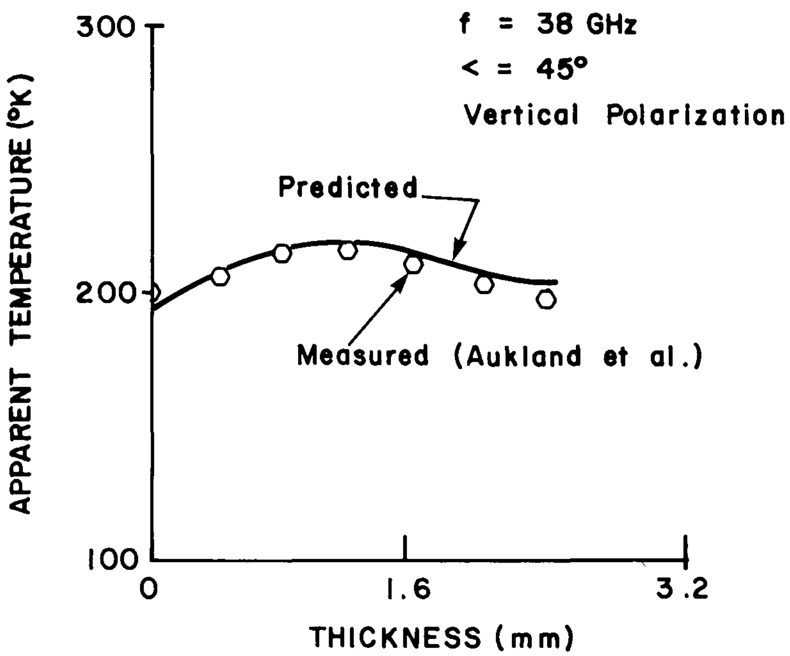
nearly identical to those of snow (Cumming, 1952; Kennedy et. al., 1965). Thus, differentiation between thin layers of snow or oil will be difficult. Although no observations at microwave frequencies of oil on ice have been reported, it appears that in the absence of a separate technique for distinguishing between cold oil and snow, no reliable conclusion regarding the presence or quantity of surface oil can be obtained with microwave remote sensors.

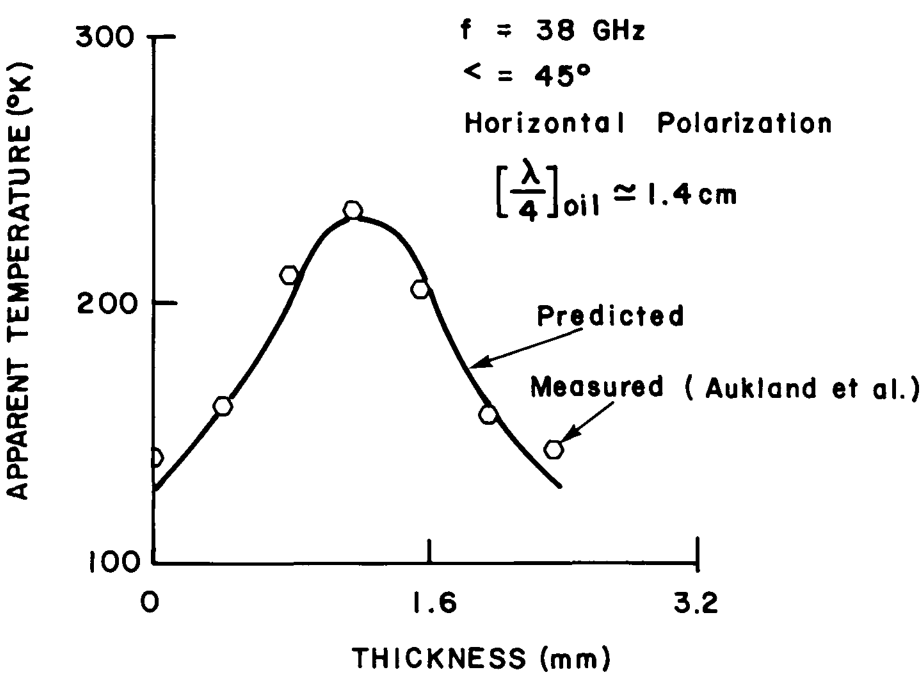
For the situation of an oil spill in ice infested waters, oil on the surface of water will change the surface brightness temperature (Jean et. al., 1971). Although the emissivity of sea water ($n \approx .35$) is considerably lower than that of sea ice, independent techniques would be required to determine the fractions of ice and water as well as ice type in a radiometer's field of view. In a reconnaissance mode, separation of a change in brightness temperatures due to oil on the water, or due to changing fraction of ice in the field of view, is unlikely.

The response of radiometers to oil on open water, however, is more amenable to treatment. This problem has been studied extensively, as its solution may be applied to the detection of oil on oceans and harbour waters in lower latitudes. Two mechanisms are responsible for brightness temperature changes in the presence of oil. Sea water of $0^{o}C$ has a permittivity of approximately 80 + j120 at a frequency of 400 MHz as compared to 2 + j0 for oil (Robar and Wood, 1974a). Thus, a layer of oil on sea water acts as a matching medium for radiation passing from the water into air. The emissivity and measured brightness temperature of the sea surface are therefore increased (Thomson, 1975; Edgerton et. al., 1970; Meeks et. al., 1971; Hollinger et. al., 1973). A second consequence of an oil spill is the damping of capillary waves and the concomitant reduction of surface emissivity. Experimental studies have suggested that these effects can be separated and the presence of oil can be clearly defined especially in horizontal polarization which tends to give better contrast between oil-covered and oil-free water.

The presence of oil on the water surface also leads to wave interference effects, similar to those observed at visible wavelengths. A further analogy between microwave and optical measurements is valid in that optical interference occurs for particular oil layer thicknesses even for wide angle diffuse illumination of the surface and wide angle measurement (Horstein, 1972). For microwave sensing, maxima and minima in brightness temperature have been observed as oil layer thicknesses changed by quarter wavelengths of the observing radiation. Questionable measurements are reported by Caruso and Oister (1973) and by Jean et. al. (1971). The latter compares predicted brightness temperature for changing oil thickness on water with measurements of Aukland et. al., (1969). As shown in Figure 1.1.7 at 38 GHz up to 100 Kelvins of brightness temperature change in horizontal polarization are obtained for an oil thickness change from 0.0 mm to 1.4 mm while, in vertical polarization, 15 Kelvins are obtained for the same change in oil thickness. Swaby and Forziati (1970) have also reported a correlation between IR scanner data and 19.6 GHz microwave radiometer data over an oil spill where a microwave brightness temperature increase of about 190 Kelvins was observed from oil compared to adjacent open water.

In recent controlled oil spill experiments Edgerton et. al.





Apparent Temperature as a Function of Oil Thickness.

FIG. 1.1.7

(1975) determined that, due to the high emission of the thick oil areas contained in slicks, positive brightness temperature anomalies were noted for all oil films measured on calm seas. For all slicks measured on rough seas the average horizontal polarization signatures were negative. Thus, the additional emission from thicker portions of the oil slicks were overshadowed by the decrease in ocean emission associated with the reduction of ocean surface roughness. Positive signatures were superimposed on the negative anomalies, suggesting that small areas of thick oil were present in the slick area. As predicted by theory, vertical polarization signatures were generally small, and no correlative patterns were established for oil films on rough seas. It was noted that negative horizontal temperatures can be uniquely associated with oil slicks, since no other phenomenon is known to cause such a signature in the open ocean environment.

During these experiments, measured brightness temperature anomalies were generally greater than required for the detection of oil slicks. Lowest amplitude signals were of the order of 5^{o} K -- well within the detection capabilities of passive microwave imaging systems.

The study investigators concluded the following:

- Oil slicks on the ocean surface provided unique and readily measurable signatures. Signatures ranging up to 70^{o}K were noted while overflying thick portions of oil slicks. All slicks encountered during the controlled oil spills contained thick portions that were detectable.
- The microwave emission characteristics of oil slicks vary with oil type and film thickness. The mass of oil per unit area is the parameter of most importance.
- The microwave emission characteristics of oil slicks vary with sea state, and provide measurable signatures over a wide range of sea-state conditions. Oil films with an average thickness of one μm were readily detected with 3.2 and 8.1 mm sensors.
- Both theory and measurements demonstrate that horizontally polarized sensors are more responsive to oil films than vertically polarized sensors.
- The microwave brightness temperature signatures of oil slicks increase with sensor frequency (vary inversely with sensor wavelength). However, atmospheric attenuation also increases with frequency. The available atmospheric and oil film signature data indicate that a frequency (wavelength) of about 37 GHz (8.1 mm) is optimal.

The study authors recommended that a horizontally polarized, 37 GHz (8.1 mm) imager with a constant viewing angle of 45^{o} and real-time video display be employed for oil spill detection. In operation, a typical ground resolution of about 30 meters diameter would be imaged at a flight altitude of 800 meters, with a lateral beam scan of $\pm 45^{o}$ being performed mechanically with a plane antenna, offset on a rotating vertical axis, and repeated at a rate adjusted to the appropriate flight altitude/velocity ratio to give continuous scans. Flight altitudes up to 3,000 meters would be possible, but with proportionately larger footprint sizes.

Parameters for an existing system developed for the United States Coast Guard (Airborne Oil Surveillance System) which could provide a model for an Arctic unit are given below:

altitude range	800 m 3,000 m
frequency	37 GHz
beamwidth	2^{0} x 2.8^{0}
ground resolution	ca. 30 m spot at 800 m alt.
polarization	horizontal
power required	ca. 500 watts
antenna size	about 25 cm x 50 cm. flat, mounted on a vertical rotating shaft to scan
antenna system weight	25 kg
source brightness temp. resolution	1.2 Kelvins
antenna rotation rate	max. 35 rev/min to give about 100 separate beam "positions" per second
data rate	for digital smoothing and processing, ten - 10 bit words per beam "position"
data processing	collect above data, average 10 values, co-ordinate shaft encoder position with signal intensity and drive output display device -- a small microcomputer
data display	processed date can be stored on magnetic tape or photographic film can be presented in real time on a CRT screen in gray-shaded or false-colour presentation for immediate observation with a reasonably inexpensive display system -- a few thousand dollars.
aircraft modifications	viewing port to allow mounting of antenna mount a radome of about 60 cm diameter and a wind deflector under aircraft
operator functions	set altitude/ground speed input (could be semi-automatic, using altimeter readings and approx. ground speed) -observe CRT display -- some training and experience would be required to identify ground features -check on operation of film recorder and/or video tape recording for permanent records

availability	units built for USCG by Aerojet Electrosystems system purchase price unknown, probably > $100K < $200K comparable system could be built in Canada.

In consideration of the available information on passive microwave detection of oil spills, it appears that radiometric detection mapping and possibly thickness measurements are possible in open Arctic waters. For sensing oil on water the optimum operating frequency would be in the range of 20-40 GHz to provide a compromise between target contrast, surface resolution, and atmospheric attenuation. Furthermore, in a reconnaissance mode, antenna scanning is possible at this frequency to provide a brightness temperature map of the ocean. Ideally, a video display should be included in the system for real-time imaging.

It is evident, however, that a single radiometer frequency or sensing method will not allow for detection of both oil below ice and oil on the water surface. Furthermore, after spill detection by passive microwave remote sensing methods, it will not be possible to determine the type of oil from its brightness temperature signature.

1.1.2 Active Methods

Active methods of microwave remote sensing include an illumination device operating at the frequency of a receiving instrument. The received energy is that reflected from boundaries between media of different dielectric properties. Since both transmission and reception are involved, more system flexibility (and complexity) are available as compared to passive devices (radiometers).

Perhaps the simplest form of active remote sensor is the scatterometer, in which a burst of energy is radiated from a transmitter and scattered back from the target. The received return signal is proportional to the average scattering coefficient of the target. As with passive radiometers, spatial scanning of the source is possible and an image can be formed by mapping the variation of the scattering coefficient over the viewed area. Certain physical properties of the scattering medium can be extracted from the scattering coefficient for a given frequency, polarization, etc. For example, Rouse (1969) and Parashar et.-al., (1974) have been reasonably successful in classifying sea ice into one of four broad thickness categories using dual-polarized scatterometers at two frequencies.

Another active technique is to measure the time from transmission to reception of the signal, and the instrument becomes more properly a radar. Page and Ramseier (1974) clearly describe the types of radar used for snow and ice measurements. These are the imaging radar techniques, where an image of a large area is built up from the returns from the various elements of the area of view, and the probing radar, where reflections from adjacent boundaries, for example the top and bottom surfaces of a snow or ice layer are measured and properties such as thickness are derived from the measured time delay. In the former type of radar, properties of the target are inferred from the surface structure identified in the radar image. Reasonably good range resolution can be obtained with this technique, but poor azimuthal resolution is obtained with rotating antennas.

To produce an operational airborne radar, considerable military research and development has resulted in the SLR, or side looking radar. With this instrument, the azimuthal scan function of a ground-based radar is performed by the longitudinal motion of the aircraft, and range perpendicular to the flight direction is determined from the time between transmitting and receiving a signal. There are two fundamental types of SLR instruments, the real aperture and the synthetic aperture SLR. The former type uses only the forward motion of the aircraft and the along-track beamwidth to provide spatial resolution parallel to the flight direction. The latter utilizes differing phase relationships between the signals received from target positions ahead of the aircraft and those perpendicular to, or behind the aircraft position to obtain fine spatial resolution in both along-track and cross-track directions. As the aircraft moves, an image can be obtained from the computer processed return signals.

Presently, three commercial systems are operating outside of military applications (Koopmans, 1975). The Goodyear APQ 102 system operates at 3.1 cm with a synthetic aperture, and a maximum swathwidth of 37 Km can be observed from flying altitudes between 6,000 and 12,500 meters. Ground resolution is 16 meters by 16 meters. The Motorola APS 94 (D) system operates at 2.5 cm wavelength with a real aperture and can measure over a 100 Km swath width with range resolution of 30 meters and along-track resolution of 48 meters at near range and 116 meters at far range. Flying altitude is about 3,500 meters. Finally, the Westinghouse system APQ97 uses an 8.6 mm wavelength with a real aperture, maximum swath width of 21 Km and resolutions at 6,000 meters altitude of 11 meters in range, 10 meters in near range azimuth and 22 meters for far range azimuth.

For further illustration some additional information about a SLAR system is presented below. This particular data pertains to the APS-94D Motorola unit as used by the USCG.

altitude range	300 m 7,000m
frequency	9.2 GHz
beamwidth	0.87^{o} x 0.9^{o}
ground resolution	30 m lateral range by 20 m/Km of range
polarization	vertical
power output	100 Kw at 3,000 m alt
antenna size	2.5 m in a pod mounted on side of aircraft, yaw stabilized
radar weight	320 kg
display	normally hard copy film 9-1/2" wide could be visual CRT display
aircraft modification	antenna pad required outside skin, or in a dielectric-covered bay

data requirements	range divided into 750 intervals -video signal output sampled for 0.2 microsec. intervals -each range interval requires a recursive digital filtering procedure using, e.g., a 768 word memory, a coefficient multiplier and a digital adder
data interpretation	a greater ground area is observed than with an imager, hence more data interpretation is required -a trained operator-interpreter is necessary
availability	units are available at cost >$1M

For real aperture systems, azimuth resolution degrades with increasing flight altitude. In all cases, aircraft stability is important in producing good imagery and turbulence must be avoided or compensated for. Also because of the side scanning mode of SLAR, a region below the surveillance aircraft about $\pm 40^{o}$ from nadir is not covered during a pass.

The Motorola system has been used by the Canadian Forces on Argus aircraft and some imagery does exist, although apparently not of the specific area of oil in an ice-water environment.

The SLR is essentially a surface imaging system and the bulk or lower boundary properties of sea ice must be inferred from the top surface scattering coefficients. Some evidence apparently exists that bulk properties of fresh water ice can be measured with SLR's (Page and Ramseier, 1974), however, this is unlikely to be true for sea ice with its much larger absorption coefficient.

Since the SLR tends to view more horizontally than vertically, strong reflections from the edges of ice floes are expected, and observed (Page and Ramseier, 1974). Specifically, a strong return was seen from the track of a ship that had passed through ice leaving chunks of floating ice. Due to these observations, the use of SLR systems in observing the effects of oil under ice or on water infested with ice appear to be severely limited.

The SLR is capable, however, of detecting oil slicks in open water where the presence of oil damps the wind-produced capillary waves and produces an area of diminished radar return (Guinard, et. al.. 1970). This diminution of radar return is most effective for vertical polarization at wind speeds greater than about 2m/sec. As an example of a SLR used in a reconnaissance mode, the AOSS (Airborne Oil Surveillance System, 1973) is an operational SLR instrument requiring real-time on board computing and is capable of producing almost real time images on film. However, there is some evidence that the SLAR may have a high false alarm rate for oil spills on open water; especially if any natural wave damping agents such as fish oil are present, even in monomolecular thickness. Further, the SLAR provides no capability for oil thickness indication.

Certain limitations of SLR, such as limited ice penetration and high cost and complexity are overcome by probing radars. It should be noted, however, that no experimental investigation of oil under ice has yet been reported for these devices. A probing radar is more applicable than the SLR for the detection of sub-surface features due to its ability to accurately measure ranges through the ice from two or more signals closely spaced in time. Such capabilities have recently become possible with technological advancement in radar components, and research prototypes are becoming available for evaluation.

Two basic approaches are being used in probing radars for sea ice measurement. These are wide-band frequency modulation of the transmitted signal (FM/CW) and short time duration modulation of the radio energy (pulse and impulse instruments). A commercial FM/CW system modelled on an aircraft altimeter and operating from 420 to 470 MHz is available from Geophysical Service Inc. Originally used on surface vehicles, it has the ability to measure sea ice thicknesses greater than approximately 1 meter, although no information is published regarding its capability of detecting oil beneath ice.

Impulse radars, using a narrow pulse of DC energy to produce wideband transmission are also in use from surface vehicles (Geophysical Survey Systems Inc.) and experimentally from low flying helicopters (Gray, private communication, 1975) and aircraft (Bogorodskii and Tripol'nikov, 1974). Active research is in progress studying impulse radar techniques at the Communications Research Center, Ottawa, and experience with an X-band system at 10 GHz, suitable for fresh water ice, is being used to design a UHF impulse radar capable of measuring sea ice (Chudobiak, et. al., 1974).

As in the case of radiometric measurement of sea ice, the contamination of oil of the electrical properties near the ice-water interface is expected to decrease the bottom surface reflection co-efficient. That is, a reduced gradient of the dielectric coefficient should reduce the return signal from this region. However, the presence of oil may be detected only as a change in bottom reflection from one horizontal position to another on similar ice, or as a change in the bottom reflection at the same location at different times.

It must be emphasized that at the present time, state-of-the-art active sensors have the proven ability to penetrate first year ice. However, there is as yet no measure of the efficacy of such techniques for detection of impurities, such as oil embedded in sea ice.

Ice penetrating radars, like radiometers are likely to have their own special problems associated with pulse discrimination or volume scattering from the bulk of the ice. For example, impulse radars are not likely to discriminate between closely spaced dielectric dis-continuities or steep gradients closer than a certain minimum value.

In view of the importance of detecting arctic oil spills, it is desirable to investigate these RF sensing possibilities by modifying ongoing microwave remote sensing programs to accommodate controlled spills in the test areas.

1.2 Optical Frequencies

1.2.1 Spectral Considerations

The controlling factor governing the effect upon the apparent reflectance or albedo from substances, such as oil, floating on the water surface, will arise from the incremental energy added to or subtracted from the background albedo by the floating substance.

The magnitude of the surface contribution to the albedo will be determined by the Fresnel reflectance formula given by (for unpolarized radiation and normal incidence)

$$\rho = \frac{(\eta - 1)^2}{(\eta + 1)^2} \qquad (1.2.1)$$

where η in Equation (1.2.1) is the index of refraction of the oil (assuming oil thickness greater than 1μ). For most oil species, η ranges over values from 1.4 to 1.6 (Fantasia, 1971) depending upon oil API density. Simple substitution of these values for η are computed in Table 1.2.1.

Surface Species	Reflectance (R %)	Contrast Ratio (Ro/Rw)
Water $\eta = 1.34$	2.11	1.0
Oil #1 $\eta = 1.4$	2.78	1.3
Oil #2 $\eta = 1.5$	4.00	1.9
Oil #3 $\eta = 1.6$	5.33	2.5

Table 1.2.1 Computed reflectances and contrast ratios for oil and water.

These calculations illustrate how highest contrast ratios will result from highest indices of refraction (under model conditions). These simple calculations ignore the effects of non-normal incidences, spectral effects, interference and polarization effects, cloud cover, haze, water colour, and wind speed (i.e. wave height). Each of these factors may separately and in combination be considered within reasonable models to compute optimum sensor characteristics for optimum contrast.

In certain situations, these factors will in fact combine to actually reduce oil/water contrast to values less than unity (i.e. oil will appear darker than water). An understanding on how such an effect could occur will be appreciated when it is understood that the albedo $\underline{A}$ generally consists of three reflectance components, a surface term R_s (water or oil), an atmospheric term R_a, and a water colour term R_w. In situations such as regions of high turbidity where the water colour term R_w is large, the blocking effect of an oil slick will actually reduce the net albedo over the slick and yield contrast values less than unity (McNeil, 1975).

In addition to the reflectance processes just described, oil on the surface can be inferred by judicious application of fluorescence and Raman techniques. Fluorescence phenomena in particular have been extensively investigated in recent years and have shown a ready ability to detect and even classify certain oil species on a day/night basis through wavelength spectral signature and more recently, fluorescent decay spectra analysis (Measures, 1974).

Raman techniques have not as yet been extensively applied to the problem of remote detection or identification of oils. Raman phenomena are worth investigation and should be presently considered for laboratory trials such as a cataloguing of Raman spectral properties of broad categories of oil species. Existing laboratory Raman spectrometer systems might easily be modified for analysis of oil samples (Howard-Locke, 1975). Fluorescence and Raman phenomena both require active or artificial illumination for application. The focus of Raman and fluorescent techniques remains spill classification.

Thermal processes remain an important key in the remote detection and quantification of surface slicks. The process is due to natural thermal emissions (black body) from all substances, which are remotely "observable" in atmospheric windows between 3-5μ and 8-14μ. Surface oils and water have differing natural emissivities (i.e. 0.993 for water and 0.972 for oil) which account for their differing thermal signatures. Oil in effect will appear "colder" (i.e. darker) than surrounding waters -- the coldest (darkest) IR tones will be associated with the thickest portions of the slick (de Villiers, 1973). Thin portions of a slick will reach thermal equilibrium with the surrounding and underlying waters and as a result will display no significant thermal contrasts. Thermal techniques, used in conjunction with optical techniques afford an excellent self-contained method of mapping the entire spill or slick while simultaneously isolating the thickest portions of the spill --a useful observation where rapid containment is required. There is also some theoretical possibility, as yet unconfirmed experimentally, that thermal remote sensing might in certain isolated situations enable remote detection of oil under ice. Wolfe and Hoult (1972), in a series of laboratory experiments have found that oil, pocketed beneath ice surfaces will act as an insulator and in effect impede the flow of thermal energy from beneath the ice. For moderate ice thicknesses, the relatively low thermal conductivity of oil beneath the surface will act to reduce the temperature drop across the ice itself to small values. Consequently, the oil beneath the surface may radiometrically appear 'colder' than the surrounding areas. However this phenomenon is not as yet known to have been observed. Moreover, for relatively thick oil layers, convection effects within the oil may dominate strongly reducing the insulating effect of the oil.

Several considerations come into play in an optimum selection of spectral characteristics for optical remote sensing of oil slicks.

For visible passive systems, these include the availability of illumination both night and day, atmospheric window, water colour effects and detector sensitivity.

For simple mapping and detection applications utilizing reflectance phenomena in the visible or near - IR, the wavelength region centred near 0.8μ would appear to be optimum -- this region affords good penetration of the atmosphere and yields the highest potential oil/water contrast (by minimizing water colour effects). Physically, for night-time operation (i.e. starlight), the near - IR also offers maximum potential for low light level applications because natural night time illumination is nearly two orders of magnitude greater than in the visible under these conditions (Engstrom and Rogers, op. cit.). An additional advantage lies in the superior sensitivity of non-blooming low light level systems in this part of the spectrum (Rodgers, 1973).

In the above applications, detection and mapping constraints were optimized -- where additional spectral information is desired, such as will be available with multi-spectral systems, spectral resolutions of the order of 5 nm should be attempted (Grew, 1973). This is the order of resolution required for sufficient detailing of most reflectance and fluorescent phenomena.

Thermal information is generally available along either the 3-5μ or 8-14μ channels. No convincing experimental evidence has yet been offered to demonstrate any particular physical advantages of either of these channels in the sometimes claimed ability to discriminate between different oil species. The 8-14μ channel is generally preferable for its superior atmospheric transmission characteristics.

1.2.2 Photometric Devices

This class of instrumentation includes a broad category of conventional imaging and non-imaging systems operating in the visible (UV to near -IR). Representative devices include conventional television, multi-channel photometers, multi-spectral scanners, image dissector cameras and multi-band photography. The common characteristic of each of these systems is that they are all passive devices capable of daytime operation only.

Mechanical multi-spectral airborne devices exist in numerous configurations. Conceptually these systems may be regarded as consisting of a modular array of three units: a scanning head, a detector-spectrometer, and a data-recorder.

A typical scanning-head will consist of a scanning mirror with imaging optics. Scanning heads have been carefully designed for aircraft (and satellite) uses and will generally include some form of roll compensation. For dual or multi-channel registration, the input optics may include a 45^{o} dichromic element. This feature commonly allows simultaneous recording and display in one thermal and at least one visible channel.

The detector-spectrometer module of a typical multi-spectral scanning system will utilize a reflection grating as the dispersing element along with a silicon photodiode detection array. Spectral resolutions of the order to 50 nm in up to 10 visible channels may be specified. Most systems utilize mercury-cadmium-telluride as the basic detection element for the thermal IR channel (i.e. 8-14μ).

The most essential element in any anticipated detection/ mapping function over the Beaufort Sea, is real time display. Conventional multi-spectral scanners are intended for data-processing at later times. Consequently, data is usually recorded in analog form on 7 or 14 track magnetic tape.

For real time TV -- format display, the scanner output must be followed by some method of scan conversion for TV compatability. This process is often accompanied by a severe loss in image quality.

Non-mechanical multi-spectral systems are available which utilize image dissectors at the scanner and detector stages. The image dissector is nothing more than a photomultiplier with a small electronically movable photocathode area·which can be operated as a television system. The output from an image dissector is a current whose magnitude is directly proportional to the input irradiance. Unlike storage camera-tubes, the output signal from an image dissector is completely independent of scan rates and previous scan history. Utilizing diffraction gratings or wedge type interference filters, the image dissector camera has a number of advantages which make it suitable for possible daytime use in smaller aircraft:

- it has no moving parts,
- it is simple and rugged in construction,
- it has potential for high real time spatial resolution,
- it has high-spectral resolution (i.e. 5 mm or less),
- image dissector characteristics are such that platform stability (roll compensation) requirements are low.

The primary disadvantages of the dissector system are the problem of channel registration (one channel only) and the lack of thermal information. However, no known conventional daytime imaging system offers such a superior combination of both spectral and spatial characteristics as these devices.

1.2.3 Intensified Photometric Systems

This class of instrumentation will include all types of instruments listed above but which have in some way been modified for low light level applications (e.g. L^3TV) or by use of some form of artificial illumination as with active systems (e.g. laser fluorosensors).

Intensified Optical Multi-channel Analysers (OMA's) are non-imaging devices capable of storage of up to 500 channels of spectral information over a wide spectral range (200 mm - 1.1μ) and at input signal levels comparable to starlight illumination under clear moonless skies. Spectral resolutions of the order of 0.1 nm are possible with these systems. Commercial devices utilize medium resolution polychromators as the dispersing element. This will be followed by an image intensifier vidicon detector similar in operation principle to the low light level TV (L^3TV) device described later.

The signal to be detected is focussed upon a fiber optic face plate with a photocathode deposited upon it. Released photo-electrons are then accelerated to an array of up to 500 silicon diodes from which data is read off by a scanning electron beam. Variable storage modes in these devices allow impressive signal to noise improvements for weak signal applications. Aircraft worthy variations of these systems (Jeffers, 1974) could be applied to various remote sensing applications. Some of these would include applications of passive high resolution reflection spectroscopy as well as applications of fluorescence and Raman phenomena using active cw or pulsed lasers as sources. The OMA's are physically small, easily configured for aircraft use and require little power while being relatively inexpensive. Various versions of real-time data output are possible (CRT, x-y plotter, paper tape, or real-time video).

Various versions of primarily experimental cw and pulsed laser fluorosensors have been in operation for several years. However, a potentially commercial second-generation multi-spectral laser fluorosensor now under development may be available for field trials early in 1977. This device is expected to provide up to 16 channels of spectral information in real-time. In addition, the system will provide two channels of temporal information for potential application of fluorescent decay spectrum applications. The system, which is being designed with existing multi-sensor systems in mind could provide an effective demonstration of a versatile commercial laser fluorosensor designed for airborne use.

The basis for operation of low light level television systems is the silicon intensifier target (SIT) tube. The tube uses a photocathode as the prime sensor. The photocathode is followed by a silicon diode array (target) to produce gain. Signal is read out on the backface of the target by a scanning beam in a fashion similar to that of conventional vidicon tubes. Overall SIT gain is a function of photoelectron acceleration voltage. A voltage near 10 KV will produce gains of the order of 3000 or low light level image intensification of this order.

'Blooming' of overloaded areas in the resultant TV image has hindered certain applications of the SIT camera. Recently developed 'non-blooming' tubes however utilize the technique of forming a structure in the silicon target array. This structure in effect acts in a passive manner during normal tube operation but 'soaks up' the excess 'holes' responsible for the blooming phenomena when the tube is overloaded by optical 'hot' spots.

Field experience with low light level imaging systems has found that they are able to extend the range of useful real time effectiveness of TV reconnaissance systems down to illumination regimes the optical equivalent of 'deep twilight'. This scene illumination is three to four orders of magnitude less than in mid-day (depending on conditions) but three to four orders of magnitude greater than the scene illuminance under starlit or overcast starlit conditions.

To overcome the problem of insufficient scene illuminance under very dark conditions, some form of artificial illuminator will be required for 24 hour application of L^3TV to 24 hours at low altitudes (U.S. Coast Guard Report, i, 1973). The recommended illuminator operates in cw mode from 28VDC & 60 A power supplies. The unit weighs less than 23 kg and is equipped with variable beamwidth will operate over a wide range of altitudes.

An optically more efficient illumination approach would be to employ some form of laser as the illuminator. For the near-IR spectral range a GaAs laser, emitting at 0.84μ, would serve as the most likely candidate for this application. Utilizing beam expansion optics, such as illuminator would have a nearly unlimited airborne altitude range. For 24 hour application of multi-spectral techniques, some form of tunable dye laser might better serve as a scene illuminator.

Recent trends in low light level imaging technology have been towards the development of all solid state or charge coupled devices (CCD's). Some quarters have suggested that CCD's will completely replace conventional scanning devices for photometric and thermal devices as well.

1.2.4 Thermal Devices

This class includes a broad range of both imaging and non-imaging infra-red sensing devices such as the IR radiometer, thermal IR line scanner (TIRLS) and the forward looking IR scanner (FLIR). Most of these systems operate in the 8-14μ region of the spectrum. Some lower resolution systems also operate in the 3-5μ region.

The basic operating principle of the TIRLS was outlined in Section 1.2.2 when discussing multi-spectral scanners. Most IR scanners of interest use these same basic optics but split the incoming radiation into its visible and thermal components via a dichromic element inserted at the scanning head.

Forward looking infrared (FLIR) thermal imaging systems are passive remote sensing devices which operate by scanning in a raster rather than a line mode. The image may be presented as a TV type display. Recently developed FLIR's have been designed for aircraft and helicopter applications. In a typical FLIR system, the sensor looks at the scene ahead of the aircraft. The elevation field of view is covered by the detector array while the scanning action of a rotating or scanning mirror covers the azimuth field of view. Use of fast response HgCdTe detectors enable elimination of scan conversion steps and permit direct interfacing with TV monitors.

The combination of image quality, real-time display, and coverage (i.e. forward looking capability) show that FLIR is a superior surveillance tool. Cost and secrecy have kept FLIR from the remote sensing community in the past. Both of these factors have fortunately been lessened and versions of this important environmental tool are available for non-military applications.

1.2.5 Environmental Constraints

This section details the results of a set of probabilistic calculations directed at arriving at a semi-quantitative determination or assessment of the probable effectiveness in the Beaufort Sea area of each of the broad sensor classes described above. The assessment is, at best, only semi-quantitative, since it is impossible to undertake a precise analysis of the Beaufort Sea area. There are virtually no meteorological observations for the offshore area and only limited numbers of stations ringing the shore (Burns, 1973-4), for which the periods of record are generally short and at which the conditions are not truly representative.

A total of six parameters which might affect the performance of downward-looking optical sensors are considered, namely; cloud cover, precipitation, fog, blowing snow, illumination, and ice cover.

The probability of unsuccessful target registration is considered to be directly proportional to the fractional cloud cover and the data utilized is a mean for Inuvik and Cape Parry. The occurrence of precipitation (snow or rain), fog or blowing snow (Cape Parry data) is assumed to signify zero probability for successful target registration. The probability of natural surface illumination during any period of the year is converted directly from "hours of daylight" data for 70° latitude.

Ice cover data are both limited in quality and variable in content, but for this assessment $\sim$ 100% ice cover from mid-November to late April is assumed. From early May through mid-September, or break-up, the probability of ice cover within the Beaufort Sea study area is assumed to linearly approach zero. In a similar fashion, the probability of ice cover during freeze-up (mid-September to mid-November) is taken to linearly approach unity. It is not considered possible, in general, to detect oil at the water/ice interface using optical techniques.

For the purposes of this semi-quantitative assessment, it is conservatively assumed that the various probabilities are independent, so that the overall probability that an efficient airborne sensor will provide positive downlooking registration of a given target will be a product of the appropriate probabilities.

Four sensing configurations are considered:

- High altitude photometric, for which all the limiting environmental parameters are included in the assessment. This case is intended to simulate a high altitude or satellite mission.
- Low altitude photometric, which is intended to simulate low level light aircraft or helicopter applications utilizing conventional photometric devices. Cloud cover restrictions are considered not to apply in this case.
- Low altitude intensified photometric, which is the same as above except that the photometric device is augmented by artificial illumination, so that the restrictions relating to natural surface illuminations are no longer included.
- Low altitude thermal, which is considered to include the same constraints as above except that two periods, October - December and April - May, are represented as having higher detection probabilities in the assessment. These periods represent times when potential thin ice or limited snow cover may occur over oil which are situations for which there is an as yet unproven possibility that thermal devices may be of use.

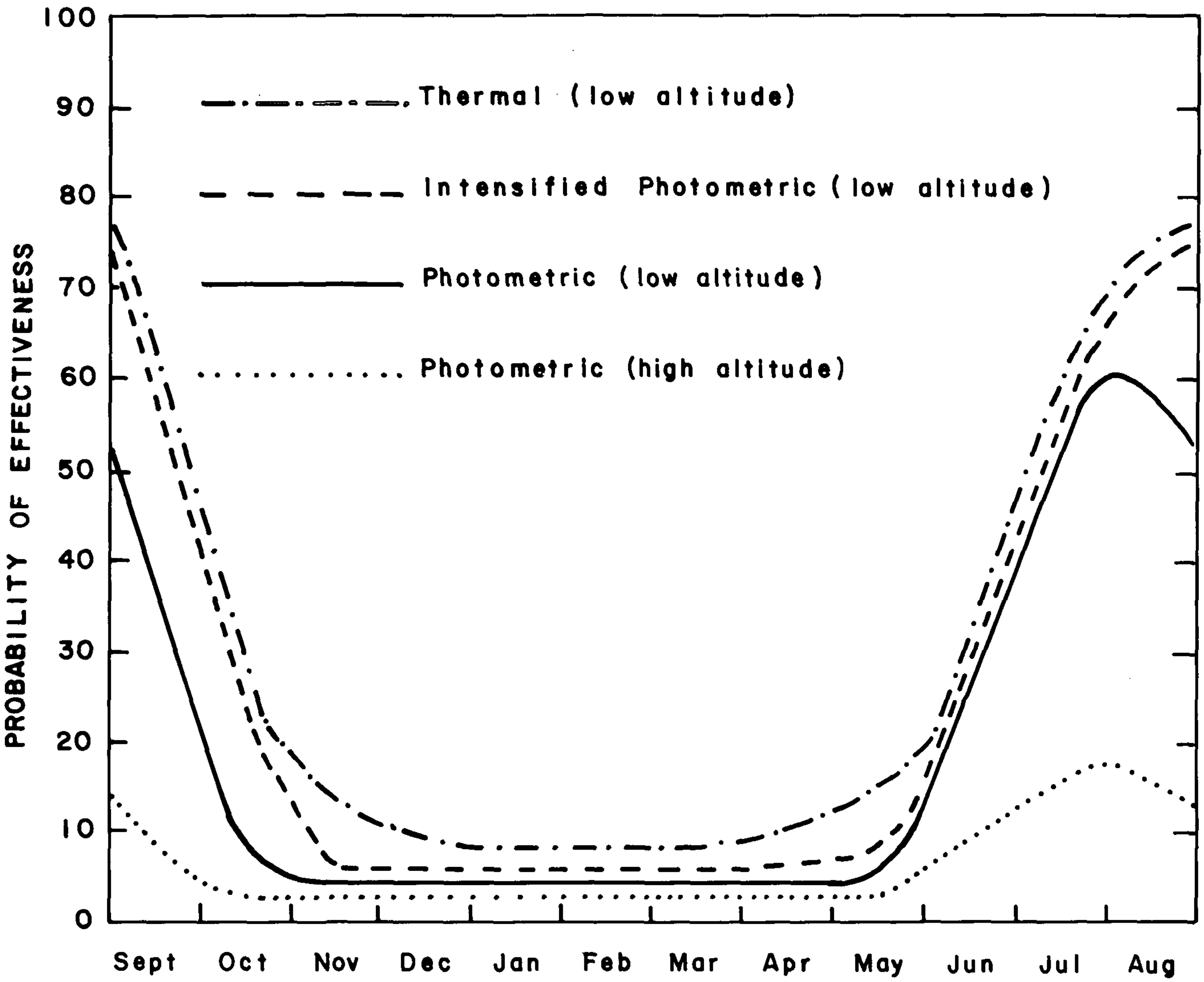
The results of the assessment illustrated in Figure 1.2.1 represent the general expected range of effectiveness of optical techniques under the "best" model conditions. For example, it is assumed that in each case the sensor is airborne. Again, it is emphasized that the results obtained are, at best, only semi-quantitative and are included merely to indicate trends.

In general, as inspection of Figure 1.2.1 will verify, ice conditions are seen to limit severely the range of optimum effectiveness of optical techniques for oil detection to the three month summer period.

The most sophisticated optical techniques are seen as ineffective for at least five months of the year. Exceptions will of course occur for oil intrusions into open leads, polynyi or in trenches that have been cut in the ice.

During open and ice infested periods, thermal and intensified optical devices operating at low altitudes will be significantly more effective than conventional photometric instrumentation.

It is possible under certain circumstances that some oil may reside on the surface of the ice. To attempt to account for this possibility, a similar assessment has been performed removing the extremely limiting



Approximate probability of effectiveness of Optical and Thermal techniques by month in the Beaufort Sea area including considerations of ambient illumination, cloud cover, precipitation, fog, blowing snow and ice cover.

FIG. 1.2.1

constraint of ice cover from the calculations. This manoeuvre will generate target registration probabilities which are considerably too high, since, in all likelihood, oil which resides on the ice surface would be covered, at least during the winter months, by blowing snow.

Shown in Figure 1.2.2, as might be expected, the performance of unaugmented photometric devices prove to be severely limited during the winter months, mainly because of lack of natural illumination. Whereas, a fair probability of success over the whole year is indicated for intensified photometric and thermal devices deployed at low altitude.

Assessments of high altitude (or satellite) deployed thermal and photometric devices are not included in the figures, when ice cover is included as a constraint in the evaluation, calculations for this case indicate, at most, only limited detection effectiveness during the July through October period. When this major constraint is removed, to simulate detection of oil on ice, a reasonable chance of success over most of the year is predicted, particularly for thermal devices.

Intensified Satellite applications of photometric techniques are not as yet feasible as they presently would require some form of ground illumination of potential targets from orbital altitudes.

1.3 Other Detection Techniques

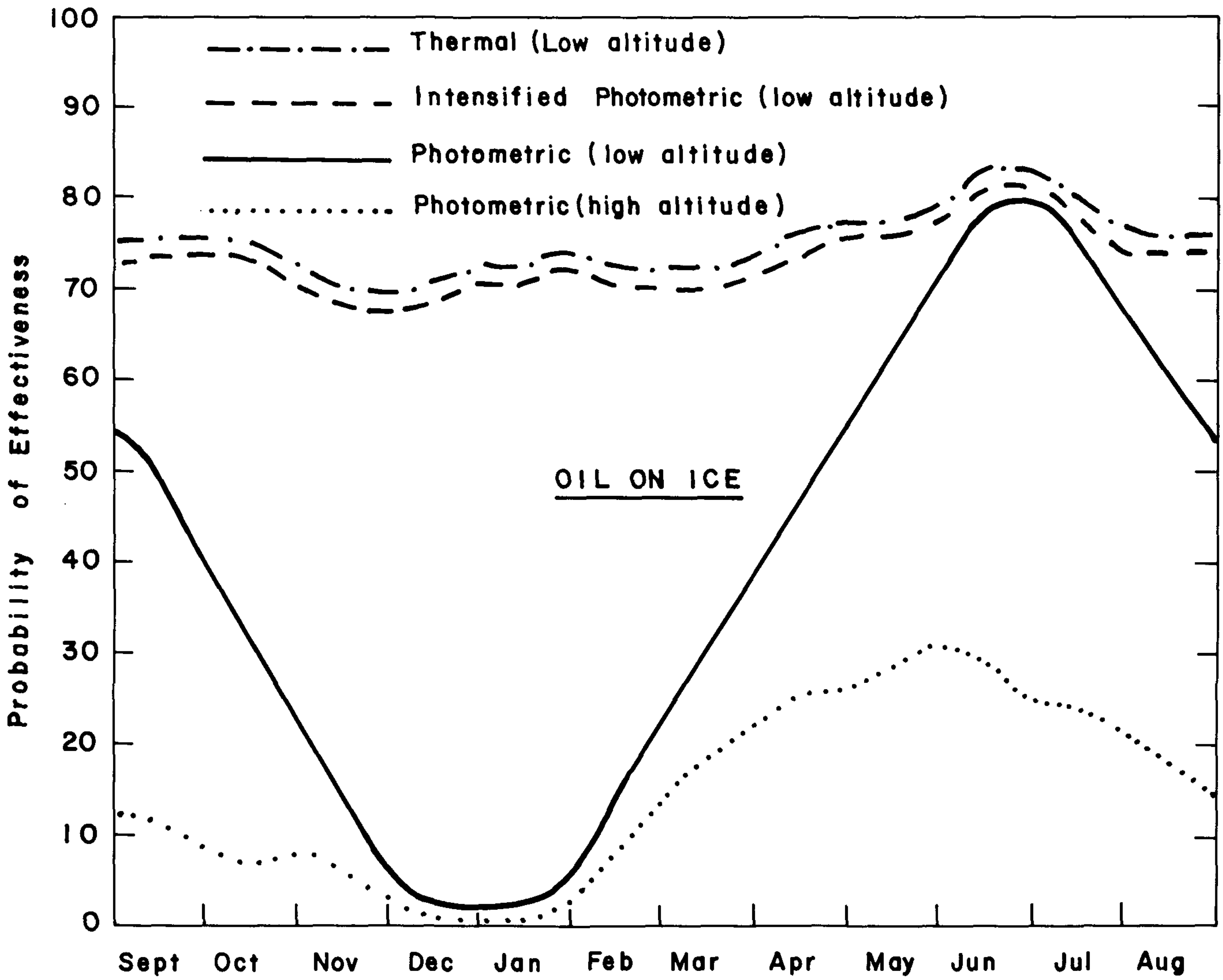
Because of the problems caused by the presence of ice and darkness for much of the year in the study area, other technologies, perhaps not normally classified as remote sensing, are considered in this section. These technologies are introduced merely to indicate their potential role in a surveillance and monitoring system and detailed scientific and technical assessment of each is not attempted.

1.3.1 Underwater Systems

Submarines have the advantages of long-range and independence from any tender ship. In fact, it is this independence which differentiates a "submarine" from a "submersible" which cannot operate without some form of tender platform. While submarines equipped with instruments such as side-scan sonar may be able to satisfy the surveillance role in under-ice conditions, they would represent a costly alternative. In addition, the submarine, which would almost certainly be diesel electric, would have to surface to snort and change the batteries. Since this must be done for two or three hours every day, consideration of submarines other than esoteric nuclear powered vessels may be excluded. However, it seems likely that a submarine, unless of very small size, would have great difficulties manoeuvering amongst the pressure ridge keels in the shallow continental shelf study area.

While submersibles are independent when in the operating mode, their limited range causes them to be dependent on a support vessel for transportation to and from the site. The Pisces I, for example, contains life support for 72 hours; Pisces II, III, IV and V for 200 hours which appears to be the maximum limit for submersibles now operating in the world (Trills, 1975).

Submersibles usually can carry an array of electronic equipment including side-scan sonar and low light level television. While it would appear that submersibles have a very limited role, if any at all,



Approximate probability of effectiveness of Optical and Thermal techiques by month in the Beaufort Sea including considerations of ambient illumination, cloud cover, precipitation, fog and blowing snow (deleting ice cover).

FIG. 1.2.2

in surveillance or monitoring because of the necessity for a support ship (not to mention access through the ice), the operation of Narwal, a submersible designed for Arctic Canadian Continental Shelf Exploration (ACCESS) of Toronto by Perry Oceanographics, should be investigated since the vehicle is designed specifically for operations under arctic ice (Trills, 1975).

Unmanned underwater vehicles can be considered in two categories: sea bed vehicles and self-propelled submersibles with at least neutral buoyance. Sea bed vehicles have been used mainly for bottom profiling, survey work, photography, and salvage work. In 1969 Troika, an unmanned towed sled designed by J.Y. Cousteau, successfully located the wreck of the Caravelle, a ship lost in 7,216 feet of water. With the sea bed rover acting as a base, it is possible to envisage a system composed of a rover and a "daughter" vehicle. The rover would contain the power system, the main propulsion unit, navigation and control systems, and the data transmission of storage equipment. The daughter vehicle would contain the oil detectors. The daughter would be released on a tether to perform a spiral search pattern controlled by the tether release. The information either would be stored on the rover or retransmitted in some form (e.g. cable or underwater transmitter). One concept considered, but then rejected, was the release by the rover of a buoyant aerial capable of penetrating the ice and permitting normal radio frequency transmission. In the final assessment, while they can carry a vast array of instruments, the through-the-ice penetration required for sea bed rovers makes them totally impractical.

However, there are self-propelled unmanned submersibles which may have a role in surveillance and monitoring. Some are extremely cumbersome and can be discounted immediately. These would include vehicles such as the CURV series (Cable-Controlled Underwater Recovery Vehicle) designed for the U.S. Navy to recover ordnance at their underwater test ranges. CURV III, the latest model, measures 2m by 5m and weights approximately 2000 kg. On the other hand, the unmanned submersible vehicle (U.S.V.) commissioned and used by the United Kingdom Ministry of Defence resembles a large torpedo -4 m in length, 33 cm in diameter and weighing 240 kg. By 1974, 27 of these vehicles had been built for military uses; mainly as targets. Designs have been produced for commercial application incorporating instrument packages such as side-scan sonar, photographic site inspection, magnetometry, physiochemical analysis, bottom profiling and seismic sonar, and television (Trills, 1975).

A vehicle, such as a U.S.V., could be employed for both surveillance and monitoring when the ice cover reaches 10/10. A hole of sufficient size could be augered in the ice and the U.S.V. lowered through. In this case, a vehicle, rather than a ship, would act as the support vessel. The U.S.V. then could be directed to the drill site for inspection. If oil discharging from the area was noted, the vehicle could be directed to monitor the areal extent (the U.S.V. can operate to depths of 365 m with a range of 22 km). In addition to these roles, a U.S.V. could be employed for regular inspection of the drill sites over the long winter months.

For the surveillance of sites in the seasonal pack and polar pack zones, a remote package detection system was envisaged which could be mounted on the ocean floor in the immediate vicinity of any drill site. This system could be installed as the drilling season is drawing to a close and the drill ship is preparing to leave the site. The system would consist of a simple device for detecting the presence of oil (perhaps some form of turbidity meter) transmitting information to a command and control station on the shore. This could be a simple go/no-go detector, triggered by the first sign of oil. Once it had been triggered, it would have no further role to play in the monitoring phase. Cable would be an extremely expensive communications link but some type of VLF transmitter to a geophone could be employed. This would transmit a signal at least to the landfast zone. The receiver on the ocean floor coupled with a retransmitter and an aerial through the ice would provide the final link. The antenna for transmission from the receiving station in the landfast zone to the command and control centre could be similar to the Arctic Data Buoy designed by the University of Washington (Trills, 1975). These buoys cost approximately $5,000 and are designed to be left unattended for up to two years (eight had been built by early 1974).

While conceptual in nature, the equipment necessary to assemble such a system is available and might prove to be the least expensive system considered to this point. Any number of sensors, including a television, for site inspection as well as surveillance, might be incorporated into the package.

1.3.2 Acoustical Techniques

During the past year, Bannister Pipelines of Edmonton, Alberta, tested an echo sounder off Byam Martin Channel for measuring the bottom surface through the ice. In this system being investigated by Bannister, the "jugs", or geophones, are placed in contact with the ice surface. (Note: it is necessary to sweep the snow away from the ice surface). Though not yet published, the results apparently exhibit close correlation with core samples.

One of the apparent benefits, although not yet investigated, is a profile of the ice. If this profile is altered significantly by the presence of oil, then the acoustical technique could hold promise for the surveillance and monitoring of oil discharges from above the ice cover.

1.3.3 Resistivity Measurements

It may be possible that simple resistivity surveys, based on inductively-coupled resistivity, could be capable of detecting oil under ice. Given ice approximately 2 metres thick and ice/oil conductivity contrast of at least two orders of magnitude, it may be possible to delineate the boundaries of contamination with a resolution of about a metre (Huntec, private communication).

The method appears promising and a more detailed technical assessment should be undertaken, including the compilation of information on the variation of electrical conductivity of sea ice with age and depth. If the technique continues to appear promising on closer evaluation, a field trial would be desirable.

1.3.4 Gas Analyzers (Sniffers)

Gas analyzers operate on the principal of detecting the decrease in energy in the incoming radiation due to the presence of an absorbing target gas. Barringer Research of Toronto have developed correlation gas analyzers suitable for aircraft mounting. However, because of the low concentrations that would be involved in this particular situation, a system mounted in a fixed wing aircraft does not appear practical.

One alternative would be to lower an instrument near the ice surface from a helicopter assuming that gases escaped through cracks or pores in the ice to reach the atmosphere. The advantage of this technique is that men and equipment would not have to be transferred onto the ice surface. The instruments also do not rely on any ambient illumination.

NORCOR Engineering and Research Limited employed a "sniffer" on the ice surface during their 1974/75 field studies for the Beaufort Sea Project Technical report #27. The system apparently performed very well. A "personal" type of sensor such as this could be considered as an alternative to a system operated from a helicopter. Gas analyzers are available commercially but the particular application we have postulated in this section remains conceptual in nature.

1.3.5 Manual and Other Techniques

Perhaps the most economical, and certainly the simplest, technique for checking the underside of the ice is to auger a hole through the ice mantle. It is estimated that a two man crew with a portable power head could auger over 10 holes per hour through ice up to 2 metres thick. However, there is little doubt that the technique is very labour intensive and constitutes a rather inefficient "trial and error" procedure.

In the surveillance mode, men and equipment would be transferred to the ice surface in the vicinity of the site. A predetermined search pattern, based on the maximum likelihood of detecting oil from a discharge given the plume characteristics, currents, and under ice profile, would establish the locations for coring. This procedure would be repeated at regular intervals throughout the period of solid ice cover.

In the seasonal pack and polar pack zones, exact determination of the areal extent and tracking would be difficult because of the ice movement. If oil is found in these regions during the coring, a simple radar reflector, such as a cube or pyramid mounted on a standard could be imbedded in the ice. These reflectors could be installed over the site at regular intervals. The spill could be tracked using the drift of these reflectors.

An alternative would be a series of beacons, or transponders each with their own internal power source. This would enable any aircraft to "home" on the signal or interrogate the transponder rather than limiting the tracking aircraft to one equipped with suitable radar instrumentation.

2.0 CONTAINMENT AND REMOVAL OF OIL

It was noted in Logan et al (1976) that countermeasures to contain and remove spilled oil following a offshore will blow-out in the southern Beaufort Sea can only be attempted with any degree of success in two situations -- on first year landfast ice just prior to the spring breakup and on reasonably open water during the summer and early autumn. The procedures and techniques for countermeasures operations in these two situations were described. In addition, the various generic type of equipment and materials and their application for open water operations were discussed.

The following section contains descriptions of some of the available equipment and material designed for offshore open water countermeasures. It is the result of a survey of manufacturers' literature undertaken by Environment Canada to illustrate to potential users the commercial application of the methods to contain and remove oil. It is not to be considered an endorsement by Environment Canada of this equipment. The equipment is presented in the following sub-sections

Booms and Barriers
Recovery Equipment (Skimmers)
Oil Spill Treating Agents
Transfer and Disposal

In each section the equipment is tabulated alphabeticaly by manufacturer. Each table when possible contains manufacturer's or Canadian agent's address, a description of the equipment and the manufacturer's operating specifications.

2.1 Booms and Barriers

2.1.1 Mechanical Booms

COMPANY

Bennett Pollution Controls, Ltd.,
119 Charles Street,
North Vancouver, B.C.

DESCRIPTION

36" Filtration Boom consisting of a flexible skirt-type barrier for offshore application

OPERATING SPECIFICATIONS

BOOM LENGTH	15m interconnecting sections.
DRAFT	0.6m (1.2m also available).
FREEBOARD	0.3m (0.6m also available).
TOTAL HEIGHT	0.9m (1.8m also available).
FLOTATION ELEMENT	Dow Ethafoam.
FLOTATION SHAPE	Cylindrical.
FLOTATION LENGTH	1.4m.
FLOTATION WIDTH	15cm diameter.
OVERALL WEIGHT	6.7 Kg/m.
STOWAGE (VOLUME)	Fits in space 1.5m x 0.46m x 0.9m.
CURTAIN MATERIAL	Cables, post dividers, vinyl-covered chain link fence, and filtration material.
BALLAST	Lead weights on bottom cable.
TENSION LINE	9.7mm steel cable.
REPAIRABILITY	Kits are available.
CLEANING	Industrial detergents and water blasting on shore.
COLOR	Yellow.

COMPANY

Clean Water, Inc.,
Court House Square,
P.O.Box 1002,
Toms River, New Jersey 08753
U.S.A.

DESCRIPTION

Offshore boom consisting of a series of 3 metre by 0.3 metre diameter air-inflatable chambers and skirt fabricated of nylon reinforced rubber for exposures requiring high abrasion and mechanical integrity under adverse conditions.

OPERATING SPECIFICATIONS

BOOM LENGTH	16.76m sections in 3m segments.
DRAFT	0.6m.
FREEBOARD	0.3m.
TOTAL HEIGHT	0.9m.
FLOTATION ELEMENT	Double chamber air-inflatable compartments.
FLOTATION SHAPE	Cylindrical with spherical shaped ends.
FLOTATION LENGTH	Each double compartment is 3.0m in length.
FLOTATION WIDTH	0.3m maximum.
OVERALL WEIGHT	With chain ballast 11.1 Kg/m with cable ballast 9.27 Kg/m.
STOWAGE (VOLUME)	33.5m of boom occupies $0.9m^3$ or 1.5m x 1.0m x 0.6m.
CURTAIN MATERIAL	1.8mm nylon-reinforced oil resistant rubber.
BALLAST	9.7mm hot dip galvanized steel chain 2.2 Kg/m.
TENSION LINE	6.0cm hot dip galvanized or 6.68 cm galvanized with rope.
REPAIRABILITY	Repair kits available from the manufacturer.
CLEANING	Industrial detergents and water blasting.
COLOR	Black with 0.3m wide gold vertical stripes each 1.0m.

COMPANY

Hurum Shipping & Trading Co., Ltd.,
300 St. Sacrament Street,
Montreal, Quebec.

DESCRIPTION

Flexy High-Sea boom is an offshore containment barrier of flexible skirt construction. Air-filled flotation supplies stability for use in moderate seas.

OPERATING SPECIFICATIONS

BOOM LENGTH	15m lengths.
DRAFT	1.2m.
FREEBOARD	0.6m.
TOTAL HEIGHT	1.8m.
FLOTATION ELEMENT	Inflatable plastic flotation.
FLOTATION SHAPE	Spherical.
FLOTATION LENGTH	15m.,
FLOTATION WIDTH	0.5m diameter each side of boom skirt.
OVERALL WEIGHT	14.9 Kg/m.
STOWAGE (VOLUME)	61m of unassembled boom occupies 2.0 m x 1.2 m diameter.
CURTAIN MATERIAL	PVC-impregnated nylon fabric, 0.53Kg/m^3.
BALLAST	12.7mm steel chain.
TENSION LINE	9.7mm steel cables on top and bottom of the skirt.
REPAIRABILITY	Kits and instructions supplied by the manufacturer.
CLEANING	Industrial detergents and water. Dry before storage.
COLOR	Yellow or orange.

COMPANY

Kepner Plastics Fabricators, Inc.,
4221 Spencer Street,
Torrance, California 90503
U.S.A.

DESCRIPTION

Ocean sea-curtain is the firm's largest containment boom. It is constructed for the ocean environment and designed for maximum mechanical resistance to wind, waves, currents, and tide.

OPERATING SPECIFICATIONS

BOOM LENGTH	30m common length, also available from 1.2 to 305m.
DRAFT	0.6, 0.8, 0.9m and 0.9 - 1.1m.
FREEBOARD	0.36, 0.36, 0.43m and 0.6 - 0.7m.
TOTAL HEIGHT	0.96, 1.16, 1.33m and 1.5 - 1.8m.
FLOTATION ELEMENT	Closed cell, plastic foam.
FLOTATION SHAPE	Cylindrical.
FLOTATION LENGTH	3.0 to 6.1m.
FLOTATION WIDTH	0.4, 0.51 and 0.76m.
OVERALL WEIGHT	10.6 - 21.6 Kg/m, 20.4 - 28.0 Kg/m and 16.^{4} - 26.8 Kg/m.
STOWAGE (VOLUME)	30m occupies 4.8^3 (1.98 x 1.98 x 2.44m).
CURTAIN MATERIAL	Vinyl-coated nylon fabric or polyethylene material for chemical spills.
BALLAST	4.5 - 14.9 Kg/m, 8.9 - 14.9 Kg/m and 8.9 - 14.9 Kg/m.
TENSION LINE	Steel cables and chain.
REPAIRABILITY	The product is readily repairable.
CLEANING	Industrial detergent and water.
COLOR	Saturn Yellow; other colors optional.

COMPANY

Trelleborg Rubber Co., Inc.,
30700 Solon Industrial Parkway,
Solon, Ohio 44139
U.S.A.

DESCRIPTION

Universal oil boom consists of a ballasted, flexible skirt and foam flotation designed for use in heavy seas and wind.

OPERATING SPECIFICATIONS

BOOM LENGTH	35m section length.
DRAFT	0.7m.
FREEBOARD	0.35m.
TOTAL HEIGHT	1.04m.
FLOTATION ELEMENT	Styrofoam flotation enclosed in PVC boom pockets.
FLOTATION SHAPE	Rectangular.
FLOTATION LENGTH	36 floats per section, each 0.9m in length.
FLOTATION WIDTH	Data not available.
OVERALL WEIGHT	7.45 Kg/m-1, or approximately 340 Kg per section length.
STOWAGE (VOLUME)	35m length occupies (1.2 x 1.5 x 1.2m)
CURTAIN MATERIAL	Polyurethane-impregnated nylon woven fabric, (0.56 mm thick, 0.42 Kg/m^2).
BALLAST	Pocketed skirt iron-powder ballast, each weighing 5.4 Kg.
TENSION LINE	16 mm polypropylene line.
REPAIRABILITY	0.9m panels are replaceable (requiring in-shop repair).
CLEANING	Industrial detergents and water, or trichloroethylene solvent.
COLOR	Light gray (standard); International Orange (optional).

COMPANY

UniRoyal, Inc.
Engineered Systems Dept.,
312 North Hill Street,
Mathawaka, Indiana 46544
U.S.A.

DESCRIPTION

Rough water sealed boom consists of a flexible, ballasted skirt and sealed-foam flotation for offshore emergency containment of spilled materials.

OPERATING SPECIFICATIONS

BOOM LENGTH	12.2m standard section lengths.
DRAFT	1.2m.
FREEBOARD	0.6m.
TOTAL HEIGHT	1.8m.
FLOTATION ELEMENT	Closed-cell Ensolite-foam, enclosed on each side of skirt.
FLOTATION SHAPE	Trapezoidal.
FLOTATION LENGTH	0.7m.
FLOTATION WIDTH	Data not available.
OVERALL WEIGHT	14.3 Kg/m, 174 Kg per section length.
STOWAGE (VOLUME)	0.13 m^3/m (approximately).
CURTAIN MATERIAL	Paracril-OZO coated fabric; resistant to oil, seawater, and sunlight.
BALLAST	Lead weights.
TENSION LINE	None.
REPAIRABILITY	Repaired on-site, or by manufacturer.
CLEANING	Industrial detergents and water, or steam cleaning.
COLOR	High-visibility yellow.

NOTE: The product is not fire resistant.

COMPANY

Vikoma International Ltd.,
(in Canada) Marine Equipment Ltd.,
112 Lisgar St.,
Ottawa, Ontario. K2P 0C2

DESCRIPTION

Vikoma seapack, a self-contained tow vessel containing 1600' of flexible, inflatable double-chamber boom with automatic inflation after laying of boom.

OPERATING SPECIFICATIONS

BOOM LENGTH	488m
DRAFT	0.4m
FREEBOARD	0.76m
TOTAL HEIGHT	1.19m
FLOTATION ELEMENT	Air compartment.
FLOTATION SHAPE	Cylindrical.
FLOTATION LENGTH	Entire length of boom.
FLOTATION WIDTH	0.68m maximum diameter.
OVERALL WEIGHT	Boom (uninflated) 4.5 Kg/m
STOWAGE (VOLUME)	244m uninflated occupies 3.54 m^3
CURTAIN MATERIAL	Butachlor-coated neoprene/nylon/neoprene fabric in the form of a cylinder.
BALLAST	0.43m diameter bottom chamber filled with seawater.
TENSION LINE	None.
REPAIRABILITY	Kits for on-site repair are available.
CLEANING	Industrial solvent and water.
COLOR	Black.

2.1.2 Pneumatic Barriers

The pneumatic barrier consists of a manifold pipe made of steel and submerged at the required depth and air supply umbilical pipes and compressor(s) for providing the required amount of air at the desired pressure.

Initially, it would appear that the pneumatic barrier design would have decided advantages over conventional solid wall barriers for operation in ice infested waters by virtue of the fact that the air manifold may be placed at sufficient depth to prevent it being damaged by the passage of ice through the containment area. However, this barrier design has not been tested under ice infested conditions in the Arctic and therefore little is known about the effects of repeated passage of ice floes through the barrier. It is possible that significant quantities of oil may be carried outside of the containment area by such ice movement.

A pneumatic barrier design has been proposed which is reportedly capable of containing oil effectively under the following environmental conditions:

(i) 64 km/h wind at standard height with gusts up to 96 km/h lasting no longer than 5 seconds each hour.

(ii) Significant wave height - 3m
Height of highest 1/10 of waves - 3.96m
Significant wave period - 7.5 seconds

(iii) Sea Current - 2 knots

(iv) No ice present.

The general requirements for a suitable air barrier for this purpose are as follows:

(i) Manifold pipe depth - 7.6m (approx)

(ii) Holes spacing along manifold 20-40 per metre of pipe 0.7 - 1.5mm

(iii) Air flow rate - 0.9 m^3 per metre of pipe (produces a surface current of 1.5 m/sec.)

(iv) Power requirement in the manifold ranges from 12 to 30 kw per metre length of pipe pending upon the pipe depth.

(v) The pipe material should be steel.

The above mentioned general requirements are fulfilled, for 64 metre of barrier, by the following equipment packages:

(i) A gas turbine-drive air compressor supplying 34,000m^3/h air at 275 kPa and requiring 1680 kw. Compressor package, skid-mounted with cradle would weigh approximately 9.5 tons.

(ii) 64m of 100 mm diameter steel pipe at 16 kg/m including clamps, umbilical and floats, would weigh approximately 1025 kg.

(iii) Mooring system including four anchor and mooring lines will weigh approximately 5400 kg.

(iv) Inflatable rubber fuel tanks; 450m^3, capacity (8 days supply).

The total weight of the system will be approximately 16,300 kg and will require three C-130 (Hercules) aircraft to transport each 60m module of bubble barrier.

It can be concluded that the pneumatic containment barrier is unsuitable for use as a containment measure in the Beaufort Sea for the following reasons:

(i) The technique has not been tested for its applicability in ice infested water.

(ii) Power and fuel requirements are too high and would therefore be extremely costly.

(iii) Support systems are too heavy to be easily deployed and recovered in remote areas and in the presence of ice floes.

2.1.3 Chemical Barriers (Herders)

COMPANY

Shell Oil Company
(in Canada)
Shell Canada Ltd.

DESCRIPTION

Shell Oil Herder is a water insoluble collecting agent which competes with oil for water surface. It has a spreading force that is greater than the spreading force of oil.

OPERATING CHARACTERISTICS

Compatibility with other Agents - The material is water insoluble, but is compatible with most hydrocarbons.

Deployment - From workboats, hand-sprayers, helicopter-mounted but is compatible with most hydrocarbons.

Compatibility with Equipment - The product contains no organic halides, heavy metals or other chemicals known to be harmful spray units, etc.

Application Rate - E.P.A. recommended rate is 4.7 l/km but not more than 3 applications in any 24 hour period.

Recovery - Standard recovery of collected oils.

SPECIFICATIONS

Density - 860 kg/m^3 at 25^oC

Coverage - 4.7 litres per kilometre (Oil Herder is effective in containing oil spills as a film one molecule thick. One litre will cover 2.8 hectares of water with a monomolecular film).

Performance - Product has undergone extensive tests, has been commercially available since October 1971 and has been found effective at a number of spill sites. In the containment of crude oils, heavy fuels oils, lubricating oil and #2 fuel oils, Oil Herder functions on both salt and fresh water.

2.2 Recovery Equipment (Skimmers)

COMPANY

Bennett Pollution Controls Ltd.,
119 Charles Street,
North Vancouver, B.C.

DESCRIPTION

The Bennett Mk IV is a inverted endless squeeze belt-weir-type, manned self-propelled vessel type skimmer.

OPERATING CHARACTERISTICS

Deployment - Unit can be launched.
Draft/Freeboard, Empty - 10.6m
Draft/Freeboard, Loaded - Poontoons on 2.1m, off 1.0m
Mounted/Stationary - Used in sweeping operations.
Velocity (Max.) in Relation to Water - 7 knots.

OPERATING SPECIFICATIONS

Overall Dimensions - 12.3m long x 3.6m wide x 3.2m shipping height
Weight - 15.4 ton
Mooring -
Power Requirements - Two GM 6V53 producing 179 kw at 2200 RPM propulsion and steering by two Schottel 360^{o} drives
Pump Type and Capacity - Moyno progressive cavity.
Pump Rate -
Sunction Hose -
Discharge Hose -
Collector Storage Capacity
Compatibility with Material Collected - Aluminium Hull; Polyester/ wool belt.
Sweep Width - 1.2m without boom attached.
Mechanical Repairability -
Maintenance -

COMPANY

JFB SCientific Corporation
2 Ray Avenue
Burlington, Massachusetts 01803

DESCRIPTION

The JBF DIP 3001 model (Dynamic Inclined Plane) is an inverted endless-belt, manned, self-powered vessel type skimmer.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - 0.89m draft; 0.51m freeboard.
Deployment - Unit can be launched or deployed using a crane of suitable lift capacity.
Draft/Freeboard, Loaded - 1.1m draft; 0.3m freeboard.
Mounted/Stationary - The unit may be used stationary or moving.
Velocity (Max.) in Relation to Water - 0-3 knots maximum effectiveness.

OPERATING SPECIFICATIONS

Overall Dimensions - 7.62m long x 1.14m wide x 1.4m high.
Weight - 6340kg.
Mooring - Moored using standard anchoring devices.
Power Requirements - Power is provided by a radiator-cooled diesel which also drives the hydraulic distribution system.
Pump Type and Capacity - Positive displacement, progressive-cavity pump.
Pump Rate - $0.23m^3/h$ at 1034.2k Pa.
Suction Hose - 50.8m
Discharge Hoe - 50.8m
Collector Storage Capacity - $5.3m^3$ (3.79 in hull tanks, 1.5 in collection well).
Compatibility with Material Collected - Marine aluminum hull; poly (-urethane or -vinylchloride) belt.
Sweep Width - 1.2m without sweeps, 4.6m with sweeps.
Efficiency - 80% recovery at speeds or currents up to 1.0 knots.
Mechanical Repairability - Good. Standard hand tools required for unit repair.
Maintenance - General cleaning and lubrication. Hatches provide internal unit access.

COMPANY

Esso Research Centre (England)
(in Canada)
John Misener Marine Equipment Ltd.
P.O.Box 278
Port Colborne, Ontario.

DESCRIPTION

Slurp skimmer is a non-selective, high-volume, floating, portable automatic hydro adjusting weir-type skimmer.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - Not applicable.
Deployment - Two men are required to deploy and place in operation.
Draft/Freeboard, Loaded - Not applicable
Mounted/Stationary - The unit has been developed for stationary applications.
Velocity (Max.) in Relation to Water - Not applicable.

OPERATING SPECIFICATIONS

Overall Dimensions - 0.93m O.A.L.; 0.62m O.A.W.; 0.42m O.A.D.; skimming head only.
Weight - 27kg (skimming head only).
Mooring - Standard anchoring devices as required.
Power Requirements - 2.2 kW 4-cycle Briggs and Stratton gasoline engine is supplied with each unit.
Pump Type and Capacity - 38mm self-priming centrifugal pump. Maximum capacity (dependent on pump) $7.57 m^3/h$.
Pump Rate -
Suction Hose - 38mm I.D.; 10m length is supplied, 10kg.
Discharge Hose - 38mm I.D. discharge hose.
Collector Storage Capacity - None.
Compatibility with Material Collected - Not applicable.
Sweep Width - 0.62m collection width.
Efficiency - Data not available.
Mechanical Repairability - Skimming head has no moving parts; engine requires standard hand tools for repair.
Maintenance - Maintenance typical of small engines; unit cleaning after use.

COMPANY

Lockheed Missiles & Space Co., Inc.
Ocean Systems Marketing
Dept. 15.50, Bldg. 150
P.O.Box 504
Sunnyvale, California 94088

DESCRIPTION

The Lockheed "Clean Sweep" model R2003 is a floating, oleophilic-disc skimmer that can be mounted in a frame for fixed installation.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - 0.45m draft on foam-filled flotation.
Deployment - By truck, then towed to spill site, or by ocean work boat. It can also be permanently mounted in an effluent channel, settling tank, or pond.
Draft/Freeboard, Loaded - 100% reserve buoyancy.
Mounted/Stationary - It may be used stationary.
Velocity (Max.) in Relation to Water - Designed to skim at speeds to 5 knots in state 4 seas.

OPERATING SPECIFICATIONS

Overall Dimensions - 7.3m long x 6.7m wide x 4.3 high.
Weight - 590 kg.
Mooring - The unit creates its own current and may be moored for still water applications.
Power Requirements - The unit is Diesel powered including propulsion.
Pump Type and Capacity - 50.8mm positive displacement, discharge pump. Nominal recovery rate is 47.7m^3/h
Pump Rate - 45.4m^3/h
Suction Hose - None.
Discharge Hose - 101.4mm
Collector Storage Capacity - 0.76m^3 on board. A 9.46m^3 floating storage bag is available as an option.
Compatibility with material collected - Compatible with most substances over a wide pH range.
Sweep Width - 2.13m
Efficiency - Oil recovery rate 45.4m^3/h. Less than 2% water in recovered oil.
Mechanical Repairability - Conventional hand tools are required. Two operating and maintenance manuals supplied.
Maintenance - Standard maintenance and cleaning as required. The disc wipers can be replaced in one hour.

COMPANY

Marco Pollution Control Corp.
(in Canada)
Dynamic Environmental Equipment
566 Cardero St.
Vancouver, B.C.

DESCRIPTION

The Marco Class III is a 17.5m self-propelled vessel type, oleophilic-belt skimmer. The twin hull designed unit is capable of operations in harbors or offshore conditions.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - 1.47m draft.
Deployment - The vessel is deployed using shipyard cranes of suitable lift capacity (minimum 50 tons).
Draft/Freeboard, Loaded - 1.75m
Mounted/Stationary - Vessel can be used stationary. (Induced flow from bow radius).
Velocity (Max.) in Relation to Water - 3 knots effective recovery.

OPERATING SPECIFICATIONS

Overall Dimensions - 17.5m overall length; 7.16m beam.
Weight - 50 tons displacement, ready for sea condition.
Mooring - Moored using standard anchoring devices.
Power Requirements - Propulsors, twin CAT 3160 diesels (rated 156 kW each) with Hamilton 1312 jets.
Pump Type and Capacity - Twin deck mounted wet sump trash handling 101.6mm pumps.
Pump Rate - 79.5m^3/h at 38m TDH
Suction Hose - 101.6mm
Discharge Hose - 101.6mm
Collector Storage Capacity - 14.3m^3 on-board storage.
Compatibility with Material Collected - The unit is compatible with petroleum products and floating debris.
Sweep Width - 4.88m vessel only. May be increased to 10.0m with water spray booms.
Efficiency - In a 25mm slick of API #30 oil, the unit's recovery rate is approximately 79.5m^3/h
Mechanical Repairability - Standard hand tools are required for unit repair.
Maintenance - Unit lubrication and cleaning as required.

COMPANY

Neurpic, Inc.
315 Park Avenue,
New York, New York 10022

DESCRIPTION

Cyclonet 100 is a vortex weir (hydrocyclone) device which operates by movement through water.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - 1.46m average draft; 0.49m board.
Deployment - Manual deployment. The unit is mounted on the side of a vessel (e.g., trawler) and requires 15 minutes to place in operation.
Draft/Freeboard, Loaded - Same as empty.
Mounted/Stationary - Mounted in a fixed position.
Velocity (max.) in Relation to Water - 7 knots maximum velocity.

OPERATING SPECIFICATIONS

Overall Dimensions - 3.0m long, 1.0m wide x 1.95m high.
Weight - 906 Kg.
Mooring - The unit is not moored.
Power Requirements - Power for pumping unit only.
Pump Type and Capacity - Two centrifugal pumps.
Pump Rate - 0.23m^3/h.
Suction Hose - None.
Discharge Hose - 300mm
Collector Storage Capacity - 121m^3 towable; collapsible tanker can be provided.
Compatibility with Material Collected - Dependent on materials selected for construction.
Sweep Width - Vessel width plus 1.0m per unit. Two units are recommended, one on each side of the vessel.
Efficiency - Efficiency from 90% depending on slick thickness, and operating speed.
Mechanical Repairability - Standard hand tools are required for unit repair.
Maintenance - Standard maintenance and cleaning using industrial detergents, solvents, or steam.

COMPANY

Oil Mop Pollution Controls Ltd.
Mississauga, Ontario.

DESCRIPTION

Oil Mop products cover a wide range of oleophilic rope equipment.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - Not applicable.
Deployment - Depends on unit size. Varies from manually portable equipment to large sea going units.
Mounted/Stationary - Depending on size. May be mounted on an open top drum, trailer, barge, boat, or stationary on shore.
Draft/Freeboard, Loaded - Not applicable.
Velocity (Max.) in Relation to Water - Mop speeds from 3.0 to 45m per minute and may be vectored for near zero relative velocity.

OPERATING SPECIFICATIONS

Overall Dimensions - Varies with model from small manually transported units to sea-going units.
Weight - Varies with model from 68Kg to 8 tons.
Mooring - Anchors, small boats, "dead men" anchors, driven stakes or dead-weight anchors.
Power requirements - Manually cranked, electric, gasoline, or diesel self-powered.
Pump Type and Capacity - The Mark 11-4 series usually without pumps; on other models, pumps vary, 50m to 100mm discharge.
Pump Rate - Usually adequate for reclamation rates of each unit; sometimes auxiliary pumps are required.
Suction Hose - None.
Discharge Hose - From 50mm diameter to 100mm diameter oil-resistant discharge hose.
Collector Storage Capacity - Depending on model, from .16m^3 to 16m^3
Compatibility with Material Collected - Excellent.
Sweep Width - Varies with machine selected; up to 610m.
Efficiency - Capacities and efficiency are a function of temperature, material viscosity.
Mechanical Repairability - Standard hand tools used for mop engines.
Maintenance - Mops are cleaned with any petroleum solvent or detergent. When detergent is used, extensive rinsing is required. Traces of residual detergent reduce sorption capacity.

COMPANY

R.B.H. Cybernetics (1970) Ltd.
P.O.Box 4205, Postal Station "A"
Victoria, B.C.

DESCRIPTION

The Slicklicker is a vessel-mounted oleophilic belt skimmer and squeeze roll recovery.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - Not applicable.
Deployment - Manual deployment.
Draft/Freeboard, Loaded - Not applicable.
Mounted/Stationary - Vessel is mounted and use in sweeping operations.
Velocity (Max.) in Relation to Water - 1 knot or less.

OPERATING SPECIFICATIONS

Overall Dimensions - Unit dimensions: 1.83m 1.83m base; 1.83m high frame, 3.35m and 4.57 boom lengths.
Weight - 680 Kg.
Mooring - Not applicable.
Power Requirements - 4.5Kw diesel engine (Standard) 6Kw or 6.7Kw gasoline, or 3.7Kw electric motor. (optional).
Pump Type and Capacity - A pump is not supplied on the standard Slicklicker.
Pump Rate - Recommended pump rate, 0.23m^3/H minimum.
Suction Hose - None.
Discharge Hose - 300mm nipple behind and below the squeeze roller.
Collector Storage Capacity - 15m^3; 9.46 m^3 recommended.
Compatibility with Material Collected - Not applicable.
Sweep Width - 0.9m without booms or guide floats.
Efficiency - Data not available.
Mechanical Repairability - Standard hand tools required for repair.
Maintenance - Clean after use with any industrial detergent.

COMPANY

Vikoma International Ltd.
(in Canada)
Marine Equipment Ltd.
112 Lisgar St.
Ottawa, Ontario. K2P 0C2

DESCRIPTION

Vikoma Seaskimmer is a oleophilic disc skimmer.

OPERATING CHARACTERISTICS

Draft/Freeboard, Empty - 0.76m.
Deployment - From deck of workboat, by derrick, or from derrick on pallet.
Draft/Freeboard, Loaded - Controlled pneumatically at operating level.
Mounted/Stationary - Not self propelled.
Relation to Water - Not applicable.

OPERATING SPECIFICATIONS

Overall Dimensions - Overall height 2.54m, OD 3.28m
Weight - 928 Kg.
Mooring - Line via derrick to workboat.
Power Requirements - Power pack 18.6 Kw diesel engine -- hydraulic drives to pumps and discs.
Pump Type and Capacity - Centrifugal 408m^3/h.
Pump Rate 90.7m^3h maximum.
Suction Hose - Not applicable.
Discharge Hose - 200mm diameter vinyl-covered nylon reinforced flat hose.
Collector Storage Capacity - Not applicable.
Compatibility with Material Collected - Not affected (GRP contruction).
Sweep Width - Torroidal shape -- 3.28m diameter with fender inflated.
Efficiency - Normally less than 5 percent free water carryover in recovered oil.
Mechanical Repairability - SEASKIMMER repairs very quickly effected by use of recommended GRP spares and replaceable snap-in plastic discs.
Maintenance - Minimal.

2.3 Oil Spill Treating Agents.

COMPANY

Conwed Corporation
(in Canada)
CIL
Branches Across Canada

DESCRIPTION

Conwed is available as water-resistant, petrophilic vegetable fiber blankets, pads, sweeps, and strips.

OPERATING CHARACTERISTICS

Deployment - Usually deployed manually.
Compatibility - Standard products cannot be retrieved by skimmers or separators.
Recovery - Recovered manually.

OPERATING SPECIFICATIONS

Size - Blankets: 0.89m x 61m x 6.4mm. Pads: 0.44m x 0.44m x 6.4mm. Sweeps: 0.44m x 0.44m x 6.4mm. Strips: 0.07m x 0.66m x 6.4mm
Density - 51 Kg/m^3
Absorption - Dependent upon hydrocarbon. Sorbent picks up and holds 15 times its own weight of lighter fuels such as gasoline and jet fuel; 20 times or more of higher viscosity products such as #6 fuel oil.
Coverage - The material must be in contact with oil. One carton of pads will pick up one barrel of oil.
Efficiency - Extremely rapid (22 times their weight of No. 2 Diesel fuel in 18 seconds, and No. 6 fuel oil in 30 seconds).

COMPANY

Oil Mop Pollution Controls Ltd.
Mississauga, Ontario.

DESCRIPTION

Oil Mop is a manually or mechanically-powered (and deployed) continuous rope mop of oleophilic hydrophobic fibers or ribbons woven into a rope. Manual mops (similar to ordinary kitchen mops) are available for hand operations.

OPERATING CHARACTERISTICS

Deployment - Oil Mops may be manually deployed and used as sorbents or barriers, or used with manufacturer's wringer units. Complete system can be transported by truck or vessel and requires several men for initial set-up.

Compatibility - Not applicable.

Recovery - Oil Mops are automatically recovered and passed through mechanical wringers.

OPERATING SPECIFICATIONS

Size - Rope sizes vary from 9.6mm to 19mm. A 9.6mm rope has minimum fiber lengths of 100mm; a 19mm rope has maximum fiber lengths of 0.9m.

Density - 650 to 920 Kg/m^3

Absorption - Absorption limits of the oil/water ratio in pick-up is good with long lift times, and little or no water is recovered. Speed of operation reduces efficiency.

Coverage - Not applicable.

Efficiency - Varies with oil viscosity and speed of recovery. Viscosity of 150 SUS oil and a lift-time of 10 seconds will recover $15.9m^3/h$. A viscosity of 900 SUS at a 10-second lift time will recover $31.8m^3/h$.

COMPANY

Parker Systems, Inc.
P.O.Box 1652
Norfolk, Virginia 23501

DESCRIPTION

Oil Snare consists of flat fibers of oleophilic/hydrophobic bundles of polypropylene ribbon yard.

OPERATING CHARACTERISTICS

Deployment - Spread by hand.

Recovery - Recovered with a rake, pitchfork, boat-hook or other suitable tool. Material is moved vertically through the oil, not from side to side.

Compatibility - The product is best used for final cleanup after skimmers have removed the bulk of the oil and are no longer effective. Also used in shallow water, ditches, etc.

OPERATING SPECIFICATIONS

Size - A 6.8Kg carton contains 30 Oil Snares (each weighing about 0.23Kg). The carton size is 0.61 x 0.41 x 0.46m.

Density - 51Kg/m^3

Absorption - This material is adsorbent and its performance is dependent on oil viscosity.

Coverage - As required.

Efficiency - Typical pickup rates (Kg of oil per Kg of Oil Snare): #6 oil - 29Kg @ 1.7°C (14.5Kg lbs. @ 21°C); #5 oil -- 10.9Kg at 21°C (7.3Kg @ 27.8°C); #4 oil -- 8.2Kg at 18.3°C Alaskan Crude 18Kg @ -1.1°C.

COMPANY

R.B.H. Cybernetics (1970), Ltd.
P.O.Box 4205, Postal Station "A"
Victoria, B.C.

DESCRIPTION

Graboil is a polyurethane foam treated to increase oleophilic properties and hydrophobic properties.

OPERATING CHARACTERISTICS

Deployment - The material is deployed by hand from piers, workboats, etc.

Compatibility - Designed for use with Slicklicker (an R.B.H. Cybernetics skimmer) or other squeeze rollers, but can be squeezed out by hand quite effectively.

Recovery - By Slicklicker or hand tools.

OPERATING SPECIFICATIONS

Size - Batts 0.6m x 0.3m x 2.5mm; also in 0.15m x 1.8m x 15.2m booms.

Density - 21Kg/m^3

Absorption - Up to 20 times its own weight under operational conditions. In lab conditions it can take up to 30 times its own weight.

Coverage - Depending on the thickness of the slick.

Efficiency - Gives very clean pickup and holds oil for an indefinite period (up to three months under lab conditions).

COMPANY

3M Company
(in Canada)
3M
London, Ontario.

DESCRIPTION

3M oil sorbent is a microfibrous (100% synthetic polymeric fiber) oleophilic, hydrophobic oil sorbent. Available as rolls, sweeps, sheets, particulate, pillow, and booms (See also booms).

OPERATING CHARACTERISTICS

Deployment - The particulate is distributed by hand or by blower. Other types are hand deployed.

Compatibility - Compatible with retrieval equipment (particulate).

Recovery - Particulate by screen scoop, seine, skimmer, and pump. Other types retrieved manually or lift by screen scoop.

OPERATING SPECIFICATIONS

Size - Rolls: 0.9m x 45.7m x 9.6mm; sweeps: 0.56m x 30.5m x 9.6mm; sheets; 0.46m x 0.46m x 9.6mm and pillows: 127mm x 0.36m x 0.6m. Particulate in 23 kg bales.

Density - 48-64 Kg/m^3

Absorption - 10 to 24 times its own weight depending upon material absorbed, temperature, and viscosity.

Coverage - Dependent on spill and water conditions.

Efficiency - Efficiency is good; cost-effectiveness is a function of the extent to which materials can be reused.

TABLE 2.3-1

Sorbents for Recovery of Oil in Ice Infested Water

(1) Speed and efficiency	generally efficiency of oil pick-up and retention increases with increasing oil viscosity, however greater mixing energy is required to achieve good sorption at low temperatures (for polyurethane foam)
(2) Cost	polyurethane reused 100 times = \$80/day; 60 times = \$135/day; no reuse = \$8,150/day (assumes non emulsified oil); for straw - 78 tons/day is required @ \$30/ton - \$2,300/day
(3) Total Capacity	polyurethane foam = 21.6 kg oil/kg sorbent; straw = 2.3 kg oil/kg straw
(4) Weight, Size; Power Supply	68-136 kg of polyurethane foam required for 299 m^3/day non-emulsified oil (foam is reused); 8 tons/day required without reuse; 70 ton/day of straw required to do same job.
(5) Complexity of Set-up and Operation	requires a certain amount of mixing energy to ensure efficient sorption; the amount of energy required to ensure efficient pick-up of highly viscous oil may be prohibitively large; must be mechanically or manually recovered and mechanically squeezed for recycle. Effects of ice on these operations is unknown.
(6) Applicability in Arctic	mixed opinions as to applicability of sorbents in ice infested Arctic waters; little actual testing has been done, however, indications are that it will work on oil of up to a certain viscosity (as yet unknown).
(7) Availability of Equipment	material is readily available, however, considerable quantity would have to be stockpiled in area in preparation for a spill. Delivery time is unknown.
(8) Versatility	reasonably versatile although it is not known what affect ice would have on performance of sorbent; would tend to work better in small ice pockets, etc. where other equipment can not reach and the sorbents should be evaluated for their usefulness for this purpose.

2.4 Transfer and Disposal

2.4.1 Pumping

TABLE 2.4-1
Pumps for Handling Highly Viscous Oils

Pump Name	Max. Viscosity it can pump	Max. Capacity at 250,000 SSU	Construction Material	Steam Jacketing	Type of Pump	Remarks
	SSU	M^3/h				
Moyno	5,000,000	13.63	Any material Hard chrome plating #316SS	-	Screw Conveyor	Can handle solid particles up to 25 mm. Hopper intake and auger
Sier-Bath	5,000,000 30,000,000 also available	20.45	High grade cast iron screw std. All materials available	Available	Double-screw external gear and bearing	Hopper type intake and hard-faced screws available. Pumps cold oil at 300,000 SSU. Unexcelled for Bunker C
Roto-King (Viking)	2,000,000 Standard up to 250,000	45.43 45kW required to produce 345kPa	Iron and steel	Standard	Internal gear rotary	332 Series
Wavkesha	700,000	34.08	Wavkesha or 316SS or rubber impeller	Jacketed cover available	Twin-blade metal rotor or *Dualobe* rubber rotor	Abrasive not recommended
Blackmer	Quoted no limit. Standard up to 100,000	-	Hard chrome plating and hardened iron	Available	Vane	Handles abrasive such as slurries. Easy to replace worn parts. Relatively small capacity.
Spate	10,000	11.36	Aluminum	-	Induced flow	Inexpensive, lightweight; portable proven reliability in spill situations
Megator	10,000	13.63	Steel	-	Sliding Shoe	Inexpensive; lightweight portable

TABLE 2.4-2

Pumps and Vacuum System Technical Data

	Megator[1] Pump	Spate [2] Pump	Trans[3] Vac
Pumping Rate (m^3/h)	13.63	11.36	45.43
Suction Life (m)	7.0	6.1	4.9
Discharge Head (m)	30.5	30.5	35
Inlet Size (mm)	75	75	100
Outlet Size (mm)	75	75	100
Max. Viscosity (SSU)	10,000	10,000	-
Driver	Diesel	Diesel	Diesel
Power (kW)	5	5	32
Total Weight (kg)	90.6	90.6	2265
Length x Width x Height (m)	1.04 x 0.36 x 0.65	0.81 x 0.61 x 0.61	0.30 x 0.18 x 0.18
Portability	Helicopter Transportable	Helicopter Transportable	Helicopter Transportable
Type	Sliding Shoe	Induced Flow	-
Availability	Commercially Available	Commercially Available	Commercially Available
Material		Aluminum Body	Steel
Approximate Cost	$2,000	$2,000	$33,000

1. Megator Pump - Supplier Hewco Equipment Ltd., Montreal, Quebec
2. Spate Pump - Supplier Peacock Brothers, LaSalle, Quebec.
3. Trans Vac - Supplier Industrial Plastics Canada Ltd., Fort Erie, Ontario

* Weight for an all steel module, aluminum module is presently being evaluated by the supplier.

TABLE 2.4-3

Summary - Pumps and Vacuum Systems

Pump Type	Advantages	Disadvantages
Megator Pump	Minimum of shear imparted to fluid	Not tested under severe Arctic operating conditions.
	Can be used with single or multiple skimmer heads.	
	Easily carried over short distances by two men.	
	Low cost ($2000).	
Spate Pump	Same as above.	Same as above.
	Used to recover spilled oil thickened to a grease-like consistency on the western beaches of Quernsey, England.	
Trans Vac	Minimum of shear imparted to fluid.	Steel construction not suitable for sea water service (unit constructed of aluminum is presently under evaluation).
	Can be used with up to three skimmer heads.	
	100 kPa air available for blowing out suction line.	High cost $33,000 for steel construction).
	Proven successful in oil spill clean up on St. Lawrence River spring 1974; able to pass twigs up to 250 mm long, 9.6 mm diameter	Not tested under Arctic operating conditions.
		Too heavy to enable it to be transported easily.
	No moving parts come in contact with recovered oil or debris.	

Table 2.4-4 presents information on flexible oil transfer hose suitable for use at low temperatures.

TABLE 2.4-4

Flexible Oil Transfer Hose

Size (mm)	Approx OD (mm)	Wt per m (kg)	Working Pressure (kPa)	Bending Radius (mm)
31.8	48.5	1.54	1035	15
38.0	29.5	1.77	1035	203
50.5	42	2.23	1035	229
63.5	82.5	2.95	1035	305
76.2	95.25	3.77	1035	308
101.6	120.6	5.15	1035	457
127.0	146.0	6.92	690	760
152.4	171.5	8.63	517	914
203.2	225.4	13.09	345	1220

2.4.2 Batchwise Transferral

The batchwise transferral of large quantities (up to 25 tons) of recovered oil or equipment to shoreline recovery teams may be achieved by means of an air cushion vehicle(s) (ACV) or suitable helicopter. ACV's are capable of carrying heavy varied loads over snow-covered ice and terrain which is inaccessible to other forms of surface transportation for prolonged periods, providing certain minor modifications are made. One machine of this type, the Bell Voyageur has been evaluated for its performance under cold weather operating conditions.

Table presents particulars on the Bell Voyageur Serial No. 004. An earlier model of this machine has undergone recent extensive cold weather evaluations in the Arctic. This particular craft operated on the Lower North Shore of Quebec in temperatures as low as -40°C.

TABLE 2.4.5
Specifications Bell Voyageur 004 ACV

Dimensions	Specification
Length (Overall)	20m
Beam (Overall)	11.2 m
Height (Overall)	6.7 m
Weight empty	16,298 kg
Maximum permissible gross wt	41,115 kg
Power plants	Two UACL ST6T-75 Twin-Pac marine gas turbines (rated at 969 kw continuous per unit)
Propellers	Two Hamilton Standard three-blade variable-pitch 2.7m diameter
Lift Fans	Two Bell/BHC centrifugal 2.1 m diameter
Fuel System Capacity:	9,000 litres
Cargo Deck Length	12.2 m
Cargo Deck Width	10.1 m
Cargo Deck Height (off cushion)	1.2 m
Cost - Lease	$100,000 per month
- Purchase	$2.5 million

Table 2.4.6 is intended to present an indication of the overall capabilities of an ACV of this type for operation in the Arctic. Several relatively minor design modifications would be required before the machine could be put into long term service in the Beaufort Sea.

TABLE 2.4.6
Cold Weather Capabilities Bell Voyageur

1. Over snow-covered smooth ice, a maximum speed of nearly 97 km/h was attainable.

2. An average speed of 64 km/h could be maintained comfortably over the river routes in the Mackenzie Delta.

3. The craft was capable of operating over snow-covered tundra of the kind found in the Mackenzie Delta, providing care was taken to avoid steep slopes.

4. Rough ice could be traversed safely, provided that ice blocks of more than 1.0 m in height were avoided.

5. Snow banks of up to 1.2 to 1.5 m could be crossed but there was risk of damage to the stability bags and keel.

6. Loads of up to 22,680 kg could be carried.

7. Increasing the load had only a minor effect on craft performance.

8. Deck equipment was required to supplement forklifts when handling most of the loads carried.

9. A portable, heated shelter was needed for prolonged servicing and repairs.

10. Obstacles of more than 1.0m in height may cause damage to the skirt, stability bags or keel.

11. The engines started at temperatures down to -40^{o}C.

Although the ACV has shown a capability for operating in the Arctic the use of such a vehicle has decided disadvantages. Among these is the fact that such a vehicle is in constant contact with the ground or in this case ice surface and is therefore partly dependent on the nature of that surface for its efficient and maintenance free operation. It is envisaged that there will be many situations and locations in the Beaufort Sea where the operation of an ACV is made difficult or impossible by the presence of rough or broken ice. In addition ACV's are not available on short notice as a general rule.

However due to the large payload capabilities of these machines they are considered to be best suited for transporting the large earth-moving equipment necessary for beach clean up operations. Should a unit be purchased (at a cost of approximately $2.5 million) it would have to be put to use during the periods when not involved in oil recovery work in order to justify such a large capital expenditure. For these reasons it is felt that the purchase of an ACV as part of the oil spill contingency plan equipment stockpile is only justifiable as part of a centralized reservoir of equipment, or in conjunction with other applications for the craft. However, should one become available for use at the time of a spill it may be utilized to its best advantage in offshore areas or as necessary for beach clean up work.

Helicopter transport of contained oil and equipment is an efficient method of transferring these components in otherwise inaccessible areas of the Arctic. However load, range and cost considerations limit the usefulness of this method to relatively low payloads (2,268 kg) thereby exempting them from use in transporting the large equipment modules required for beach clean up operations.

2.4.3 Temporary Storage

Table 2.4.7 shows the ranges of sizes and capacities of flexible tanks suitable for transport by a medium lift helicopter (2,265 kg capacity for slung loads) or by ACV. Storage containers up to approximately 1.9m^3 capacity are helicopter transportable using medium lift helicopters.

TABLE 2.4.7
Flexible Storage Bags - Technical Data

Capacity (m^3)	0.2	0.95	1.4	1.9	3.8
Weight empty (kg)	22.65	113.25	56.63	129	35
full (kg)	199	906	1359	1812	3624
Physical dimensions(m)	0.9x0.6	1.5x0.9	1.8x1.2	1.5x1.2	3.0x2.4
Mode of Transport	helicopter	helicopter	helicopter	helicopter	ACV
Material of construction	neoprene	neoprene	neoprene	neoprene	nylon/ polyurethane
Temperature range (°C) range of use	-34 to 74	-34 to 74	-34 to 74	-34 to 74	-51 to 74

Conventional steel tanks are available in sizes ranging up to 31,240 m^3. The larger sizes are generally fabricated and sized for land based storage. Smaller shop fabricated tanks may be installed onboard a recovery barge. An obvious advantage associated with the use of steel tanks is their ability to be heated. However they are considerably heavier and more bulky than flexible rubber storage containers. Smaller, 15 to 76 m^3 capacity metal containers are generally used as debris boxes. Steel drums have been used quite commonly throughout the Arctic to store and transport fuel.

2.4.4 Lagoons and Pits

Lagoon pits and containment dykes have been used on land in the Arctic as a safety measure to contain oil spills from tank farms. In general, there is no standard approach to the construction of these pits; however, it has been recommended that due to the relative scarcity of clays or other impermeable soils in the north, a synthetic impermeable barrier should be used. The plastics used as impermeable films include polyvinyl chloride (PVC), oil PVC, Polyethylene (PE), Chlorinated Polyethylene (CPE), Chlorosulphated Polythene (COSE) Urethane and Butyl rubber. The properties of liner materials are shown in Table 2.4.5.

TABLE 2.4.8
Properties of Commonly Used Lining Materials for Lagoons and Pits

Property	Polyethylene		Polyvinyl Chloride	Chlorinated Polyethylene	Polypropylene	Nylon	Butyl Rubber	Natural Rubber	Hypalon
	Low Density	High Density							
Specific grativy	0.92-0.94	0.94-0.96	1.20-1.5	1.35-1.39	0.9-0.91	1.08-1.4	0.92-1.25	0.91-1.25	
Tensile kPa	8900-17200	16500-33000	24100-68900	12400 min.	27500-220000	62000-75800	6900-27400	6900-24100	6900-12700
Elongation	200-800	10-650	60-200	375-575	40-400	250-550			
Shore "A" hardness							15-90	20-100	55-95
Operating temperature range, C	-57 to 82	-57 to 116	-51 to 93	-40 to 93	-51 to 104	-51 to 193	-46 to 163	-57 to 121	-43 to 116
Resistance to acids	P-G	G	G-E	G-E	G-E	P			G
Resistance to bases	G-E	G-E	G-E	G-E	G-E	E			G-E
Resistance to oxygenated solvents	P-G	P-G	G	P					G
Resistance to aromatic and halogenated solvents	F	F	G	P	G	G	P	P	F
Resistance to aliphatic (petroleum) solvents	P-F	F-G	G	G	G	E	P	P	G
Water vapour permeability, perm mils	3-14	1.8-2.2	3-18	0.040-0.048	0.25-1	0.09-1.0	0.15		2.0
Weatherability	P	P	G	E	P	F	G	F	E
Time to crack, h	900	300	No crack till 2,500 hr	No effect to 4,000 hr	100	1,200			
Time to chalk, h	No effect till 2,500 h	600	300	Ditto	600	No effect till 2,500 h			
Time to fade, h	300	300	100	Ditto	900	200			

Note: Data not shown were unavailable to the authors

Source: Kim, B.C. Support Systems to Deliver and Maintain Oil Recovery Systems and Dispose of Recovered Oil. Dept. of Transport, U.S. Coast Guard. January 1974.

P - Poor G - Good
F - Fair E - Excellent

2.4.5 Disposal

TABLE 2.4.9
Disposal by Burning Incineration

	Kenting Unit(A)	Thermal Engineering(B)		John Zinc(B)		Johnston Sea Dragon(C)	Otis Burner(D)	Baker Inc.(E)
Speed & Efficiency	max. water content 40% max. solids - N.I.	N.I. tested on 90%	N.I. No. 6 Oil	10% water only		up to 50% water up to 30% solids	up to 50% water	
Cost	\$40,000 - \$45,000	\$76,000	\$346,000	\$97,000	\$611,000	\$100/day rental only	N.I.	\$25,500
Total Capacity	1.6 - 1.93 m^3/h	0.38 m^3/h	0.38 m^3/h	3.8m^3/h	3.8 m^3/h	19 - 131 m^3/h	1.36-79 m^3/h	65 m^3/h
Weight; Size;		2.44x6.09m	3.65x21.34	2.44x6.09m	4.88x30.48m			
Power Supply	13,600 Kg	15 tons	78 tons	15 tons	155 tons	222 Kg	N.I.	634 Kg 1.71x1.22x1.04m
Complexity of Set Up and Operation	30 min. warm up time	N.I.	N.I.	N.I.	N.I.	very simple	very simple	N.I.
Applicability in Arctic	non air transportable	non air transportable		non air transportable		not been tested but appears feasible	not been tested appears feasible	not tested
Availability of Equipment	only available as non air transportable unit	N.I.	N.I.	N.I.	N.I.	available from Inuvik	N.I.	N.I.
Versatility	poor - too heavy low flow rate	poor	poor	poor	poor	good	N.I.	N.I.
Comments	Impractical to use in Beaufort Sea, too heavy					May possibly find uses in Beaufort Sea. No major modifications are likely required.		

(A) Manufactured by Kenting Oilfield Services Calgary, Alberta.
(B) Availability unknown.
(C) Manufactured by Johnston Testers Div. of Schlumberger Canada Ltd., Calgary, Alta.
(D) Manufactured by Otis Engineering Co. Ltd. Calgary, Alta.
(E) Manufactured by Baker Transworld Inc. Calgary, Alta.

TABLE 2.4.10
Baker/Zinc "Maxi-Mini" Crude Oil Burner*
Specifications

Specification		Description
Oil Flowrate		66.24 m^3/h
Oil Pressure		690kPa
Air Flowrate requirement (at 690kPa)		2040 m^3/h
Water Flowrate requirement (@ 690kPa pressure)		
	Water shield	44.3 m^3/h
	Water injection manifold	44.3 m^3/h
Auxiliary Service requirements		
Electricity	i) pilot ignition	1 phase, 220V, 50/60 cycle
Compressed air	i) pilot ignition	42.5 to 48.1 m^3/h @ 103-138kPa for approx. 30 sec during lighting
	ii) atomizing	2040 m^3/h @ 552kPa
Fuel Gas	i) pilot ignition	4.25-4.8 m^3/h at 105-138kPa for 30 sec
	ii) pilot burner	31.2 m^3/h @ 103-138kPa through burning period
Weight	Burner	583.5 kg
	Starter and Pilot Ignition panel	120 kg
Dimensions (m)		1.7 x 1.22 x 1.04
Cost	Purchase (burner only)	$25,500 (June 1974)
	Rental (depending upon duration)	$888 to $2961/mo.
Boom	Weight Total	4395 kg
	Cost Total	$20,179 (June 1974)

* Manufactured by Baker Transworld Inc., Calgary, Alta.

TABLE 2.4.11
Flopetrol One Head Smokeless Burner*
Specifications

Specification		Description
Oil Flowrate	Nominal	19.8m^{3}h @ 1725kPa
	Minimum	0.4m^3/h
Air Pressure and Flowrate required		
	Pressure	689kPa
	Maximum Flowrate	543.6m^3/h
Water Pressure and Flowrate required		
	Pressure	2000kPa
	Maximum Flowrate	22.36m^3/h
Weight of Burner		200 kg
Dimensions (m)		1.09 x 0.99 x 0.79
Cost (Rental only)		$100/day

* Manufactured by Johnston Testers Div. of Schlumberger Canada Ltd., Calgary, Alta.

The Kenting Kleen-up incinerator, manufactured in Calgary, Alberta has a one chamber combustor and a water bath for cooling the cleaned material. The estimated capacity is 1/2 ton per hour. Costs for the Kenting and the Envirogenics incinerators were not provided in the literature reviewed.

The Bartlett Snow Products incinerator was recommended for use by the U.S. Coast Guard. The Incinerator was designed for disposal of oil and seawater contaminated debris and absorbent materials such as straw. However, it is believed that it could be modified to suit the needs of incineration of oil contaminated beach material.

The Bartlett Snow incinerator consists of a refractory-lined, rotating combustion chamber and a secondary chamber for after-burning. The effluent from the after-burn chamber is scrubbed with water in a low energy wet scrubber. Incinerator equipment and cost data for units with capacities of 1000 and 150 kg per hour are summarized in Table 2.4.12.

TABLE 2.4.12
Summary of Solid Waste Incinerator

Waste Disposal Rate [a], kg/h	147	996.6
Purchased Equipment Cost, dollars (1973)	75,000	180,000
Installed Equipment Cost [b], dollars (1973)	105,000	252,000
Weight, tons	11.7	117
Utilities		
Electricity, kw (110 v. 1 phase and 220/440 v. 3 phase)	21	118
Auxiliary fuel, k W/h	1172	7911
Water, m^3/h	2.27	22.7

(a) For wastes containing 50 percent Bunker C Oil, 42 percent sea water, and 8 percent straw.
(b) Based on erection cost at 40 percent of the purchased equipment cost.

3.0 Shoreline Clean-up

3.1 Equipment

The investigations for shoreline protection and clean-up revealed that sand beaches and some parts of shingle beaches only lend themselves to practical methods of equipment and personnel deployment necessary to successfully carry out the task.

The logistics and equipment evaluations pertaining to the above beach clean-up are dealt with in Logan et al (1976), while the equipment specifications, are presented in the following tables.

TABLE 3.1.1
Carterpillar 12G Motor Grader Specifications

Flywheel power, kW	100
Operating weight, ton	1.31
General dimensions, m (l, w, h)	8.35, 2.4, 2.53
Minimum turning radius, m	7.3
Standard blade	
Length, m	3.66
Height, m	0.61
Cost FOB Inuvik, $	72,000 to 75,000

TABLE 3.1.2
Specifications for 46 to 56 kW Type Bulldozers

	Caterpillar Model	
	D3, PS	D4D, PS
Flywheel power, kW	46.2	55.9
Operating weight, tonne	5.49	7.74
General dimensions, m (l, w, h)	3.69, 2.40, 1.74	3.90, 3.12, 1.74
Maximum blade cut below ground, mm	350	365
Maximum angle of blade, ^{o}	25	25
Speeds forward (reverse), Km/H		
Gear 1	3.0 (5.1)	3.2 (4.6)
Gear 2	5.6 (5.1)	5.7 (8.3)
Gear 3	11.2 (5.1)	9.3 (13.4)
Cost FOB Inuvik, $	30,000 to 32,000	42,000 to 45,000

TABLE 3.1.3
Specifications of the Athey 7-11 Force-Feed Loader

Engine	diesel
kW: Loading	44.75
travelling	61
General dimensions (l, w, h), m	9.1, 2.29, 3.2
Operating wt, Kg	6795
Capacity, m^3/h	382
Drive speed, loading, km/h	3.2
Cost FOB Inuvik, $	55,000 to 60,000

TABLE 3.1.4
Specifications for the Canadair CF-360
Tracked Vehicle

Engine	8750 cm^3 V-8
Operating weight, tons	33.3
General dimensions, m (l, w, h)	8.6, 3.7, 2.9
Capacity, tons	18
Ground pressure, loaded, kPa	28.68
Max. speed km/h	16.6
Climbing ability	60% grade
Cost	N.A.

TABLE 3.1.5

Specifications for Large Farm Cultivation Machinery

Item	Plow	Disc	Harrow*	Rotor Tiller
Make, mode	Kongskilde Sal 700 GL	Bush Hog 1438 - 222	Vibratong S-2919	Howard M-130
Length, m	9.1 approx.	N.I.	1.8	1.5 to 2.7
Width, m	3.0 approx.	N.I.	2.9	3.2 approx.
Weight, kg	1678	2591	272	1790
kW requirements	78 - 116	67	37	93
Width of tillage, m	3.2	6.4	2.9	3.2
Speed of operation, km/h *	up to 8	up to 8	up to 8	up to 8
Costs, FOB Inuvik	N.I.	N.I.	N.I.	N.I.
(Not firm quote)				

* Dependant on soil conditions.

TABLE 3.1.6

Specifications of a Caterpillar 950 Front-End Loader

Power, kW	97
Weight, kg	11,550
Dimensions (l, w, h), m	6.37, 2.56, 3.17
Capacity of bucket, m^3	2.68
Costs, FOB Inuvik, $	74,500

TABLE 3.1.7

Specifications of a Typical Tandem Axle Gravel Truck*

Model	Mack 685
Flywheel power, kW	177
Operating weight, kg	8.15 - 9060
Payload, ton	22.5
Dimensions (l, w, h) m	6.7, 2.74, 2.44 (approximate)
Cost FOB Inuvik	$40 - 45,000

* Courtesy of Mack Truck

TABLE 3.1.8
Specifications of the Flextrac Nodwell Terra Tired Carrier
Model FN-300TT

Flextrac Nodwell	FN-300TT
Engine	Detroit Diesel 6V53
Gross weight (approx.) kg	26,000
Ground pressure kPa	38.2
Speed at 2800 rpm, km/h	43.
Gradeability - forward - side	60% 40%
Cost	N.A.
General dimensions, m (l, w, h)	10.16, 3.35, 2.99

TABLE 3.1.9
Specifications of the International Harvester Model 412
Elevating Scraper

Flywheel power, kW	111.8
Operating weight, ton	13.5
General dimensions, m (l, w, h)	9.91, 2.28, 3.35
Capacity, kg	11,860
Cleanup rate, hr per ha	0.59
Cost FOB Inuvik, $	70,000

4.0 Conceptual Techniques

4.1 The Recovery Barge Concept

Barges have been considered for the handling and storage of large quantities of oil over extended periods of time, as work platforms, for the stockpiling of oil recovery equipment, for heating recovered oil/water mixtures and for achieving some degree of gravity separation of such mixtures throughout the course of recovery operations.

The present discussion considers the concept of locating a barge in the immediate vicinity of the well head. This barge would act as an equipment deposit, living quarters for oil control and recovery teams as well as a command center. The barge would be used in the polar pack zone during the drilling season and be designed to withstand the hull pressures associated with an ice sheet 2.4m thick. In this way the barge may also be utilized in the landfast ice zone throughout the year.

Some of the alternative approaches considered were:

1. charter a regular ship and modify;
2. charter a Class 1 (strengthened for navigation in severe ice conditions) ship;
3. purchase a ship and modify;
4. charter a barge and modify.

Table 5.1.1 presents a cost comparison for the above alternatives. The figures shown in Table 5.1.2 are for a vessel capable of storing 300,000 bbls of oil or approximately nine months flow of oil. In this way oil could be recovered and stored on a continuous basis as necessary throughout the entire winter season and then transported to a landbased disposal facility.

The costs associated with acquiring and outfitting a vessel of this size are prohibitive. If an alternative barge of smaller size is considered for this purpose, such a vessel must have sufficient deck area to accommodate the following:

1. Ice penetration module;
2. Pumping equipment;
3. Separation module;
4. Disposal module;
5. Helicopter landing pad;
6. Crew accommodation; and
7. Ancillary equipment such as power generating, washroom and kitchen facilities.

In this way oil will be disposed by means of facilities located on board the barge rather than at a landbased disposal facility. It is therefore necessary that a nominal oil storage capability be available on board the barge to allow some separation of recovered oil/water mixtures by gravity and to provide a reservoir from which oil may be pumped at high pressure to the incinerators for disposal.

TABLE 4.1.1

Summary - Costs per Annum Oil Recovery Vessels

(The vessels shown here are sized to store 300,000 bbls of oil).

	Charter Regular Ship and Modify	Charter Class 1 Ship	Purchase Ship & Modify	Charter Barge and Modify
Purchase/Hire Cost	$3,000,000	$4,000,000	$5,000,000	$2,000,000
Strengthening	2,000,000	---	2,000,000	1,500,000
Removing Strengthening	1,000,000	---	---	500,000
Incidental Operating Costs	5,000,000	500,000	500,000	250,000
Repairs	---	---	1,000,000	---
TOTAL	$6,500,000	$4,500,000	$8,500,000	$4,250,000
Less Residual Value			5,000,000	
			$3,500,000	

Source: J.E. Balfour, Alcan Shipping Services Limited
Montreal, Quebec
May, 1975, Personal Communication

From the information presented in Table 5.1.2 it would seem that to purchase and modify an existing barge or to build a barge to the required specifications are the best alternatives from the point of view of capital expenditures. However, to modify an existing barge to render it suitable for the task at hand is a fundamental and very expensive task. To ice strengthen an existing barge would require the intermediate frames be installed throughout the entire length of the barge and shell plating placed over the entire length of the barge from a point above the load water line to a point below the ballast water line. As indicated in Table 5.1.2 approximately one half the capital cost of procuring a suitable existing barge is required to carry out the necessary modifications. For this reason, it would appear that construction of a barge to the required specifications is the most viable of the alternatives considered.

It is estimated that a barge, for example about 61 m long by 15 m wide, fully equipped with suitable countermeasures equipment would cost approximately $3 million. During standby conditions with a skeleton crew of, say, 4 men the estimated operating cost is approximately $30 thousand per month. In the event of a spill this operating cost might be expected to rise to about $100 thousand per month.

4.2 The Ice-Retention Boom

The concept of an ice retention boom has been in existence for some time. A device of this nature has been in service in the Beauharnois Canal, Quebec for a period of approximately twelve years. The proposed ice retention and oil containment boom is a modification of this design involving a double boom system - the outer boom designed to retain ice and the inner boom designed to contain oil. The ice control boom would be designed to not only retain ice but also minimize the effect of wind, wave and current action on the inner oil containment boom. The boom system would be designed to remain in place around the drill ship for the duration of the drilling season and in the event of an uncontrolled blowout throughout the winter in the Landfast Ice Zone.

The ice retention boom would be deployed in a polygon on the sea surface around the oil well location. The boom would be designed to prevent ice from penetrating the enclosed area and destroying the inner oil containment boom.

The ice retention booms used in the Beauharnois Canal, Quebec, for example, have an ice holding capacity of approximately 4,200 kg per linear metre and they are anchored to the canal bottom at spacing of 38 m.

Preliminary calculations show that forces in the order of 14 kg/m would be expected from a static build up of small ice floes on the boom. This value was calculated for a wind velocity of 100 km/hr., a current velocity of 1.8 km/hr. and ice floes of thickness about 2 m.

Although the frequency of ice floe impact is not certain, the size of ice floes which can be deflected or retained has been calculated for different anchoring systems. It is difficult to calculate exactly the size of ice forces that the boom is capable of handling. However, preliminary investigations have shown that by using the 7.6 cm anchor chain an ice floe in the order of 15-30 m diameter, 2 m thick travelling at 0.3 m/s could be retained. If the 9.5 cm chain or 10.01 cm wire rope

TABLE 4.1.2

Costs for Oil Recovery Barge

	Purchase and Modify[1] Existing Barge	Purchase Ice[1] Reinforced Barge	Charter and[1] Modify Barge	Construct Ice[2] Reinforced Barge
Purchase/Hire Cost	$500,000	$1.5 to $2.5 million	$250,000 p.a.	$1.1 million
Ice Strengthening	$500,000		$500,000	
Removal of Ice Strengthening			$200,000	
TOTAL	$1.0 million	$1.5 to $2.5 million	$950,000	$1.1 million

(1) For 24,000 bbl oil storage barge (68 m long; 20 m wide).
(2) For oil recovery barge 3,000 bbl oil storage capacity (61 m long; 15 m wide).

is chosen similar calculations indicate that it could retain an ice floe of the order 61-91 m diameter 2 m thick travelling at 0.3 m/s.

For ice floes in excess of these sizes both the drill ship and the boom would have to be removed. Airborne surveillance would be necessary to provide adequate warning to the drill ship. The boom capabilities can be altered by changing the angle of its cable thus the strength of the system is governed by the strength of the anchor chain and the pull-out capabilities of the anchor.

Two different anchoring systems have been investigated, one using Danforth anchors (if the bottom is sand or clay) and the others using drilled in anchors (if there is bedrock or permafrost). The advantage of using Danforth anchors over drilled in anchors is that they can be pulled up and re-used for other locations.

Although the costs show that cable is incrementally cheaper, the chain is preferable because of its relative flexibility for storage and use. A cable would have to be reeled on a large diameter reel and would become weaker with use, whereas a chain would not lose its strength to the same degree and would require less maintenance.

The ice retention/oil containment boom excluding the cost of the anchoring systems is estimated to cost in the order of $1,480,000. The anchoring costs will vary depending on the depth and the type of anchors used which in turn will depend on soil and bedrock conditions pertaining at the particular site. The anchoring costs range from a minimum of $347,000 at location A to a maximum of $1,200,000 at location F. shown on Fig. 5.2.1. Installation costs (including dismantling and removal at the end of the drilling season) are estimated to cost $300,000. The total cost of the boom can be summarized as follows:

	Minimum	Maximum
Boom	1,480,000	1,480,000
Anchoring System	347,000	1,200,000
Installation	300,000	300.000
	$2,127,000	$2,980,000

4.3 Trenching Techniques

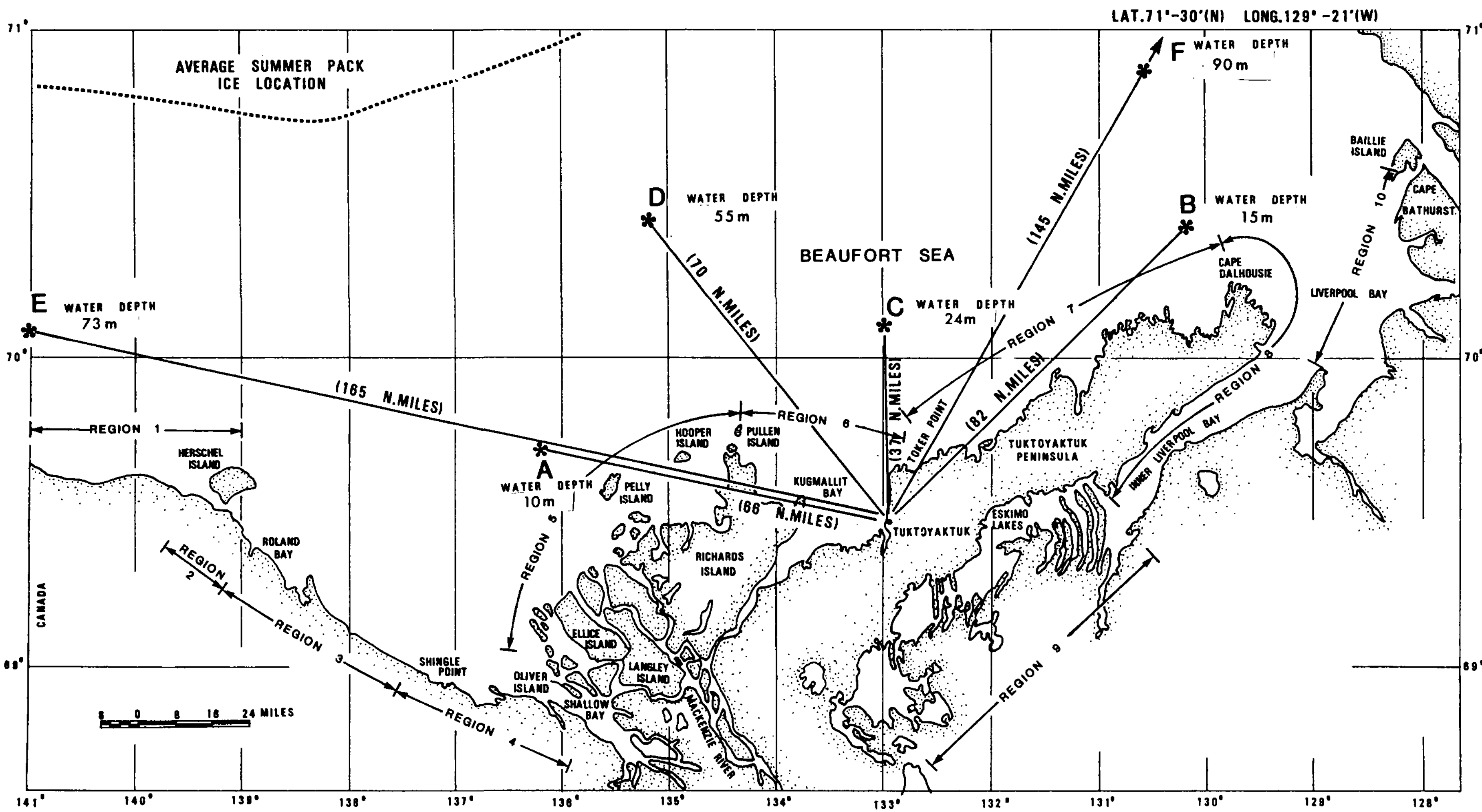
The large number of trenching techniques that could be used to trench in ice are summarized in Table 5.3.1. These methods can be conveniently divided into six categories, these being;

a) Integrated trenching machines
b) Cutting and removal of discrete ice blocks
c) Linear charge blasting
d) Multiple charge delay deck blasting
e) Crater blasting
f) Other methods

Each of these methods will be discussed separately.

4.3.1 Trenching Machines

There are a number of manufacturing companies producing trenching machines, mainly for work in soils, frozen ground and low strength rocks such as shales, sandstones and coral. Very little work has been done with respect to trenching in ice with the main exception



THEORETICAL DRILLING LOCATIONS
SHOWING WATER DEPTH

FIG. 4.2.1

TABLE 4.3.1 - Summary of Ice Trenching Techniques

TRENCH METHOD	ICE CUTTING METHOD	TRENCH EXCAVATION METHOD
Integrated Trenching Machine		Machine Excavated
Cutting and Removal of Discrete Ice Blocks	a) High Velocity Water jets b) Preshear with Explosives c) Rotary Saws d) Ice Cutter (eg. Coal Cutter type)	Mechanical Lifting
Linear Charge Blasting	a) Rotary Saws b) Ice Cutters	Explosives
Multiple Charge Delay Deck Blasting	Ice Drilling	Explosives
Crater Blasting	Ice Drilling	Explosives
Other Methods	a) Compressed gas b) Other blasting methods	Various

of Polar Gas through its development work with Banister Pipeline Co. and Montreal Engineering Co. Unfortunately their results are confidential at this time. Also, some work cutting ice during the winter months around artificial islands near the Mackenzie Delta has been performed using commercially available, small trenching equipment.

Sergeev (1956) reports work done in 1955 in the USSR using a conventional trencher in frozen ground. The trencher was modified by having alternate cutters and chopping wedges replace scoops. The machine cut trenches 3 m wide in ground frozen to a depth of 1.3 m. It was, however, extremely slow producing at the rate of 5-6 m per hr.

However, an indication of the adaptability of conventional mining and trenching equipment to working in ice is given by Abel (1961) who tested a 3JCM Joy continuous miner in ice during the last two seasons of a 5 year ice mining programme in Greenland 1955/59. He reports that production rates of 1000 kg of ice per minute could be achieved for an extended number of periods, which approaches the planned production of this equipment working in coal.

One of the most significant operating problems in ice, which would have direct bearing on trenching or ice cutting machines, was the accumulation of ice on the cutting head. The ambient temperature during this operation was given as -7°C. Abel describes his theory of this ice accumulation as follows:

> "The (ice) particles are heated, either during the cutting process or from contact with the warm chain. This heat produces a surface film on the particles. The particles come in contact with the cold head of the continuous miner while travelling through the groove under the ripper chain. The surface water film freezes the particles. The heat liberated goes into the ripper head which acts as a large cold reservoir. Once started, the deposit of ice will continue to accumulate as more particles are frozen to the head. The ripper head is continually cooled below freezing because of its large size and high conducting capability".

It appeared that the problem was overcome by providing continuous scraping of the problem area thus removing the ice as it built up.

This certainly indicates a major area for concern in the development of any trenching or cutting equipment for work in ice. This problem would be compounded when trenching or cutting sea ice in the Beaufort Sea by the possible -40° to -50°C air temperatures and by continual splashing of sea water on exposed parts of the machinery.

Another pertinent study conducted by S.I.P.R.E. in snow and ice was an extensive test programme designed to produce trenches on the Ice Cap in Greenland. This trench work was done in wind-drifted snow to depths of at least 3 m using a track-mounted Peter snow miller manufactured by Konrad Peter Co. Inc., Liestal, Switzerland (Waterhouse, 1960). The snow miller weighed 12,000 kg and was capable of a single pass cut 1.2 m deep and 2.5 m wide. The density of the snow varied from 0.4 gm/cc at the surface increasing to an undetermined density at depth. The rate of cut varied from a high of 590 m/hr in the low density snow, this being reduced with increase in snow density.

Peter (1975) reported that 9 Peter snow millers are being used in both Greenland and Antarctic by the US government working in hard snow and ice. The present machine design is such that the tracks are supported by the bottom of the excavated trench which is unsuitable for this sea ice application. However, Peter also stated that it is thought that a satisfactory machine could be developed to produce trenches in sea ice to Beaufort Sea requirements using the snow milling principle.

The Polar Gas trencher is capable of producing a 2 m wide trench in up to 4.5 m of ice, and has a gross weight of about 27,000 kg. Based on the film "Trial by Ice" produced by Polar Gas, it is estimated that this trencher operates at a rate of about 90 m per hr.

To relieve ice stresses around artificial islands in the Beaufort Sea, a commercially available 48 kW ditching machine was reported to cut a 15.5 cm slot through ice 1.5 m thick at a rate of about 120 m per hr. Similar machines are also available which are capable of trenching to a depth of 2.5 m and operate using a 100 hp power source. These machines weight 5000-6000 kg. Machines which cut only narrow trenches require double trenching runs and subsequent ice block removal to produce trenches of adequate width.

Other soil and rock trenching machines are commercially available, weighing up to about 23,000 kg.

In summary, trenching machines, with suitable development, could dig clean trenches in sea ice at relatively high production rates. The larger machines are rather heavy and cumbersome for the application considered here, although they are capable of producing quite wide trenches. The smaller machines sacrifice trench width but gain in regard to such factors as mobility, cost and transportability.

4.3.2 Cutting and Removal of Discrete Ice Blocks.

The technique considered in this section is the insitu cutting of ice blocks followed by their removal to form a trench.

A block of sea ice measuring approximately 2 m x 2 m x 2.5 m would weight about 7,000 kg and require a small crane or large helicopter to lift it from the trench. A more desirable alternative is to push the ice block down through the water and to one side of the trench. The same size of block would require a load of only 1,800 kg to push it under the water. In this position, on the uncontaminated side of the trench, the block could aid the oil retention characteristics of the trench by acting as an artificial ice keel. A small back-hoe should be capable of performing this work. A back-hoe would also be effective for removing ice chunks and slush from the open trench.

The small trenching machinery discussed in Section 5.3.1 would be very suitable for the task under consideration. The cutting chain may be mounted offset from the side of the tractor, allowing the vehicle to pass on secure ice either side of the trench being cut. Further, the motive tractor may be ordered with a back-hoe attached, suitable for pushing the ice blocks beneath the adjacent ice sheet.

A considerable amount of development work has been carried out recently on the use of high velocity water jets to cut rock, frozen ground and ice. Specifically Mellor (1972A and 1974A) and Shvaishtein (1973) have done studies on cutting both frozen ground and ice.

Shvaishtein's work is of limited extent, being mainly theoretical, although some testing is mentioned. He does not report penetration rates or cutting speeds in ice but concludes with the statement, "The results obtained have shown that ice cutting with continuous high-pressure water jets is extremely effective".

Mellor reports tests done in ice using nozzle pressures from 176 to 7,000 kg/cm^2 traverse speeds from 0 to 109 m per min. and nozzle diameters from 0.0203 to 0.058 cm. Maximum penetration depths in freshwater ice of 87.6 cm are reported for a stationary jet 0.041 cm in diameter with a pressure of 563 kg/cm^2 acting for 20 seconds. This represents a penetration of 2,000 times the nozzle diameter.

Traversing tests in lake ice and ice blocks for nozzles 0.0305 to 0.051 cm in diameter, nozzle pressures of 3,520 - 4,220 and 7,000 kg/cm^2 with traverse speeds of 20 to 109 m per min. produced penetrations of from 7 to 18 cm. These penetrations are up to 400 times the nozzle diameter.

Scaling up from these tests, Mellor estimates 2.4 m of ice could be cut at a traverse speed of 2 m per min. using 0.3 cm diameter nozzle, a water pressure of 700 kg/cm^2 and hydraulic power of 244 hp. This power requirement was almost halved to 139 hp by halving the traverse speed to 1 m per min. and using a nozzle of 0.38 cm diameter and 352 kg/cm^2 water pressure.

There is still clearly some doubt that this method will cut 2.4 m of ice, although Mellor (1974B) expresses confidence that scaling for this thickness of ice appears to be valid.

The advantages of jet cutting are that it would be a relatively fast cutting method, provided that scaling laws hold, and the water jet power supply can be positioned well away from the cutting operation. This would be of particular advantage if the ice were weak.

Disadvantages include the large equipment requirement and support. The power unit used for the reported tests weighed 6,800 kg (without motive power) and, even with new high pressure pump developments, power units for thick ice would run to many thousands of kg. Again, there is the equipment operational difficulties with severe climate. A further difficulty is that the slot that is produced is only 4 times the nozzle diameter in width. Thus, say, even for the 2.4 m of ice condition the slot would be only 1 cm wide, which could present further problems in ice block removal.

To summarize, this ice cutting method is in the development stage. Although it promises to be a rapid ice cutting technique it will require large ancillary equipment and will produce only very thin slots.

Another potential method for cutting ice blocks utilises the preshearing technique, which is used extensively in civil engineering works and some mining operations, to produce smooth wall rock cuts.

In this application the sides of the ice blocks would be outlined using rows of small diameter holes of say 7.5 cm in diameter. The hole would be lightly loaded with approximately 0.37 kg of explosive per m of hole using 3.8 cm diameter dynamite cartridges and then fired simultaneously using detonating fuse and a single cap. Upon detonation the ice between the holes would be "sheared" across, effectively cutting the ice into blocks.

For 7.5 cm diameter holes the hole spacing is usually in the order of 1 m in rock. It can be expected to be somewhat higher in ice but test work would be necessary to evaluate the ideal spacing. The number of holes required for an advance of 2 m of trench 2 m wide would be in the order of 6-8, depending on the test results.

Mellor and Sellman (1974) report penetration rates of from 1 m to 2.3 m per min. for a gasoline powered hand held ice auger of 3.8 cm diameter whilst a 11.2 cm diameter ice coring drill, using similar power, penetrated at from 0.73 to 1.7 m per min. It would appear that 0.6 m per min. for a 7.5 cm diameter hole is a reasonable penetration rate requiring 5 minutes to drill a 2 m deep hole when associated operations are included.

Thus the 6 to 8 holes per 2 m advance of trench would require 30 to 40 minutes drill time. Even with a number of drills being used simultaneously, this is a slow method of trench production especially considering the holes must still be loaded and fired and then the ice blocks removed.

An alternative explosive for this type of work would be one of more heavy grained detonating fuses loaded along the complete hole length. This explosive form is easier to load, as charges can be put together quickly. Also, it could achieve a lighter uniform loading rate making it possible to use smaller, more quickly drilled holes. However, the benefit of the higher penetration rates that could be expected for the smaller holes would be more than lost by the need for a closer hole spacing.

This method, then, requires very little equipment to cut the ice and would be reliable in the severest climatic conditions, although the technique involves a considerable amount of "bare-hand" work. However, the cutting rate is slow and the technique is highly manpower intensive.

Thermal lances utilize the melting and "cutting" action of a jet flame to produce the slots in ice. A typical burner suitable for this application would be the Browning Engineering Corporation FA-300A model. This burner has a 3.2 cm diameter nozzle, burns 57 litres of fuel per hour and requires a 8,500 litre per min. compressor delivering at a pressure of 7 kg/m^2. This burner is a "hand held" model but can be used with an overhead support which would be necessary for the extensive operation considered here. The burner, hoses, etc. weight 45-55 kg and the compressor would weigh 2,000-2,300 kg, not including the fuel.

Some limited test work has been carried out in ice using this system. Browning and Ordway (1963) report a penetration rate or 1 m per min. for this burner tested in a commercial ice block producing a 19 cm diameter hole. Browning (1974) stated that his experience suggested that between 15-18 cm is the smallest hole size that can be expected in ice.

Averaging the 1963 reported results in ice gives 0.026 m^3 per min. as the volume removed. Assuming a maximum slot width of 15 cm, a 2 m advance of trench in 2 m of ice would require 1.5 m^3 of ice slot removal. This represents approximately 1 hour burning time. This, then, is even slower than preshearing.

To summarize, this method is very slow. Although more equipment is necessary than for preshearing, it is of acceptable size but probably would have some reliability problems. Also, the large quantities of steam produced would make poor working conditions for the operator.

Sergeev (1956) describes the development of a coal cutter type excavater, having two chains mounted on adjustable parallel booms on a Caterpillar chassis, for cutting frozen ground. He reported that parallel cuts up to 2 m deep could be made at the rate of 20 to 27 m/hr. in frozen clay soil, and up to 37 m/hr. in frozen sandy soil.

A Joy 15RU coal cutter was used by U.S. Army Snow, Ice and Permafrost Research Establishment for test work in their under-ice mining project reported by Abel (1961). This machine was used for various periphery cutting techniques around face blasts for mining the Greenland ice cap. The cutter was able to cut a 3 m deep slot, 15 cm wide, at the rate of 0.3 m per minute. The major disadvantage of this system is that the machine weight is 14,500 kg.

With the standard long boom attachment this same machine could cut vertical slots in ice to a depth of 14 feet.

Some experimental work has been done using rotary saws to cut both ice and frozen ground. Perhaps the most significant to this project is the mechanical ice cutter designed and tested for the Department of Transportation United States Coast Guard by Lecourt and Voelker (1974).

This paper describes the design of an ice cutting rotary saw 3 m in diameter and 7.6 cm thick which could be mounted on the front of a specially designed river craft to cut ice 0.6 m thick at 5,000 m per hr. and 1 m thick at slower speeds. Three such cutters were envisaged for the design, each wheel consuming 350 hp at a rotation speed of 300 rpm. The concept upon which this craft is based is that after the ice is cut the ice chunks are forced under the vessel using a sloping keel and then pushed out on either side under the adjacent ice sheet using a skeg. This machine, as conceived, would produce an ice free trench in ice thicknesses of up to 1 m.

A 1/6 scale model has been produced with a cutting wheel diameter of 45 cm, which proved very effective in ice a few inches thick.

As conceived, the full scale model was estimated to cost $645,000. Clearly, a vessel which could negotiate through pressure ridges would have to be sized many times larger will work effectively in up to 1 m of ice in the Beaufort Sea, but the estimated cost of $645,000 does not make it worthwhile considering it could only handle a limited amount of the shorefast ice depending on the time of year.

A small scale circular saw has been developed and used by the City of Ottawa to aid ice breakup by cutting slots in ice on the Rideau. This saw is 1.2 m in diameter, 1 cm thick and has a total weight of 680 kg. The unit is skid mounted, powered by a 4 cylinder Wisconsin 45 kW gasoline engine and can cut up to 56 cm thick ice at a rate of 4,800 m/hr. Four men are used to operate the saw. Where the ice is greater than 56 cm in thickness, additional cutting is done with a chain or hand saw.

Other commercially available earth, rock and concrete saws include the Vermeer T600B rock cutter capable of slots 10 to 16.5 cm wide to depths of 80 cm. Also, there is the Ditch Witch Earth Saw manufactured by a division of the Charles Machine Works Inc. The largest model is the ES30 capable of 10 cm wide slots to 80 cm depths. This saw weighs 1,100 kg and is approximately 2 m in diameter.

The design and manufacture of a suitable ice saw for producing ice blocks could well be possible, the advantage being the probable high cutting speed of about 80 m/min. However, the disadvantages and associated problems are considerable when the thick ice conditions are considered. The weight of a 3 m wheel alone, used to cut only 1 m of ice would be an estimated 2,000 kg. The associated power requirements and support frame would be massive.

Although this method may be slightly more attractive for the thinner ice conditions it is considered unacceptable for even these ice conditions when compared with more viable techniques.

4.3.3 Linear Charge Blasting

This method is proposed as the placement of a linear explosive charge at a predetermined depth in the ice which would be blasted to explosively excavate the trench.

The choice of explosive for this application would be prilled TNT. Initiation would be achieved using 0.45kg pentolite primers, regularly spaced at 8 m intervals, detonating fuse and one blasting cap. Downline detonating cords would connect the primer with a surface trunkline which would be extended to the shot firing position at which point the cap would be attached.

Extensive experience blasting frozen layers in Labrador and Northern Quebec using spherical charges has shown that the most effective explosive position with respect to fragmentation is at a depth of 2/3 to 3/4 of the layer itself. This type of blasting is analogous to blasting sheets of ice and this depth value is, therefore, considered to be optimum for ice fragmentation. For example, it is estimated that an explosive charge weight of 26.5 kg per metre of trench detonated at a depth of 2.6 m in ice 3.7 m thick would produce a trench approximately 7.6 m wide at the surface. If the optimum depth ratio of 2/3 to 3/4 is adhered to, equipment considered in Section 5.3.1 would be required to produce the slot for subsequent explosives emplacement. Clearly, this method is not particularly desirable, requiring the time-consuming sequence of equipment operation, explosives emplacement and detonation, and finally generating a trench which has all the undesirable characteristics of any explosively produced trench -- uneven sides and associated debris. Some time and equipment requirement could be minimized if the line charges were placed at the ice/water interface. However, placement at this location is relatively inefficient and massive charges are required for ice thickness greater than about 1.2 m. At or below this ice thickness, the technique is more viable.

Table 5.3.2 illustrates the charge weights per m for single charge lines necessary to produce explosively excavated trenches of the given dimensions.

Charges suitable for these different ice thicknesses would be:

(i) 4 Primaflex 400 grain primacords tied together for the 0.3 m ice.

(ii) Cast TNT charges strung on a high strength cord and connected with a heavy explosive grained primacord for the 0.6 to 1.2 m ice.

Both of these charges could be prepared on skid mounted spools which could be placed at appropriate positions on site and then be unrolled for charge placement.

The quickest and most convenient placement method would be by using under water divers. A series of holes could be blasted along the proposed trench line at, say, 16 m intervals, the best distance between holes being found following experience with the method. The appropriate spools of linear charge would be positioned by each hole. One end of the charge would be given to the diver who would transport it under the ice to the next hole where it would be suitably fastened. Fastenings against the under ice surface could be made at intervals if required. This could be done using a ramset gun to anchor a tie in the ice each side of the charge at suitable intervals along the charge.

All charges would be fired instantaneously being tied-in using primacord.

TABLE 4.3.2 Linear Charge Blast Design Parameters for Various Ice Thicknesses with the Explosive Charge Placed at the Ice/Water Interface

ICE THICKNESS (METRE)	CHARGE WEIGHT/METRE (KG)	TRENCH WIDTH (METRE)
0.3	0.4	1.2
0.6	1.5	2.5
0.9	3.3	3.7
1.2	6.0	4.9

4.3.4 Multiple Charge Delay Deck Blasting

This method refers to the technique, described by Mellor (1972B), of using 3 or 4 small charges, spaced in a single drill hole, to blast steep sided holes in thick sea ice. An attempt to clear the hole of ice fragments is made with a "scour" charge situated in the sea water below the drill hole. The separate charges are delayed to allow for successive breakage to the surface.

Mellor (1974B) stated that he had used this method successfully on a number of occasions to produce holes 2 m in diameter in 3.7 m thick sea ice to enable divers access below the ice sheet. He reported that the surge charge initially clears the hole quite well but the large volume of water that is also displaced tends to drag a large proportion of the ice fragments with it, upon flowing back into the hole.

The blast design, used by Mellor for 3.7 m of ice, utilized a 7.6 cm diameter hole having a 0.45 kg charge at 1.2 m depth, 0.9 kg at 2.4 m depth and a scouring charge of 2.25 kg suspended in the water beneath the ice. These charges were gelatin dynamite and delayed at intervals of 5 Ms from the top down, using short period delay caps.

A trench produced using this type of loading would require 6 holes per 4.3 m of trench advance, a square pattern on 2.1 m centres with one extra hole in the centre of each square. Drilling time for these holes for ice 3.7 m thick, using similar equipment to that described in the preshearing section, would be 70 to 75 minutes.The suspension of the appropriate charges at the required depths together with the handling of 3 sets of cap leg wires per hole would take some time although the loading could commence following the completion of the first hole. Including blasting connections, this method would take approximately 2 hours to produce 4.3 m of trench.

The resulting trench, after blasting, would contain a considerable amount of ice fragments as the small charges are designed to only break the ice. The hole or trench cleaning afforded by the "scouring charge" can be expected to be even less effective in this multiple hole situation than in a single hole.

There is also doubt as to the effectiveness of the delays used in this system. Due to the close proximity of the charges, there may be sympathetic detonation or damage to the delay or the charge itself. If this was found to be the case in test work then the charges could be initiated using ordinary detonating fuse eliminating the delay altogether. This would have the added advantages of removing the 3 caps per hole from the system, with the associated increase in safety and the elimination of the relatively complicated electrical hookups.

To summarize, this method has the advantage of requiring a limited amount of equipment and a small explosive consumption of only 4.9 kg/m of trench.

The disadvantages of the technique include the tedious loading method and relatively slow rate of trench production. There is an extra safety hazard if short period delay caps are used. The resulting trench is expected to have more ice debris in it compared with an explosively excavated trench. There is some doubt that this method would successfully produce an adequate trench.

The disadvantages are considered to far outweigh the limited advantages of small equipment requirements, which can be met using other blasting techniques, and small explosive consumption.

4.3.5 Crater Blasting

The method uses regularly spaced crater charges designed to explosively excavate a trench.

As with linear charges, the optimum explosive depth for ice sheet fragmentation is at a depth of 2/3 to 3/4 of the ice sheet. It is estimated, for example, that 97 kg of prilled TNT detonated at a depth of 2.4 m in ice 3.7 m thick would generate a crater of average diameter about 8.5 m. In order to generate a trench, charges should generally be spaced apart about twice the depth of burial. In the example just considered, the 97 kg of explosive would be emplaced with its' centre of gravity at 2.4 m in a hole 3.5 m deep, of diameter 30 cm, drilled using a mechanical auger.

Prilled TNT was selected as the desirable explosive since its performance is not dependent on ambient temperature or pressure. It handles perfectly in the coldest climatic conditions as it is in the free-flowing prilled form. It stores well for long periods of time without requiring special magazine construction or heating. Finally, and most importantly, prilled TNT is safe to handle and use.

Priming and initiation systems for this method of blasting would utilize 0.45 kg pentolite primers, cold climate detonating cord, eg., Scufflex, and standard #8 electric or safety fuse blasting caps. These blasting accessories are unaffected by temperature other than a slight stiffening of Scufflex cord experienced at temperatures below -30°C.

Each hole would be primed with a 0.45 kg pentolite primer being connected to the surface with a detonating fuse downline. The holes would be stemmed with the ice cuttings from the hole if available. The downlines would be connected across the surface by a detonating fuse trunkline which would be extended to a safe shot firing position where the blasting cap would be attached. No delays would be used between holes. A safe distance would be in the order of 0.5 to 0.8 km from the nearest charge.

It is estimated that about 35% of the trench volume will remain as slush and broken chunks floating in the trench. The presence of such a large amount of ice fragments would severely hamper oil recovery equipment. Blasting technique is estimated to be about 20 m/hr if a well-trained crew of 5 or 6 men are employed. Table 5.3.3 gives a summary of various explosive parameters for selected ice thicknesses.

In summary, then, the method is quite a rapid method producing large trenches in thick ice, and would, perhaps, be of use in ice which trenching machinery could not handle. It has the same basic disadvantages that are associated with the all explosives techniques -- a considerable amount of "bare-hand" work is required to lay the charges, and the trench produced and adjacent ice sheet will have a considerable amount of debris present. Finally, of course, a crew of highly-trained, well-disciplined personnel must be available to lay safely the charges in the severe conditions expected in the Beaufort Sea during the winter.

4.3.6 Other Methods

Limited success has been achieved using compressed gas blasting to break relatively thin ice covers over water. In particular, Mellor and Kovacs (1972) report work done on lake ice of approximately 0.6 m thickness. Charge weights of 15 to 16 kg were used at various depths under the ice with some successful breakage. Very little excavation was experienced. This method requires extensive development work before a viable system could be used.

There are, of course, other explosive positions capable of trench production other than at 2/3 to 3/4 into the ice as has been proposed in the crater blasting technique.

The two most common positions other than in the ice are:

(i) On the ice surface

(ii) At the ice/water interface as already discussed in Section, 5.3.5.

Explosives detonated on the ice surface, because they have virtually no containment, transfer most of their energy to the air. However, Van de Kley (1965) has produced explosive weight estimates for breaking through various ice thicknesses having scaled up from small test shots together with the aid of a certain amount of mathematical analysis. His estimate of a charge that would just break through 4 metres of ice is 655 kg.

To reduce this large explosive consumption a succession of smaller charges could be used to successively break through and eventually excavate a trench. However the explosive consumption would still be very high and it is thought not to be a viable method, certainly in the thick ice covers.

TABLE 4.3.3 - Crater Blast Design Parameters for Various Ice Thicknesses

ICE THICKNESS (METRE)	DEPTH OF BURIAL (METRE)	HOLE DEPTH (METRE)	HOLE DIAMETER (CM)	HOLE SPACING (METRE)	CHARGE WEIGHT * (KG)	EXPLOSIVE CONSUMPTION (KG/M OF TRENCH)
1.2	.84	0.9	20	1.7	4.5	2.7
1.5	1.1	1.2	20	2.1	8.2	3.9
1.8	1.3	1.4	20	2.6	14.5	5.7
2.1	1.5	1.8	20	3.0	24	7.9
2.4	1.7	1.9	30	3.4	32	9.7
2.7	1.9	2.2	30	3.8	46	12.6
3.0	2.1	2.4	30	4.1	59	14.3
3.4	2.2	2.7	30	4.4	74	16.5
3.7	2.4	3.0	30	4.9	98	20.0

* All charges are prilled TNT

5.0 Operational Considerations

5.1 Transport

As noted in Logan et al (1976) air transportation is the only reliable method for moving men and materials for about nine months of the year in the Beaufort Sea. Therefore the constraints of flight length and weather must be considered. Inuvik is the major airfield in the area and distances from Inuvik are shown on Figure 6.1.1. In addition Inuvik is the only airfield equipment with an instrument landing system (ILS). From all other airfields visual flight rules (VFR) must be employed. It will be noted from Figure 6.1.2 the probability of flying a VFR mission is reduced considerably in the winter months. Figures 6.1.3 to 6.1.5 show the monthly probability of a successful airborne mission at Sachs Harbour, Cape Parry and Inuvik.

LOCATION PLAN

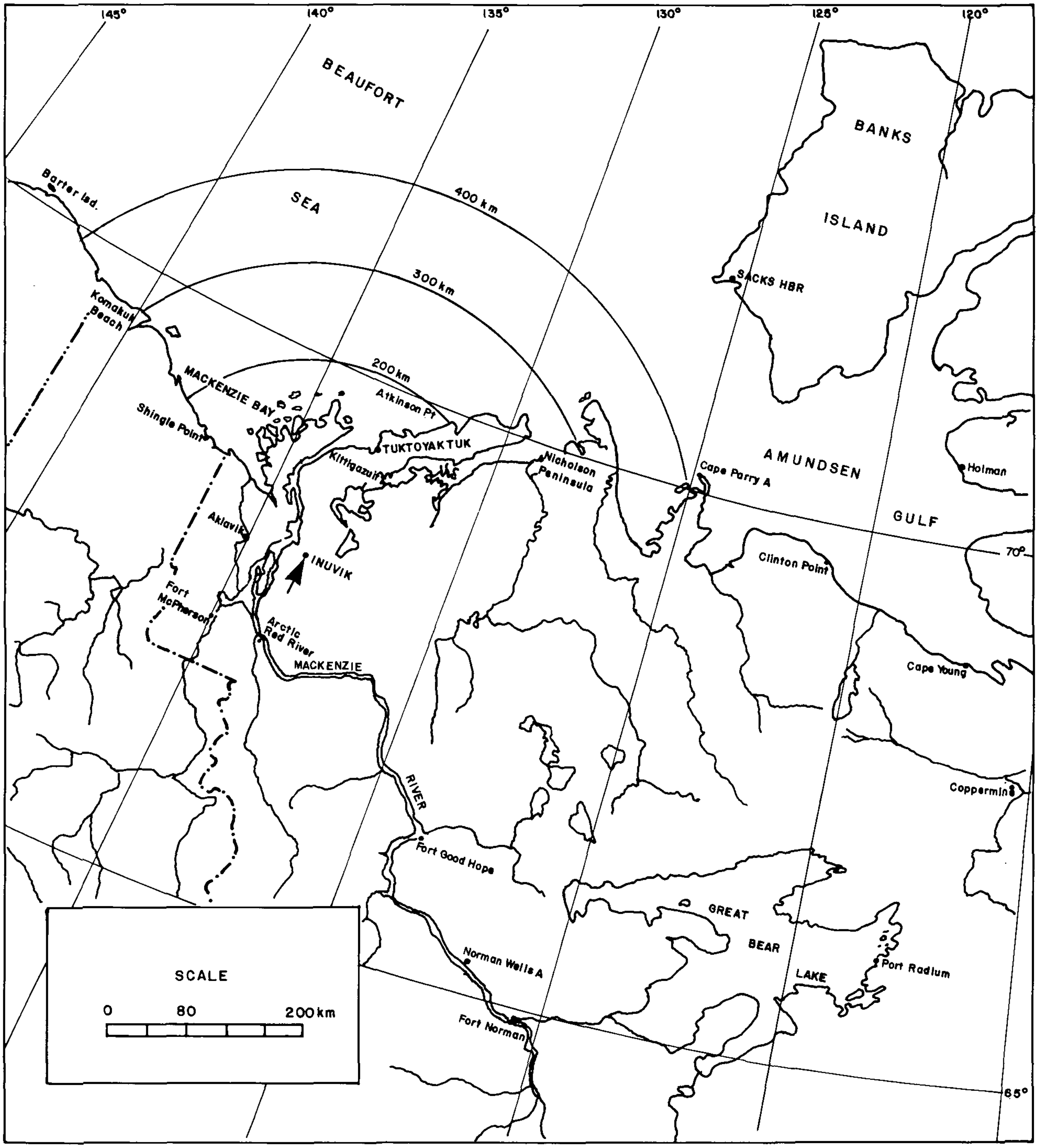
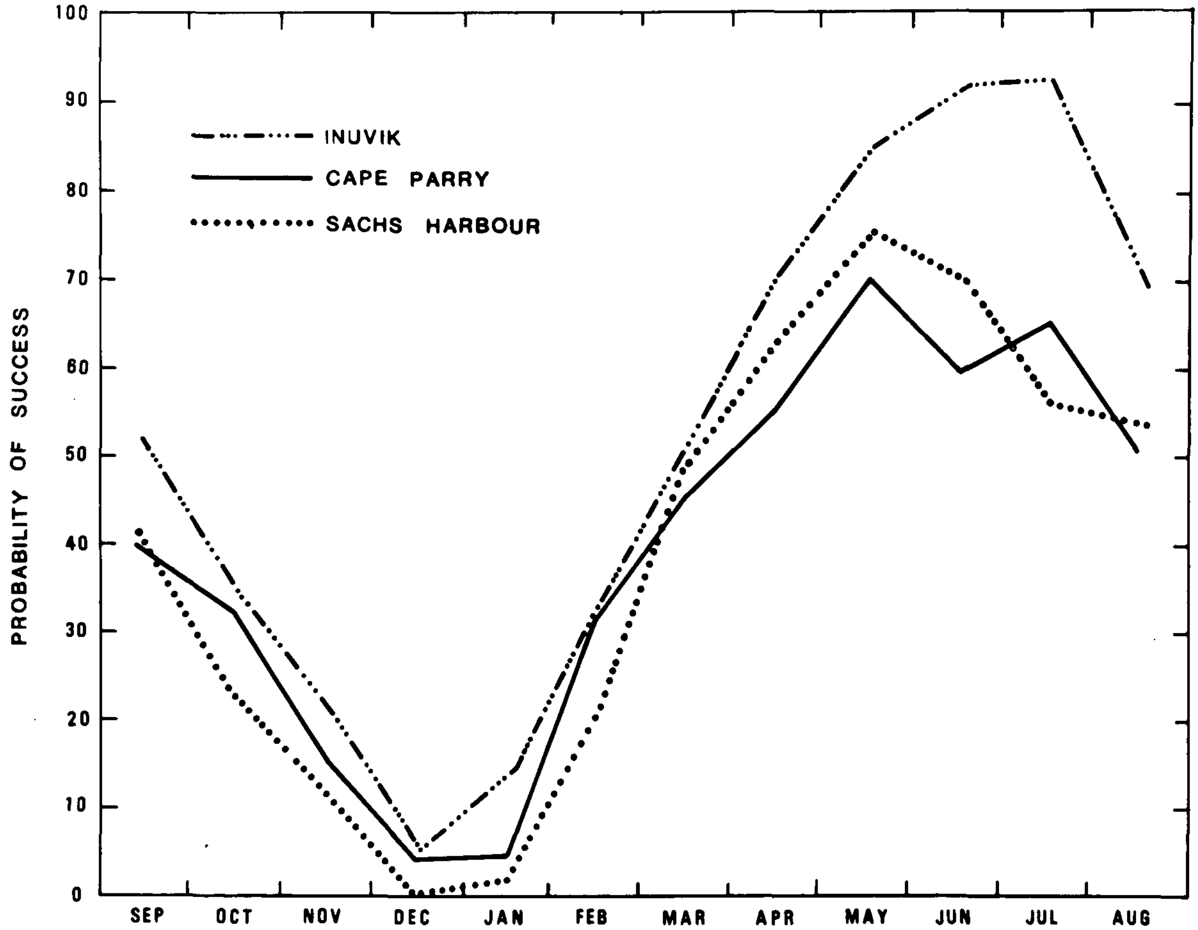
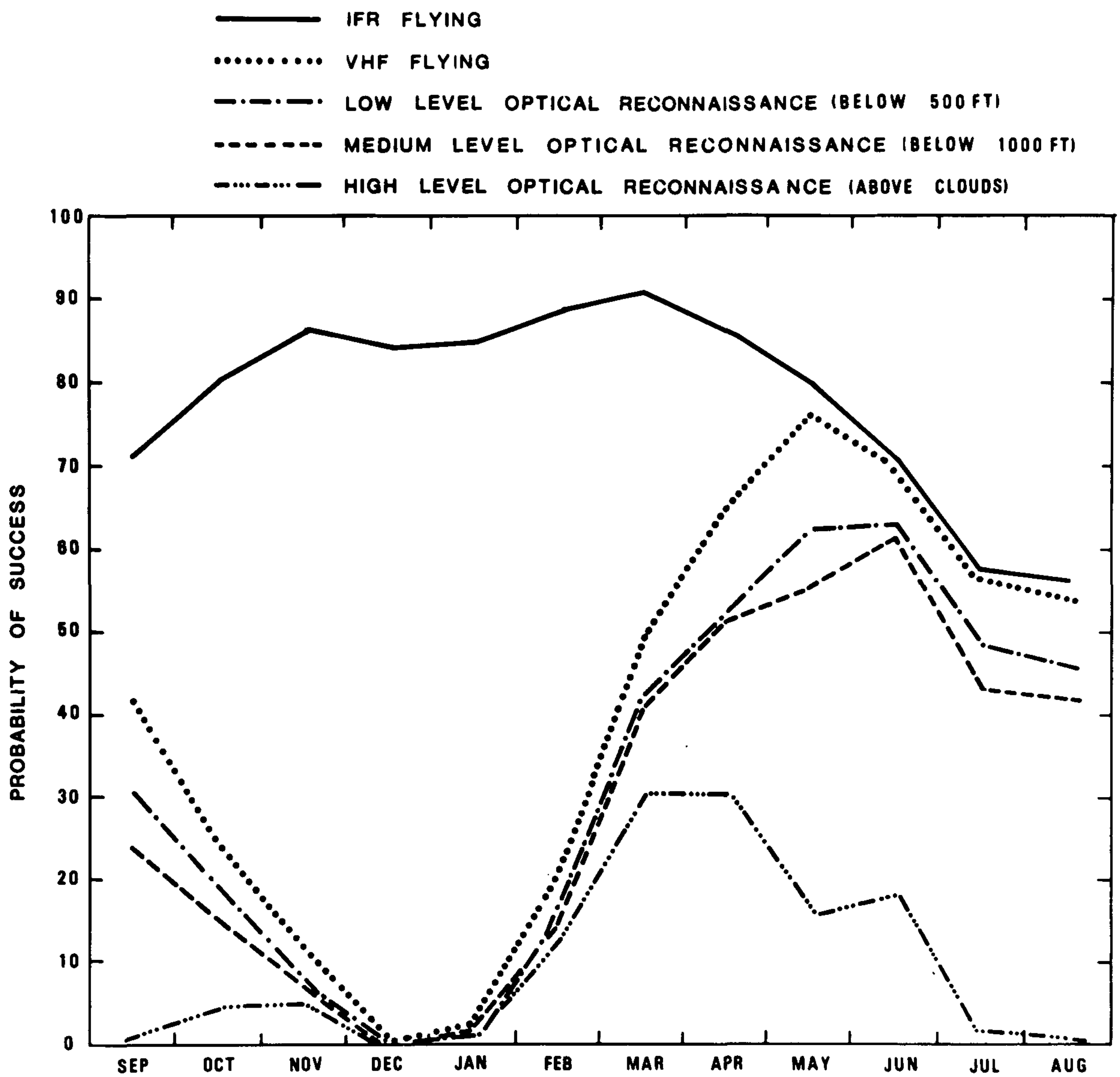


FIG. 5.1.1



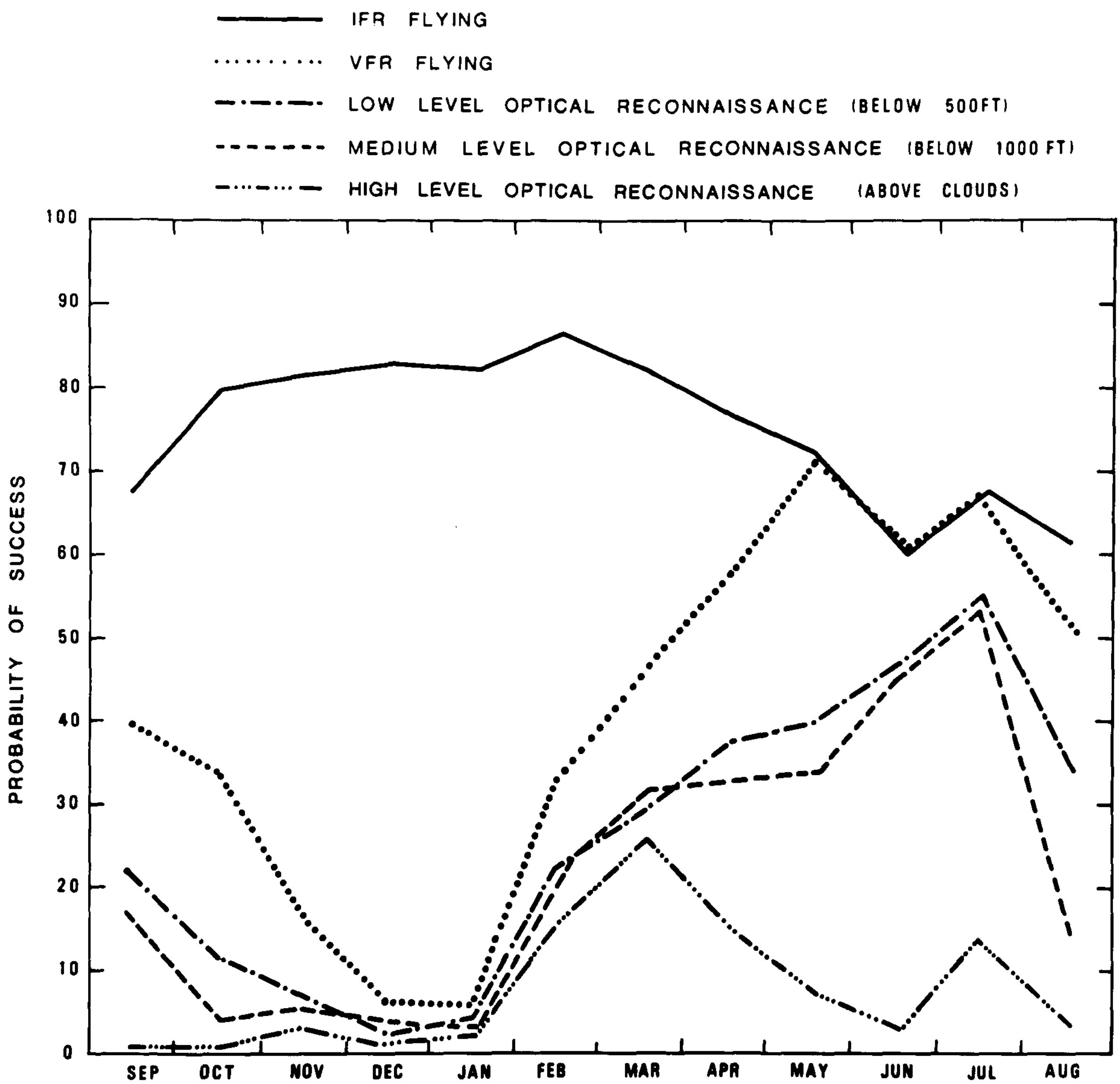
COMPARATIVE PROBABILITY OF FLYING VTR MISSIONS

FIG.5.1.2

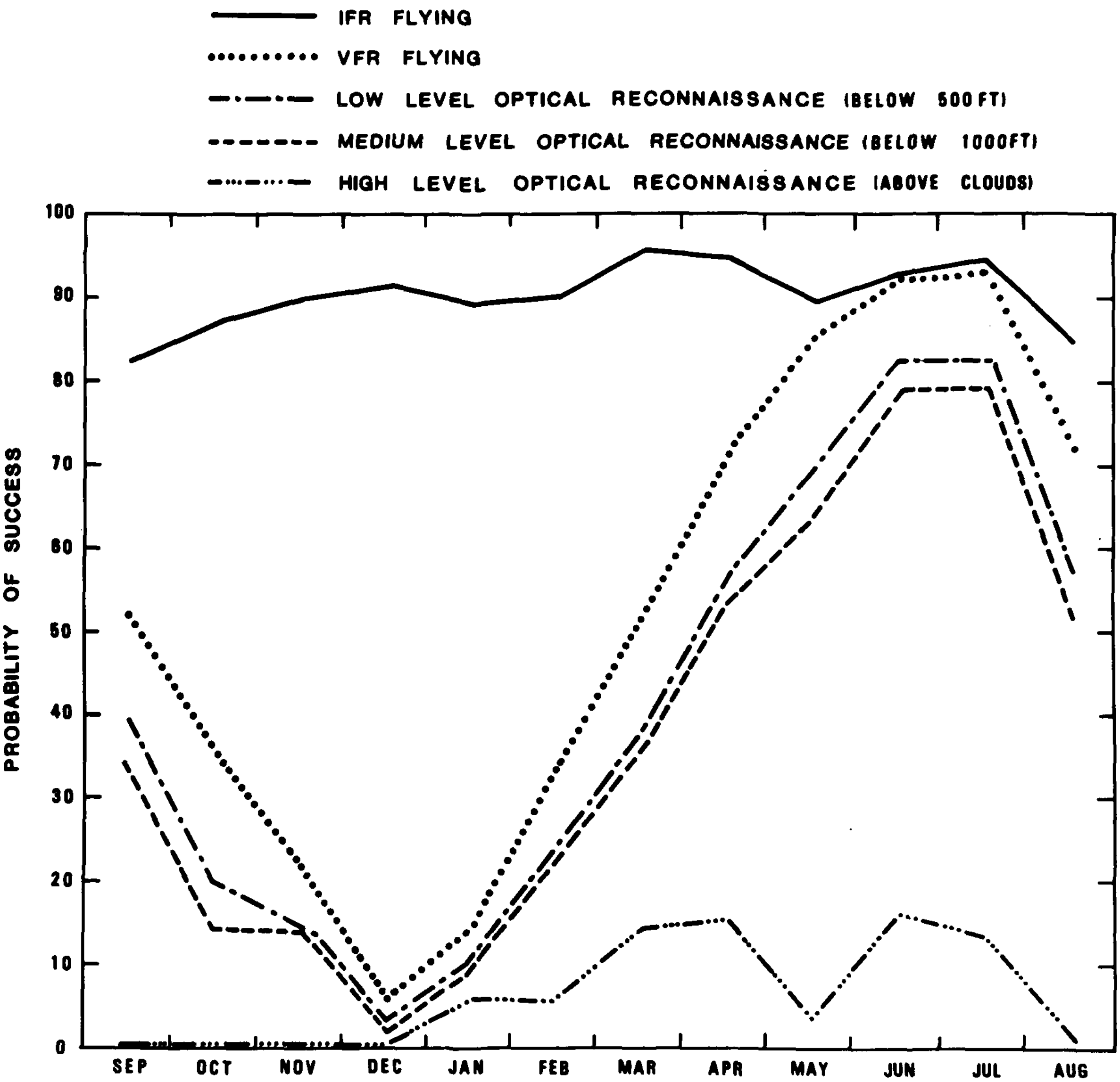


MONTHLY PROBABILITY OF SUCCESS
OF AIRBORNE MISSIONS FROM SACHS HARBOUR
(FROM 10 YR. AVERAGES)

FIG. 5.1.3



MONTHLY PROBABILITY OF SUCCESS
OF AIRBORNE MISSIONS FROM CAPE PARRY
(FROM 10 YR. AVERAGES)
FIG.5.1.4



MONTHLY PROBABILITY OF SUCCESS
OF AIRBORNE MISSIONS FROM INUVIK
(FROM 10 YR. AVERAGES)

FIG.5.1.5

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