VOLUME 7

REPORT OF TASK GROUP SIX
Operating Seasons

FOR THE
BEAUFORT SEA STEERING COMMITTEE
April 1991

Printed on recycled paper.

REPORT

by

TASK GROUP NUMBER SIX

OPERATING SEASONS

for

BEAUFORT SEA STEERING COMMITTEE

APRIL, 1991

Canada Oil and Gas Lands Administration
Administration du pétrole et du gaz des terres du Canada

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13 March 1991

Mr. R. Hornal
Chairman
Beaufort Sea Steering Committee

Dear Mr. Hornal:

Submitted herewith is the final report for Task Group Six. It is the culmination of five months work by government and industry personnel having unique and expert knowledge in Arctic offshore exploration. All drilling systems currently in use in the Beaufort have been described and analyzed with respect to their operational capability. For units subject to seasonal limitations, a formula is proposed to ensure that immediate relief well capability is always provided for Beaufort Sea drilling. Because of time constraints, it was necessary that review by the Task Group and relevant governmental authorities proceed while the finishing touches were being made to the report. A total of six meetings and numerous telephone calls between myself and Group members assured that all views were aired.

Perhaps the most contentious issue concerned the determination of end of season for floating operations. In this regard, two versions of the controlling formula are presented. The extreme end of season date is the same for both. However, in the first version, conservative estimates for contingency time and for suspension of operations due to ice incursion are made. The second version is simplified so that an overall contingency period of 30 days time is proposed. Either formula can be used but the second version is administratively preferable.

In closing, a few words are needed on the subject of risk assessment as it applies to offshore relief wells. Obviously, if one is unwilling to assume even a slight risk, nothing would ever be accomplished. In this report, the worst case scenario that an oil blowout has occurred and that a relief well is required to control it has been assumed. This event is so rare that it has not yet occurred in the Canadian offshore. Further, it is assumed that the blowout occurred at total depth of the well, that this occurred on the last operational day permitted for the season and that the drilling unit on the well has been irreparably disabled. Given this already unlikely chain of events it is not reasonable to further assume both a bad year for ice (30 day contingency) plus the least favourable drilling progress (15% contingency). Accordingly, one version or other of the formula is reasonable but not a combination of both.

I would like to take this opportunity to thank each member of the Task Group and the many people in industry and the Canadian Coast Guard that contributed to this report. In particular, the expert assistance of two consultants, Bill Scott and Dave Stenning, is gratefully acknowledged.

Yours sincerely,

Flepine

F.H. Lepine
Chairman
Task Group #6

REPORT OF TASK GROUP #6

Task

The Environmental Impact Review Board, in its review of the Kulluk Drilling Program, asked government to review its procedure for determining the cut-off date for "risk drilling" to take into account new technologies and the Industry's operating experience. It proposed that an "end of season" date be determined for each drilling system and that the cut-off date for risk drilling be determined by subtracting the number of days required to drill a relief well from the end of season date.

History

With the advent of drillships in the Beaufort Sea in 1976, the Government of Canada instituted the policy of "Same Season Relief Well Capability". This policy prohibits drilling into potential hydrocarbon-bearing zones (i.e. below the "risk threshold" depth) without the ability to drill a relief well in the same season.

In practice, this policy has meant that on September 25th, for floating drilling units, the status of operations is reviewed and any further operations conducted below risk threshold depth need a separate and distinct approval. This approval depends on many factors including; weather conditions, the availability of a relief well drilling system, depth of the well being drilled and the types of geological formations expected to be encountered. In only a few cases, have conditions been appropriate to allow drilling below the risk threshold depth beyond September 25th. This September 25th date, was originally chosen as it would allow a period of at least 65 days to mobilize a relief well rig, drill a relief well and kill the blowout prior to the time ice conditions became so severe that drillships, with the ice support level and ice management techniques available at that time, could no longer operate.

The policy of same season relief well capability and the practice of the September 25th review have been maintained since 1976 even though the technology, equipment and operational practices employed by Industry have undergone extensive development. This development includes the addition of several new powerful ice breakers, a new conical drilling unit specially designed for the Beaufort Sea, more effective ice detection equipment and ice management procedures, improved station keeping ability and fourteen years of experience.

When developing a relief well drilling contingency policy, as in all other risk management assessments, the degree of safety designed into the policy must consider the overall risk; that is both the severity of the consequences of an oil blowout requiring a relief well and the expected likelihood of such an event. In truth there is little likelihood of having to drill a relief well to kill an oil blowout. Statistics cited in Operating Seasons Appendix (Volume 7) indicate that only 0.4% of all offshore wells drilled worldwide have experienced a blowout, and only 7% of those blowouts flowed oil (the other 93% flowed gas or water) and relief wells were required to kill only 16% of the oil blowouts. The remainder were controlled by natural formation bridging or by surface kill techniques. Therefore, the incidence of the need for a relief well to kill an offshore oil blowout is about 1 in every 18,000 wells drilled. Task Groups 1, 2 and 3 have addressed the potential consequences of an oil blowout.

Final Report

A comprehensive seven-part report has been prepared by Task Groups' Technical Committee Operating Seasons Appendix (Volume 7). In it, an equipment specific methodology was developed for determining the end of season dates for each drilling system that was likely to be chosen to act in a relief well drilling capacity. Operating limit criteria, for emergency operations such as relief well drilling, were specified for each drilling system. For floating mobile offshore drilling units (MODUs), i.e. Drillships and the Kulluk and for ice islands, these operating limits include among other considerations, ice and weather conditions. Bottom founded MODUs, i.e. Molikpaq and SSDC/MAT, can conduct relief well drilling operations year round once deployed, but face seasonal deployment and/or installation constraints.

Floating MODUs: Methodology to Determine End of Season Dates

Since ice conditions are variable, both in a geographic sense and on a year to year basis, the operating limit criteria and the equipment specific methodology were applied to site specific examples. To account for geographic variations in ice conditions, specific sites were chosen that represent potential drill sites over the next few years. To account for year by year variations in ice conditions, ice data for these specific sites for the last ten years was analyzed. Based on the operating limits, the corresponding operating efficiency for each floating drilling system was determined as a function of the time of year for each of the last ten years and then averaged. The date when the average operating efficiency dropped below an acceptable economic limit was considered the end of season date (DE).

Ice Islands: Methodology to Determine End of Season Dates

Ice islands present a unique form of Arctic drilling platform and offer winter relief well capability to all drilling units operating in the landfast ice zone. The restrictions on the use of an ice island relate to its construction scenario and abandonment date. Construction requires cold temperatures and stable ice cover which generally restricts ice island drilling to the landfast ice area. The construction scenario for a particular ice island depends on water depth, time of year, ice movements, and the drilling rig mobilization schedule. As these are all site specific considerations, the suitability for using an ice island must be considered on a site by site basis. The end of season date for an ice island was conservatively chosen to be the average ice breakup date in the landfast ice area.

Bottom Founded MODUs

Bottom founded MODUs (SSDC/MAT and Molikpaq) are capable of operating year round, so they actually have no end of season date for use as relief well systems. However, their deployment and/or installation are subject to seasonal constraints and site specific constraints. Accordingly, their ability to provide relief well capability to other drilling systems is generally limited to open water and early freeze-up conditions.

End of Risk Drilling Formula

Task Group 6 Technical Committee developed a formula which can be used to determine the cut-off date for "risk drilling" for drilling systems which use floating MODUs or ice islands as their specified relief well system. The formula is based on the site specific end of season dates derived for these relief well systems. Bottom-founded MODUs proposed as relief well systems and other unique circumstances affecting a particular operation must be examined on an individual basis.

The formula determines the cut-off date for risk drilling (DE) for the primary system by subtracting each of the following terms from the site specific end of season date (DE) for the relief well system:

a) the number of days required to mobilize the relief well drilling system to the drill site and set it up;

b) the number of days required to drill a relief well, taking into account the operational efficiency of the drilling system, which is a function of ice and weather conditions, and

c) the number of days required to kill the blowout after drilling is compelled.

As a further safety measure, a contingency factor is added to the report of the Task Group Operating Seasons Appendix (Volume 7).

Recommendations

The Task Group recommends that the Minister of DIAND reaffirm the government's commitment to same season relief well capability and that the regulator:

a) Assess each drilling application to ensure that a viable relief well drilling system is available and suitable for the proposed well.

b) Use the formula developed by Task Group 6 to determine the cut-off date for risk drilling for systems using floating MODUs or ice islands as their specified relief well drilling system.

In these cases:

i) in conjunction with the Canadian Coast Guard, determine a relief well drilling system's end of season date (DE) on a site specific basis; however, (DE) shall not be later than January 31st for the Kulluk, when the Kulluk is the specified relief well drilling system for another floating MODU, and not later than December 31st for a drillship;

ii) set the Contingency Time Factor at 15%;

iii) do not allow risk drilling from a drillship beyond October 15th in any year;

iv) review the calculation using the formula ten days before the original cut-off date to determine if there is reason to modify the cut-off date for risk drilling (DC);

v) allow operators to drill beyond the original cut-off date only if the revised calculation shows that a relief well can be drilled in the same season.

In closing, it is worth noting that the worst case scenario has already been assumed when designing the formula. Assuming that the blowout occurs on the last day of risk drilling and that the relief well must drill as deep as the original well, result in a very conservative estimate of the window available for relief well drilling.

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REPORT OF TASK GROUP SIX

Operating Seasons

A Report Prepared On Behalf of the Canadian Petroleum Association

Appendices

FOR THE

BEAUFORT SEA STEERING COMMITTEE

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TASK GROUP NUMBER SIX

OPERATING SEASONS

A REPORT PREPARED ON BEHALF OF
THE CANADIAN PETROLEUM ASSOCIATION

for

BEAUFORT SEA STEERING COMMITTEE

APRIL, 1991

OPERATING SEASONS

for

BEAUFORT SEA DRILLING SYSTEMS

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Prepared for:
TASK GROUP 6
Beaufort Sea Steering Committee

February 1991

PROLOGUE

Basic Policy

There is some risk associated with all industrial development activity. The possible effects of oil exploration on the ecological systems, on the neighbouring communities and on the health and well-being of the workforce must be carefully evaluated before any action is undertaken. Before approving drilling operations, the regulator must affirm that careful pre-planning by the explorer ensures that the operation, once started, proceeds expeditiously and that countermeasures for any foreseeable eventuality are in place. Specifically, every possible preventative measure to assure that a blowout does not occur in the Beaufort Sea must be taken. Crews must be trained to stringent standards and the best available equipment and procedures are the minimum acceptable.

Contingency planning must address an uncontrolled flow of oil even though it is most unlikely. The idea of an oil blowout occurring and then persisting for more than the minimum length of time is unacceptable. Should a blowout or other incident occur, the operators have a legal obligation to make full assessment of the circumstances relating to the incident and decide on the appropriate action. There are a range of responses that might be appropriate to minimize damage to the environment; drilling a relief well is an important one. As shown in the 1984-85 Manadrill study "An Assessment of Relief Well Drilling Capability on Canada Lands", offshore blowouts are rare. Only 7% of those that do occur flow oil (the other 93% being gas or water) and relief wells are the "final solution" for only 16% of the oil blowouts. The remainder are controlled by natural bridging and by surface kill techniques. As a first approach, an operator is likely to try a surface kill through the original wellbore, since this technique is the quickest solution if successful. At the same time, he will begin mobilization of the designated rig in case a relief well is necessary.

The policy of "same season relief well capability" was approved by Cabinet when drilling from floating units was introduced to the Beaufort Sea by Canadian explorers. Its purpose was to ensure that when a well was being drilled from a floater, there would be another drilling system in the area that could complete a relief well before the ice conditions became so severe that the drilling equipment could no longer operate. The overall objective was to avoid the situation where blowout control measures could not be implemented until the next open water season.

This report describes the operational characteristics of each of the different drilling systems used in the Beaufort Sea with particular emphasis on their late-season capabilities. It is a technical document and has not been accepted in its entirety by all technical reviewers. This is not an unusual circumstance considering that exploration in the Beaufort spans only two decades and *is still a pioneering exercise. It is a credit to the operators and to the regulatory government agencies that 89 wells have been drilled to date in the Beaufort Sea without a major human or environmental mishap.*

The main area of contention concerns the ability of drillships to operate in heavy ice conditions late in the season. Simply put, the view of the operators presented in this report is that effective drilling operations could continue, from a drillship, until new ice reaches a thickness of 60 cm. This scenario would be with the support of five or more ice-breakers and with an unlimited budget, circumstances associated with a relief well. The Canadian Coast Guard (CCG) has expressed reservations that a drillship would be effective in this thickness of new ice. It is recognized that the regulator, must adopt a conservative policy when granting approvals. At the time of writing the Canada Oil and Gas Lands Adminstration (COGLA) is the federal regulatory agency. COGLA is being disbanded but its successor will be bound by the same legislation, guidelines and policies. In granting approvals for activities, COGLA is guided by the advice of the Canadian Coast Guard and other governmental agencies having relevant expertise such as the Department of the Environment, the Department of Fisheries and Oceans and the territorial governments to name but a few.

Improvement of Drilling and Support Equipment

It is important to recognize that drilling technology in the Beaufort Sea has advanced considerably since the original relief well policy was formulated in 1976. At that time, Canmar was the only operator of floating drilling units in the Beaufort and icebreaker support was less extensive than today. Then, as now, the end of the season was determined by the failure of ice management systems to counter the prevailing ice conditions. With the icebreakers available in 1979 a drillship continued to operate in a drilling mode until November 29th. In all subsequent approvals for floating units, the limiting date for risk drilling operations was set at September 25th to allow about 65 days for a relief well. A few extensions beyond this date have been allowed on an individual basis where circumstances warranted.

The Kulluk, introduced into the Beaufort in 1983, offers distinct advantages for drilling in ice infested waters. It is a conical 24-sided floating unit with a flared skirt housing 12 of the heaviest anchors available. Thus, it can stay on location and withstand heavy ice coming from any direction more capably than a drillship. It has demonstrated in practice that it can remain operational until mid-December.

Several of the drilling units and support craft first developed for the Canadian Beaufort Sea are now working in the Alaskan Beaufort and Chukchi Seas. This equipment remains available to Canadian operators in an emergency.

With the advent of bottom founded drilling units (Molikpaq, SCRI and SSDC), year-round operations became feasible in the transition zone (the area of ice interaction between landfast ice and the mobile polar pack). In this area, open water leads are a common occurrence at any time during the winter months. A unique feature of the Molikpaq is its potential capacity to act as a storage tank. In certain circumstances, the oil from a blowout would be collected within the walls of the caisson. In these cases, the pollution from an oil blowout would be diminished or eliminated and there would be more time available for the Kulluk, or a drillship, to mobilize and drill the relief well. During this period, devices for burning or transporting the oil could be installed thereby further extending the available pollution-free window. In the event that the blowout was exterior to the caisson, the caisson rig itself would be used to drill a relief well.

At present, there are four Class IV icebreakers available to Beaufort Sea operators. These vessels and the drilling unit Kulluk, also a Class IV, are authorized by the Regulations made under the Arctic Waters Pollution Prevention Act to operate in the Southern Beaufort until January 31st of each year. Moreover, COGLA has been assured by the Canadian Coast Guard that year-round operation of these units in the ice transition zone is practical and, in emergency, appropriate amendments to the Regulations could be made to allow them to operate through the winter.

Modern techniques for ice management include; remote sensing, real time transmission of ice condition imagery, alert levels for each vessel, and improved procedures for cutting dangerous ice floes and ridges into manageable pieces by the expert use of icebreakers.

Other ways in which technology has advanced include the ability to predict ice movement and the actual measurement of ice forces by instrumentation installed in the caisson walls. Canada leads the world in the development of Arctic drilling technology and units from the Canadian Beaufort have secured many contracts in the U.S. Beaufort and Chukchi Seas.

In shallower water, sand-dredged islands and ice islands may be used for winter drilling. In such cases, an ice platform would be constructed for supporting relief well drilling operations.

Decision Approval Process

In addition to the review meetings between the regulator and the prospective operator, contingency plans are circulated for review by a dozen other governmental agencies. The Arctic Waters Advisory Committee is provided with those parts of the application pertinent to environmental concerns. Comments are received from the reviewers and appropriate conditions are attached to any approvals given. It is emphasized that every drilling application is carefully assessed and a relief well plan, suitable for the particular circumstances, must be in place before approval is given to drill. COGLA also works closely with Canadian marine and air transport *authorities and other regulatory agencies in determining the conditions that apply to a specific drilling program.*

Conclusions

The essential elements of the original relief well policy remain unchanged after careful examination in the light of this report.

In the case of the floating drilling units, drilling above risk threshold depth after September 25th is allowed. Testing in fully-cased hole with "fail-safe" production devices is also allowed beyond September 25th in some individual cases. The need to select a cut-off date of September 25th (or earlier in September in the case of a very deep well) for risk drilling from a floater is seen as essential. Review of the progress of the well before the onset of autumn and winter allows a better risk assessment than at the start of the season. On the review date such factors as the supporting equipment available in the Beaufort, the predicted productive formations in the well, and the predictions for ice formation and movement may be very different from those anticipated at the outset of the season. If safe to do so, limited additional operations may be allowed beyond the review date under stipulated conditions that would reduce risk to an acceptable level.

Similarly, where caissons and artificial islands are utilized as the primary drilling platform, provisions for relief well capability is an important prerequisite for approval of drilling programs. The operator must also demonstrate the capability for an immediate response to contain a blowout and to start a relief well. In every case, a limiting date for risk drilling is specified as a condition of approval. This date is established separately for each type of drilling system and must provide sufficient time for a relief well to be completed within the drilling season for the particular system.

It remains the responsibility of the operator and of the regulator to be certain that relief well contingency is available wherever and whenever exploratory drilling operations take place in the Arctic frontier.

ACKNOWLEDGEMENTS

This report was prepared for the Beaufort Sea Steering Committee Task Group #6 Stakeholders, whose interests, for the purpose of this report, were represented by;

• *Mr. Fred Lepine (Chairman)*	*Canada Oil and Gas Lands Administration (COGLA)*
• *Mr. Peter Bannon*	*Department of Indian Affairs and Northern Development*
• *Mr. Doug Burch*	*Government of the Northwest Territories*
• *Mr. Brian Love*	*Yukon Territorial Government*
• *Mr. Bill Scott*	*Inuvialuit Regional Corporation*
• *Mr. Dave Schilling*	*Canadian Petroleum Association (CPA)*

This report was the result of a joint effort by industry and government. It was written under the guidance of a CPA member committee consisting of;

• *Mr. Dave Schilling (Chairman)*	*Amoco Canada Petroleum Co. Ltd.*
• *Mr. Gary Pidcock*	*Gulf Canada Resources Limited*
• *Mr. Peter Meyer*	*Esso Resources Canada Limited*
• *Mr. Paul MacMillan*	*Chevron Canada Resources Ltd.*
• *Mr. Jamie Sutherland*	*Shell Canada Limited*

Valuable input and guidance was received from Mr. Fred Lepine (COGLA) throughout the duration of this work.

Special thanks are extended to those employees of the CPA member companies who spent many hours researching, writing, compiling and editing this report. In particular, the following people made significant contributions to this report;

- *Mr. Hank Vrielink, Mr. Dave Schilling, & Mr. Colin Birkbeck (Amoco),*
- *Mr. Joe Foose, Mr. Gary Pidcock and Mr. Brian Wright (Gulf),*
- *Dr. Jeff Weaver (Esso), and*
- *Mr. Ben Danielewicz (Canmar).*

Special thanks are also due Mr. Dave Stenning (AOE Consultants Ltd.) who edited all of the material into a cohesive report.

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1.0 INTRODUCTION

1.1 Background

Over the past two decades of Beaufort Sea exploration both Industry and government have adopted policies relating to potential loss of well control. In extreme circumstances, loss of well control could result in a blowout which may require a relief well to bring it under control. Relief well contingency planning has been a continuous, integral and evolving component of industry's contingency planning and government regulation since the onset of drilling in the Beaufort Sea. Now, increased public concern and awareness requires industry and government to communicate these plans and policies more broadly than it has in the past. The overall purpose of this document is to provide a basis for communication between industry, government, local communities, and concerned public.

Embodied in both industry plans and government regulations are three basic principles which apply to relief well contingency measures; the action taken must be practical, immediate, and lead to the timely control of the blowout.

Present Policy: Present relief well policy is based on the concept of "same season relief well capability". Its purpose is to insure that relief well operations could continue without prolonged delays until the blowout was controlled. This policy was formulated in the mid-1970s when most exploration was undertaken by drillships. September 25th became the date after which drilling into potential hydrocarbon zones was generally prohibited unless conditions were extremely favourable and the operator demonstrated "same season" relief well capability. In these special circumstances[1], drilling operations were permitted up to October 15th. The September 25th cut-off date was based on the ability of the drillships and their support fleet at the time. With the advent of the Kulluk and large Class IV icebreakers, the capability of the Beaufort drilling fleet in the late season was enhanced, yet the same cut-off date remains in effect. Furthermore, COGLA is empowered by legislation to halt drilling any time that it believes viable relief well contingency is jeopardized.

This policy also applies to fixed structures such as gravel islands, ice islands, and bottom founded MODUs. However, in these instances, the September 25th cut-off date does not apply but rather the operator must establish that well control procedures, including drilling a relief well, could be completed in a timely manner.

1.1 Since COGLA was established in 1981, there have only been 3 occasions where approval for risk drilling beyond September 25th was given.

Technology has advanced significantly since the inception of these regulations and this review of industry's present relief well capability will be important when considering updates to the regulations.

1.2 Study Mandate

Authorization of Beaufort Sea Steering Committee: The Beaufort Sea Steering Committee (BSSC) was formed in September, 1990 by the Honourable Mr. Tom Siddon, Minister of the Department of Indian Affairs and Northern Development (DIAND). The BSSC first met on September 12, 1990, and agreed that the BSSC's mandate was to assess:

- the nine (9) recommendations made by the Environmental Impact Review Board (EIRB), in the EIRB's June 28, 1990 report on the public review of the "1990-1992 Gulf Kulluk Drilling Program", and
- the six (6) recommendations made in the March 21-22, 1990 Workshop on Wildlife Compensation, which was held as a result of a recommendation made by the EIRB in their November 1, 1989 report on the public review of the "Esso Chevron et. al. Isserk I-15 Drilling Program".

Timing of Investigation: The BSSC was to forward specific recommendations stemming from their investigation of the above mentioned 15 recommendations to the Minister of DIAND, in time to allow drilling to commence in 1991. Hence, January 31, 1991 was set as the target for having their findings forwarded to the Minister of DIAND.

Organization of Tasks: At the inaugural September 12, 1990 meeting, the BSSC divided the above mentioned 15 recommendations amongst 7 task groups. Task Group #6, whose work will be the subject of this report, was assigned to assess EIRB recommendation #8 which was presented in their report on the public review of the 1990-1992 Gulf Kulluk Drilling Program.

Authorization and Timing of Task Group #6: Mr. Fred Lepine; Director, Exploration Engineering, Engineering Branch, of the Canada Oil and Gas Lands Administration (COGLA), was appointed as the Chairman of Task Group #6. Task Group #6's role was introduced in a September 26, 1990 letter to all of the stakeholders. The first stakeholders meeting was subsequently held on October 11, 1990 to initiate the process.

Problem Statement of Task Group #6: The mandate for Task Group #6 was defined as addressing the EIRB's Recommendation #8, made in their report on the public review of Gulf's 1990-1992 Kulluk Drilling Program. This recommendation states:

"More appropriate criteria must be developed to establish dates to define the safe operating season for each drill system employed in the offshore Beaufort Sea, and within that season, the cut-off date for risk drilling. The date for the operating season should be fixed for each drill system, based on the individual characteristics of that system as they affect the ability of that system to operate safely in the conditions likely to be encountered. Within each operating season a cut-off date for risk drilling should be determined based upon the length of time required to drill a relief well before the season ends. No extensions should be granted with respect to the operating season or the cut-off date for risk drilling".

This recommendation appears on page 66 of the subject EIRB report, and is discussed on page 67. Further discussion of the operating season appears on pages 27-29.

1.3 Objectives and Work Scope

The objective of Task Group #6's investigation was to review the methodology required to determine the prudent end of the risk drilling season, for each drilling system used offshore in the Canadian Beaufort Sea and thereby ensure "same season" relief well capability.

The scope of work required to achieve the objective was defined as two somewhat independent tasks;

1) To review and specify the end of the operating season criteria, for emergency operations purposes, such as relief well drilling, for each drilling system that could act in a relief well drilling capacity, and to determine the expected dates of occurrence of such criteria.

2) To review and specify the basis for relief well drilling and well kill times, for the drilling systems available in the Beaufort, namely;

   a) Floating MODUs[2],
      - Drillships
      - Kulluk

   b) Bottom-founded MODUs,
      - SSDC/MAT
      - Molikpaq

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c) Bottom-founded fixed structures,
- Artificial islands
- Caisson retained Islands
- Ice islands

To achieve the stated objectives, this work required the formalization and documentation of the cumulative knowledge of the main Beaufort operators[3] and COGLA in relation to relief well contingency. It would be wrong to leave the impression that the ideas and thoughts presented herein are new; they are not. The results are based on the experience of the operating companies and are very much in line with the way relief well contingency planning has been undertaken in the past. What is new, is the collection of these ideas into one document that is intended to clearly communicate the relief well capability now existing in the Beaufort.

1.4 Methodology

In order to systematically review the capability of the Beaufort Sea drilling systems from a relief well perspective, the methodology outlined in Figure 1.1 (for floating systems) was generally followed. Each of the Beaufort Sea drilling systems shown in Table 1.1 was first assumed to experience a blowout during the course of a normal operating season. The relief well support potentially available to these systems was then identified and screened on the basis of water depth, mobilization, installation and/or performance constraints to establish the most practical relief well approaches for each situation. The results of this initial screening are shown in Table 1.2 where the preferred relief well drilling systems are noted.

1.3 Amoco Canada Petroleum Company, Esso Resources Canada Ltd., & Gulf Canada Resources Inc.

TABLE 1.1
BEAUFORT SEA DRILLING SYSTEMS

DRILLING SYSTEM	NORMAL OPERATING ENVIRONMENT	NORMAL OPERATING SEASON
Kulluk	Floating Mid to Deeper Waters	Break Up to Early Winter
Drillships		Open Water to Freeze-Up
Artificial Island	Bottom Founded Landfast Ice	Freeze-Up to Break-up[4]
Caisson Retained Island		Year-round
Molikpaq		Year-round
SSDC		Year-round
Ice Island		Winter
Molikpaq	Bottom Founded Transition Zone / Mobile Pack Ice	Year-round
SSDC		Year-round

TABLE 1.2
RELIEF WELL SYSTEM OPTIONS

	RELIEF WELL				
ORIGINAL WELL	DRILLSHIP	KULLUK	MOLIKPAQ	SSDC	ICE PAD
DRILLSHIPS	√	√	X	X	n/a
KULLUK	√	X	X	X	n/a
ARTIFICIAL ISLANDS	X	X	X	X	√
CAISSON RETAINED ISLAND	X	X	X	X	√
MOLIKPAQ	X	X	X	X	X
SSDC	X	X	X	√	X
ICE PAD	n/a	n/a	n/a	n/a	√

√ In All Cases   X In Some Cases   n/a Not Applicable

1.4 In shallow, protected waters artificial islands can be used year round. It is also possible to construct year round artificial islands for deeper waters but this is generally considered too expensive for an exploration well.

Relief well drilling scenarios were defined on this basis and the candidate relief well systems were considered in more detail in terms of their design and operating constraints. In an actual relief well situation, the best option available would be chosen from the potential relief well units based on the specific conditions such as; water depth, ice conditions, mobilization times etc.. For example, if the Kulluk was the primary unit the possible relief well units are a drillship, the SSDC, the Molikpaq or, if undamaged, the Kulluk herself. In general a drillship is the preferred relief well system for the Kulluk, due to water depth compatibility, ease of mobilization, and expected station-keeping performance. However, in specific circumstances where mobilization could take place in relatively open water, the SSDC/MAT or the Molikpaq may be the preferred alternate providing the water depth and seabed conditions were appropriate. The relief well planning process examines all options and establishes the optimum plan which would be followed in the event of a blowout.

Since the objective is to address the most practical and generally applicable relief well drilling systems for the Beaufort Sea, this assessment methodology was followed and a variety of "special circumstance" approaches eliminated. As a result, the relief well operating season assessment focused on floating and bottom founded Beaufort Sea drilling systems working within their normal operating environment in a relief well role. The Kulluk, Canmar drillships, the SSDC, the Molikpaq and ice islands were the key relief well drilling systems considered and are discussed in detail in Section 3.

As shown in Figure 1.1 the capability of these drilling systems in a relief well role was evaluated probabilistically where relevant. Where probability based assessments were not relevant then conservative deterministic methods were used.

The probability approach was most useful for the floating systems as their ability to stay on location and drill is a function of ice conditions which can be described in statistical terms. Using this approach, year to year variations in the environmental conditions which affect the station-keeping performance of the floating systems and the construction times for grounded ice island platforms were realistically addressed. Conceptually, design or performance limitations for the system under consideration were defined and compared against historical environmental conditions on a year by year basis. This resulted in a statistical estimate of the expected drilling capability and efficiency for the particular system being considered over the relief well drilling period assumed. Additionally, the end of season could be statistically identified as the time when environmental conditions consistently exceed the capability of the drilling system. This probabilistic approach formed the basis for evaluating the performance capability of the floating drilling systems in a relief well role.

The relief well capabilities of bottom founded structures, which are generally independent of the ice environment once installed, were best addressed using deterministic methods. Conservative deployment times were estimated for various times of year and then these times were combined with any other constraints on the system to determine the relief well capability of each system.

1.5 Report Organization

After this introduction, the main sections of the report deal with;

- **Risk of Blowout**
  Provides a synopsis of current blowout statistics and information

- **Operating Season of Drilling Systems**
  This section describes each available relief well drilling system and specifies its deployment timing and operational efficiency in various relief well scenarios.

- **Drilling Operation**
  First the constraints on the surface location of the relief well are addressed and then a description of relief well drilling operations and timing is provided.

- **Supply of Drilling Materials**
  The logistics of supplying the drilling materials for the relief well are described.

- **End of Risk Drilling Date**
  In view of the drilling systems' operating capability, this section puts forward a methodology to determine the end of risk drilling date for each system.

- **Summary & Conclusions**
  The main conclusions of the study are summarized.

The Appendices provide back-up information on each of the drilling systems addressed in this report and the reader is encouraged to examine these appendices if questions arise while reading the main text. References, where appropriate, are included at the end of each section, after the figures.

There are numerous figures in this report and they are organized in numerical order at the end of each section whereas the tables are contained within the text.

The focus of this document is on the methods and timing of a relief well response to a blowout in the Beaufort Sea. Several peripheral issues are synoptically addressed in order to provide the reader with some background information. This document is not intended to replace the detailed site specific relief well contingency plan which would be submitted as part of an application to obtain drilling program approval.

1.6 Definition of Key Terms

The following phases and terms have specific meaning and are crucial to the understanding of this report;

Blowout refers to an uncontrolled flow of gas, oil, or water from a wellbore.

Relief Well refers to a well drilled adjacent to an uncontrolled well with the specific purpose of intercepting the blowout wellbore and killing the flow. The interception only has to be close enough to allow fluid communication between the wells (within a few metres).

Same Season Relief Well Capability refers to the capability to drill a relief well and kill a blowout in the same season in which the original well was being drilled. Same season relief well capability requires the ability to begin mobilization of an alternate relief well drilling system as soon as a blowout occurs, and once relief well operations are started, the ability to conduct those operations on a relatively continuous basis, to a successful conclusion.

Risk Threshold Depth refers to the depth below which liquid hydrocarbons (oil) are reasonably expected to be present.

Risk Drilling is defined as drilling below the risk threshold depth. Logging, casing and cementing operations are not considered risk drilling operations. Similarly, all cased hole operations, including testing, are not considered risk drilling operations.

Effective Drilling Days and Operating Days both refer to the time available to actively conduct drilling operations.

OPERATING DAYS AND END OF SEASON DEFINITION FOR DRILLING SYSTEM

METHODOLOGY

DEFINE PERFORMANCE LIMITATIONS IN TERMS OF EXPECTED DOWN-DAYS PER WEEK DUE TO:

- OLD ICE
- THICK FIRST YEAR ICE
- ICE PRESSURE

DEFINE SITE SPECIFIC ICE CONDITIONS ON A WEEKLY BASIS FOR A NUMBER OF YEARS (N) INCLUDING:

- ICE CONCENTRATIONS
- ICE TYPES
- ICE THICKNESS

EXPECTED DOWNTIME ON A WEEKLY BASIS AND END OF SEASON FOR N YEARS

PROBABILITY OF ACHIEVING A GIVEN NUMBER OF OPERATING DAYS AND END DATE FOR THE SEASON UNDER CONSIDERATION

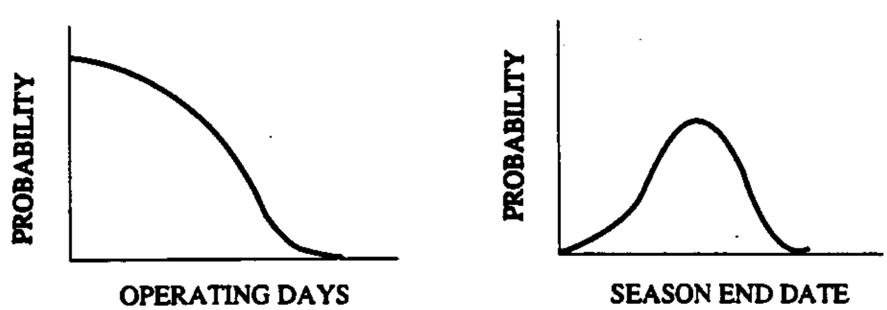

FIGURE 1.1 METHODOLOGY FOR DETERMINING OPERATING SEASON

2.0 RISK OF BLOWOUT

2.1 General

The reason for requiring operators to be prepared to drill a relief well is because, a relief well may, in fact, be needed. This obvious statement raises the important question of likelihood. To understand the implications of this report the reader needs to have some idea of the approximate likelihood of a blowout and the consequential need for a relief well. The intent of this section is to provide this perspective. For a detailed account of blowout statistics the reader is referred to the list of references at the end of this section.

For a relief well to be required, two major events must occur;

- An uncontrolled flow of formation fluids[1] (a blowout), and
- failure to control the blowout from the original wellbore.

It is also important to address the issue of the type and amount of well effluent reaching the surface. It is reasonable to classify blowouts as follows;

- Gas or water blowouts
- Oil blowouts
- Oil blowouts with cumulative spilled volumes in excess of 8000 M^3 (50,000 bbls)

The reason for this classification is that gas and/or water blowouts cause little or no environmental damage. They can cause damage to the drilling facilities but the social and environmental costs[2] are slight. Oil blowouts can cause environmental damage and large oil blowouts may have large environmental and social costs.

2.2 Statistics

Data on oil spills is essentially 100% in the public domain. Many studies[3] have collected and analyzed this data. The principle references for this report are the 1985 COGLA study prepared by Manadrill Drilling Management Inc (Ref. 11), and the 1990 discussion paper prepared by COGLA which is included in this report as Appendix C.

2.1 Formation Fluids refer primarily to oil, gas, and water.

2.2 Cost in this sense includes both dollar losses and losses relating to the effect the blowout has on the people and wildlife which use the environment (for whatever reasons; food, recreation, livelihood, etc.).

2.3 A list of references is provided at the end of this section.

The following table summarizes the statistics on offshore blowouts.

TABLE 2.1
BLOWOUT STATISTICS

DESCRIPTION	OCCURRENCES (Total Number)	FREQUENCY (Number Per 1,000 Wells)
WORLDWIDE STATISTICS (1955 to 1980)		
Total Offshore Wells Drilled	36,633	-
Total Blowouts of All Types	162	4.42
Total Gas and/or Water Blowouts	150	4.09
Total Oil Blowouts	12	0.33
Total Large Blowouts	5	0.14
Total Relief Wells	10	0.27
Total Oil Relief Wells	2	0.05
CANADIAN STATISTICS (1973 to 1989)		
Total Offshore Wells Drilled	385	-
Total Blowouts of All Types	4	10.39
Total Gas and/or Water Blowouts	4	10.39
Total Oil Blowouts	0	0
Total Relief Wells	0	0

This data is presented in graphical form in Figure 2.1.

The location of the "large" oil blowouts (>8,000 m^3) are as follows;

- Santa Barbara: 9,540 m^3 (60,000 bbls)
- Iran: 76,311 m^3 (480,000 bbls)
- Saudi Arabia: 15,900 m^3 (100,000 bbls)
- Nigeria: 31,800 m^3 (200,000 bbls)
- Mexico: 492,845 m^3 (3,100,000 bbls)

The Mexico blowout (Ixtoc I) is by far the largest (non-war related) offshore oil blowout to-date and is especially significant since it is the only major spill stemming from an exploration well. Together these 5 blowouts represent 3.1% of the total offshore blowout occurrences and 14/1000th of 1% of the total offshore wells drilled (.014%). The vast majority of oil blowouts spilled minor amounts of oil (mostly between 100 and 200 barrels).

The Canadian database is too small to make statistical inferences on a rare event such as a blowout. However worldwide statistics can be applied to Canada to make statistical observations providing that, the worldwide statistics are the same in the future as the past, and that they are representative of Canadian drilling operations in the long run. Assuming that the worldwide statistics apply and that, on average, about 24 offshore wells per year will be drilled on Canada lands[4], then the following observations can be made with regard to offshore drilling in Canada:

- A relief well is expected once in every 150 years and a relief well directed at killing an oil well is expected once in every 750 years.
- A blowout of any type is expected once in every 9 years.
- An oil blowout of any size is expected once in every 127 years.
- A major oil blowout is expected once in every 305 years.

The basic conclusion that can be drawn is that it is unlikely that an oil blowout would occur, especially one of major size, and that even if one occurred it would most likely be controlled through the original wellbore. To put this in perspective, Beaufort exploration and development is likely to span several decades with several hundred wells. Even when taking into consideration the full span of possible Beaufort development the statistics indicate that a major oil spill is very unlikely.

2.3 Application to Beaufort Sea

Finally it is instructive to note some of the differences between Beaufort Sea drilling and drilling in other offshore petroleum provinces, around the world.

Presence of Sea Ice: This effects the floating MODUs most and does cause them to move off and on location during the drilling season, which could be difficult in certain critical drilling operations. To mitigate the ice impact on drilling, the operators use substantial marine and ice reconnaissance support to manage the ice when it is present. The operators also adjust drilling procedures to ensure that any movements off location do not threaten the well.

Sea States: Sea states in the Beaufort are modest compared to the Gulf of Mexico, the North Sea and most other open ocean areas. Vicious storms cause serious accidents offshore and could lead to loss of well control. The Beaufort is a relatively calm environment in this regard and the drilling vessels and equipment are in most cases designed for much rougher weather than is experienced in the Beaufort.

2.4 The present drilling rate on Canada lands is less than 10 wells per year. The 24 well per year average took into account all past drilling. If the drilling rate is lower then the return periods for a blowout are more favourable.

Icing: Icing can cause stability and operational concerns in an open ocean situation where temperatures are below normal and winds are high. The North Atlantic is notorious for serious icing. Icing in the Beaufort is mild when compared to other Northern operating areas.

Crews: In comparison to the average crew operating worldwide it is safe to say that Canadian crews are more safety conscious, better educated, and better trained.

Regulations: Canada has made substantial efforts in developing regulations that extract the best of the worldwide regulations and apply them to Canadian conditions. The requirement for relief well contingency is an example of where Canadian regulators have identified a potential problem and created a policy to insure maximum safety, consistent with resource development.

Logistics: There is no doubt that the supply of materials to the Beaufort is expensive. Heavy lifts are normally restricted to times when barge transport up the Mackenzie river is possible. However, in an emergency situation, it is possible to airlift almost anything needed for drilling, including the drill rig. A section in this report deals with logistics.

Shallow Gas: Many areas of the Beaufort Sea have gas accumulations near the seabed which can be difficult to control. One of the 4 Canadian blowouts noted in Table 2.1 was the shallow gas blowout at Immiugak in 1989. These shallow gas zones have limited amounts of gas and while operationally difficult, they do not present a hazard to the environment.

Technology Improvements: Offshore Drilling technology has made rapid safety gains in the past 20 years. It is reasonable to expect this to continue and drilling operations to become safer with time. If this turns out to be the case then the above noted statistics overpredict the frequency of blowouts in the future.

On balance, it is reasonable to use these statistics to estimate the likelihood of a blowout in the Beaufort Sea. The main conclusion is that a relief well is very unlikely to be needed. However, due to the sensitive and pristine environment of the Arctic, relief well contingency plans are required by COGLA as a necessary condition for permission to drill a well. This report describes the relief well drilling systems available to operators and their operating seasons.

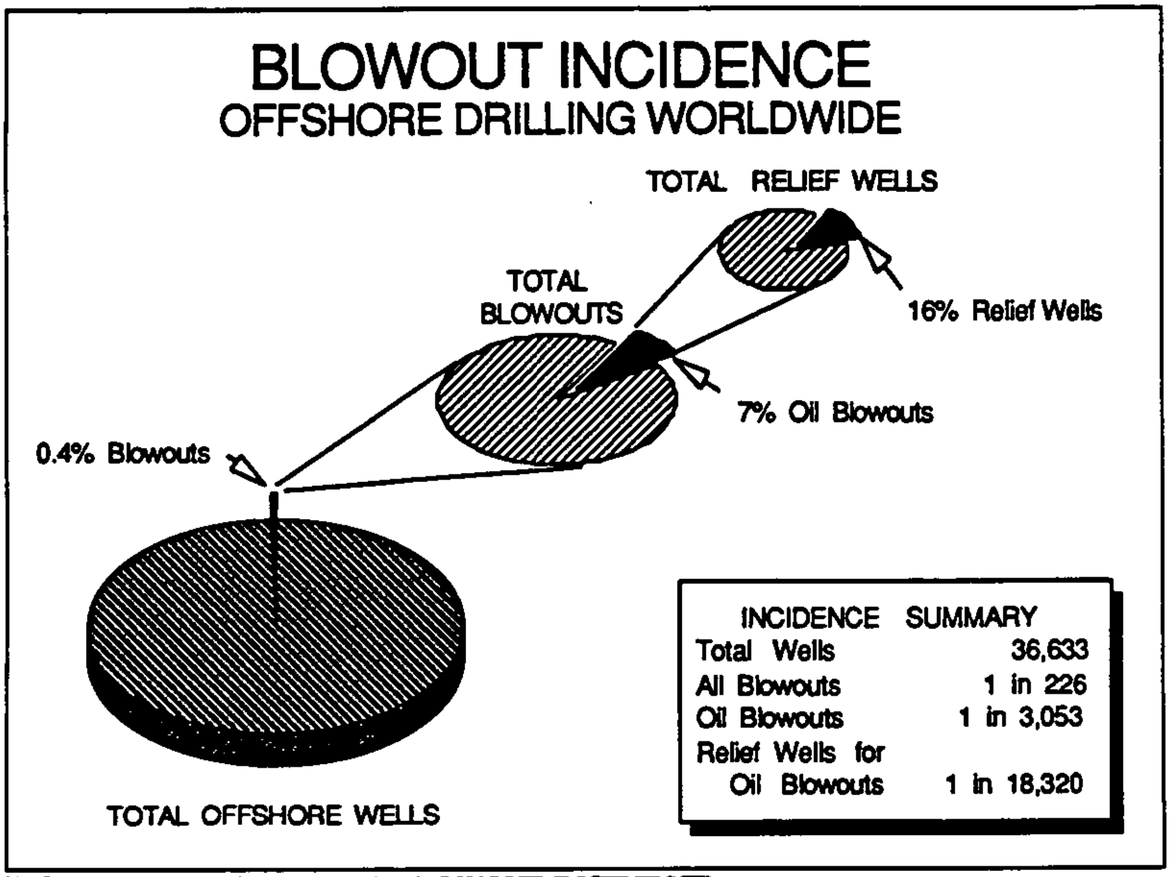

FIGURE 2.1 WORLDWIDE BLOWOUT INCIDENCE

REFERENCES

1 Adams, N., Contingency Plans Save Lives and Ease Troubles. Oil and Gas Journal, pp. 221-240, November 1980.

2 Adams, N., How to Drill a Relief Well, Oil and Gas Journal, pp. 93-97, September 29, 1980.

3 Adams, N., Surface Kill Procedures Use Existing Equipment for Control, Oil and Gas Journal, pp. 79-82, September 22, 1980.

4 Adams, N., Establishing Communications is Key to Relief Well Kill, Oil and Gas Journal, pp. 176-279, October 13, 1980.

5 Analysis of Accidents in Offshore Operations where Hydrocarbons were Lost. Gulf Research and Development Company, Houston, July 1981.

6 Barnett, R.D., A Logical Approach to Killing an Offshore Blowout West Cameron 165 Well No. 3 - Offshore Louisiana, SPE 6903, 52nd Annual Fall Technical Conference, Denver CO, October 9-12, 1977.

7 Bercha, F.G., Probabilities of Blowouts in Canadian Arctic Waters, Report EPS 3-EC-78-12, October 1978.

8 Blount, E.M., Soelinah, E., Dynamic K.U.: Controlling Wild Wells in a New Way, World Oil, pp. 109-126, October 1981.

9 Bruist, E.H., A New Approach in Relief Well Drilling, Journal of Petroleum Technology, pp. 713-723, June, 1972

10 Canadian Petroleum Association & the Independent Petroleum Association of Canada, Oil Spill Preparedness in the Upstream Petroleum Industry, 1989

11 Canadian Oil and Gas Lands Administration, Relief Well Drilling Capability on Canada Lands (1985). Environmental Protection Branch, Technical Report No. 4, prepared by Manadrill Drilling Management Inc.

12 de Lange, J.I. and Darling, T.J. Improved Detection of Blowing Wells, IADC/SPE 17255, 1988 IADC/SPE Drilling Conference. Dallas Texas, February 28 to March 2, 1988.

13 Ely, John W. and Holdich, Stephen A. Polymers used to direct kill fluids to blowout. Oil and Gas Journal, August 1, 1988, pp 44-48.

14 Flak, L.H. Goins, W.C. New Techniques, Equipment Improves Relief Well Success. World Oil, pp 113-116, January 1984.

15 Grace, R.D., Branton, J. Operations at a Deep Relief Well. The TXO Marshall SPE 18059: 63rd Annual Technology Conference and Exhibition, Houston, October 2 to 5, 1988.

16 Gulf Canada Resources Ltd., Kulluk Relief Well Contingency Plan, 1990.

17 Joint Industry Program for Subsea Blowout Control Capability, Subsea Well Control Inc., October 1986.

18 Kuckes, A.F. et al An Electromagnetic Survey Method Directionally Drilling a Relief Well Into a Blowout Oil or Gas Well. Society of Petroleum Engineers Journal, pp. 269-274, June 1984.

19 Leonard, James, E., New Method Helps to Find Both Distance and Direction from Relief Well to Blowout. Oil and Gas Journal, May 12, 1982.

20 Maduro, W.P. et al Enchova Blowout: Record Relief Time SPE/IADC 18717: 1989 SPE/IADC DRI Drilling Conference, New Orleans February 28 to March 3, 1898.

21 Sumatra, K. Nugroho, B. Dynamic Killing Method as Applied to Well PSJ-4 Proceedings, Indonesia Petroleum Association, 14th Annual Convention, October 1985.

22 Voison, J. et al Deep Relief Well Parallels Capping Efforts. Petroleum Engineer International pp 28-33, March 1988.Joint Industry Program for Subsea Blowout Control Capability, Subsea Well Control Inc., October 1986.

23 Warren, Tommy, N., Directional Survey and Proximity Log Analysis of a Downhole Intersection. 56th Annual Technical Conference and Exhibition, San Antonio, Texas, October 7 to 7, 1981.

24 Warriner, Richard, A. and Cassity, T.G. Relief Well Requirements to Kill a High-Rate Gas Blowout from a Deepwater Reservoir. Journal of Petroleum Technology, December 1988.

25 West, C.L. et al. Successful ELREC Logging for Casing Proximity in an Offshore Louisiana Blowout. SPE 11996:58th Annual Technical Conference and Exhibition, San Francisco, October 5 to 8, 1983.

26 Westergaard, R.H., Subsea Dispersant Injection Option on Large Oil Blowouts, Offshore, February, 1990.

3.0 DRILLING SYSTEMS

3.1 Overview of Drilling Systems

Beaufort Sea drilling systems can be broadly classified into;

- Floating MODUs[1] (e.g. drillships)
- Bottom founded MODUs (e.g. the Molikpaq)
- Bottom founded fixed structures (e.g. artificial islands, ice islands)

Floating MODUs are designed to operate in the Beaufort in the summer, fall and early winter. Their operating efficiency depends primarily on ice conditions. Marine support is required for supply, ice management and anchor handling. Floating MODUs can provide relief well capability to any system providing the relief well can be completed within the operating limits of the particular MODU chosen for the relief well. One key operating limit is water depth; the drillships require 15 metres and the Kulluk requires 20 metres.

In the Beaufort there are two basic categories of floating MODUs;

- conventional drillships specially adapted for Arctic service and,
- the Kulluk, a specially constructed conical drilling unit designed for Arctic service.

Bottom Founded MODUs, as the name suggests, are designed to be set-down on the sea floor. Typically they are installed in the summer months and operate year-round. Sufficient drilling supplies are placed on board during the summer and minimal re-supply is required during drilling operations. The main restrictions to the use of a bottom founded MODU are its mobilization and installation requirements.

The main constraints on MODU mobilization and installation are related to; water depth, ice conditions, distance to travel, operating status, foundation strength, seabed preparation, and core fill requirements. At present there are three bottom founded MODUs in the Beaufort, namely;

- SSDC/MAT (operated by Canadian Marine Drilling)
- Molikpaq (operated by BeauDril)
- CIDS (operated by Global Marine)

The mobilization and installation requirements of each system are different and so must be evaluated on an individual basis.

3.1 Mobile Offshore Drilling Unit

Unlike MODUs, Bottom founded fixed structures cannot be moved with the drilling system aboard. These drilling platforms typically require the following steps;

- Construction
- Rig mobilization
- Drilling operations
- Rig demobilization
- Platform removal (by natural processes or actual removal)

Fixed structures used in the Arctic can be broadly categorized as;

- Caisson retained islands
- Artificial islands
- Ice islands

Both caisson and artificial islands rely on dredged material for their construction. Therefore their construction must be carried out during the summer season and typically requires several weeks. It is industry's present view that land filled islands, in most cases, are not practical for a relief well platform because of the construction time and the fact that more rapidly deployed systems are available in the summer months. For this reason, landfilled systems such as artificial islands and caisson retained islands will not be addressed herein.

Ice islands are constructed in the early to mid winter and drilling proceeds during the mid to late winter. The main requirement for ice island construction are cold temperatures. Once the island is constructed, the drill rig and ancillary facilities must be mobilized by ice road or by air lift.

Table 3.1 summarizes the present Beaufort drilling systems and their normal operating season. After a brief discussion of the operating environment each of these systems will be described in detail.

TABLE 3.1
BEAUFORT SEA DRILLING SYSTEMS

DRILLING SYSTEM	NORMAL OPERATING ENVIRONMENT	NORMAL OPERATING SEASON
Kulluk	Floating Mid to Deeper Waters	Break Up to Early Winter
Drillships		Open Water to Freeze-Up
Artificial Island	Bottom Founded Landfast Ice	Freeze-Up to Break-up[2]
Caisson Retained Island		Year-round
Molikpaq		Year-round
SSDC		Year-round
Ice Island		Winter
Molikpaq	Bottom Founded Transition Zone / Mobile Pack Ice	Year-round
SSDC		Year-round

3.2 The Operating Environment

The predominant concern with respect to relief well mobilization and operation is sea ice. Open water conditions in the Beaufort are relatively mild. Therefore, open water environmental factors such as sea states are not addressed herein. For purposes of this work the ice environment can be broadly classified into;

- The land-fast ice zone, where bottom-founded structures and ice islands are proposed as relief well systems.
- The pack ice zone, where floating systems are proposed as relief well systems (in the shallower areas of this region bottom founded structures may have application).
- The transition zone, which forms the boundary between the pack ice and the landfast ice, where both bottom founded and floating systems have application.
- The polar pack zone, which lies to the north of the pack ice zone, where none of the present drilling systems have application.

The purpose of this summary of environmental conditions is to provide the reader with some insight into the impact of these conditions on each of the proposed relief well systems. The summary presented herein does not begin to describe the data, analysis and experience gained over the past two decades of Beaufort operations. The reader is referred to the expansive literature on

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3.2 In shallow, protected waters artificial islands can be used year round. It is also possible to construct year round artificial islands for deeper waters but this is generally considered too expensive for an exploration well.

the subject for a more detailed appraisal of the environmental conditions imposed on Beaufort operations. None the less, it is hoped that this brief synopsis is sufficient to understand the significance of the environmental limitations imposed upon relief well operations.

Landfast Ice: First-year ice thickness in the Beaufort Sea is very site specific immediately after freeze-up and becomes more uniform with time. Near the shore, in the landfast ice zone, a 60 centimetre thickness of first year ice can be expected by early December. The average growth of first year ice is shown in Figure 3.1. The outer boundary of the landfast zone normally extends to about the 20 metre water depth contour and is characterised by frequent ridging caused by the interaction of the landfast ice with the more mobile pack ice.

Pack Ice Zone: The pack ice zone extends from the edge of the landfast ice to the polar pack. The boundaries of this zone change as the landfast ice grows and decays and as the polar pack advances and recedes. One major influence on this zone is the clockwise rotation of the Polar pack (the Beaufort Gyre). This rotation plus the protrusion of the Bathurst peninsula create a characteristic sub-region in the pack ice zone commonly referred to as the Bathurst Polynia (*Ref. 3.1*). It is within this sub-region that much of the recent Canadian Beaufort exploration drilling took place.

In the Bathurst Polynia open water recurs as a result of the periodic offshore drift of the pack ice during seasonal offshore winds from the south east or south west directions. New ice forms quickly in the open water, but it too is often moved offshore. As a result, even when ice covers this area, its thickness is typically significantly less than the landfast ice near the shore or within the pack. Data from upward looking sonar deployed at Tingmiark (also within the Bathurst Polynia), showed that level ice in that region did not reach 60 centimetres until after mid-January (Figure 3.1 & Table 3.2). As illustrated in Figure 3.1 ice thickness varies significantly through the Beaufort. Visual and near infrared imagery, from NOAA[3] satellites, usually shows warmer surface temperatures associated with open water and thinner ice, well into January.

3.3 the U.S. National Oceanographic and Atmospheric Agency

TABLE 3.2
ICE GROWTH RATES WITHIN THE BATHURST POLYNIA

GROWTH RATES - FIRST YEAR ICE		
THICKNESS	TINGMIARK	TIME*
22.5 cm	Dec. 17	-
40 cm	Dec. 30	13 days
60 cm	Jan. 17	31 days
80 cm	Feb. 5	50 days
90 cm	Feb. 14	59 days
100 cm	Feb. 23	69 days
110 cm	March 5	78 days
120 cm	March 15	88 days
NOTE: TIME refers to elapsed time from freeze-up		

Multi-year ice in the drilling area can be another source of interruptions. This is not a common occurrence especially after freeze-up when first year ice growth precludes additional encroachment of the polar pack into the drilling area. The attached graph (Figure 3.2) illustrates the probability of encroachment of multi-year ice into the South Kogyuk drilling area in the late season (November). The data are based on AES[4] weekly ice charts between 1979 and 1989. Interruptions to the drilling program would most commonly be caused by; heavy ice ridging, old ice incursion, or pressured ice, all of which are usually the result of prolonged periods of onshore winds. Winds at Tuktoyaktuk and Cape Parry, with speeds exceeding 10 knots and with any onshore component, occur only 16% of the time.

Estimates of the occurrence of ice pressure were obtained from wind speed, direction and duration information along with the regional ice concentration and thickness data. When the ice cover was greater than 30 cm in thickness and continuous to the landfast ice edge, and winds from the northerly quadrants exceeded 15 kts for two days, pressure was assumed to occur. Analysis of climatological wind data indicated pressure occurrences, on average, for 1/2 day per week when the ice was greater than 30 cm and continuous to the landfast ice edge.

Sources of Ice Information: The historical ice concentration and type information for this work was obtained primarily from weekly AES ice charts. These charts are available on a week-by-week basis, typically from mid June until late November or early December. The data is very much a regional, average representation of ice conditions since substantial variations occur over

3,4 Canada's Atmospheric Environmental Service shorter time and smaller space scales. Ten years of information were considered, 1980 to 1989, since the quality of some of the earlier data is questionable. In addition to the AES ice charts, NOAA satellite imagery, overflights, U.S. Navy ice charts, rig based observations and the data from field programs were reviewed to verify and extend the ice concentration and type information over the required period. Ice thickness data was inferred on the basis of ice type during the freeze-up period. For ice thickness estimation later into the season, a growth rate curve was determined from ice thickness data measured directly by upward looking sonar systems deployed at Tingmiark (Figure 3.3) and Nerlerk in 1978-79 and 1982-83, respectively. The average growth rates from the measurements were then applied to the ice beyond its "grey white" stage to estimate ice thickness for each week during the late season across the ten years of data.

For the winter ice thickness, the data sources were again the upward looking sonar data plus ice data from fixed platform locations (Table 3.3).

TABLE 3.3
WINTER ICE DATABASE

YEAR	LOCATION	WATER DEPTH	DATA SOURCE
1979	Tingmiark	29 m	upward looking sonar
1983	Nerlerk	58 m	upward looking sonar
1984	Kogyuk	26 m	rig based observations
1985	Tarsiut P-45	23 m	rig based observations
1986	Amauligak I-65	32 m	rig based observations
1988	Amauligak F-24	33 m	rig based observations

Ice Scour: Ice scour occurs when keels of large ice features scrape along the sea bottom. Glory holes[5] are utilized by floating MODUs in order to protect the wellhead and the subsea BOP[6] stack (should the location be vacated for the season on account of ice) from potential ice scour. The need for a glory hole is evaluated based on a site survey and ice scour assessment. Generally, if the original well did not require a glory hole, a relief well would not require a glory hole. If the original well utilized a glory hole where the probability of ice scour was evaluated to be relatively low, then the glory hole may be deleted from the relief well program in order to save drilling time. If the site survey indicates a high probability of ice scour, then a glory hole will be excavated.

3.5 A glory hole is an excavation in the seafloor into which the well head is placed for protection from ice scour.

3.6 Blow-Out Preventer

Visibility: Reduced visibility, as a result of fog, precipitation and darkness, generally reduces the efficiency of ice management. However, in the event of a relief well, complete ice reconnaissance would be provided. This would include SAR[7] overflights, helicopter and airplane overflights, icebreaker reconnaissance, radar and weather forecasting. The frequency of the reconnaissance would, in the case of a relief well, be as often as necessary and would not be limited by cost concerns. Therefore, although reduced visibility would have an effect on ice management, and an allowance has been made for this, its main effect would be to increase the cost rather than significantly decrease the efficiency of operation.

Drilling operations in the Beaufort Sea are not affected by darkness. The rigs are designed to be operated 24 hours per day and excellent lighting is provided in all working areas. A comparison of tripping times in dark and light conditions at various Kulluk locations revealed no significant difference in efficiency.

This brief overview of the environment will be referred to in the following description of each drilling system.

3.3 Floating Mobile Offshore Drilling Units (MODUs)

If a blowout is encountered on a well drilled by a floating MODU, it is unlikely that the MODU would be damaged beyond use for the relief well. Floating drilling equipment allows for emergency evacuation from a location in less than one hour through remote anchor release and winch off capability. Generally, blowouts are not instantaneous events but are preceded by a succession of increasingly complex events during which location evacuation may occur. As noted before, in most circumstances, the original drilling system would be able to drill its own relief well.

The following sections describe the floating MODUs available, their operating season, and all phases of vessel preparation required prior to spudding a relief well.

3.3.1 Kulluk (see Appendix A)

System Description
The Kulluk is a second generation floating drilling system that was purpose built to drill in the ice infested waters of the Beaufort Sea. This unit is equipped with state of the art drilling

3.7 Synthetic Aperture Radar - which "sees" thorough cloud cover and darkness.

equipment and has the capacity to carry consumables for a complete well. The Kulluk can operate in water depths ranging from 20m to 100 m.

The vessel has a unique twenty-four faceted circular hull which, combined with its radially symmetrical mooring, provides an omni-directional capability to resist ice and storm forces. The Kulluk's inverted conical hull form fails the oncoming ice in flexure at low force levels while the outward flare near the bottom of the hull ensures that broken ice pieces clear around it and do not enter the moonpool or become entangled in the mooring lines. This efficient ice breaking and clearing of the Kulluk's hull minimizes the tensions in the unit's mooring lines along with the vessel's response motions in ice.

The Kulluk's mooring system provides resistance to environmental forces and is comprised of twelve radially deployed anchor wires. An important feature is the through hull path of the mooring lines and the underwater fairleads which, combined with the unit's hull form, eliminates the threat of ice fouling the lines.

The Kulluk is designed for continued drilling operations in the wind and waves associated with one-year return period Beaufort Sea storms and to maintain location and survive 100 year return period events. In terms of the ice, the Kulluk is designed to operate in level, unbroken first year ice up to 1.2m in thickness. The vessel is built to Arctic Class[8] IV specifications and as such, has a normal design operating season from June 1st until January 31st.

The operating and survival capabilities of the Kulluk in ice are enhanced by the ice management support provided by BeauDril's four Class IV ice-breaking vessels[9]. These icebreakers fragment thicker ice within the general ice cover along with more extreme features such as pressure ridges and old ice floes. This ice management support reduces the ice forces on the Kulluk's mooring system and allows drilling operations to proceed in more severe ice environments. In level, 1.2m thick ice BeauDril's 24,000 and 14,900 HP icebreakers proceed continuously at speeds of seven knots and four knots respectively. In addition to ice management, these support vessels carry out supply, anchor handling and towing operations.

Operating Experience

Since entering the Beaufort Sea in August 1983, the Kulluk system has drilled nine wells in water depths ranging from 25 to 60 m. During drilling operations, the Kulluk has been exposed to a wide range of ice conditions and has developed ice management techniques and procedures for safe and efficient operations.

3.8 Arctic Class - is a Canadian Coast Guard classification system which rates icebreakers.

3.9 At present, one of the four icebreakers is working in the North Sea.

The conditions in which the Kulluk has operated can be subdivided into three characteristic ice scenarios;

- spring break-up with thick moving first year ice and some old ice,
- summer open water with first year and old ice intrusions, and
- freeze-up/early winter with a growing first year ice cover and some old ice.

The Kulluk has experienced very little downtime in these conditions and has commenced drilling operations as early as June 1st and continued working as late as December 11th. The reason that the Kulluk has not drilled later than December 11th are;

- drilling into potential hydrocarbon zones was not allowed at this time of year due to relief well contingency concerns,
- all non-risk work had been completed, and
- economics.

Ice management has been a key element to the success of the Kulluk's station-keeping in thick first year ice, large pressure ridges and old ice intrusions. In rare cases, large, thick first year and old ice floes moving rapidly towards Kulluk were not manageable and the Kulluk was temporarily moved off location to allow the ice to safely pass by. Occasionally, early winter or continuous pack ice situations involving convergence of the ice cover and associated ice pressure has also required the Kulluk to suspend operations.

During five full operating seasons, 1984 to 1989[10], the Kulluk experienced 44.7 down days and 7 moves off location out of a total of 585 operating days, an operating efficiency rate of 92%. This extensive experience in various operating environments is the basis for estimating the Kulluk's operating efficiency during relief well drilling.

In a relief well situation the Kulluk must first be mobilized to the site. During Kulluk operations in the Beaufort Sea, the unit has been towed in a wide variety of ice conditions. In ice, tow speeds vary from roughly one to four knots depending upon ice concentrations, roughness and type. Three support vessels, one for towing and two for ice management are generally required. Occasionally, in continuous ice conditions, convergence of the ice cover has resulted in ice pressure and some towing stoppages. In open water and very low ice concentrations, tow speeds of 5 to 6 knots can be achieved with only one tow vessel. To date, tows ranging from a few tens of kilometres to several hundred kilometres have been carried out with no significant delays. The earliest tow that has been conducted was in late May and the latest in late December.

3.10 Although the Kulluk arrived in 1983 it was a partial season and so is not counted. No operations were carried out in 1987 and so 1987 is not counted either.

Deployment Timing
The time to deploy the Kulluk as a relief well system depends to a large extent upon the activity of the Kulluk at the time of need. Two basic situations are likely;

- the Kulluk is actively drilling; in which case it must suspend its current operations, or
- the Kulluk is stacked for seasonal shutdown; in which case it must be started up in a "cold" condition.

Each of these two situations pose different time requirements to mobilize the Kulluk to the relief well site. In addition to start-up or site suspension, as the case might be, the Kulluk would also have to be towed to the relief well site, moored and a glory hole excavated (if required).

Site Suspension: In the case where the Kulluk was engaged at a location and needed to be mobilized for a relief well operation, a period of time would be required to suspend its current operations prior to departing for the blowout.

The specific operations involved in suspending a well would depend on the status of the well and drilling operations at the time but typically would include:

- Setting open hole cement plugs; on bottom, across hydrocarbon bearing zones and at the last casing shoe.
- Setting a bridge plug(s) above the last cement plug and possibly setting cement on top of that plug.
- Displacing the fluids in the hole with a freeze point depressed fluid.
- Pulling and laying down the riser and LMRP[11]. The BOP would most likely be left, as the Kulluk has a second BOP available.
- Pull anchors and prepare for tow to the relief well location.

The time required to carry out each of these operations would vary depending on the wellbore configuration but typically this group of operations would take 2 or 3 days to accomplish. Since the Kulluk was active in this scenario, the towing and support vessels would also be active and ready for service.

Cold Start-up: If the Kulluk was "cold" when required to drill a relief well, then it would have to be started up before drilling could take place. Depending on the duration of the tow and the readiness of the towing vessels many of these start-up operations would be carried out while underway. Since in this case the Kulluk is "cold" it is reasonable to assume that the towing and support vessels would also be "cold" and require start-up.

Figures 3.4 and 3.5 are start-up schedules prepared by BeauDril Marine Engineering personnel familiar with the Kulluk and her support vessels. Figure 3.4 shows the activities of a typical

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3.11 Lower Marine Riser Package

Kulluk start-up. These activities include certification and non-critical maintenance which would not be carried out in an emergency. Figure 3.4 also shows the "fast track" emergency start-up schedule while Figure 3.5 shows the "fast track" emergency start-up of the support vessels.

For relief well contingency planning the Kulluk "cold" start-up is estimated to take 8 days, and after 3 days the rig would be ready to be towed. The support vessels would be ready to commence operations within 6 days of notification. Past experience with accelerated start-up schedules demonstrates that these times are achievable. For example, the M.V. Ikaluk[12] was made ready for her transit to the North Sea in 6 days (from October 1 to 6, 1990).

Towing: The tow would proceed once the Kulluk and her towing vessels were ready. In normal open water or light broken ice conditions the Kulluk can be towed at 6 knots, however ice or large sea states can slow progress considerably. Ice conditions which are between 0.5 & 1.2 metres thick would limit the towing speed to between 1 to 2 knots. For example, if moored in Herschel Basin the time required to break the Kulluk out of Thetis Bay would range from 1 to 3 days in December/January and 8 to 14 days in March/April.

Materials Supply: Some basic consumables and equipment will be necessary prior to spud. Depending upon the previous location and status of the relief well vessel, it may be necessary to allow some time for loading this equipment. In view of the fact that these items are readily available to spud a relief well (see Section 5) one day is sufficient for this operation, if required.

Mooring Time: Once on site the Kulluk must be anchored to the seafloor. Over 30 anchors are typically available in the BeauDril system for use with the Kulluk. An adequate number are normally carried at the location to facilitate operations with some back-up, and the remainder are left at a nearby storage site. Also available are two complete Remote Anchor Release (RAR) systems (24 units). This provides 100% back-up and alleviates the need for recovery and refurbishment of any RAR's prior to re-anchoring.

Anchoring is comprised of several basic operations, shared between the Kulluk and the vessels. These include having the rig pick up and prepare the wires, the vessels pick up and dress the anchors, the vessels laying the anchors, and the rig pretensioning each anchor. The preparation work can be accomplished concurrently. That is, the Kulluk can pick up wires while the vessels are picking up and preparing anchors. Anchors may come from storage, or the previous location whichever is more efficient.

Knowledge of the seabed conditions is an important factor in determining anchoring time. In a relief well situation the seabed conditions will be known from the original well operations and site

3.12 The M.V. Ikaluk is a 14,900 BHP ice breaking supply vessel.

surveys. This information would lead to a measurable improvement in mooring speed. The following anchoring statistics from previous Kulluk locations demonstrate the mooring time improvements when anchoring up at a location for the second time.

- Average time of first mooring operation: 1.50 days
- Average time of repeated mooring operation: 0.75 days

These times represent a normal working situation where cost considerations may not allow the optimum number of support vessels. During a relief well operation cost considerations would not restrict the number of support vessels and so actual mooring times shorter than these average times are likely. For purposes of relief well contingency planning a mooring time allowance of 1 day is reasonable and conservative.

Glory Hole Time: Depending on the location and the potential for ice scour, there may be a need for a glory hole to protect the wellhead and BOP. The Kulluk carries on board a 7.3m diameter bit, operated by seawater hydraulics. The bit is used to excavate a 12m deep glory hole into the seafloor and can leave a steel caisson in the hole, if needed. This operation typically requires 2 days to complete.

Operating Efficiency

Past experience has established the towing and station-keeping capabilities of the Kulluk system for both the "late season" period and in a range of ice conditions representative of winter conditions. The Kulluk has not operated through the winter period nor in some of the conditions characterizing year-to-year variations in the late season ice environment. Accordingly, certain assumptions regarding ice management effectiveness, vessel performance limitations, and the ice environment have been made to quantitatively evaluate the Kulluk's expected performance.

The general methodology used to assess the Kulluk's relief well operating season is summarized in Figure 3.6. First, the system's performance limitations are defined for specific environmental factors in terms of the expected number of downdays per week. Concurrently, the ice conditions are identified on a weekly basis over a number of years from historical data for the location under consideration. By comparing the Kulluk's expected performance limitations with the week-by-week ice information, expected downtime on a weekly basis is generated over a number of years which, in turn, provides statistics on the expected number of available operating days within a season. Additionally, the end of season can be statistically identified as the time when the environmental conditions consistently exceed the capability of the drilling system. Within this methodology, the year-to-year variations in ice conditions that are known to occur are realistically addressed.

The performance limitations for the Kulluk system that have been used in this relief well drilling assessment are defined in Table 3.4. These criteria assume that the Kulluk is supported by four Arctic Class IV icebreakers for ice management on an as required basis.

TABLE 3.4
KULLUK SYSTEM PERFORMANCE CRITERIA IN ICE

CRITERIA	DOWNDAYS/WEEK
First Year Ice Thickness	
0-80 cm	0.0
30-70 cm (pressured*)	0.5
80-90 cm	1.0
90-100 cm	2.0
100-110 cm	3.5
110-120 cm	3.5
Old Ice Concentration	
0 to 3 tenths	0.0
3 to 5 tenths	3.5
5 to 10 tenths	7.0
Visibility	
Nov. 15th to Jan. 15th	0.5

* onshore winds > 15 kt for 2 days with complete ice cover

The key objective of ice management is to enhance the ability of the Kulluk to maintain station in ice conditions which, in the cases considered here, become increasingly more difficult with time. The performance criteria shown in Table 3.4 are approximate but reasonable given the Kulluk's operating experience and the level of ice management support assumed. Additional icebreakers could be used but would not significantly enhance the Kulluk's station-keeping ability. It must be emphasized that the relief well operation cannot be compared to a normal drilling operation where cost considerations may stop operations once they become inefficient. In a relief well operation the Kulluk may have to work inefficiently, moving off location and reconnecting frequently because of severe conditions. This is particulary true in the winter relief well drilling case. It is assumed that the relief well operation would be provided with a full range of environmental monitoring and forecasting services to identify potentially hazardous ice situations. It is also assumed that an appropriate alert system would be in place to ensure safe operations.

As indicated by the criteria, downtime and moves off location are expected and time allocations for waiting on ice along with re-anchoring are included within the downtime estimates. One half a day per week downtime has also been included to allow for visibility/detection of ice hazards during the November 15th to January 15th "polar night" period.

These criteria and the general methodology have been applied at the North Amauligak location for two example situations;

- late season operations (November through January), and
- winter operations (February through May).

The assumptions made regarding the Kulluk's performance limitations and the ice environment in these examples are realistic and thus the expected number of operating days within these seasons are representative of the Kulluk's capability as a relief well unit.

Late Season Relief Well Scenario at North Amauligak

Using the methodology outlined above, the expected performance of the Kulluk was evaluated by combining the defined station-keeping criteria with historical ice information (see Sub-section 3.2) on a yearly basis. The late season time frame that was considered here began on September 25th and ended on January 31st. This assumes a late September blowout but is only one of many scenarios that could be evaluated. The results of the assessment are summarized in Figures 3.7 and 3.8, and Table 3.5

Figure 3.7 shows the probability of achieving a given number of relief well drilling days with the Kulluk over the 129 available days from September 25th through January 31st. This analysis yields an extremely high probability of successfully drilling a late season relief well with the Kulluk; since in one of every two years 105 drilling days are expected (50% probability level), and in every nine of ten years 91 drilling days are expected (90% probability level). These estimates are significantly longer than the relief well drilling time requirements outlined in Section 4. Figure 3.8 shows the cumulative number of operating days with time over the late season period for the most severe year, 1983, and the best year, 1980. Table 3.5 gives the expected number of operating days and the downtime on a year-by-year basis from 1980 to 1989. Most of the downtime during the late September to late November period is associated with old ice intrusions while downtime in the December and January periods reflects increasingly severe first year ice conditions. Table 3.5 also provides a break down of the average percentage downtime by month. The monthly year-to-year variability in the Kulluk's relief well drilling efficiency is also shown in Table 3.5. Difficult ice conditions, such as those experienced in the early fall of 1983, can result in significant downtime whereas favourable ice conditions, such as those in January of 1985, result in highly efficient drilling operations even in the early winter.

TABLE 3.5
DOWNTIME DAYS AT NORTH AMAULIGAK (Late Season)

YEAR	SEPT. 25 TO OCT. 31	NOV. 1 TO NOV. 30	DEC. 1 TO DEC. 31	JAN.1 TO JAN. 31	TOTAL
1980	0.0	1.0	6.5	6.5	14.0
1981	0.0	1.5	7.0	7.0	15.5
1982	0.0	2.0	8.0	13.5	23.5
1983	21.0	4.0	3.5	10.0	38.5
1984	0.5	8.5	6.0	6.0	21.0
1985	17.0	2.5	1.0	4.0	24.5
1986	0.0	8.0	8.0	8.0	24.0
1987	0.0	2.0	12.0	12.0	26.0
1988	0.5	3.0	8.0	13.0	24.5
1989	0.0	4.5	7.0	13.0	24.5
Average	3.9	3.7	6.7	9.3	23.6
% Average	10.5%	12.3%	21.6%	30.0%	15.6%

In terms of the overall results of this assessment, it is clear that the Kulluk system provides reliable same season relief well drilling capability for late season operations in the mid to deeper waters of the Canadian Beaufort Sea. The definition of end of operating season for the Kulluk is not relevant in the context of this "late season" relief well scenario since the Kulluk system can operate throughout the freeze-up and early winter period. Clearly, downtime increases if operations are required in late December and January but the ice conditions do not preclude Kulluk station-keeping.

Winter Season Relief Well Scenario at North Amauligak

The same approach was used to evaluate the expected number of Kulluk operating days for the winter relief well drilling scenario. However, reliable time sequential ice information for the winter period is much more limited than that available in the late season time frame. Using the Kulluk station-keeping criteria outlined in Table 3.6 and six years of winter ice data as described in Sub-section 3.2, the Kulluk's expected number of operating days for a winter relief well drilling scenario was assessed. The winter time frame considered here began on February 1st and ended on May 31st. The results of this evaluation are given in Figure 3.9 and Table 3.6.

Figure 3.9 shows the probability of achieving a given number of relief well drilling days with the Kulluk over the 130 days available from February 1st to May 31st. Clearly, the Kulluk experiences significant downtime but has a reasonable chance of drilling a relief well.

In concept, the Kulluk operates throughout the winter in a discontinuous mode, suspending operations when severe conditions occur and, working when more mild "environmental windows" are experienced at the relief well location. The average number of drilling days expected between February 1st and May 31st is 61 and the median value (one in every two years) is 56 days. In a mild winter such as 1985, up to 86 days of operating time would be available and in a more severe year such as 1984, only 50 days drilling would be achieved within the 120 day winter drilling scenario. Average percentage downtime are also shown in Table 3.6. In an average sense, the Kulluk is down for about 50% of the time from February 1st to May 31st with April being the month with the highest average ice constraint. The year-to-year variability in expected operating days per month is significant as shown in the Table.

TABLE 3.6
EXPECTED OPERATING DAYS AT NORTH AMAULIGAK (Winter)

YEAR	FEBRUARY	MARCH	APRIL	MAY	TOTAL
1979	23	15	0	28	66
1983	15	30	3	8.5	57
1984	16	10	10	14	50
1985	26	17	30	15	88
1986	16	2	16	20	54
1988	10.5	16	5	23	55
Average	17.5	15	10.7	18.0	62
% Average	63%	50%	36%	58%	52%

3.3.2 Drillships (see Appendix B)

System Description

Currently there are three drillships in the Beaufort Sea, the Canmar Explorer, Explorer II, and Explorer III. All of these vessels are conventional drillships specially adapted [13] for Arctic service. They are self propelled and have a conventional ship shape.

Two of the ice strengthened drillships are capable of drilling in water depths from 15 to 200 metres and the third can operate in water depths from 20 to 300 metres. All of the drillships have a 6,000 metre drilling capability and are capable of carrying large volumes of bulk material and fuel in order to minimize resupply requirements.

Appendix B contains more detailed information with respect to drillship specifications.

Operating Experience:

Canadian Marine Drilling Ltd. (Canmar) has used a fleet of up to four ice strengthened drillships to conduct drilling operations since 1976. A total of 39 wells have been completed in the Beaufort and Chukchi Seas to an average depth exceeding 3000 metres. During this period, in compliance with government regulations, drillship operations have generally been completed prior to the onset of hazardous ice conditions at the well sites.

The fleet utilized in a typical well program usually consists of one of Canmar's ice strengthened drillships supported by a combination of icebreakers and ice breaking supply vessels. The actual vessels utilized are tailored to specific well programs to ensure safe and efficient operations. A typical fleet for the Beaufort Sea consists of the following:

- Canmar Explorer Class ice strengthened drillship
- Class III or Class IV icebreaker
- Class II ice breaking supply vessel
- Class IA ice strengthened supply vessel

As the drillships are self propelled vessels with a conventional shaped ice strengthened hull they can, with icebreaker support, manoeuvre to a well site through ice conditions that are heavier than those which can be tolerated during normal drilling operations. This generally allows the drilling fleet to be mobilized to the drill site before local ice conditions allow drilling operations to proceed.

3.13 Their hull strength, mooring arrangements, consumables storage, and rig arrangement have all been extensively modified for Arctic conditions.

Drillships are normally able to start drilling after break-up in ice concentrations of 4/10 of thick first year ice. The fleet, consisting of those vessels noted above, can continue to operate in 30 centimetres of total cover of new ice at freeze-up. In a few circumstances, where there was no risk to the environment, drillship operations were continued into heavier ice conditions. In 1979 for example, in a demonstration of late season capability, the drillship Canmar Explorer IV operated until November 28 at the Kopanoar well site. The drillship was supported by one Class IV icebreaker (Kigoriak), four Class II supply boats and three small ice strengthened boats for resupply. The drillship operated successfully in up to 40 centimetres of ice.

In 1978, the Canmar Explorer II operated until November 5 in first year ice over 30 centimetres thick. At this time, it was supported by the CCG[14] Class II icebreaker John A. MacDonald and two Class II ice breaking supply boats. In a number of other cases, such as those outlined in the table below, normal drilling operations were conducted during the late season in significant ice conditions. In each of these cases, the available ice breaker support was significantly lower than that utilized during the 1979 demonstration. With the exception of the 1978 case, maximum available ice support consisted of the Class IV Kigoriak, four Class II ice breaking supply vessels and several ice strengthened supply vessels. The support vessels were often being shared among a number of drillships which were operating concurrently.

From the time of it's early efforts in 1976, Canmar has made continuous progress in terms of;

- the experience of it's personnel,
- the suitability of its equipment,
- ice management techniques and equipment, and
- well control and alert procedures.

As a result of considerable operating experience in the Beaufort and Chukchi Seas, a significant historical database has been developed on the use of drillships in Arctic waters.

3.14 CCG - Canadian Coast Guard

TABLE 3.7
SIGNIFICANT LATE SEASON ICE CONDITIONS AT CANMAR WELL SITES

YEAR	WELL SITE	ICE CONDITIONS	DATE
1978	Kaglulik	30 to 70 cm 1st year ice	Nov. 05
1979	Kopanoar	40 to 50 cm 1st year ice	Nov. 28
1979	Koakoak	1st year ice*	Nov. 11
1980	Orvilruk	5/10 old ice	Sep. 16
1980	Kopanoar	5/10 old ice	Sep. 21
1981	Kopanoar	15 to 30 cm grey white Ice	Oct. 28
1981	Koakoak	15 to 30 cm grey white Ice	Oct. 31
1981	Irkaluk	15 to 30 cm grey white Ice	Oct. 22
1982	Natiak	15 to 30 cm grey white ice	Oct. 21
1982	Orvilruk	15 to 30 cm grey white ice	Oct. 25
1982	Aiverk	30 to 70 cm first year ice	Nov. 13
1983	Arluk	3/10 old ice	Sep.19
1983	Siuluk	4/10 old ice	Sep. 20
1983	Aiverk	6/10 old ice	Sep. 25
1983	Havik	2/10 old plus new ice*	Sep. 29
1984	Arluk	15 to 30 cm grey white ice	Oct. 23
1985	Arluk	2/10 old ice in grey white ice*	Arluk
1985	Havik	4/10 old ice in new ice*	Sep. 30

* variable thickness

Deployment Timing
Mobilization time would depend on the operating status of the drillship at time of need. As with the Kulluk, there are basically two eventualities;

- either the drillship is active, in which case site suspension is required, or
- it is stacked and "cold" start-up is required.

In both cases the drillship would also require transit to relief well site, mooring and glory hole preparation.

Site Suspension: In the case where an active drill ship was required for relief well operations, a period of time would be required to suspend operations at that site prior to departing for the blowout site. The operations involved in suspending a well would depend on the well and drilling status at the time of suspension but typical operations involve;

- Setting open hole cement plugs; on bottom, across hydrocarbon bearing zones and at the last casing shoe.
- Setting a bridge plug above the last cement plug.
- Displacing the hole to freeze depressed inhibited fluid.
- Pulling the BOP stack, and laying down the riser.
- Pull anchors and prepare for transit.

The time required to carry out each of these operations would vary depending on the wellbore configuration, but these operations would generally require 2 to 3 days.

Cold Start-up: If a drillship is stacked for a seasonal shut down, then crews would need to be mobilized and the rig started-up. The emergency start-up time for a drillship is about 12 days (see Figure 3.10). This is slightly longer than the Kulluk start-up because of the different drilling systems and the additional start-up requirements for the propulsion systems of a drillship. Of the 12 start-up days, 2 could be concurrent with the transit to site.

Transit Time: For drillships, the transit rates will be largely dependent on environmental conditions. Wind, sea state and ice conditions can greatly reduce the transit speed. The open water transit rates of the Canmar drill ships are summarized in the following table;

TABLE 3.8
DRILLSHIP OPEN WATER SPEEDS

VESSEL	PROPULSION	OPEN WATER SPEED
Explorer	Self Propelled	8 knots
Explorer II	Self Propelled	8 knots
Explorer III	Self Propelled	12 knots

With the relatively short mobilization distances involved in the Beaufort Sea, transit rates will have a minor impact on relief well mobilization and drilling schedules. If the drillship is in the Canadian Beaufort Sea, a reasonable time allowance for transit is about 2.5 days. If in the Chukchi Sea, a drillship would take about 5 days to mobilize providing the Point Barrow route was not impassable. The Point Barrow transit window normally extends from late July to late October for a drillship with icebreaker support.

Mooring Time: Mooring and anchoring times would depend upon; amount of support, environmental conditions and seabed conditions at the well site. Throughout most of the Beaufort Sea, single anchors are sufficient to provide station keeping ability. Occasionally, in areas where the bottom is very hard and an anchor has difficulty biting into the seafloor, or if the seabed materials are very soft, "piggy back" (tandem anchors) are required. Since the site's bottom conditions would be established by the site surveys and experience of the original well the required anchoring system would be prepared in advance. -

The Canmar drillships generally set eight 6.5 tonne anchors prior to spudding. Running times are approximately one hour per anchor and one and one half hour per anchor in the case of piggy back anchors. Including time for soaking and pretensioning the total anchoring time would be less than 12 hours, provided two supply vessels are available to set anchors. Figure 3.11 provides the historic average anchor running times for the Canmar Fleet.

Glory Hole Time: The drillships utilize a 6.2m diameter bit to drill glory holes to a depth of approximately 9 m. Completion of a glory hole typically requires 2 days. Figure 3.12 shows historic average glory hole drilling times.

Operating Efficiency

Past experience demonstrates that drillships, supported with ice management, could be used on an extended season basis in order to drill a relief well. Under normal operating circumstances the cost of the ice management may make extended drilling uneconomic, but in an emergency situation these costs would be inconsequential.

The extended season operational efficiency of a drillship has to be based on past experience and current technology. Canmar personnel have made realistic assessments of the effect of enhanced ice management capacity under emergency conditions. Experience with ice management under a number of conditions, such as those listed above, forms the basis of this prediction of late season relief well capability. The optimum level of ice management for a Canmar drillship in a late season relief well scenario, would consist of four Class III or IV icebreakers and one or two Class II ice breaking supply boats. With this level of support, drillships are expected to operate safely, in up to 60 centimetres of new level ice, with no additional changes to Canmar's proven operating procedures.

Drillship Performance: The well sites which would be appropriate for drillship relief well contingency are located within the Bathurst Polynia (see Sub-section 3.2 for description of ice conditions). The first year ice thicknesses in this region would not normally exceed 60 cms until mid January. As a result, experience indicates that significant progress on a relief well from a drillship would be possible in this region until late December given the level of ice management support described above and more or less normal ice conditions. Table 3.9 refers to a late season relief well operating scenario and is estimated from Canmar's experience with management of new ice using various levels of ice support in the late season. The effective drilling days listed include the effects of ice ridges and rubble fields, high ice speeds, ice confinement by onshore winds (pressured ice) and reduced visibility.

TABLE 3.9
NEW ICE THICKNESS vs DRILLSHIP EFFICIENCY

NEW ICE THICKNESS	EFFECTIVE DAYS PER WEEK
0 cm	7
10 cm	7
20 cm	7
30 cm	6
40 cm	5
50 cm	4
60 cm	3
70+ cm	0

Temporary interruptions to drilling operations during late season operation are expected at times when areas of ice rubble, piled into ridges are encountered. These ridges form naturally during ice motions. In addition, man-made ice rubble fields are created by ice management around a drilling location. These refrozen rubble fields can re-enter the drilling area as a result of a reversal of the ice drift direction, and can also interrupt drilling operations. Table 3.10 is an estimate of drillship efficiency in old ice assuming a late season relief well operation. It includes the effects of floe speed, ice thickness and consolidation, floe size, and obstructions to visibility.

TABLE 3.10
OLD ICE CONCENTRATION vs DRILLSHIP EFFICIENCY

OLD ICE CONCENTRATION	EFFECTIVE DAYS PER WEEK
0 tenths	7
1 tenths	-6
2 tenths	5
3 tenths	4
4 tenths	3
5+ tenths	0

Drillship Performance Hindcasts: The number of effective drillship operating days per week, with four Class III or IV icebreakers and two Class II supply boats, was estimated from ice conditions for each week over the past ten years. The effective drilling days were averaged by week for the entire 10 year interval. The results are shown in the attached Figure 3.13. The figure indicates that an average of 6.9 drilling days per week can be expected through September, this falls to 6.3 days per week in October, 5.6 days per week in November, and 5.2 days per week in December. Drillship effectiveness falls dramatically over January, from an average of 5 days per week at the beginning of the month to near zero at the end.

Two other figures (Figure 3.14 & Figure 3.15) show the annual variations in available relief well drilling days at South Kogyuk. The figures are based on the same assumptions of performance in ice that are outlined above. Figure 3.16 shows the cumulated effective relief well drilling days beginning on September 25 for each year, over a ten year interval between 1980/81 and 1989/90.

The above analyses indicates that drillships provide a viable late season relief well capability and provide "same season" relief well capability until approximately the end of December.

3.4 Bottom Founded Mobile Offshore Drilling Units (MODUs)

3.4.1 SSDC/MAT

System Description (see Appendix C)
The SSDC was the first completely self-contained, bottom-founded, mobile offshore drilling unit in the Arctic. One of its key design features was the ability to achieve the required ice resistance with water ballast only. Previous Arctic structures had relied on sand fill to provide the weight required to resist ice loading. With only water ballast the SSDC/MAT is easily and quickly removed from one site and installed at a new site. The entire ballasting and control system is on board.

The SSDC drilled through the winters of 1982/83 and 1983/84 at two different locations in approximately 30 metres of water. To work in these water depths the SSDC required sand berms about 20 metres in height. In 1985 design work was carried out on a MAT system which would underlie the SSDC to allow direct placement on the seabed in up to 24 metres of water, thus eliminating the need for a berm. Furthermore the additional buoyancy provided by the MAT reduced the minimum draft of the SSDC allowing it to work in water depths as shallow as 8 metres.

In 1986 the MAT was constructed, mobilized to the Beaufort and mated to the SSDC. The combined SSDC/MAT system covers a water depth range of 8 to 24 metres. The structural design and construction configuration of the MAT allows the SSDC/MAT to be ballasted down on virtually any seafloor without any dredging or other sea bottom preparation.

The SSDC/MAT has been constructed and ice-strengthened in order to withstand the ice loads imposed on the structure by first year and multi-year ice. The combination of the large base area of the MAT, the integral skirt system on the base, and the strength of the total unit alleviates the need for an external ice barrier or berm surrounding the unit. This allows uninterrupted year-round drilling in all conditions expected in the U.S. and Canadian Beaufort Sea, within its operating water depth range.

The following information summarizes the design and capabilities of the SSDC/MAT; more detailed information on the SSDC/MAT is provided in Appendix C.

The ice design load used for the structural design of the SSDC/MAT is 680 tonnes per metre along the length of the unit giving a total design load of 110,000 tonnes. These design loads are representative of a large, 8 metre thick, cold, multi-year ice floe impacting the structure. The load determination is based on full scale measurements, experience with other structures, and ice mechanics. To determine the structural loading these loads were factored according to the appropriate provisions of the DNV and ABS[15] guidelines for the design of offshore structures.

The SSDC/MAT has a base area of 17,840 square metres. This very large base area, together with a 2-metre high skirt system, enable the unit to generate a substantial resistance in a wide range of soil conditions without site preparation. The design of the SSDC/MAT allows setdown of the unit on a wide range of seabed topographies and soil strengths. Setdown can be achieved without modification at most locations in its applicable water depth range with the provision that a small lateral shift may be required to miss rocks or other local prominence on the seafloor.

Ice alert procedures are normal on Arctic fixed platforms and the SSDC has a complete environmental monitoring system. In addition to the monitoring system an alert and evacuation procedure is in place in case of an emergency.

Operating Experience

The SSDC/MAT successfully completed its first well in the U.S. Beaufort Sea at the Phoenix location during the winter of 1986/1987. The unit was relocated in September, 1987 to the Aurora location, also in the U.S. Beaufort Sea. Following completion of the Aurora well, the SSDC/MAT was demobilized to Herschel Island in the Canadian Beaufort Sea. The unit is now operating at the Fireweed location west of Prudhoe Bay.

The following table lists the pertinent projects involving the SSDC and the SSDC/MAT:

TABLE 3.11
SSDC & SSDC/MAT DRILLING LOCATIONS

WELL NAME	LOCATION	OPERATING DATES
Uviluk	Cnd. Beaufort	Oct. 1982 - Oct. 1983
Kogyuk	Cnd. Beaufort	Oct. 1983 - Sep. 1984
Phoenix	U.S. Beaufort	Sep. 1986 - Aug. 1987
Aurora	U.S. Beaufort	Sep. 1987 - Sep. 1988
Fireweed	U.S. Beaufort	Sep. 1990 - Present

Once installed the SSDC can normally operate with 100% efficiency year-round. No stoppages for ice or weather would be expected. The most critical factor in using the SSDC/MAT as a relief well system is its mobilization ability. As evident in the above table the SSDC is typically moved

3.15 DNV - Det Norske Veritas, ABS - American Bureau of Shipping; these are international bodies which determine rules and guidelines for the design, fabrication and installation of offshore structures.

in the August to October time period when relatively open water can be expected. However the SSDC has been moved in substantial ice conditions. For example, in September 1987 the SSDC/MAT was relocated a distance of 172 nautical miles from Harrison Bay to a site just east of Barter Island; the schedule was as follows;

• Deballasting	2 days	Sep. 6 to Sep. 8
• Towing	5 days	Sep. 8 to Sep. 13
• Installation	1 day	Sep. 13 -

Average tow speed over the complete move was 1.5 knots despite the occurrence of multi-year ice conditions that exceed 6/10ths over portions of the route. With respect to set-down, the most difficult ice conditions occurred during the original mating of the SSDC to the MAT. This exacting operation was carried out in multi-year ice concentrations of 8/10ths. The set-down procedures have been optimized through experience and engineering so that ice conditions at the site would not be the limiting factor. If it is possible to move the SSDC/MAT to the site then it can be setdown.

Based on the experience gained in past mobilizations, it is reasonable and conservative to mobilize the SSDC/MAT within a July 1 to December 1 time frame. November and December mobilizations would require increasingly greater icebreaker support than normal but under emergency conditions this support would be available. Mobilization could take place much later than December 1 depending on specific ice conditions along the route. With suitable icebreaker support it is feasible that the SSDC could be moved as late as February 1, especially if the entire route was within the pack ice zone where ice thicknesses are less (than the landfast area). If mobilization from Mckinley Bay was required then the most difficult section of the route would be out of McKinley Bay and through the first year ridges along the boundary of the pack ice zone. For situations in which significant ice is present the towing fleet would need to be supported by substantial icebreaker support, i.e. 3 or 4 Class IV icebreakers.

Deployment Timing

In the case where the SSDC/MAT was required for relief well operations while active at another well site, a period of time would be required to suspend operations at that site prior to departing for the blowout site, otherwise the SSDC/MAT would have to be mobilized from a "cold" stacked condition.

Site Suspension: The operations involved in suspending a well would vary depending on both the stage the well was at and the wellhead system in use. The SSDC normally operates with either a mudline suspension type wellhead system or a Texas deck style wellhead system where all the casing strings are landed in the moon pool. In either case, suspension of the hole itself would be carried out in the manner similar to that for the floating systems;

- Set open hole cement plugs; on bottom, across hydrocarbon bearing zones and at the last casing shoe.
- Set a bridge plug above the last cement plug.
- Displace the fluids in the hole with a freeze point depressed inhibiting fluid.

Following suspension of the hole in a mudline suspension case, the BOP stack and casing bowl would be removed then the casing strings backed off at the mudline. Following suspension of the hole when the casing strings are landed in the moon pool, the BOP stack and casing bowl would be removed after which the casing strings would be cut or blown off at the mudline.

The time required to carry out these operations would vary depending on the wellbore configuration but would typically require 2 to 3 days.

Cold Start Up Time: If the SSDC/MAT was on seasonal shut-down, then emergency start-up procedures would be required. If the SSDC had drilled during the season, then the ballast tanks would not be frozen and the unit could be ready for towing in 10 days. If the SSDC had been shut-down all season, then the tanks require dewinterization prior to tow. Modifications to the ballasting system and ballast tanks in the last few years allow for rapid thawing and drawdown of the ballast water (note - only a small portion of the water would be frozen). These modifications plus experience in dewinterization demonstrate that the additional time would not be required in this circumstance. Figure 3.17 outlines the schedule of these emergency start-up procedures.

Deballasting & Transit Time: Once ready, the SSDC/MAT can be deballasted and hooked up for towing from one site to another within 2 days. Experience to date has shown that average tow speeds in the range of 1 to 2 knots can be expected during the normal open water season. For a late season move additional ice breaking support would be required and speed of between 0.5 to 1.5 knots would be expected. If the distance to the site was, for example, 100 nautical miles, then the total time required for deballasting and transit would be about 5 days in November and 7 days in December. These times are conservative representations for relief well contingency planning. In a real situation, the specific ice conditions and available marine support will dictate the transit time which would normally be expected to be lower than those given here.

Site Preparation: As the SSDC/MAT is bottom founded, the seabed must meet minimum requirements to provide an adequate foundation. The SSDC/MAT was designed to maximize the range of tolerable foundation conditions and in all but extreme cases no site preparation would be required. The large footprint in conjunction with the skirt penetration fully mobilizes the shear strength of the foundation soils and adequate lateral resistance is provided even in weak soil conditions.

In a relief well situation the initial site surveys would be utilized to confirm that no site preparation would be required for the SSDC/MAT. Should the initial site survey not cover the relief well location, then a reconnaissance dive would be done to confirm the bottom conditions. This would have no impact on the relief well timing as this survey would be done during the SSDC/MAT mobilization period.

Installation: Once at site the SSDC would be positioned over the relief well site and ballasted to the sea-floor. This operation is routinely done in less than a day in non-emergency situations, so one day is a reasonable allowance for this activity in the relief well plan.

Capacity of SSDC/MAT to drill its own relief well

The SSDC/MAT is a special case of bottom founded MODU in that it has been designed with a built-in relief well capability. The expansive main deck length of the SSDC/MAT provides sufficient separation of the primary well slots (located on the aft deck) and the fore deck area to accommodate a secondary moonpool for a relief well. This secondary moonpool is available in the starboard foredeck of the SSDC at a distance of 135 metres from the axis of the nearest main well moonpool[16]. In the event of a blowout, a helicopter transportable rig could be placed on the deck of the SSDC to drill a relief well through this moonpool.

Engineering analysis demonstrates that it is feasible to conduct relief well drilling operations utilizing the relief well moonpool in conditions resulting from a blowout of up to 10,000 BOPD burning upwind of the relief well slot in an 80 KPH wind.

To ensure the safety of the heli-rig and the personnel during relief well drilling operations, a radiation heat shield was designed and constructed specifically for the SSDC/MAT and is stored at Canmar's base at Tuktoyaktuk. The shield is 18m high and, when installed, will span the complete breadth of the SSDC deck at a distance of 66m from the main wellbore axis. The dimensions, deck location and construction details allow this shield to reduce the heat intensity at the relief rig site, the accommodation unit, and the existing bulk silos. The shield is installed from the direction opposite the main wellbore area so it is possible for installation to take place while the well is out of control. High capacity water monitors are strategically positioned so that the shield and other critical areas can be cooled if necessary.

To accommodate the heli-rig over the relief well moonpool some deck levelling would be required since the deck of the SSDC is not level in this location. This deck levelling would be constructed of fabricated structural sections which would act as a levelling substructure to the heli-rig. It would be fabricated in the south and transported by air to site. Once at site, it would be welded to the deck of the SSDC/MAT prior to the installation of the Heli-rig. The time to fabricate,

3.16 There are four main well slots in the aft deck of the SSDC/MAT.

transport and install the deck levelling is estimated at 3 weeks which is well within the mobilization time for the heli-rig and so will not be on the critical path. The heli-rig mobilization itself is addressed in the Sub-section 3.5.2.

3.4.2 Molikpaq (see Appendix D)

System Description

The Molikpaq is a purpose-built mobile Arctic caisson designed to remain on location throughout the year and withstand year-round ice forces any time of year. This permits drilling and fully testing one or more wells during the same season. The Molikpaq was designed to have a deep set-down draft of 21.3m. The deep draft of the caisson reduces the height and cost of the berm on which it sits for deeper water locations. For overall stability sand, of sufficient mass and density to resist ice loads, is normally pumped into the core of the Molikpaq.

The Molikpaq is basically an octagonal steel annulus which supports a deck which houses modular drilling and support systems. Its height is 29.0m and the deck and base diameters are 73.2m and 110.0m respectively. A 4.6m ice deflector extends above the deck. The Molikpaq can operate in water depths ranging 10m to 40m by dredging a subcut or varying the height of the berm.

The almost-square deck is supported on bearings on the inner wall of the caisson. As well as acting as a support structure for the drilling and topside facilities, the deck houses the caisson control room containing many of the systems required for operations. The caisson is divided into twelve major ballast compartments for lifting or lowering the caisson when moving from one location to another in summer. Prior to lifting the caisson, some sand is removed from the core. Freezing is avoided in the ballast tanks and sand core using insulation, heat and bubbler system.

Operating Experience

The Molikpaq has been utilized at four Beaufort Sea locations, Tarsiut P-45, Amauligak I-65 and F-24, and Isserk I-15, in water depths ranging from 11.5 to 32 m. Three of these locations were in the moving pack ice zone while the Isserk well was in the landfast ice zone. The structure has performed very well, withstanding the loads from all first year ice and the extreme multi year ice interactions which occurred during the March/April time frame in 1986. Systematic ice force and structure response measurements during these deployments have enabled the deployment design to be tailored to the expected environmental conditions at any given site. The Molikpaq has been deployed both on berms and directly onto the seafloor and has been operated with full and partial core fill depending upon the resistance requirements at a particular site. The Molikpaq can be deployed in a range of conditions but normally some foundation preparation and core fill are required to ensure its stability.

Since the Molikpaq derives the majority of its resistance to ice and other environmental loads from the sand fill placed within its central core, it generally requires dredging support. In addition, the seafloor on which the unit or its submerged berm is placed normally requires some level of preparation to ensure adequate stability of the structure. Both dredging and foundation levelling operations are time consuming[17] and limited to essentially open water conditions. In view of these normal Molikpaq deployment requirements and the fact that a rapid late season response is desirable to initiate relief well drilling activities, the Molikpaq has a limited capability as a relief well unit.

In the case where seabed conditions were adequate for the Molikpaq to drill a relief well, a period of time would be required to either suspend operations at an active site or mobilize from cold storage.

There are however, particular circumstances where the Molikpaq could be used as a relief well drilling system option, for example;

- if the water depth was in the 10 to 20 metre range, and seafloor conditions were suitable, and
- if relief well drilling was required during the open water or early freeze-up period, then

the Molikpaq could be setdown directly on the seafloor, ballasted down with water and operated with no sand core. The structure's resistance to ice loads during ice intrusions would be marginal but ice management could be used to fragment any oncoming ice and minimize loads on the caisson structure. Figure 3.18 shows the Molikpaq's resistance as a function of water depth and generic seafloor conditions if it was used in this manner.

Deployments for relief well drilling during the late fall, winter or break-up periods would be limited by;

- mobilization constraints in heavy ice,
- the time required to fill the caisson's core, and
- the time required for foundation preparation.

Site Suspension: Time requirements for permanently abandoning a well will vary depending on the status of the well. Suspension of the hole itself will be carried out in the following manner;

- Set open hole cement plugs on bottom, across hydrocarbon bearing zones and at the last casing shoe,
- Set a bridge plug above the last cement plug,
- Displace hole with freeze depressed mud, and
- Cut and pull casing.

3.17 Typically several weeks are required to prepare a berm and level foundation for a Molikpaq deployment.

Cold Start-Up Time: A typical start-up for the Molikpaq requires 21 days from call-up to tow. If required for a relief well, an emergency fast track start-up can be initiated, readying the Molikpaq for tow in 9 days (Figure 3.19).

Deballast and Transit Time: Once core dredging operations are complete, the Molikpaq can be deballasted within 24 hours. Tow speed in open water is 4 knots. During a late season move, additional ice breaking support will be necessary. Late season tow speeds may be as low as 0.5 knots.

Site Preparation: A seabed survey, including bathymetry, would be required at the relief well site to ensure that the foundation conditions were suitable for setting down the Molikpaq.

In a relief well situation, the original well site surveys would be used to confirm that site preparation would not be required for the Molikpaq. If the initial site survey did not cover the relief well location, then a reconnaissance dive would be done to verify that the bottom conditions were suitable. This survey would have no impact on the relief well schedule as it would be carried out during the Molikpaq mobilization period.

Installation: Without a berm, the Molikpaq is limited to water depths between 10 and 20 metres. Once at the site, the Molikpaq would be positioned over the relief well location and ballasted to the seabed. These activities would be completed within 24 hours. If ice conditions are favourable, driving the conductor can be initiated immediately after setdown. Under normal operating conditions, the core is partially filled with sand to ensure stability before drilling operations begin. Experience has shown that two dredges can fill the Molikpaq core in four days. This time varies, depending on ice conditions and the distance of the borrow pit from the relief well site.

In cases where a relief well was required during the freeze-up through early winter period in the landfast ice zone, a grounded spray ice annulus could be constructed to enhance the Molikpaq's resistance to ice forces. However, normal methods of drilling in the relatively shallow waters of the Beaufort Sea involves winter wells and makes a spray ice pad the preferred relief well option in this situation. Figure 3.19 shows start-up schedules for the Molikpaq.

Molikpaq Oil Storage and Disposal

In the event of a blowout on the Molikpaq, much of the oil will be contained in the core area. Providing personnel can access the Molikpaq during the blowout then the Molikpaq's ballast tanks can also be used to store oil. Oil storage in the core is comprised of:

- The air gap between the sand fill and the deck which has a volume of 24,000 m^3.

- The dry and dewatered sand core into which the oil will penetrate. It is estimated that this represents an additional volume of 11,000 m^3.

These two components yields a total volume of 35,000 m^3 (220,000 barrels). This volume represents 22 days of storage at a flow rate of 10,000 bbls/day. In addition to the core volume the twelve ballast tanks have a combined volume of over 80,000 m^3 (500,000 barrels) which represents an additional 50 days storage at 10,000 bbls/day. In total the Molikpaq has a storage capacity of 72 days, assuming a blowout rate of 10,000 bbls/day.

The equipment to transfer oil from the Molikpaq core areas to a waiting disposal icebreaker is detailed in the "Molikpaq 1985/86 Relief Well Plan for Amauligak I-65" which was submitted to COGLA on June 26, 1985. Three complete sets of transfer equipment have been installed on the Molikpaq. Each set consists of;

- two air operated submersible pumps with an operating capacity of 12,342 bbls/day,
- king posts positioned at the appropriate deck location,
- swivel sectioned cradle boom, and
- flexible hoses for icebreaker hook-up.

No personnel or power is required on the Molikpaq for off-loading oil from the core area. The oil transferred would be contained in a bladder or in deck mounted tanks on the vessel. This in turn would be transferred for disposal, by burning, at a safe location.

Through oil containment and disposal the effects of a blowout from the Molikpaq would be significantly reduced. If a winter relief well effort for the Molikpaq was required (e.g. by the Kulluk), the environmental impact would be substantially mitigated.

3.4.3 CIDS (see Appendix E)

System Description
CIDS is an acronym for "Concrete Island Drilling System" and was designed and built by Global Marine and continues to be operated by them. This structure is presently in the U.S. Beaufort Sea and was not studied for this report. However this unit has drilled in U.S. Beaufort waters and is included in this report for identification purposes. If this unit was to be considered as a possible relief well candidate, further information on mobilization times and operating criteria would be required.

General Description: CIDS is made up of four modular elements mated together;

- a steel mud base (to provide the foundation),
- a concrete "brick" section (to resist ice loading),
- and two top steel barges (to accommodate the topside facilities).

The central brick element is constructed of a concrete "honeycomb" structural system, providing strength to resist ice forces. The light dry weight of the "honeycomb" design provides shallow draft capability during tow and relocation. The ballast water in the "honeycomb" cells and the dry weight combine to provide sufficient weight at the seabed for resistance against ice forces.

The two top steel barges are used to support the drilling and accommodation facilities. The barges are compartmentalized so that various drilling fluids, cuttings, and fuel can be carried on board. The plan area of the deck provides about 6,300m^2. of deck space for the land drilling rig. The rig has a depth rating of 6,000m.

The unit is also equipped with water cannons which, together with any rubble field developing around the structure, are used to create a grounded ice barrier around the structure and so enhance stability.

The CIDS is designed to carry enough fuel and other consumables for 12 months of operations and enough tubulars and drilling supplies for three 4,600m wells. It can operate in 10 to 17 metres of water depth without berm construction.

Mobilization: The unit can be ballasted or deballasted within 48 hours. The spraying of a protective ice berm requires approximately three weeks for a water depth of 12 m.

Site Preparation: The capability of the CIDS to operate without site preparation is dependent on the required sliding resistance. The soil properties at a site must be known before any assessment of the CIDS suitability can be made.

3.5 Bottom Founded Fixed Structures

3.5.1 General

As discussed in the introduction to this section there are two main fixed structure types; those that use landfill as the major structural component and those that use ice. Since land filled systems requiring substantial summer construction are very unlikely candidates as a platform for a same season relief well, they are not considered in this report. Ice islands, in contrast, are constructed in the winter and provide a viable means of supporting relief well drilling for wells which are drilled during the winter months from either a bottom founded MODU or an artificial island. This section deals exclusively with ice islands which are, at present, the most likely bottom founded fixed platform which can offer practical same season relief well capability.

3.5.2 Spray Ice Islands (see Appendix F)

System Description

Spray ice islands have a history of use as relief well contingency platforms. Spray ice platforms have been built to support relief well drilling rigs in water depths ranging from 6m (at Nipterk P-32) to 21m (at Tarsiut N-44).

There are essentially two different construction methods for spray ice islands in landfast ice. In the first method the island is built using several medium-sized pumps positioned on the floating ice cover at the site. This method is similar to that employed at the Angasak and Nipterk spray ice islands. The pumps weigh about 6 tonnes each and are moved to the site via an ice road or Sky-crane helicopter. This technique is safe and feasible in mid winter from shore out to within 2 to 5 km of the edge of the landfast ice (i.e. about 15m water depth). In the second method the island is built using two large pumps positioned on the deck of an icebreaker. This method was used in 1983 to construct the McKinley Bay experimental island using the Canmar Kigoriak.

There are several rig options for drilling a relief well from a spray ice island. Given that currently the most suitable local rig is Esso Rig 2, the present most likely options are:

- a non-local land rig: if Esso Rig 2 used for the exploration well
- a non-local Herc-rig: if Esso Rig 2 used for the exploration well
- the Tuk-based Esso Rig 2: if a non-local land rig used for the exploration well
- a heli-rig: if the water depth at the site is greater than 15m (due to the hazards of mobilizing a conventional rig over an ice road in these water depths).

The key constraint in using an ice island as a relief well platform relate to its construction and rig mobilization limitations. The spray ice island must be built in cold weather, in stable ice conditions, and must be abandoned before summer thaw destroys the integrity of the island. The drilling rig transportation must either be over ice roads, which have construction limitations or by air which necessitates the use of either a heli-rig which has a fairly long mobilization time or a herc-rig which requires an ice air strip at site. A herc-rig could also be airlifted to Tuk and from there, mobilized by ice road to site.

The remainder of this section addresses these issues in light of the two construction scenarios and four relief well options.

Design & Construction

The primary design requirements for a spray ice relief pad are twofold;

- the island must withstand the landfast ice pressures without failing in shear along a horizontal plane, and
- the island must remain operable during spring, breakup and early open water season despite ablation processes induced by above zero seawater and air temperatures and minor wave action.

These two issues are discussed under the headings, "Stability Under Ice Loads" and "Stability Under Ablation Processes".

Foundation creep settlement beneath the rig is not considered to be a governing design concern. Previous experience (*ref 1 & 2*) has demonstrated that settlement rate of the rig due to creep of the spray ice will be less than about 30 cm per month. This rate can be readily accommodated by the drilling operations.

Stability Under Ice Loads: An analysis of spray ice pad stability is included in Appendix F and from this analysis the following design parameters are judged appropriate for application of an ice island as a relief well platform:

- safety factor = 1.5
- ice thickness = 2 m
- minimum foundation soil strength = 5 kPa

In light of the above parameters, the required design pad diameter is 350 m.

The in-place volume of the relief island (V) is defined in terms of the freeboard (h), the water depth (w) and the diameter (D),

$$V = \frac{[\pi D^2 (w+h)]}{4} \qquad (3.1)$$

Equation 3.1 is presented graphically in Figure 3.20 for a constant freeboard of 12m and a diameter of 350 m.

The volume of spray ice could be minimised by building the spray ice pad on top of an existing rubble field. In essence this strategy reduces the effective water depth for the spray ice island. Observations from fixed platforms indicate that rubble fields tend to build up around them and so it is considered likely that rubble ice could be expected in the vicinity of the blowout[18]. Therefore for construction planning it has been assumed that the average rubble thickness is 4m and the effective water depth is the actual water depth minus 4 m. The revised spray ice volumes for the rubble case are also presented in Figure 3.20.

If a sand or caisson-retained island is used as the platform for the exploration well it is likely that a small sand berm would also be built as an extension to the main island to serve as a base for a relief well. This berm would be built to within about 14m of sealevel in order to promote grounded rubble formation during freeze-up. The presence of the berm would result in a higher minimum soil strength in the seabed and therefore allow a smaller island. Additionally, the presence of grounded rubble would reduce the volume of spray ice needed. In this scenario it is likely that the volume of spray ice would be less than 1 million cubic metres.

Stability Under Ablation Processes: The distance between the relief pad and the blowout is an important factor in the planning of the relief well contingency program and must be determined in advance of the well. The minimum distance would depend on the potential blowout conditions (safety and radiant heat considerations). Similarly, the maximum distance is governed by the depth of the blowout, the capabilities of the relief well rig and the geological conditions. Both the minimum and maximum distances would be calculated on a well-by-well basis.

The relief well pad would be located beyond the range of radiant heat influence of the blowout and therefore need only be designed against ablation from atmospheric and oceanographic effects. For the purposes of this review it has been assumed that the centre of the relief well pad would be located within 300 to 1500 metres of the blowout.

In 1989 ERCL[19] conducted a field research program on the Nipterk P-32 Island to determine if it was feasible to protect a spray ice island from ablation processes and allow drilling operations to continue through to breakup. The conclusions of this study are presented in an internal ERCL report (ref. *22*). Based on this work, it is concluded that drilling could continue until breakup and

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3.18 Ice islands are unlikely to be considered as a relief well option for a floating system as the water depth is too great.

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island abandonment (via icebreakers and barges) could be as late as 2 weeks after breakup if the following design conditions are satisfied,

- island freeboard > 6m
- island diameter > 300m
- the entire working surface area of the island be covered with rig mats overlying insulation
- the remaining area of the island is covered with light coloured tarps (e.g. "Ruffco")
- all heated buildings, including the rig, be supported on 2 layers of rig mats separated by a 15cm air space

The first two of the above conditions would be satisfied by virtue of consideration of island stability under ice loads. The remaining 3 conditions would be incorporated into the design of the pad.

Based on the experience gained from the Nipterk research project the surface ablation by July 1 is expected to be 1.8m in areas protected by the Ruffco tarps and 0m beneath the rig mats (for reference, unprotected spray ice would be expected to ablate about 3.5m).

Construction: Construction procedures for each of the two types of ice island construction methods (on ice or from icebreaker based) are now described.

In the "on ice" method, the island is built using 4 medium-sized pumps positioned on the floating ice cover at the site. The pumps weigh about 6 tonnes each and could be moved to the site via an ice road or Sky-crane helicopter. Each of these pumps would have a capacity of about $10m^3$ water per minute.

In the "off-ice" method the island is built with 2 large pumps positioned on an icebreaker. The capacity of the pumps would be about $60m^3$ per minute. A detailed description of the spray pumps and how they were installed on the Canmar Kigoriak is presented in reference *23*. The spray pumps weigh about 21 tonnes each and could be transported by Hercules aircraft to Tuktoyaktuk where they would be trucked, along with the generators, via ice road to McKinley Bay where they would be loaded onto the icebreaker. The maximum weight of each truck load is assumed to be 50 tonnes. An ice thickness of 110 cm is needed to safely support 50 tonnes (Figure 3.21).

The thickness of the natural ice cover in the landfast zone as a function of time is presented in Figure 3.1. From this figure it can be seen that after Jan 1 the natural ice cover thickness alone is sufficient to support the pump mob operation. Therefore minimal ice road construction would be required.

The icebreakers provide winter long access to any area of the landfast ice in water depths greater than about 10m (*Ref. 25*).

Deployment Timing

The issues affecting the relief well drilling window schedule are presented and discussed in this section. These issues are described for "average" or "most likely" conditions, but wherever appropriate they are also presented in probabilistic terms. -

The critical timing issues in determining the relief well drilling window are:

- mobilization of the construction equipment
- construction of the ice island
- mobilization and rig-up the drilling rig
- drilling the relief well and killing the blowout
- rig-down and demobilization of the rig onto barges
- the date that the relief island must be abandoned

If a conventional "non-heli-portable" relief well rig is used, then the closure dates for the offshore and onshore ice roads also impact on the drilling window.

Construction Equipment Mobilization: The time required to mobilize the pumps to the site includes preparation and delivery of the pumps and construction support equipment.

The four medium pumps are presently owned by ATL and are based in Tuktoyaktuk. For the purposes of this study it is assumed that Tuktoyaktuk would be the origination point for these pumps in the event of a blowout. Given the current condition of the pumps they could likely be prepared and readied for mobilization to the site within 7 days notice. The actual mobilization time would range from 2 to 7 days depending on whether a Sky-crane were used or not. In this analysis it is assumed that the mobilization time for the medium pumps is 14 days.

The two large pumps are owned by Exxon and based in Houston, and so Houston was the assumed origination point for these pumps in the event of a blowout.

During planning of the Isserk I-15 well in 1989, ERCL investigated the feasibility of the Exxon pumps to construct a spray ice island. It was concluded that the pumps were in excellent condition and that, in an emergency, they could be air lifted to Tuktoyaktuk within 14 days. Within the next 2 days the pumps, generators and fuel would then be trucked to McKinley Bay where they would be loaded onto the Canmar Kigoriak (or one of the Beaudril icebreakers in Herschel Basin). By this time the Kigoriak would be ready to sail (*Ref. 25*). The time required to sail to the site depends on annual ice and wind conditions and the water depth. A site close to the edge of the landfast ice in a 15 to 20 metres water depth is much more accessible via icebreaker than a site in a 10m water depth[20]. In light of the above it is assumed in this study that icebreakers would not be used in water depths less than 15 m, and based on average ice conditions, it is reasonable to assume a sailing time of 7 days (*Ref. 25*) for sites in water depths greater than 15 days.

In consideration of the above it is assumed that a reasonable mobilization time to the relief well site, for the large pumps, is 23 days.

The above mobilization schedule implies that the pumps and support equipment (ie icebreakers, generators etc) are available and in reasonable condition. This assumption would be verified on a well-by-well basis and an up-front financial commitment may be required to ensure that the equipment is in an acceptable condition.

Construction Time: The time required to construct the island is defined as the total number of days, including downtime, needed to complete all spraying operations.

Based on experience, engineering and research ERCL has developed an analytical model which accurately predicts ice build-up rates for a range of pump configurations, meteorological and water conditions (*Ref. 26*). This model has been used in this study to predict the spray ice build-up rates as a function of date for the 60 m^3/min and 10 m^3/min pumps. In using this model, it has been necessary to make several assumptions regarding seawater and meteorological conditions and spraying parameters. These assumptions are tabulated in Table 3.12 and are based on published and proprietary data and experience relating to previous spray ice construction projects particularly; Angasak spray ice island (*Ref. 27*), Nipterk spray ice island (*Ref. 28*), McKinley Bay large spray gun experiments (*Ref. 24*) and the Antares (*Ref. 29*) and Orion (*Ref. 30*) spray ice barriers.

3.20 Available icebreaker drafts range from 7 to 8.5 metres which, in 10 m of water leaves minimum underkeel clearance during ice breaking procedures.

TABLE 3.12
SPRAY ICE CONSTRUCTION ASSUMPTIONS

PARAMETER	10 m^3/min PUMP	60 m^3/min PUMP
Number of Pumps	4	2
Water Salinity	30 ppt	30 ppt
Water Nucleation Temp.	-10 °C	-10 °C
Water Losses	10 %	10 %
Spraying Downtime	45 %	45 %

It is likely that the actual salinity in the upper part of the water column over most of the shelf will be in the range 10 to 20 ppt. Since spray ice production is enhanced by lower water salinity, actual construction rates will probably be greater than predicted herein. The downtime factor accounts for all forms of lost spraying time including mechanical, weather and ice movement downtime. The model also incorporates an efficiency factor to account for water which is lost through evaporation and overspray. The results of the predictions are presented in Figure 3.22 for an individual pump with zero downtime and zero water losses.

The design spray ice production rate for a given island on a given date is defined as the spray ice build-up (Figure 3.22) multiplied by one minus the downtime factor (45%) multiplied by the number of pumps (2 or 4) multiplied by 1 minus the water loss factor (1%). The spray ice build-up on a given day is determined from the design spray ice production rate and the average design offshore daily temperature for that day. The average design offshore daily temperature is estimated[21] to be 1°C warmer than the average daily temperature for Tuktoyaktuk and is presented in Figure 3.23. The computed design spray ice production rates, as a function of date, for the two construction methods are presented in Figure 3.24.

It is conservatively assumed spray ice production will cease after the average design offshore daily temperature exceeds -15°C. From Figure 3.23, the average end of spray ice construction season is April 19. A probabilistic distribution for this date (based on data from 1973 to 1989) is presented in Figure 3.25.

From Figure 3.22 it can be seen that the design daily production rates are about 125,000 m^3/day for the large pumps and about 45,000 m^3/day for the medium pumps.

3.21 Based on meteorological data collected during the drilling of the Nipterk P-32 and Isserk I-15 wells.

Given the production rates in Figure 3.24, the design spray ice volumes in Figure 3.20 and the end of spraying season date of April 19 it is now possible to determine the latest date for starting construction of a spray ice island as a function of water depth. This analysis has been carried out and the results are presented in Figure 3.26.

Ice Road Closure Dates: Motor vehicle access to Inuvik and then to Tuktoyaktuk is dependent on the winter ice roads joining these communities to the Dempster Highway. These roads are closed during freeze-up and break-up periods each year. The Inuvik to Tuk section of the road normally closes (to heavy traffic) at about the same time that surface river water has been observed at the mouths of the major river channels. The surface flooding can be seen on the satellite images and forms a convenient marker for hindcasting the closure of the Inuvik to Tuk ice road. Figure 3.25 summarizes this hindcast of closure dates and reveals that on average the Inuvik to Tuk ice road closes on or about April 28.

The influence of the increased and warmer MacKenzie River outflow does not cause deterioration of the landfast ice away from the coastline until early June. Usually the critical factor in causing deterioration of an ice road in these areas is meteorologic ablation (ie warm weather). Based on previous experience, offshore ice roads can remain open until the average daily temperature exceeds 0°C. A probabilistic summary of the closure date for the Tuk to site ice road is also summarised in Figure 3.25. Inspection of this figure reveals that on average, ice road access between the site and Tuktoyaktuk would be lost on or about May 28.

It should be noted that the ice in the vicinity of the coastline at Tuktoyaktuk will deteriorate more rapidly due to enhanced radiation absorption by the darker colour of the beaches. However this effect can be countered by maintaining a 0.5m layer of snow or spray ice over the ice road in these areas.

Drilling Equipment Mobilization: The time required to prepare and mobilize the drilling equipment, consumables and support facilities and rig-up is termed the rig mobilization time. The rig mobilization time depends on which rig system is to be used for the relief well. As previously described there are four primary relief well rig options for spray ice relief pads;

- locally based Esso Rig 2,
- non-local Herc-Rig,
- non-local based land Rig, and
- non-local based heli-Rig.

Each of these rigs has its own characteristic mobilization time which is described below.

Esso Rig 2 is currently stored in Tuk. The rig together with the consumables, camp and other support equipment would be mobilized to the relief platform via ice road from Tuktoyaktuk before May 28. The estimated breakdown of average mobilization time is as follows;

- Mobilize supplies, prepare rig and contract services
  (coincident with constructing ice road from Tuk to site) .... 12 days
- Move rig and materials to site .... 5 days
- Rig-up .... 8 days

TOTAL TIME .... 25 days

The non-local based Herc-rig scenario is similar to the Esso Rig 2 option in that the rig, consumables, camp and other support equipment must be mobilized to the relief platform via ice road from Tuktoyaktuk before May 28. The average critical path mobilization times are as follows;

- Mobilize supplies, prepare and fly rig north and contract services
  (coincident with constructing ice road from Tuk to site) .... 17 days
- Move rig and materials to site .... 10 days
- Rig-up .... 10 days

TOTAL TIME .... 37 days

In the non-local based land rig scenario, the rig would likely be too heavy to be flown to Tuktoyaktuk. Therefore the rig must be trucked to Tuktoyaktuk before the Inuvik ice road closes on April 28. The average critical path mobilization times are as follows;

- Mobilize supplies, prepare and truck rig north and contract services
  (coincident with constructing ice road from Tuk to site) .... 17 days
- Move rig and materials to site .... 5 days
- Rig-up .... 8 days

TOTAL TIME .... 30 days

In the non-local based heli-rig scenario, the heli-rig, consumables, camp and other support equipment would Herc'd to Tuktoyaktuk and trucked to a staging area close to the site in about a 15m water depth. All of the equipment would then be flown with large helicopters (ie Chinook and/or Sky-Crane) to the relief well island before the offshore ice road closes on May 28. The average critical path mobilization times are as follows;

- Mobilize supplies, prepare and herc rig to Tuk and contract services (coincident with constructing ice road from Tuk to staging site) .... 17 days
- Truck rig and materials from Tuk to staging site .... 5 days
- Sling rig and materials from staging site to relief pad .... 20 days
- Rig-up .... 8 days

TOTAL TIME .... 50 days

Rig-down and Load-out Time: It is assumed that in the extreme end-of-season scenario, all of the equipment would be loaded out onto a nearby barge immediately prior to breakup. The rig-down and load-out time is estimated to be about 10 days for the Esso Rig 2 and land rig options and 14 days for the herc-rig and heli-rig options.

Date of Island Abandonment

Valuable experience was gained from studying the deterioration of the Nipterk P32 spray ice island during the spring and early summer of 1989. Based on these observations, it is concluded that spray ice islands can be protected from meteorologic and man-induced ablation through the use of surface insulating materials and ventilated building foundations. Ablation due to oceanographic processes (ie waves) can also be slowed down through the use of protective edge tarps. However, unless elaborate ground freezing techniques are used, edge erosion cannot be prevented. Given a design island diameter of 350m and suitable tarp protection, as previously described, the working surface area of the island (ie within 75m of the island centre) would remain intact until 3 to 6 weeks after breakup. For the purposes of this study, it is conservatively assumed that the island must be abandoned by complete breakup of the landfast ice.

Spedding (*Ref. 7 through 18*) and Lussenberg (*Ref. 19 through 21*) have documented the breakup dates of the landfast ice since 1973. Based on these dates, a probabilistic summary of island abandonment date is summarised in Figure 3.25. Inspection of this figure reveals that the average island abandonment date is about July 19.

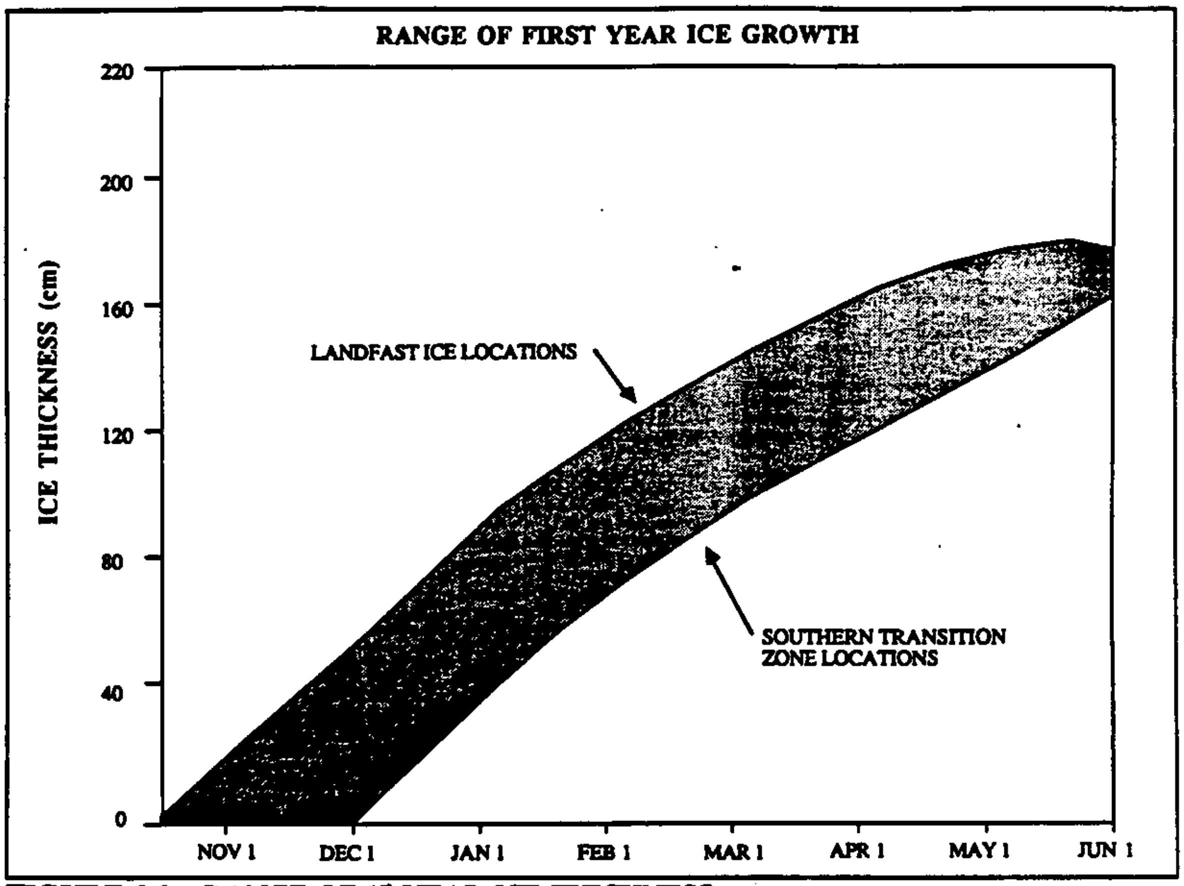


FIGURE 3.1 RANGE OF 1st YEAR ICE THICKNESS

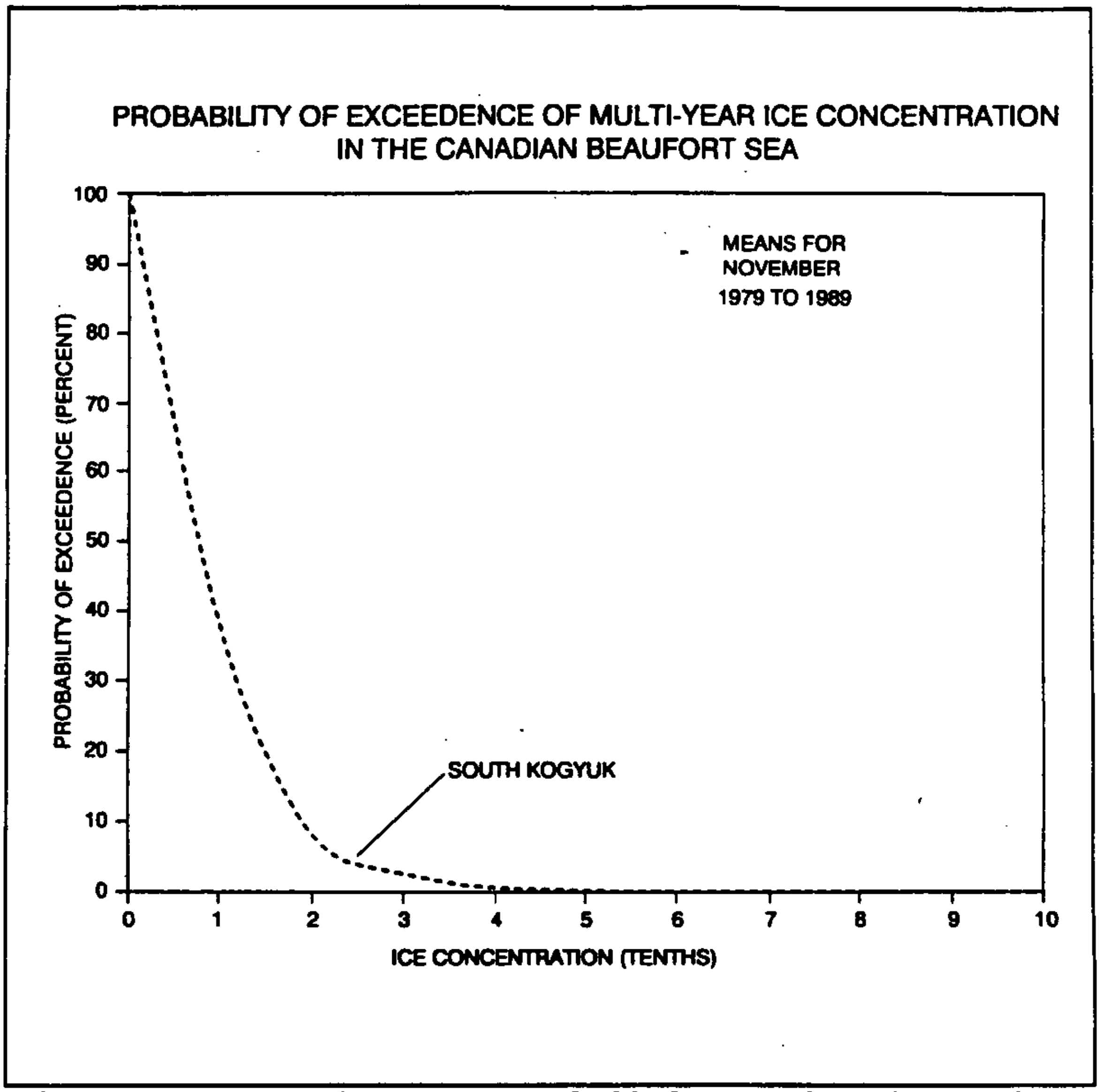
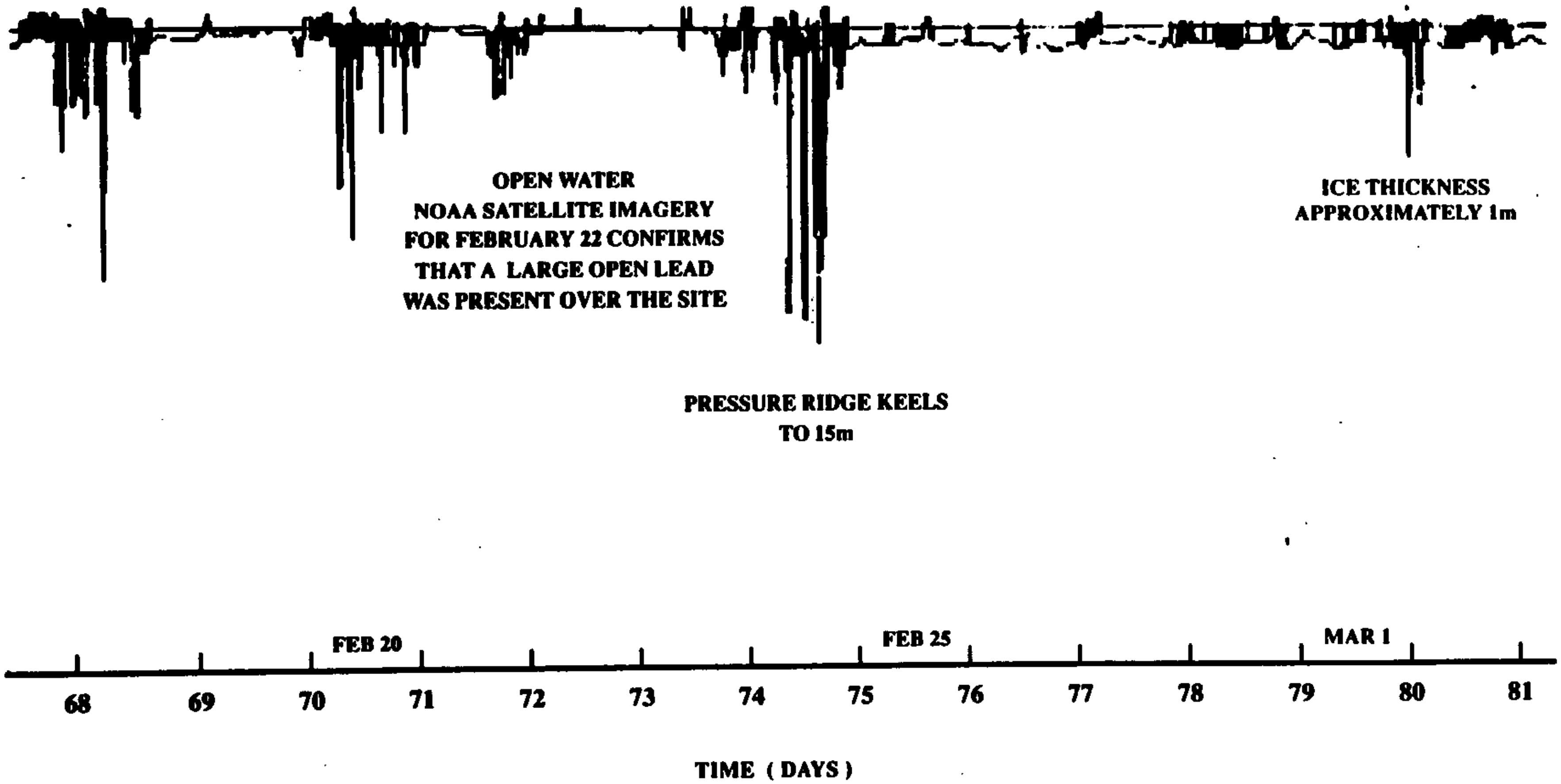
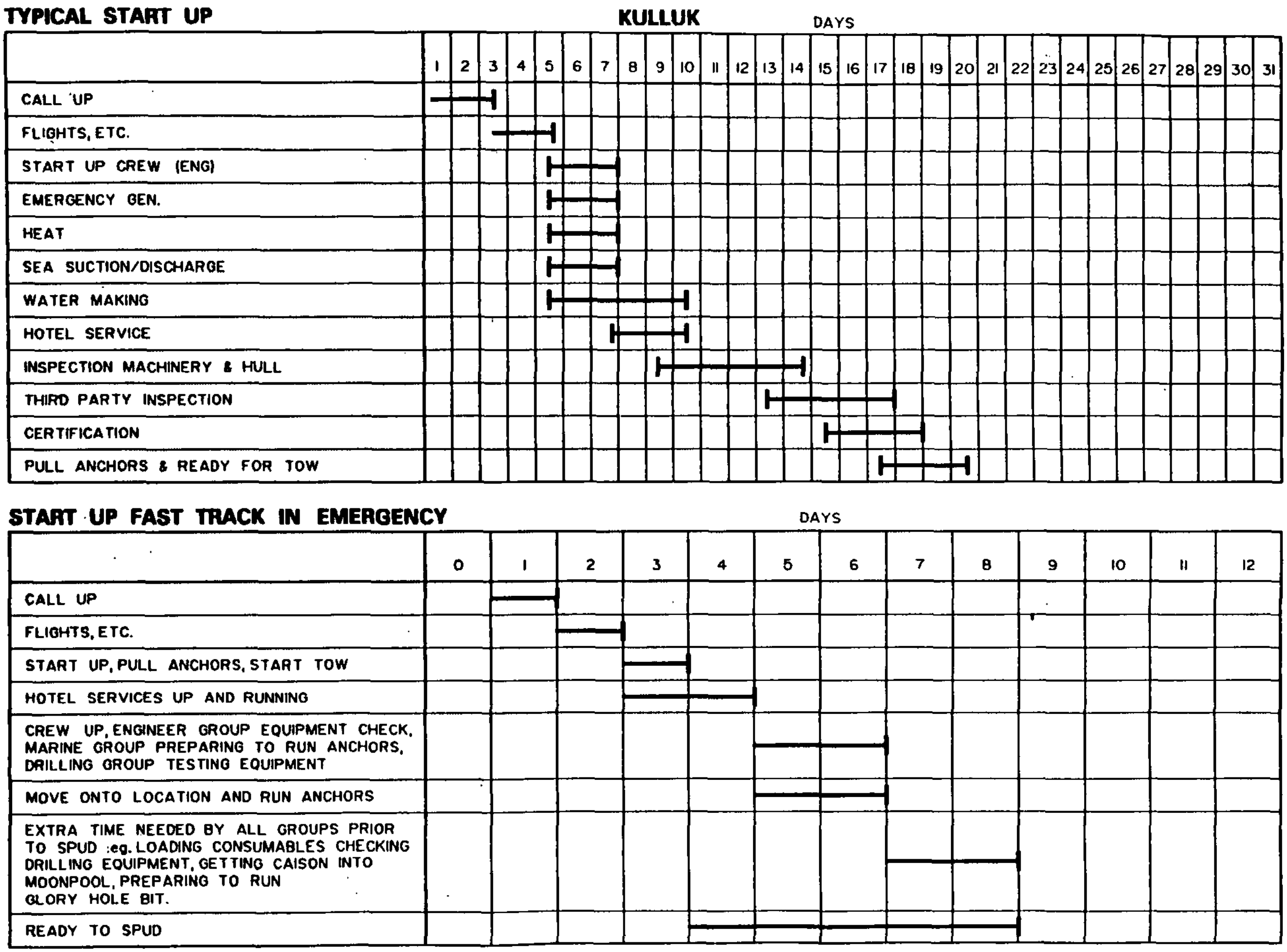


FIGURE 3.2 LATE SEASON MULTI-YEAR ICE CONCENTRATIONS (SOUTH KOGYUK)



ICE THICKNESS FROM UPWARD SONAR - 1979

FIGURE 3.2 UPWARD LOOKING SONAR DATA AT TINGMIARK



NOTE: SCHEDULES DO NOT REFLECT SURVEYS INSPECTION OR MAINTENANCE

FIGURE 3.4 KULLUK START-UP SCHEDULES

VESSEL START UP
FAST TRACK IN EMERGENCY
NO MAINTENANCE EXTRA CREW
TO FACILITATE PROCEDURES

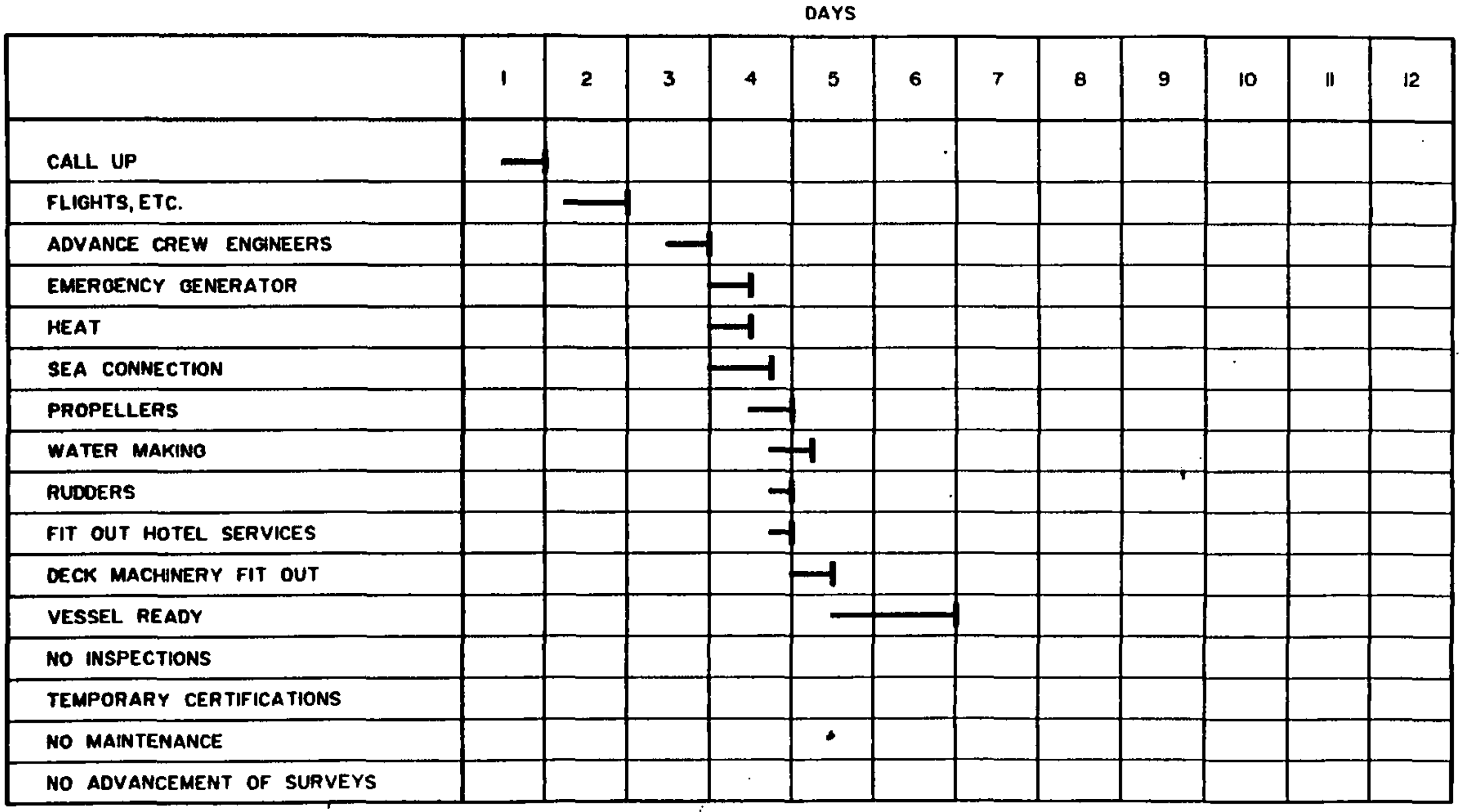


FIGURE 3.5 "FAST TRACK" EMERGENCY START-UP OF KULLUK'S SUPPORT VESSELS

OPERATING DAYS AND END OF SEASON DEFINITION FOR DRILLING SYSTEM

METHODOLOGY

DEFINE PERFORMANCE LIMITATIONS IN TERMS OF EXPECTED DOWN-DAYS PER WEEK DUE TO:

- OLD ICE
- THICK FIRST YEAR ICE
- ICE PRESSURE

DEFINE SITE SPECIFIC ICE CONDITIONS ON A WEEKLY BASIS FOR A NUMBER OF YEARS (N) INCLUDING:

- ICE CONCENTRATIONS
- ICE TYPES
- ICE THICKNESS

EXPECTED DOWNTIME ON A WEEKLY BASIS AND END OF SEASON FOR N YEARS

PROBABILITY OF ACHIEVING A GIVEN NUMBER OF OPERATING DAYS AND END DATE FOR THE SEASON UNDER CONSIDERATION

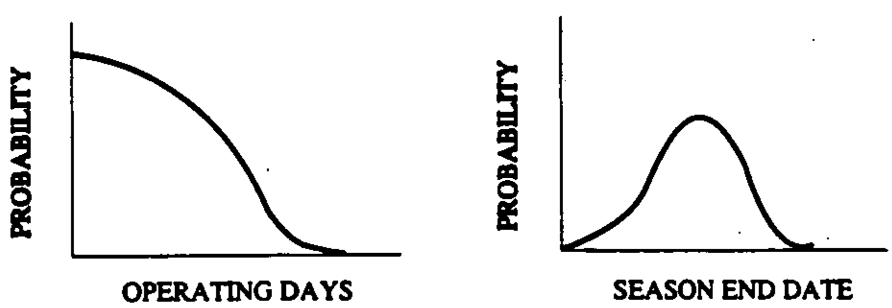


FIGURE 3.6 GENERAL METHODOLOGY FOR DETERMINING END OF SEASON DATE

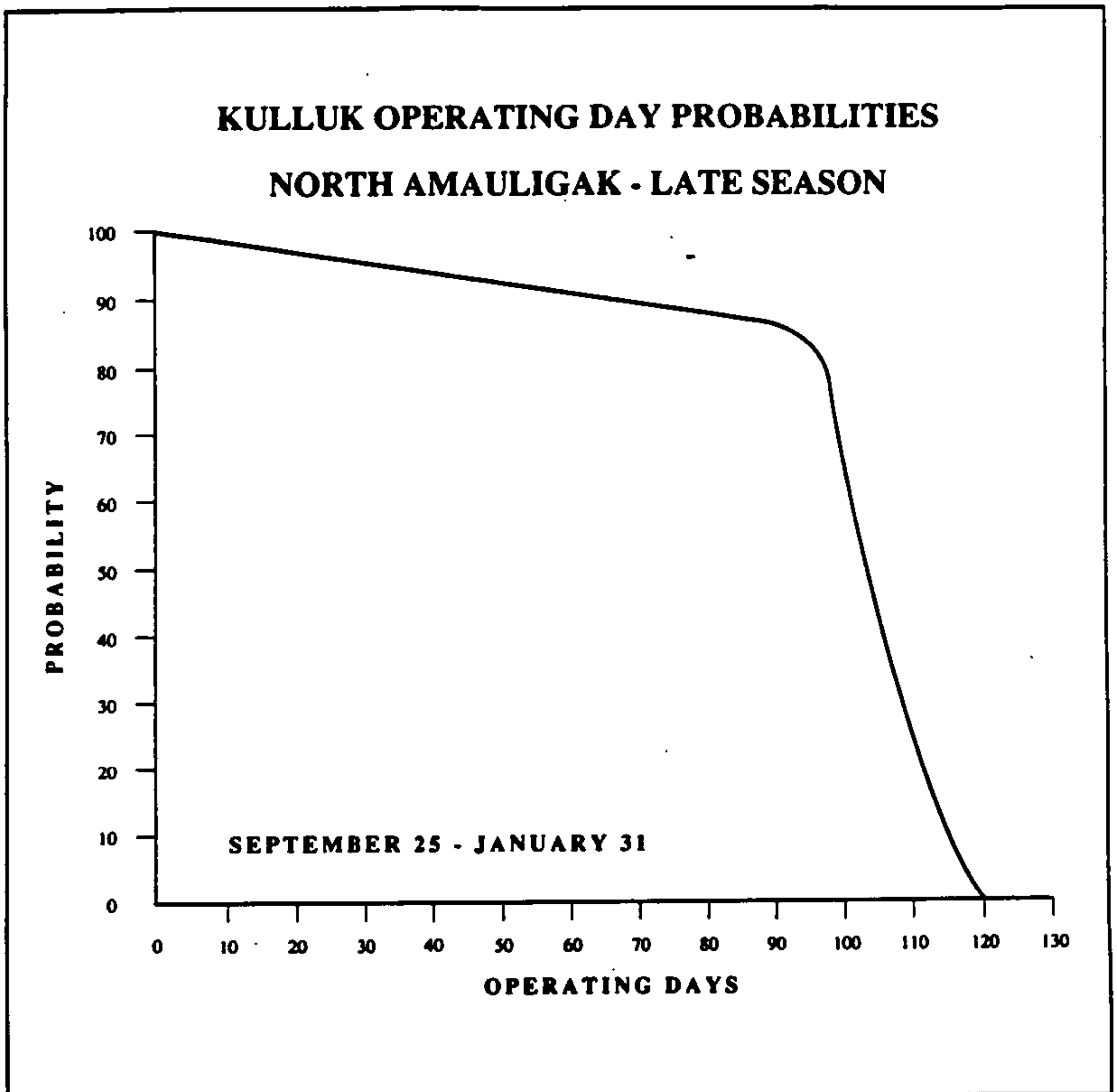


FIGURE 3.7 KULLUK OPERATING DAY PROBABILITIES (LATE SEASON)

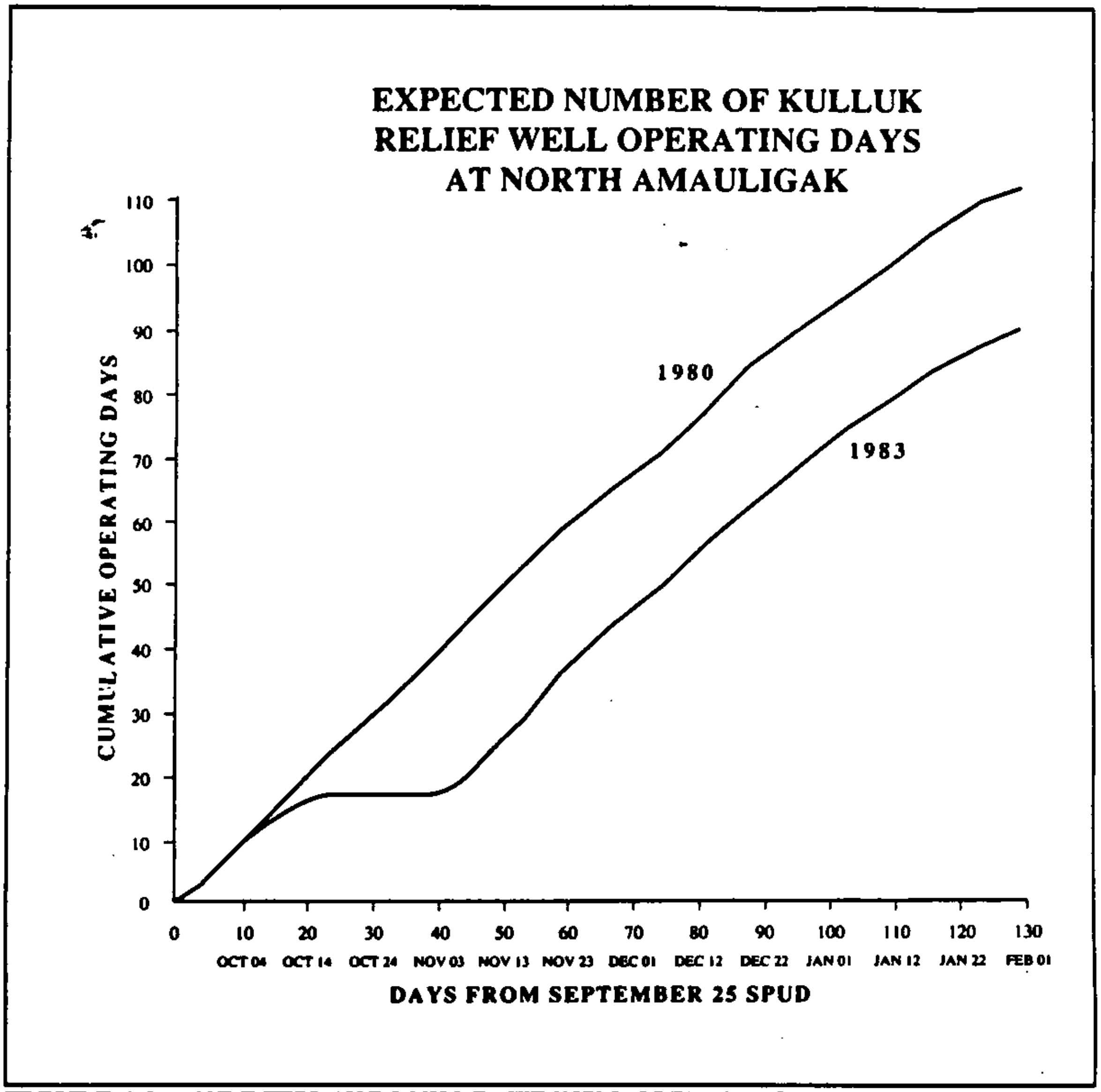


FIGURE 3.8 EXPECTED KULLUK RELIEF WELL OPERATING DAYS (N. AMAULIGAK)

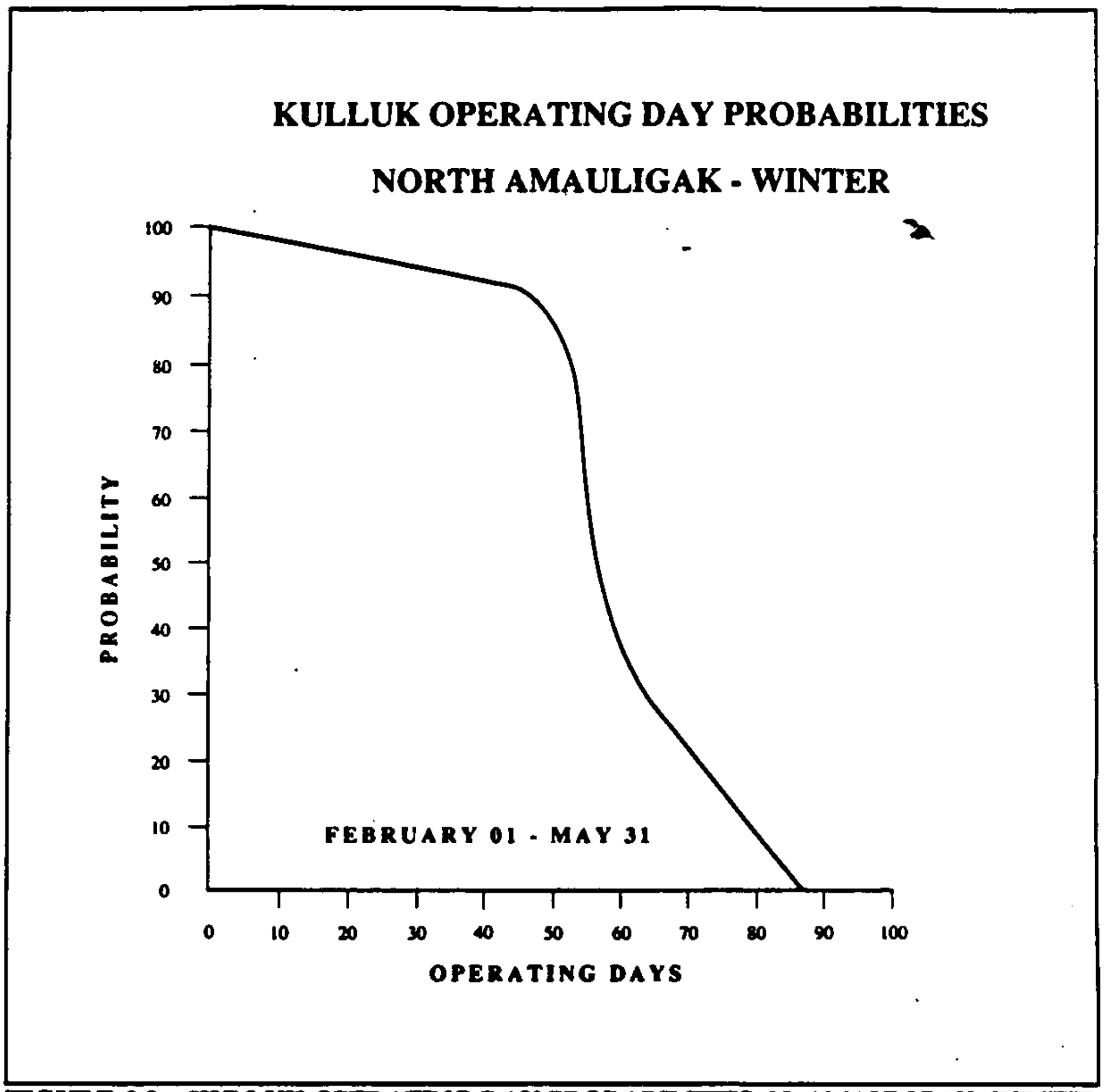


FIGURE 3.9 KULLUK OPERATING DAY PROBABILITIES, N. AMAULIGAK, WINTER

CANMAR DRILLSHIP

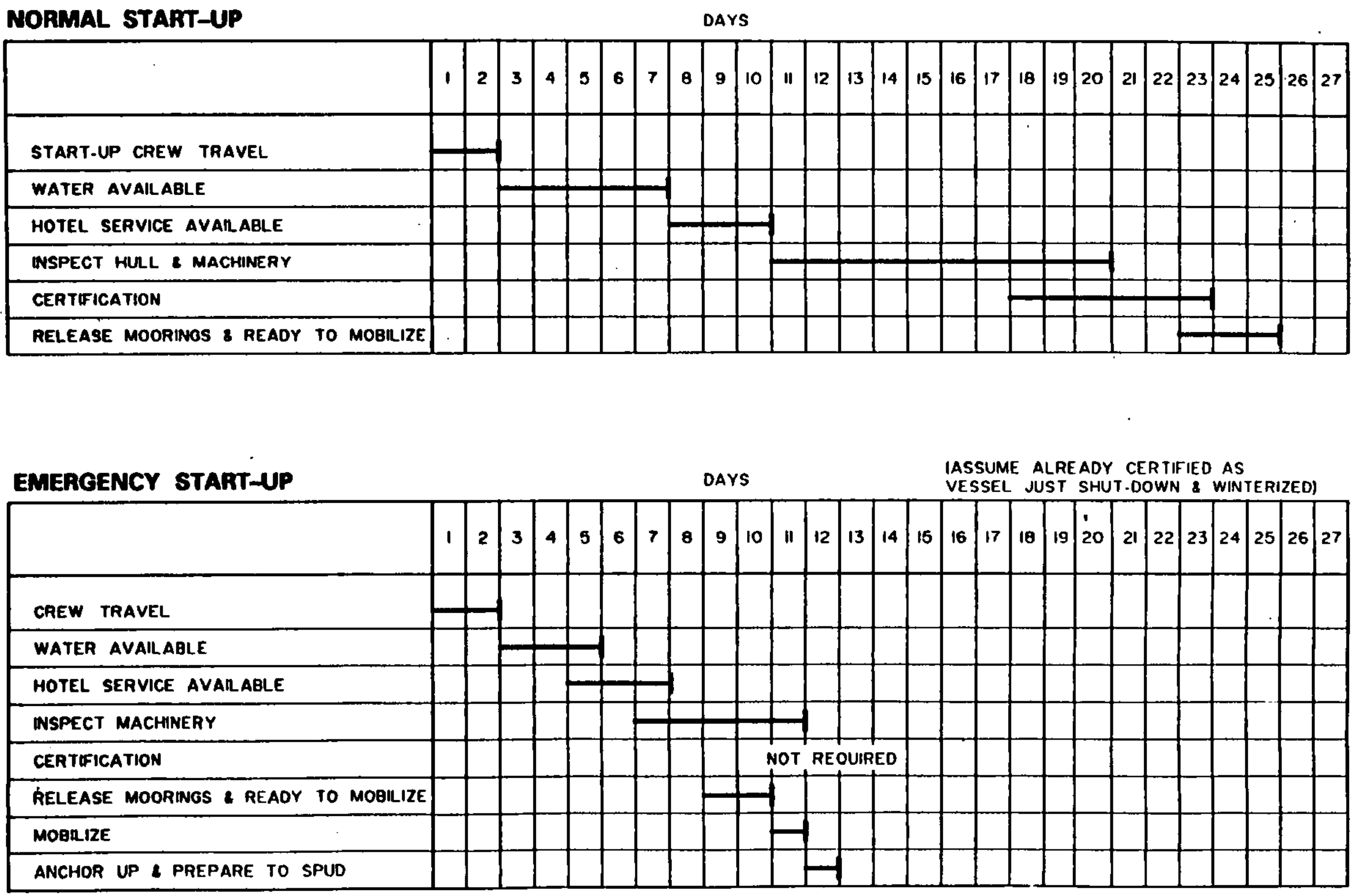


FIGURE 3.10 CANMAR DRILLSHIP START-UP SCHEDULES

Drilling Systems

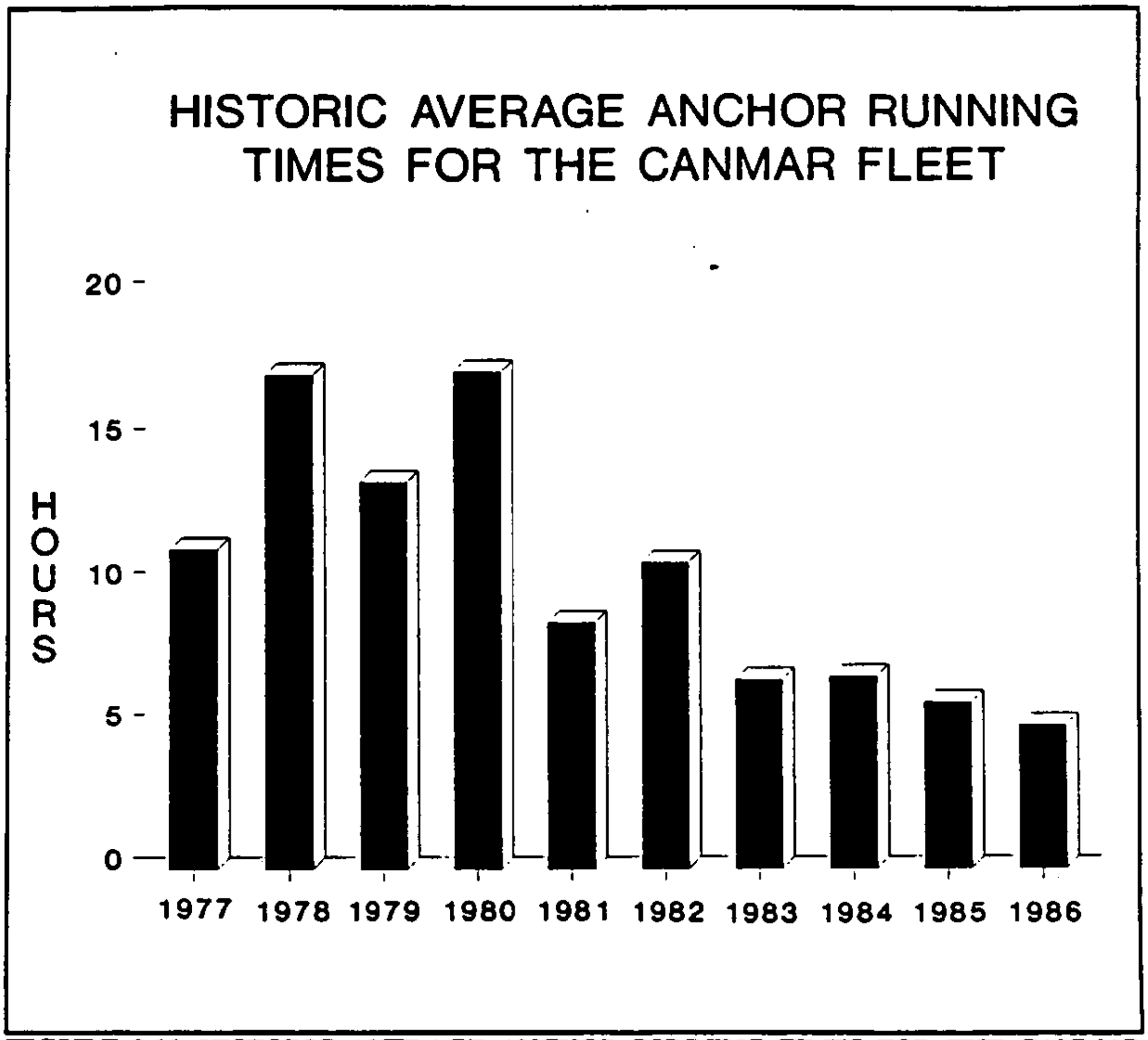


FIGURE 3.11 HISTORIC AVERAGE ANCHOR RUNNING TIMES FOR THE CANMAR FLEET

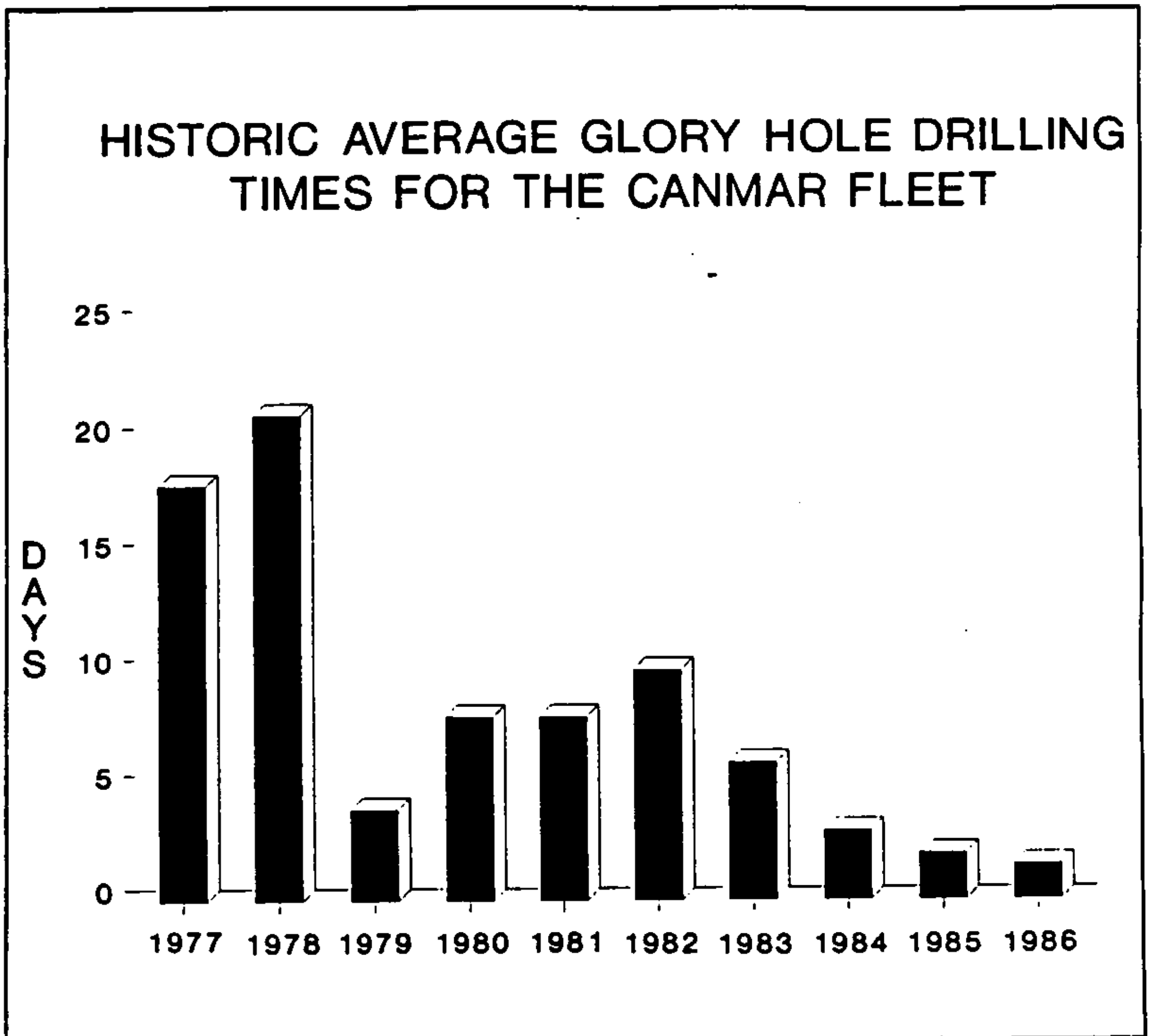


FIGURE 3.12 HISTORIC AVERAGE GLORY HOLE DRILLING TIMES FOR CANMAR FLEET

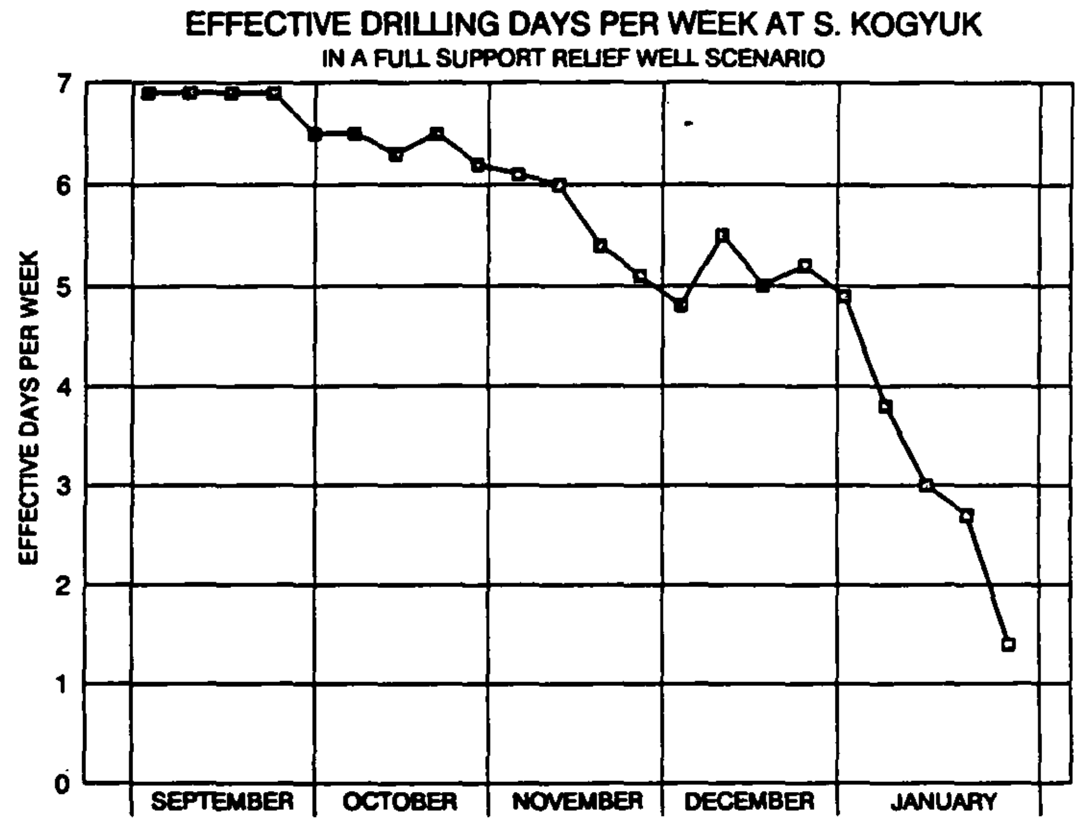


FIGURE 3.13 EFFECTIVE DRILLSHIP OPERATING DAYS PER WEEK

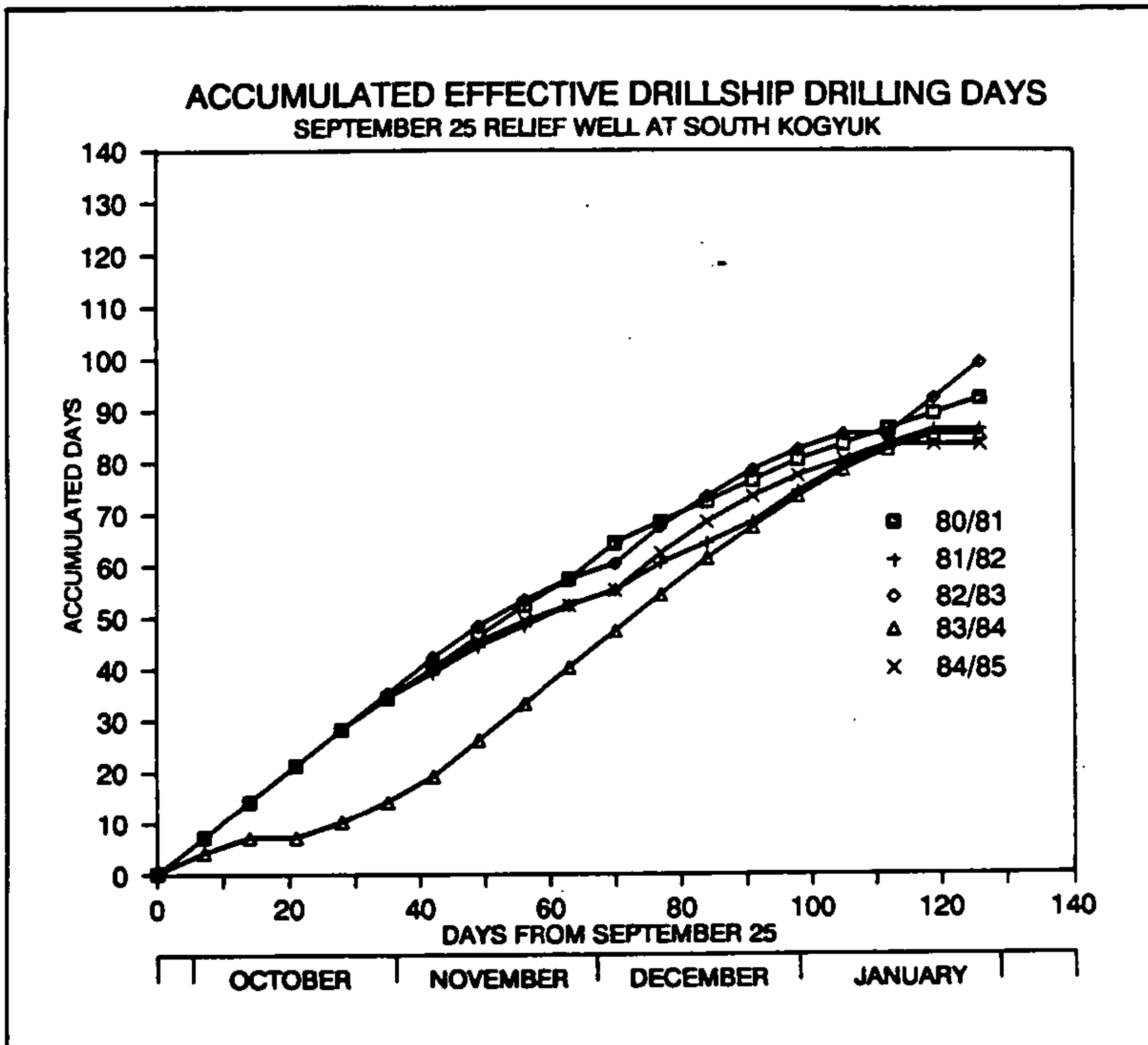


FIGURE 3.14 ANNUAL VARIATIONS IN EFFECTIVE DRILLSHIP DAYS (1980 TO 1984)

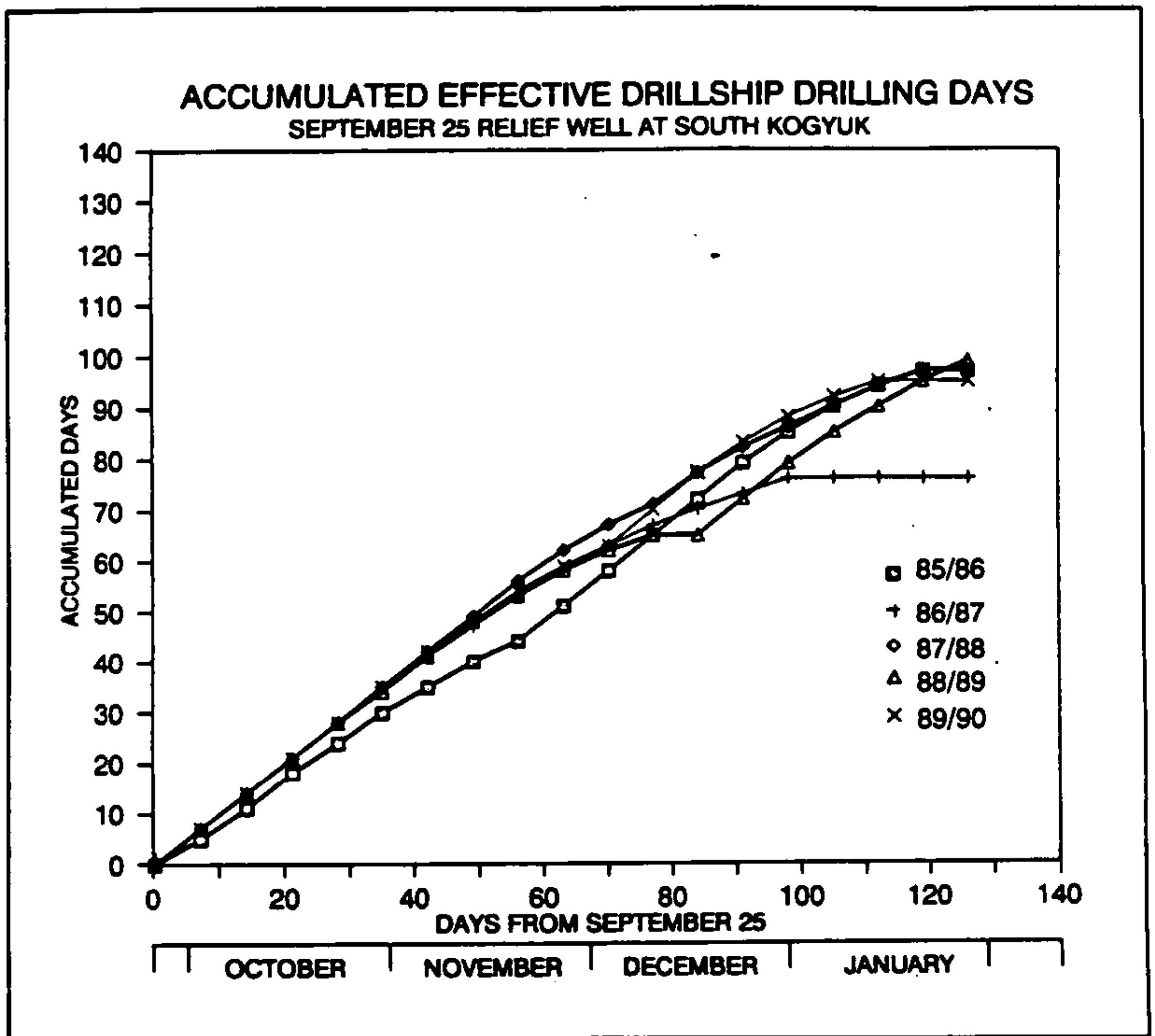


FIGURE 3.15 ANNUAL VARIATION IN EFFECTIVE DRILLSHIP DAYS (1985-1989)

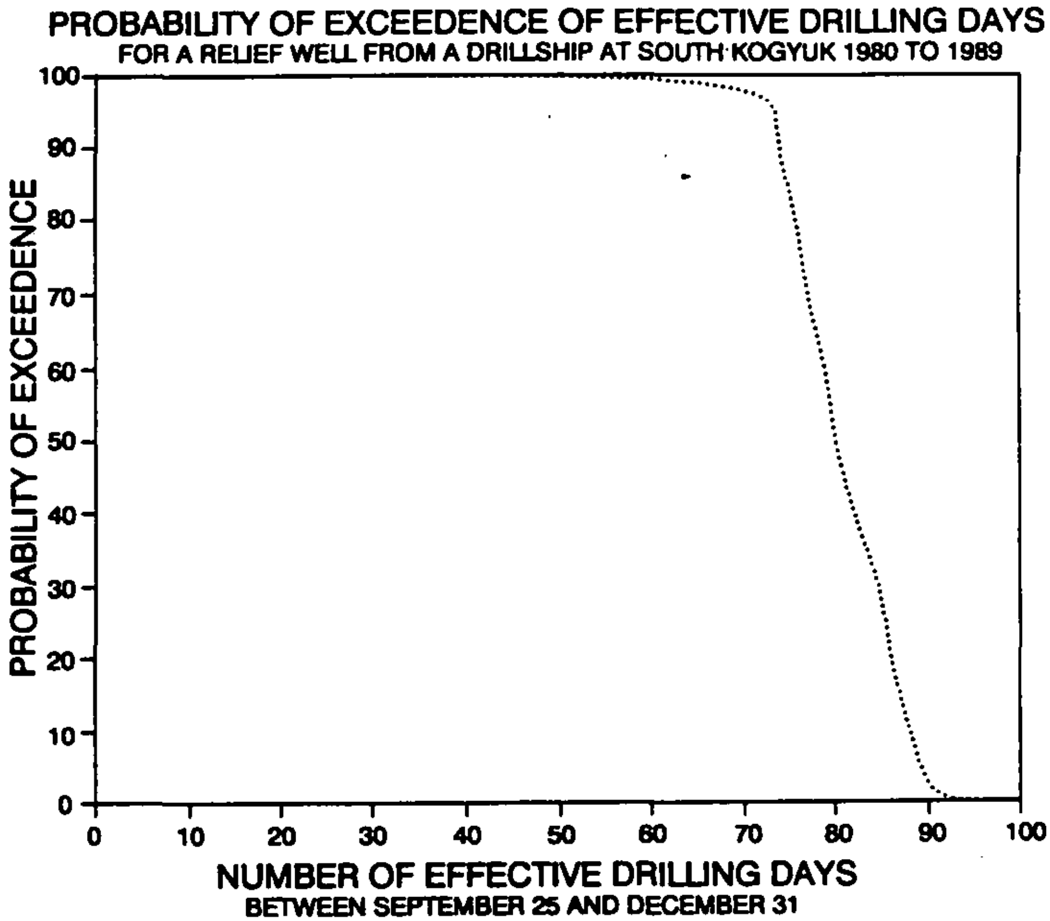
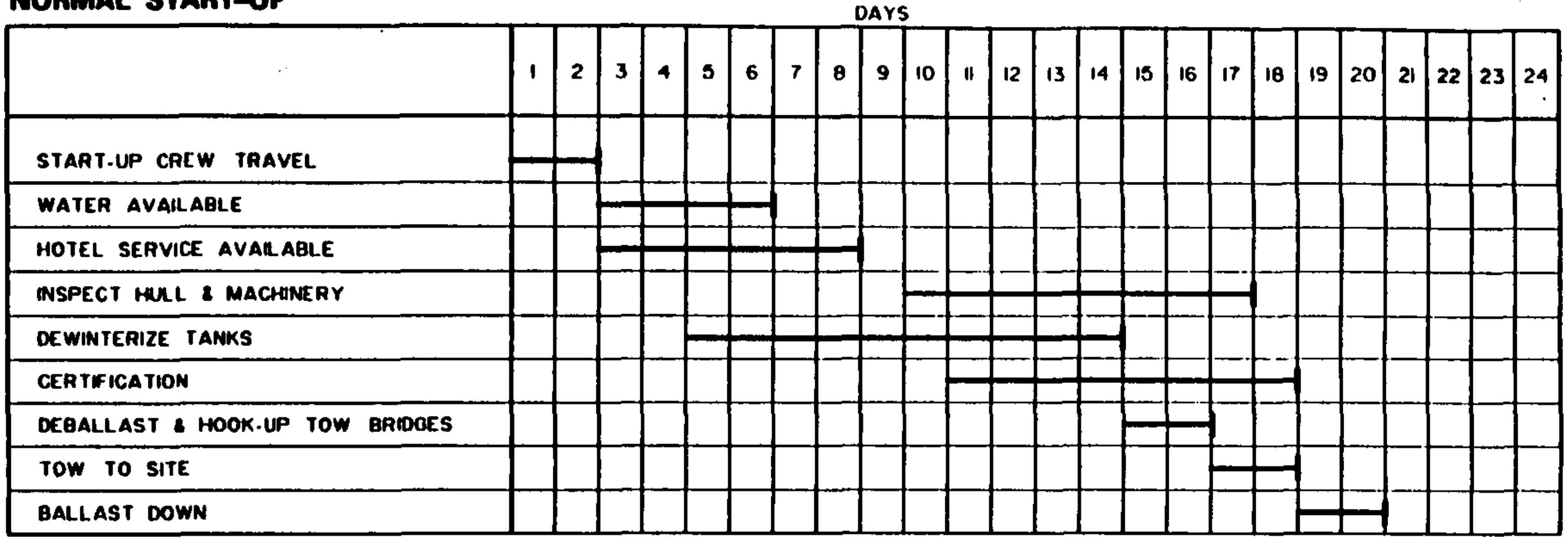


FIGURE 3.16 PROBABILITY OF EXCEEDENCE OF EFFECTIVE DRILLSHIP DAYS

SSDC

NORMAL START-UP



EMERGENCY START-UP

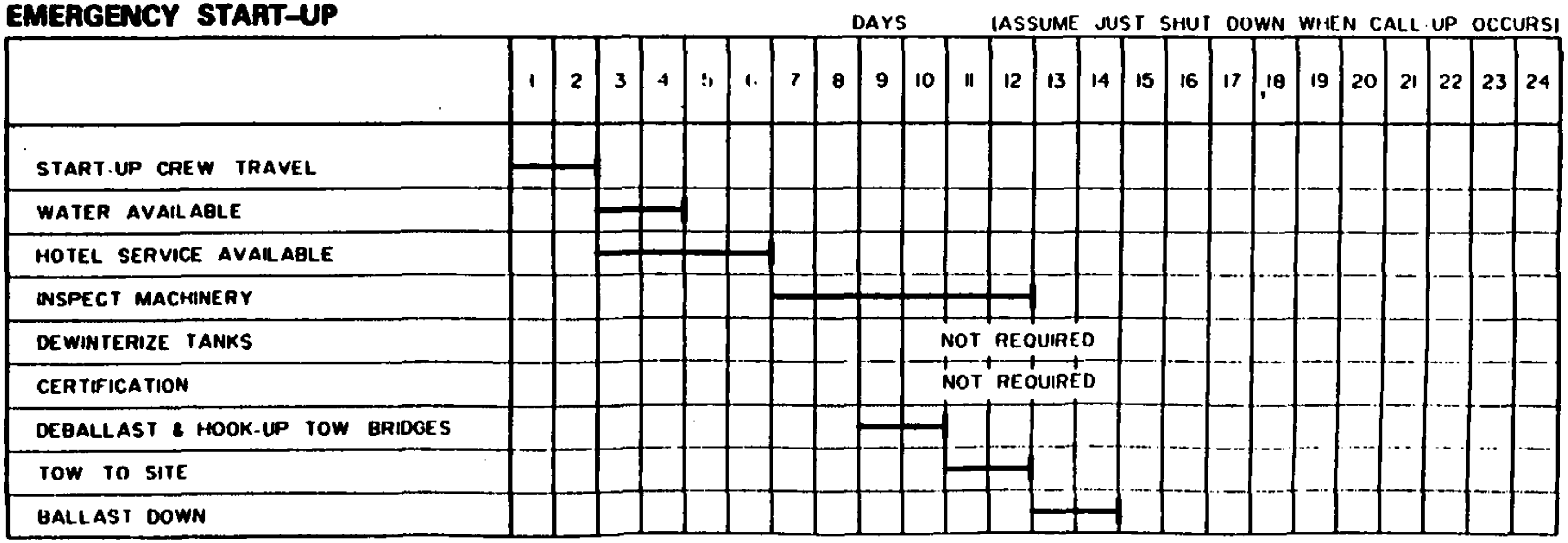


FIGURE 3-17 SSDC COLD START-UP SCHEDULES

Drilling Systems

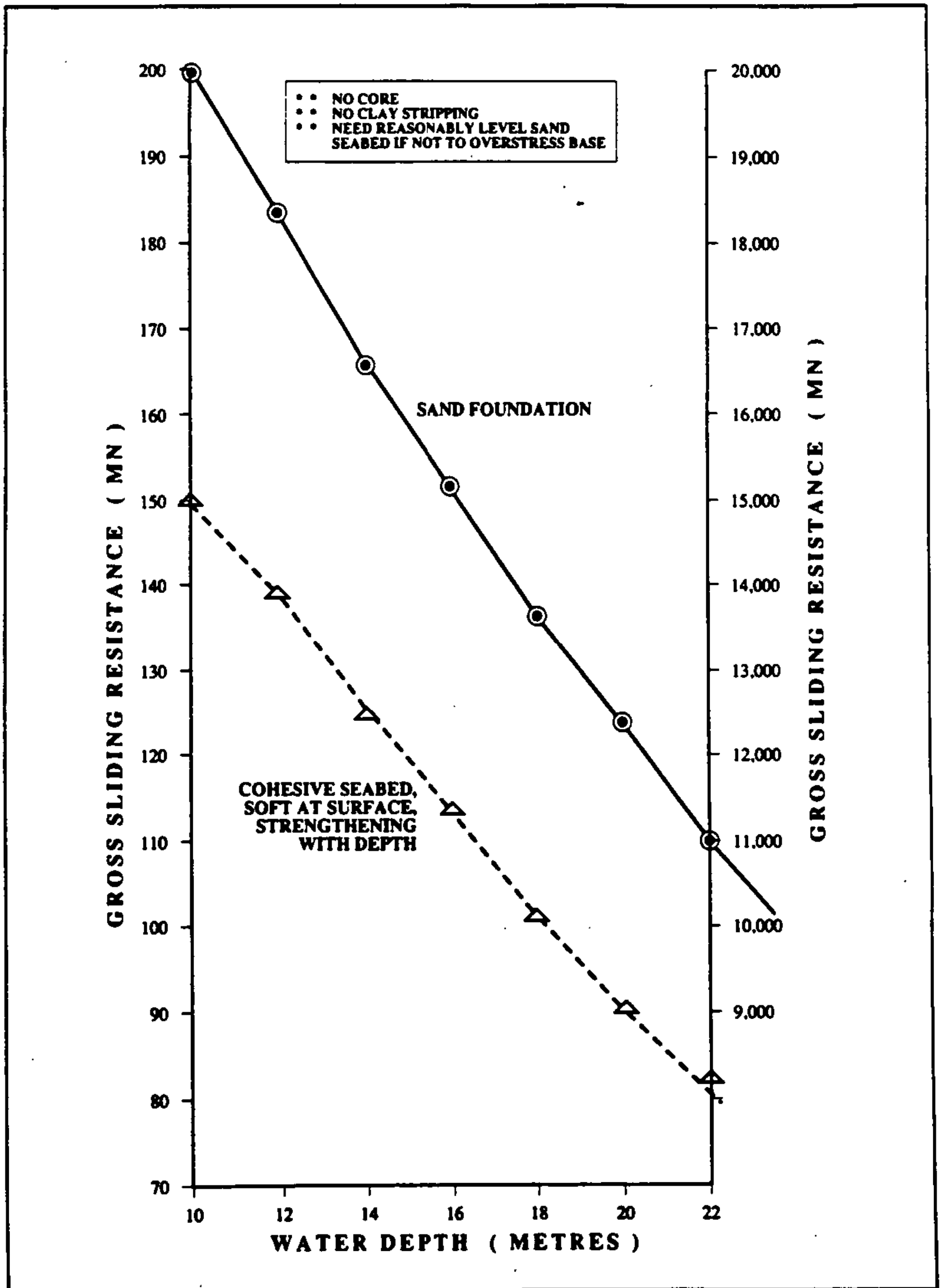
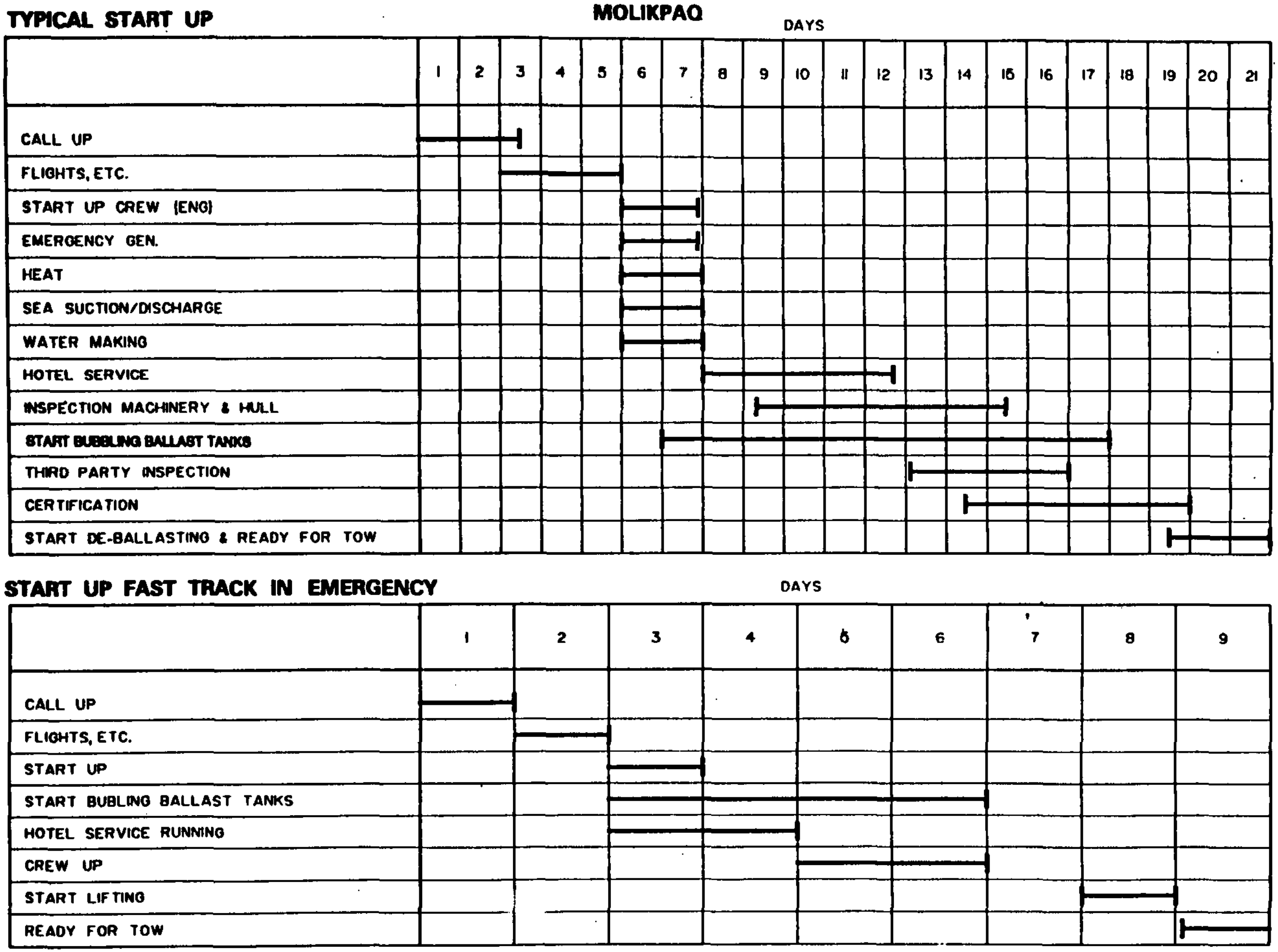


FIGURE 3.18 MOLIKPAQ'S RESISTANCE AS A FUNCTION OF WATER DEPTH



Operating Seasons for Drilling Systems

Drilling Systems

FIG[redacted] 3.1[redacted]MOL[redacted]Q C[redacted] ST[redacted]–UP[redacted]HEDULES

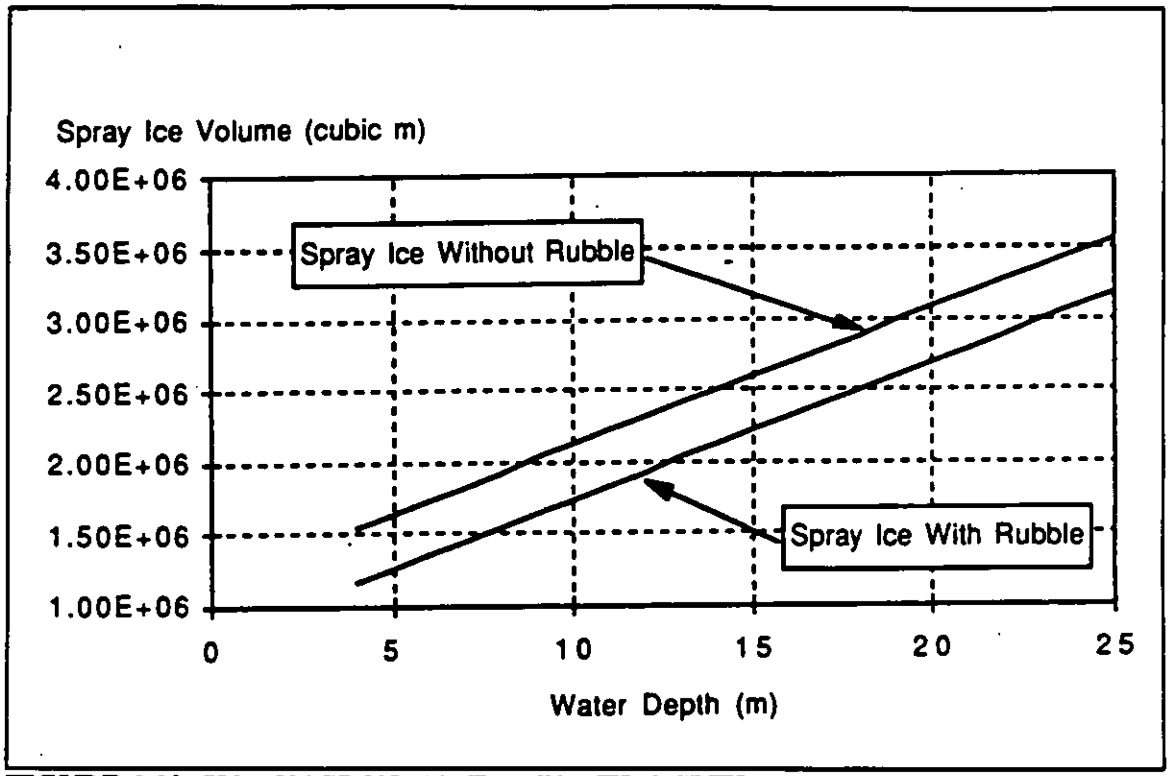


FIGURE 3.20 SPRAY ICE VOLUME vs WATER DEPTH

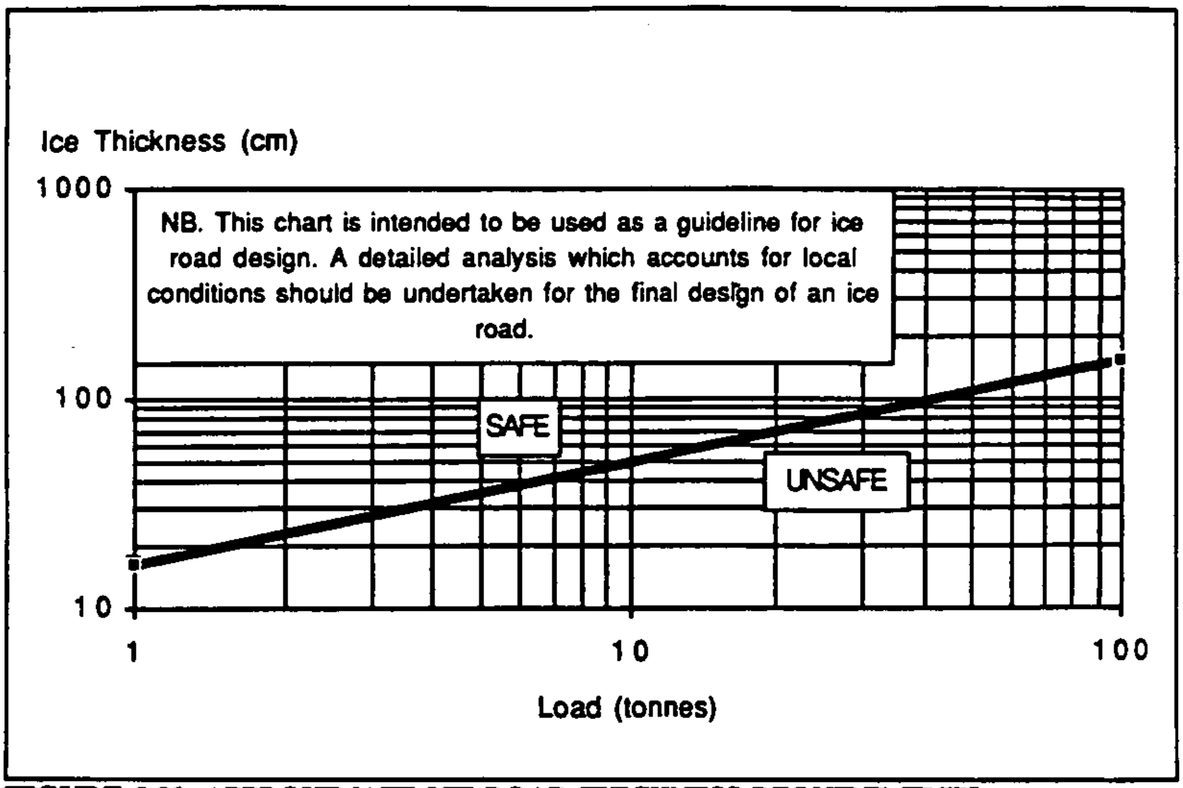


FIGURE 3.21 APPROXIMATE ICE ROAD THICKNESS REQUIREMENTS

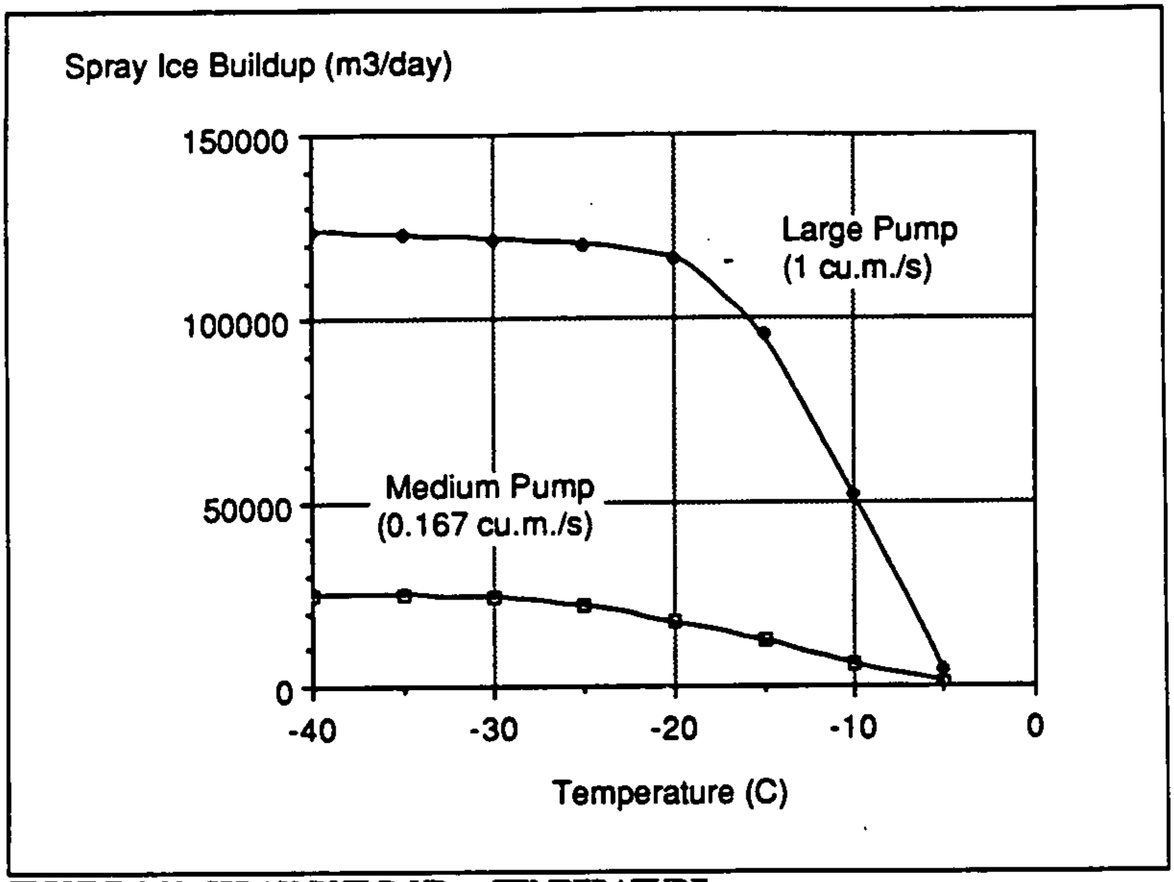


FIGURE 3.22 SPRAY BUILD-UP vs TEMPERATURE

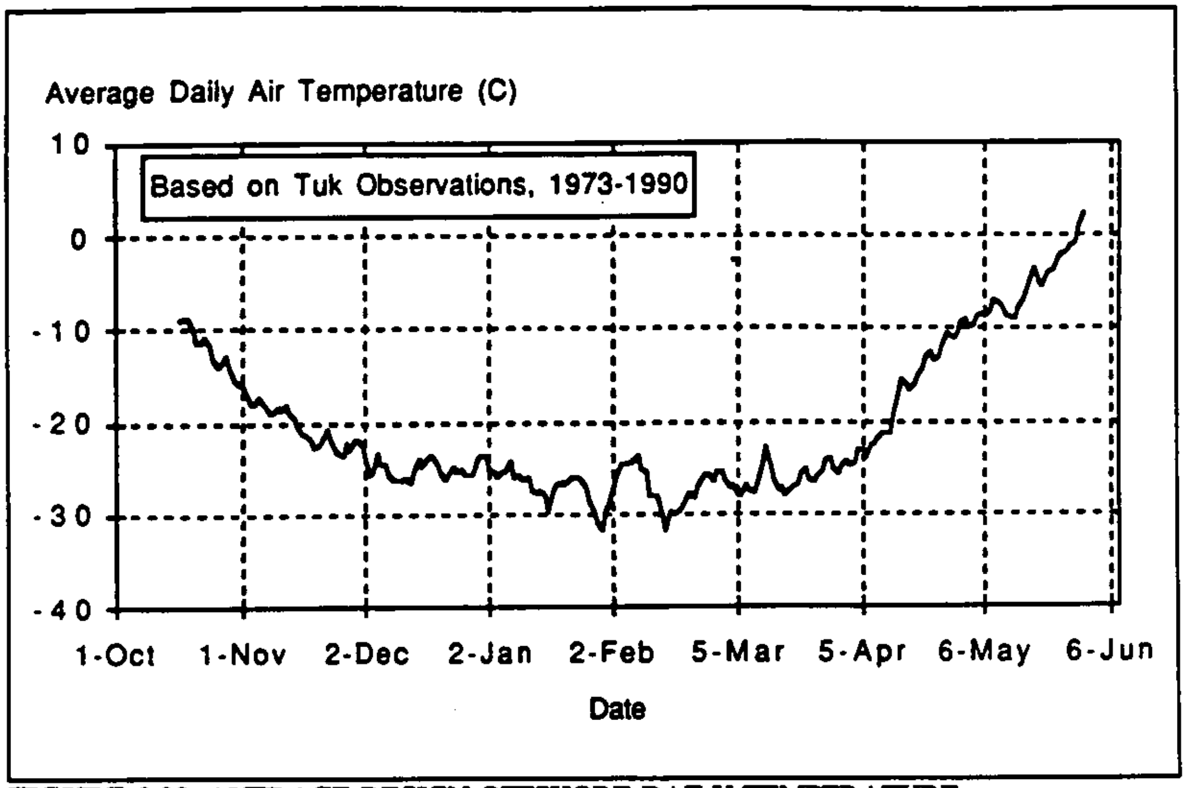


FIGURE 3.23 AVERAGE DESIGN OFFSHORE DAILY TEMPERATURE

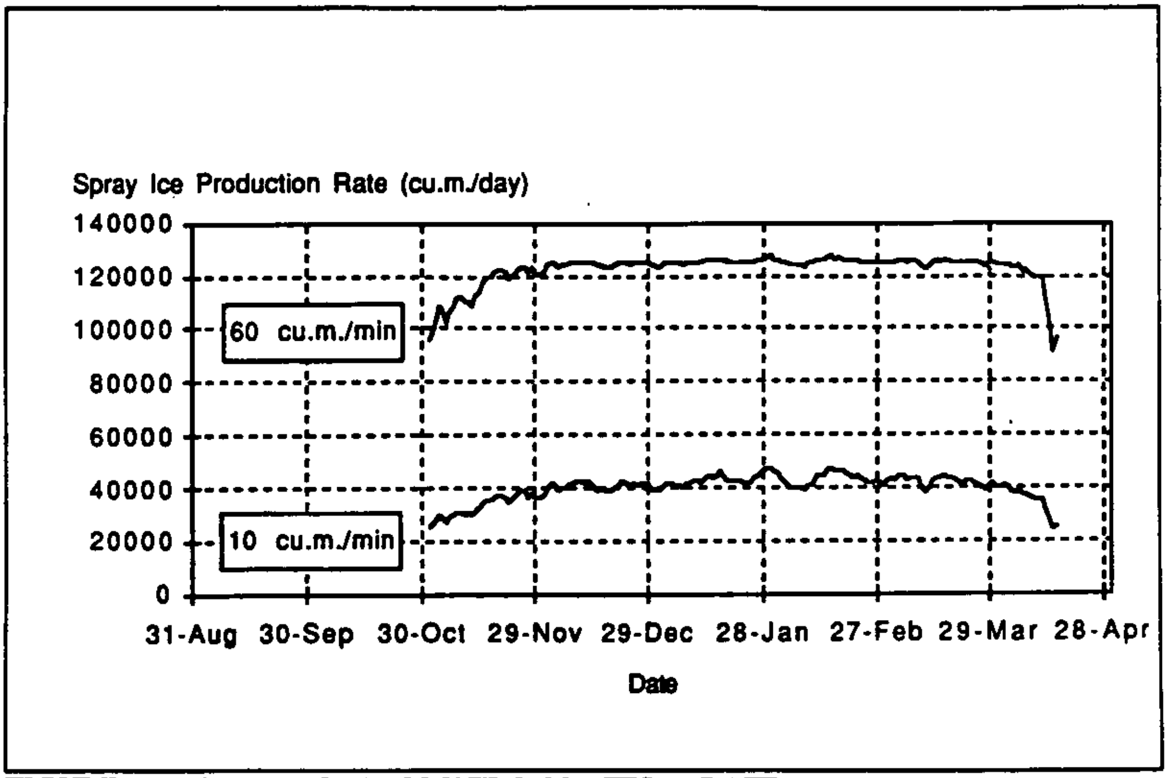


FIGURE 3.24 SPRAY ICE PRODUCTION RATES vs DATE

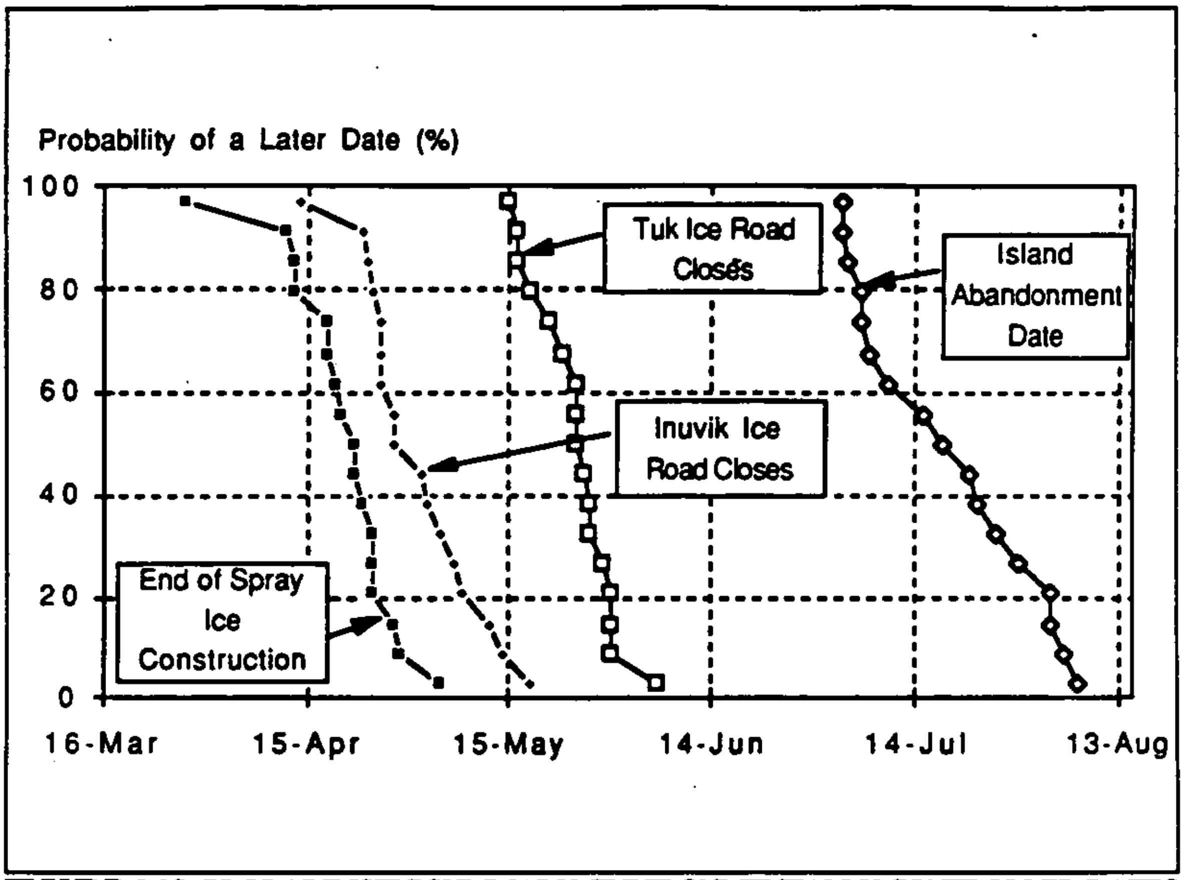


FIGURE 3.25 PROBABILISTIC SUMMARY: ENVIRONMENTALLY CONTROLLED DATES

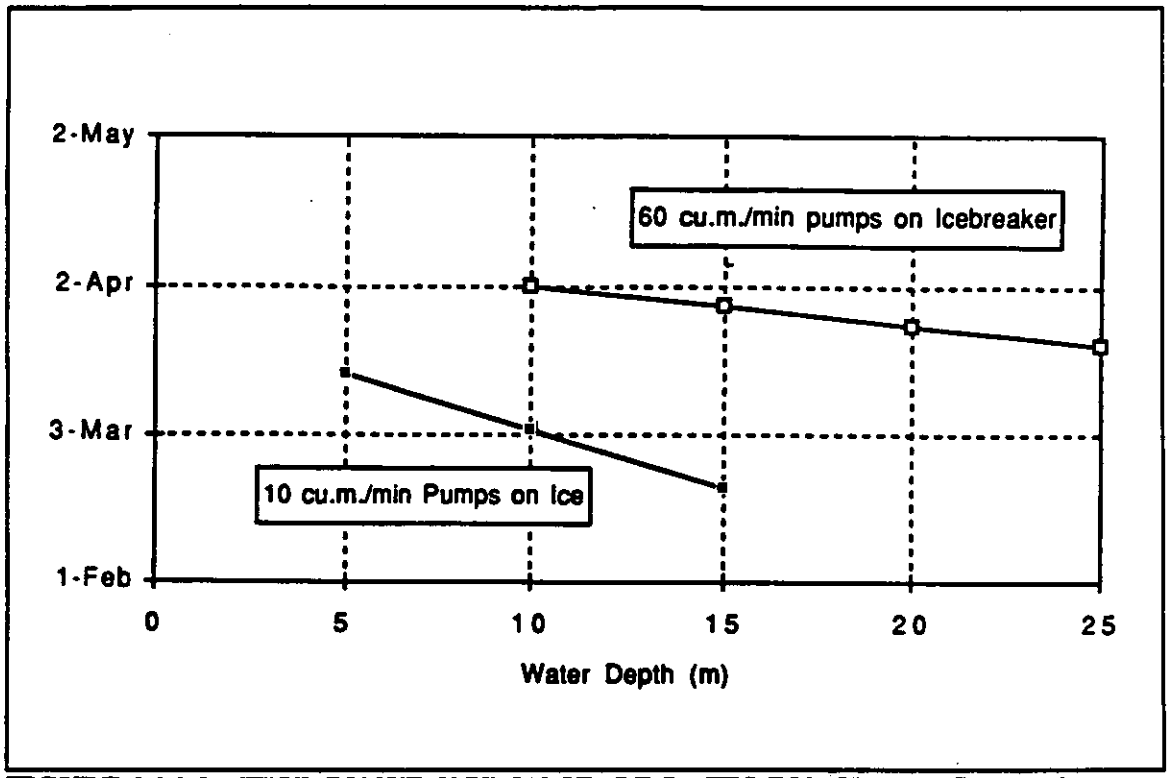


FIGURE 3.26 LATEST CONSTRUCTION START DATES FOR SPRAY ICE PADS

REFERENCES

1 Stirling, I & Cleatro, H., Canadian Wildlife Service Paper #45, 1982

2 Weaver, J.S. and Gregor, L.C., 1988. "The Design, Construction and Verification of the Angasak Spray Ice Exploration Island". 7th Int. Conf. on OMAE, Feb 7-12, 1988, pp177-183. (FULL PAPER IS ENCLOSED AS APPENDIX F)

3 Funegard, E.G., Nagel, R.M. and Olsen, G.G., 1987. "The Design and Construction of the Mars Ice Island" 6th Int. Conf. on OMAE, Mar 1-6, 1987, pp25-32.

4 Sayed, M., 1987. "Mechanical Properties of Model Ice Rubble", Structures '87 Proceedings, ASCE, Orlando, Florida, Aug 17-20, 1987, pp647-659.

5 Weaver, J.S., 1988. "Design of Nipterk P-32 Spray Ice Island", Internal ERCL proprietary report, ERCL.RS.88.17, 49p.

6 Spedding, L.G., 1974. "Growth and Extent of Landfast Ice in the Southern Beaufort Sea". IPRT-19ME-74, ERCL proprietary report.

7 Spedding, L.G., 1975. "The Extent and Growth of the Pattern of Landfast Ice in the Southern Beaufort Sea, Winter 1973/74". IPRT-10ME-75, ERCL proprietary report.

8 Spedding, L.G., 1976 "Spring Break-up in the Mackenzie Delta and Southern Beaufort Sea in 1974". IPRT-3ME-76, ERCL proprietary report.

9 Spedding, L.G., 1976 "The Extent and Growth Pattern of Landfast Ice in the Southern Beaufort Sea, Winter 1974/75" . IPRT-10ME-76, ERCL proprietary report.

10 Spedding, L.G., 1978. "Landfast and Shear Zone Ice Conditions in the Southern Beaufort Sea, Winter 1975/76" . IPRT-38ME-78, ERCL proprietary report.

11 Spedding, L.G., 1979. "Landfast and Shear Zone Ice Conditions in the Southern Beaufort Sea, Winter 1977/78". IPRT-16ME-79, ERCL proprietary report.

12 Spedding, L.G., 1980. "Southern Beaufort Sea Ice Conditions in the Vicinity of Issungnak 0-61, Winter 1978/79". IPRT-ME-80-14, ERCL proprietary report.

13 Spedding, L.G.,1982. "Southern Beaufort Sea Ice Conditions, Winter 1979/80". IPRT.ME.82.04, ERCL proprietary report.

14 Spedding, L.G., 1983. "Sea Ice Conditions in Vicinity of Beaufort Sea Drilling Locations, Winters 1980/81 and 1982/82". IPRT.ME.83.07, ERCL Proprietary Report.

15 Spedding, L.G., 1984. "Ice Conditions in the Vicinity of the Itiyok I-27 Artificial Island, Winter 1982/83". ERCL.RS.84.10, ERCL proprietary report.

16 Spedding, L.G., 1985. "Ice Conditions in the Vicinity of Kadluk H-08 Artificial Island, Winter 1983/84". ERCL.RS.85.07, ERCL proprietary report.

17 Spedding, L.G., 1986. "Southern Beaufort Sea Ice Conditions, Winter 1984/85 Amerk 0-09 and Nipterk L-19". ERCL.RS.86.03, ERCL proprietary report.

18 Spedding, L.G., 1987. "Southern Beaufort Sea Landfast Ice Conditions, Winter 1985/86". ERCL.RS.87.03, ERCL proprietary report.

19 Lussenburg, Y.L., 1990. "Landfast Ice Conditions in the Southern Beaufort Sea, Winter 1986-1987". Proprietary report to ERCL prepared by Micep Consulting Inc.

20 Lussenburg, Y.L., 1990. "Landfast Ice Conditions in the Southern Beaufort Sea, Winter 1987-1988". Proprietary report to ERCL prepared by Micep Consulting Inc.

21 Lussenburg, Y.L., 1990. "Landfast Ice Conditions in the Southern Beaufort Sea, Winter 1988-1989". Proprietary report to ERCL prepared by Micep Consulting Inc.

22 Weaver, J.S., 1990. "Assessment of Molikpaq Stability After Final Verification Program". Proprietary ERCL report ERCL.RS-TM.90.01.

23 Poplin, J.P., 1990. "Nipterk P-32 Spray Ice Island Ablation Protection Experiment". Proprietary ERCL report ERCL.RS.89.24.

24 Petrie, D.H., 1984. "Spray Ice Barrier Field Test Construction Report". Proprietary Report EPR.103PS.84.

25 Canmar, 1990. Personal Communication with Gary Price and Mel Walsh, November 5, 1990.

26 Weaver, J.S., 1990. "Field Investigation of Spray Ice Spraying Techniques". Proprietary ERCL report in preparation.

27 Weaver, J.S. and Gregor, L.C., 1988. "The Design, Construction and Verification of the Angasak Spray Ice Exploration Island". 7th Int Conf on OMAE, Houston, Texas, pp177-183.

28 Weaver, J.S., 1988. "Design of Nipterk P-32 Spray Ice Island". Proprietary ERCL report ERCL.RS.88.17.

29 Jahns, H.O. and Petrie, D.H., 1986. "CIDS Spray Ice Barrier". 18th Annual OTC, pp 575-584.

30 Blanton, L.B., Chen, A.C.T., Gram, K.G. and Jahns, H.O., 1986. "Spray Ice Mound Field Test Orion Site". Proprietary EPRCo Report EPR.53PR.86.

4.0 DRILLING OPERATIONS

4.1 General

This section deals with the factors involved with deciding where to position the surface location of the relief well and the drilling operations required to successfully control the blowout and abandon the wells.

4.2 Surface Offset

4.2.1 Factors Involved

The surface offset of a relief well will be dictated by a variety of considerations that cannot be accurately predicted in advance. Atmospheric conditions existing at the blowout location, prevailing winds, local gas levels and radiant heat, will affect the number of operating days on location as well as the safety of the personnel. Movement of an oil slick affected by prevailing winds and current as well as any need for other vessels working in the area may play a role in selecting the offset location. Operational considerations such as; anchor patterns, directional drilling, and shallow hazards will also have an effect on selecting the surface location.

4.2.2 Blowout Gas Levels

An understanding of the behaviour of a gas plume resulting from a blowout is critical to a successful relief well operation. During years of normal prevailing winds, computer gas plume modelling suggests the relief well be located northwest of the blowout (*Ref. 1*). Changes in local ice conditions have been known to affect prevailing winds offshore. During a gas blowout, current wind conditions will be studied, maximum acceptable gas levels determined and entered into the decision process. Several industry accepted models are available to predict plume behaviour for surface blowouts (*Ref. 2*). These models predict a maximum reduction in overall effective operating time of the relief well of less than 5%. One important mitigating factor in a subsea blowout, which is not a factor in a surface blowout, is the dispersion of the gas as it rises through the water column. In fact, during recent examples of offshore gas blowouts, with the relief well being drilled by a floater, there has been no time lost due to high gas levels. The amount of time expected to be lost due to blowout gas levels is insignificant in terms of the other factors considered in this study (e.g. ice downtime). Therefore this factor is disregarded.

4.2.3 Radiant Heat & Ice Island Construction

Igniting the gas resulting from a blowout would not affect relief well operations from a floating rig or bottom founded MODU. During calm conditions approach distances down to 200 metres could be made without protective clothing. For example, the Lodgepole blowout in western Alberta burned 7,000 BOPD and 50 MMCF/D of gas while operations were conducted 250 m away from the wellhead without protective clothing (*Ref. 3*).

Constructing and drilling a relief well from an ice island may be affected by radiant heat from the blowout. The degree of this effect can be determined through temperature measurements near the flare site or by calculations of radiant heat based on known oil and gas flow rates at the time.

By way of example, the offset well to the Panarctic King Christian blowout had an AOF[1] of 400 MM ft^3/day. The exact flow rate of the blowout is unknown, however it is believed to be similar to the offset well. Ice and snow melted in a 240 to 300 metre radius around the flare. In view of this data an ice island could be safely constructed beyond a 300 metre radius.

4.2.4 Oil In the Vicinity of the Relief Well Site

Initial oil to surface would be affected primarily by water current; surface winds play a minor role in directing an oil slick. Computer modelling shows that within a very short period of time any slick would completely encompass the blowout site (*Ref. 4*). This oil does not represent a significant problem to drilling operations. Should it be deemed a potential safety problem clean-up operations could be concentrated in this area. For these reasons, an oil slick is not viewed as a critical factor in determining the relief well offset location.

The relief well drilling vessel would be unaffected by small amounts of oil entering the seawater intakes as they are located well below sea-level. Heat exchanger efficiency may be reduced slightly due to oil coating the heat exchanger plates, however, the present cooling capacity exceeds the amount required for normal drilling operations and would not be unmanageable.

The potable water making system would be shut down in the unlikely event that oil is detected at the water intakes. The Kulluk, the drillships, the SSDC/MAT and the Molikpaq all have fresh water storage capacity for at least four days of normal operations. This may be stretched to 10 to 12 days through rationing. The drilling units are also capable of taking fresh water from supply vessels. An ice island would have on-site storage capacity for fresh water which could be resupplied by truck.

The design of the cooling system on the drilling units and fresh water storage capacity will prevent the occurrence of oil in the seawater intakes from impacting the relief well operations.

4.2.5 Anchor Pattern and Anchor Handling Operations

The Kulluk and the drillships could be successfully moored at a relief well location without being unduly affected by the blowout. In the case of a floating MODU, the surface offset location would likely be located 500 to 750 metres from the blowout.

4.1 Absolute Open Flow - The potential flow rate of the well with no back pressure.

The Kulluk is moored with 12 anchors. In 40 m of water the optimum distance to place the anchors is about 850 m from the rig. Since the normal radial anchor pattern is evenly spaced, the angle between anchors is 30 degrees. However, two of the anchors may be spaced up to 44 degrees apart and still retain 95% of the maximum mooring load capacity. By spreading two of the anchors and thereby "straddling" the blowout the distance between the anchors and blowout can be maximised. Drillships use a radially deployed 8 anchor system which results in a normal 45 degree spacing.

For example, if the Kulluk is the relief well drilling system for a blowout in 40 metre of water, and the surface location of the relief well is 500 m from the blowout, then the nearest anchors would straddle the blowout and be 130 to 240 metres on either side. During deployment, the anchors handling vessels would be able to maintain an even greater separation distance from the blowout, thus not affecting their operation.

The Kulluk was successfully moored at the Immugiak A-06 location, at a distance of 700 metres from the Immugiak N-05 gas boil.

4.2.6 Directional Drilling

In determining the surface offset, consideration must also be given to the trajectory of the original well. A blowout may have occurred where a well was directionally drilled downwind of the prevailing winds. If the relief well were placed upwind of the gas boil, it may be physically impossible for the relief well to intersect the original wellbore. In this instance, the relief well could be located a greater distance downwind and drilled directionally into the original wellbore. Although the relief well may be located at a less than optimum position, it will have a minor effect on overall relief well drilling efficiency.

4.2.7 Shallow Hazards

Site surveys are required as a normal part of the DPA process. The minimum grid coverage is 2 kilometres square although it is usually considerably larger. The site survey will normally more than adequately cover the anticipated relief well area. It provides the data for a re-evaluation of the anchoring conditions in the case of a floating unit, or the bathymetry in the case of a bottom founded unit.

Shallow seismic from the site survey along with the well history of the blowing well can be used to determine the location of any shallow gas within the proposed relief well area. This same information can be used to predict the permafrost base to help design the casing program.

4.3 Drilling Operations: Spud to TD

4.3.1 General

This section reviews the time dependent considerations involved in the drilling of a relief well. One of the key factors in planning a relief well is the knowledge gained from the original well. By examining the original well, the relief well program can be designed to maximize drilling efficiency. A drilling time model was used to assist in comparing the drilling time of an initial well to the comparable time needed for a relief well. A factor has thus been established to estimate the time required to drill a relief well at any stage of the initial well. This drilling time factor can then be used in the methodology to establish the end of risk drilling date as described in Section 6.

4.3.2 Drilling Time

Methodology: In utilizing the drilling time modelling program, a hypothetical scenario was chosen that was representative of the type of situation which would require a relief well. This scenario envisages a blowout drilled from a floating MODU which requires the mobilization of an alternate relief well unit and the drilling of a relief well.

The major operational factors which impact the relief well drilling time are:

- Relief Well Directional Plan
- Rate of Penetration
- Control Drilling
- Pilot Holes
- Casing Design
- Formation Evaluation
- Detection of the Blowing Wellbore

In conjunction with these factors, three major assumptions have significant effects on the times generated by the model. Although these three key factors are assumptions in this hypothetical case, they would be known factors in a real situation.

1. **Depth of Intersection**
   For development of the model, a TD[2] of 3500 meters was assumed, with the relief well intersect occurring at TD. This approximates a Kugmallit formation well in the Amauligak area and also corresponds to the approximate 244mm casing setting depth in normally pressured areas, such as Amauligak.

4.2 Total Depth

The selection of this TD provides a conservative influence on the relief well drilling time factor. If a deeper TD had been selected, further evaluation time would exist in the original well, which would be removed from the relief well. Also, should a blowout occur below the 244mm casing shoe, an off bottom kill becomes a possibility. The possibility of killing[3] a well by intersecting above TD, would serve to further reduce the relief well drilling time.

Refer to section 4.4 for further information on criteria for establishing the depth of intersection.

2. **Surface Offset**
   The directional plan utilized for the relief well model was based on a surface offset of 750m. For further discussion on surface offset refer to section 4.2

3. **Estimated Time For Initial Well**
   The time estimates used in the initial well model are based on historical Beaufort Sea drilling data (*Ref. 5*) and therefore provide the best possible starting point for determining the relief well drilling time. The times utilized for each function of the drilling operation are listed in Table 4.3 (at end of section). All standard operation times common to both the initial well and relief well have been kept constant to provide a valid comparison.

By examining each factor under these three key assumptions the expected time to drill the relief well can be determined and compared to the original well. The following discussion focuses on each factor independently.

Directional Planning: The directional plan for a relief well is dependent on the surface offset and the depth of intersection. Most relief wells are drilled utilizing an "S-curve[4]" vertical profile. In some shallow blowout cases a "build and hold[5]" profile must be used; in these circumstances, less time would be needed than for the modeled case.

The relief well model utilizes the S-curve technique, this is illustrated on Figure 4.2. With a kick off[6] point below the 508mm casing at 800m, and 2.5 deg/30m build[7] and drop rates, the relief

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4.3 Killing the well refers to controlling the flow in the original well.

4.4 In order to reach the wellbore of the original well the relief well must bend towards it. An "S-curve" technique means that the well is first deviated towards the original well and is then curved to a more vertical profile for intersection, sort of a flattened "S" shape.

4.5 This technique first increases deviation towards the original well until a certain deviation is achieved and then this deviation is held constant.

4.6 Depth at which deviation begins. The well is vertical until this point.

well approaches the blowing well prior to the 340mm casing point at 2400m TVD[8]. Initial detection of the blowing well can then be made prior to setting the 340mm casing. Following initial detection the positions of the two wellbores relative to each other are known, and from this point the relief well will parallel the blowout well to the intersection point.

With current directional drilling equipment and technology, the relief wellbore position and trajectory can be controlled well within the tolerances required to achieve intersection. Experience in Alaska (*Ref. 6*) has verified the ability to kick off in the permafrost zone using conventional technology. No special operational problems have been experienced while kicking off and building angle in permafrost.

Rate of Penetration (ROP): To justify a correlation between the rates of penetration in a vertical wellbore to those of a directional wellbore in the Beaufort area, a comparison was made between four Amauligak wells (*Ref. 7*); two vertical (J-44 & O-86) and two directional (I-65A & 2F-24). As the extended reach directional parameters of the Amauligak wells result in much longer departures than necessary for a relief well to reach the same TVD, the analysis was based on equivalent measured depths for all four wells.

A comparison of cumulative rotating time versus measured depth (Figure 4.1), indicates a decrease in ROP for the directional wells in only the 444.5mm hole section. The additional rotating hours in the 444.5mm hole section are the result of pilot hole drilling. Directional drilling technology has since eliminated the need to drill directional pilot holes in 444.5mm hole.

Averaging the total rotating hours required for the two directional wells and comparing this to the O-86 vertical well, it can be concluded that penetration rates are not affected by directional drilling in the Amauligak area up to angles of 45 degrees. The J-44 well was not included in this comparison because of higher mud densities than the other wells.

Amauligak J-44, while removed from the above comparison due to a higher mud density and subsequently lower penetration, serves as an excellent example of the manner in which relief wells would be drilled because of optimization of penetration rates. J-44 was the initial well drilled on the Amauligak structure, and as such, geologic sequences and pore pressure regimes were encountered for the first time. The three subsequent wells drilled (O-86, 2F-24, and I-65A), show a substantial decrease in rotating time as a result of optimizing drilling mechanics in a known geology and pore pressure regime. Averaging the total rotating hours for the later three wells and comparing them to J-44, it is evident that a 43% reduction in rotating time was achieved.

4.7 The inclination increases 2.5 degrees every 30 metres of drilling.

4.8 True Vertical Depth

In the relief well model, a conservative approach was taken with regard to penetration rates. Penetration rates below the 508mm casing point have been increased by 25%, to reflect knowledge gained from the initial well, and optimization. This is conservative when compared to the 43% saving at Amauligak. In addition no increase in ROP was made for the pilot hole sections. Penetration rates while directional drilling in an oriented mode[9] have been reduced by 20%. The penetration rates utilized in the model are shown in Table 4.3 "ROP Summary".

Control Drilling: As most proposed drilling in the Beaufort Sea is exploratory drilling, significant amounts of time are spent control drilling. Penetration rates are deliberately reduced to allow for better interpretation of samples and evaluation of pressures. When drilling a relief well, the geology and pore pressure regime will be known and control drilling practices will not be required.

To account for control drilling time, the model includes a circulating time of 1.5 hole volumes/50m from the 762mm casing point to the TD of the original well. This circulating time was removed from the relief well model.

Pilot Holes: It is common practice in the Beaufort Sea to drill pilot holes in both the 914mm and 660mm hole sections. One of the purposes of a pilot hole is to reduce the risk involved in drilling potential shallow hazards. With the information gathered from the original well, in conjunction with shallow seismic interpretation, site selection for the relief well would in most instances eliminate the need for pilot hole drilling.

In the model, pilot hole drilling was removed from the relief well. This results in a 3.57 day, or 10.4%, reduction in the total drilling time.

Casing Design: For this evaluation, standard casing setting depths for a normally pressured, 3500m, Amauligak type well have been utilized. The casing programs for both the initial and relief wells are listed on Table 4.3 and illustrated in Figure 4.2. For comparison purposes, the relief well casing setting depths down to the 244mm casing are at the same vertical depths. The 244mm casing in the relief well will be set 50m above the point of intersection to provide the maximum possible formation integrity for the kill operation. In actuality, the relief well casing design will be optimized based on the pore pressure data from the initial well.

In developing the model, additional time was included for the setting of the 244mm casing string in the relief well, as it will be set above TD.

4.9 Oriented mode refers to the process by which the hole direction is changed.

Formation Evaluation: During the drilling of every well geologic information is obtained through evaluation techniques including; wireline logging[10], conventional and sidewall coring, and drillstem testing. The evaluation requirements vary widely from one location to the next, and from operator to operator. The reduction in relief well drilling time and its subsequent effect on the relief well drilling time factor must therefore be considered on a site specific basis.

To demonstrate the general impact that formation evaluation has on drilling time, an analysis of nine wells (past and proposed) in the Beaufort Sea/MacKenzie Delta area indicated an average of 14% of the total drill and case time is spent on logging alone. During the drilling of a relief well, evaluation requirements would be restricted to detection of the blowing wellbore. With present MWD[11] capability; Neutron, density, resistivity, and gamma ray information is available while drilling thus establishing geologic control without the need for wireline logging.

In generating the initial well drilling time model a conservative approach was taken in establishing the evaluation time. Only the time associated with a minimal logging program at casing points above TD was included in the initial model; this amounts to 9.9% of the time *required* to reach TD.

Formation evaluation time was removed from the relief well model. In cases where a deeper TD or a more extensive evaluation program existed, the formation evaluation impact would be to lower the ratio of the time required to drill the relief well compared to the original well, thus making the time estimate for the relief well more conservative.

4.3.3 Detection of the Blowing Wellbore

Wellbore Detection Tools: The state of the art in the tracking and intersection of a blowout wellbore permits a relief well to be drilled in a single pass (*Ref. 8 & 9*). There are currently two types of tools available that are capable of performing this function, Vector Magnetics' Wellspot tool and Tensor's Magrange tool. Both tools utilize magnetics to determine range and direction when seeking out casing or drill pipe in the blowout well. Initial detection can be obtained at distances up to 70m in good conditions. Initial detection was made on the first run at a distance of 60m during the drilling of a relief well at Boundary Lake, British Columbia in 1986 (*Ref. 10*). Following initial detection the tool would be rerun each time the distance to the target is halved to decrease the uncertainty and maintain a safety margin for drilling. In a typical relief well situation, three detection runs and a contingency run would be planned, at distances of 60m, 30m, and 15m from the blowout wellbore. When within 10m of the blowout wellbore, the tool can be

4.10 Method of measuring formation characteristics by way of instruments run into the wellbore.

4.11 Measurement While Drilling

run in non-magnetic drill collars, similar to the way a single shot survey tool is run. This mode of operation is utilized to assist in tracking the blowout wellbore and making the final intersection.

The tools are run on *standard* electric wireline. Station stops of one minute are made every 7 to 15 m. Rough analysis of the data for BHA[12] selection is available instantaneously, and detailed analysis can be completed within two hours (before the drilling assembly is back on bottom).

Running times for a typical relief well would be as shown in Table 4.1.

TABLE 4.1
WELLBORE DETECTION TOOL RUNNING TIMES

RUN #	INTERVAL (m)	WELLBORE SEPARATION	STATIONS	RUNNING TIME	COMMENTS
1	2200-2400	60 m	10 m	2.9 hrs	Initial Detection
2	2400-3000	30 m	10 m	3.9 hrs	
3	3000-3450	15 m	10 m	4.0 hrs	
4	3500	<10 m	nil	2.2 hrs	Run in drill pipe
Note: Running time includes 1 hour of rig-up & rig-down time per run.					

In the relief well model, 4 hours each have been allocated for runs 1 and 3, which would take place at the 340 mm and 244 mm casing points. In the case of run 2, where the drillstring must be tripped out during of the 311 mm hole section, 16 hours have been allocated.

On a relief well, gyro surveys would be conducted at each casing shoe prior to detection of the blowing wellbore to reduce the cone of uncertainty in the relief wellbore.

Current gyros can operate in both an earth rate mode and a fixed high speed mode. The earth rate mode is utilized at inclinations up to 15 degrees. At inclinations greater than 15 degrees operating in the fixed high speed mode reduces the errors associated with high angle directional surveying.

Gyros are run on standard electric wireline. Station stops of 2 minutes/station are made while operating in the earth rate mode. When switching from earth rate to high speed mode a 5 to 15 minute period is required for tuning. Running speed while operating in the high speed mode is 40m/minute. Surface analysis of the data is available as the tool is being run. Running times for a typical relief well would be as indicated in Table 4.2.

4.12 Bottom Hole Assembly, bottom part of drillstring

TABLE 4.2
GYRO SURVEY RUNNING TIMES

CASING DEPTH	CASING SIZE	OPERATING MODE	STATIONS	RUNNING TIME
800 m	508 mm	Earth Rate	10 m	4.0 hrs
2500 m	340 mm	Earth Rate/Fixed	10 m	5.7 hrs
4000 m	244 mm	Earth Rate/Fixed	10 m	6.5 hrs
			TOTAL	16.2 hrs
Note: Running Time includes 1 hour of rig-up & rig-down time per run.				

In the relief well model, time was allocated to run gyro surveys at the 508mm and 340mm casing shoes. The run at the 508mm shoe is utilized to establish a starting position for the initial directional work. The run at the 340mm shoe is to confirm the relative positions of the two wellbores following initial detection.

4.3.4 Drilling Time Summary

Utilizing the factors previously discussed and listed in Table 4.3[13], drilling times for the initial well and subsequent relief well have been generated. The times have been generated by hole section and general operation and are shown in Table 4.4. They appear as drilling time curves in Figure 4.3.

The total drilling time required to reach TD on the initial well is 34.23 days. The total drilling time required to attain intersection with the initial well at TD for the relief well is 27.92 days. By dividing the relief well drilling time by that of the initial well, a relief well drilling factor of 0.8 is attained.

There are many variables that effect the evaluation of a relief well drilling time factor: The directional plan, ROP's, control drilling, pilot holes, casing design, formation evaluation, and detection of the blowing wellbore. Each of these variables are very site specific leading to the potential for a varied range of relief well drilling time factors. However, a factor of 0.8 is realistic and the assumptions made to arrive at this value are conservative.

4.13 Tables 4.3 and 4.4 are located at the end of this section.

4.4 Well Control

4.4.1 Kick and Blowout Control Philosophy

In oil well drilling operations, well control procedures have been developed and standardized to control the influx of formation fluids into a wellbore. Training for all drilling supervisory positions on the rig from the driller to the rig manager include the requirement to demonstrate the ability to circulate out such an influx on either an actual well or a well control simulator. The most commonly used well control methods are;

- **Wait and Weight Method:** Utilized when an increase in fluid density is required to control bottom hole pressure. The well is left shut in while the kill fluid is mixed and the influx is circulated out using this kill density fluid.

- **Drillers Method:** Utilized primarily when circulating: trip gas, gas show, a swabbed in kick, or when sufficient barite cannot be mixed into the system in a reasonable time. The drillstring must be on bottom to utilize this method. The use of the Drillers Method to kill a well involves two distinct steps. During the first step, the invading formation fluids are circulated out of the annulus using the original mud density. In the application of the second step, the well is killed by pumping a higher density drilling fluid into the well to replace the original fluid.

These standard well control methods are applicable only if the well can be shut in and thereby the influx of fluid into the well, and the expansion of gas in the well can be controlled.

As an extension to these well control methods, in the case in which the drillstring is still in the hole, and the capability to shut-in the well does not exist due to insufficient casing shoe formation strength or equipment failure, a diverter/low choke method of well control would be implemented. With this method of well control the formation fluid is diverted away from the rig while high density kill fluid (which is premixed on standby) is pumped down the well at maximum rate in an attempt to "out run the formation". This method of well control is successful in cases where the source of the influx is limited in extent, and in cases of low permeability where the influx rate is sufficiently low to allow the pumping equipment to outrun the formation influx.

The above methods of well control are considered to be standard, conventional methods of well control and applicable provided some degree of influx control is maintained (shut in or diversion). In the case of a blowout, where control was absolutely lost and the presence of the oil/gas at the drill site may have forced evacuation of the personnel and/or equipment from the site; the drilling of a relief well and utilization of unconventional well control methods would be required.

4.4.2 Intersection Depth; Dynamic and Overbalance Kills

The primary factor to be evaluated in relief well planning is the intersection depth where the relief well is to establish communication with the blowout wellbore. From the standpoint of minimizing the time required to drill the relief well, an intersection depth as shallow as possible in the hole is desired. The intersection depth is determined based on the well kill procedure and blowout factors such as; formation pressure, wellbore geometry, formation fluid properties, kill fluid properties, and blowout rate. In the kill operation, a combination of hydrostatic pressure developed by the kill fluid and the friction pressure of the flowing fluid in the wellbore, is used to balance the formation pressure at the point of the influx. The relative contribution of the dynamic and hydrostatic component of bottom hole pressure determine if the kill is termed a dynamic kill or an overbalance kill.

A **dynamic kill** is a kill operation in which the fluid used to perform the kill has a lower hydrostatic gradient than that required to statically kill the well. In a dynamic kill the friction pressure generated in the blowout wellbore is required to balance the formation pressure. Normally water is used to perform a dynamic kill as it is readily available.

An **overbalance kill** is a kill operation in which the fluid used to perform the kill has a higher hydrostatic gradient than that required to statically kill the well. In an overbalance kill, the kill fluid is pumped at a high rate to outrun the formation influx and minimize cutting of the kill fluid. The overbalance kill is what would be used in the diverter procedure described above.

The required pumping rate for a given kill fluid and intersect depth is calculated using a multi-phase flow simulator. The results of applying this simulator to several hypothetical blowout cases in the Beaufort Sea have provided the following observations[14].

Formation Pressure and Hole Size: Provided the pressure gradient at the blowout zone is normal, the dynamic kill is a viable option. Much of the Beaufort Sea contains minor to significant over pressure. When open hole diameter is relatively large, the friction pressure component is small and a dynamic kill utilizing sea water is operationally impractical in such cases. Pressure gradients in excess of 11 - 11.5 Kpa/m in the 311mm hole size and 17 - 18 Kpa/m in the 216mm hole section become impractical candidates for a dynamic kill using sea water. In these cases an overbalance kill would be more applicable.

Formation Fluid and Blowout Rate: The type of formation fluid and blowout flow rate has an impact on the minimum kill fluid pumping rate that is required to complete a dynamic or an overbalance kill. This is due to mixing of the kill fluid with the formation fluid. In the case of

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4.14 In the example described in this section an intersection at TD is assumed: this provides the most conservative estimate of relief well drilling time.

a high pressure dynamic kill, the rate needed to generate the required friction pressure most often exceeds the minimum rate required to out run the formation. In the case of a lower pressure gas blowout, the dynamic kill rates required to complete the kill would be dictated by the mixing concern rather than the friction pressure concern.

The observations indicate that a true dynamic kill using sea water is not always practical in the Beaufort Sea. The likely kill method of choice in this application would be a combination dynamic/overbalance kill. The initial fluid pumped would be water. This would be used to jet a sufficiently large flow path between the wellbores. Approximately 8,000 to 10,000 hydraulic horsepower would be mobilized to jet this flow path while decreasing the blowout rate. Having decreased the blowout rate, the final kill operation would be an overbalance kill using a high density kill fluid. Approximately 3 - 5 hole volumes of kill fluid would be required to complete the kill operation.

By utilizing such a combination, a trade off is made between hydraulic horsepower and liquid mud storage. Should less hydraulic horsepower be available more liquid mud storage will be required, and similarly if more horsepower is available less kill fluid storage will be required to complete the second stage of the operation.

4.4.3 Time Required to Complete the Kill Operation

The success of a dynamic or overbalance kill is highly dependent upon placing the relief well within the immediate wellbore area of the blowout. If the relief well directly intersects or penetrates the drawdown radius of the blowout wellbore, circulation would be lost and the kill operation would commence immediately. The high pressure differential between the relief well and the blowout zone would initiate and hydraulically jet a flow path through the unconsolidated sands present in Beaufort Sea reservoirs. If the near wellbore drainage area is not penetrated with the relief well, then stimulation may be required to initiate communication with the blowout well.

Upon drilling out the final casing shoe above the proposed intersection depth, the high pressure pumping equipment would be rigged up to pump down the annulus. As circulation is lost the annulus would be continuously filled from the top. Once direct communication is achieved, pumping of the initial fluid would begin. This pumping would likely continue for 2 to 4 hours until the blowout is dead or the flow rate noticeably reduced. Circulation of the final kill fluid would then commence and would require an additional 2 hours of pumping. Should stimulation (acid) be utilized an additional 6 to 8 hours would likely be required. The entire kill operation should easily be completed in one day.

4.5 Abandonment

Following completion of the kill operation both the blowout and relief well bores would be full of kill density drilling fluid. Upon confirming that both wellbores are under control, procedures for final abandonment would be implemented.

In most cases where re-entry of the blowout wellbore is not feasible, a plug would be pumped from the relief well unit, down the relief wellbore and into the blowout well. The plug volume pumped would be based on sealing the blowout well up to its last casing string. Consideration in this operation must be given to the possibility of losing circulation to the blowout zone. Following the plug setting operations, the wellbores would be monitored to assure that they remain dead, allowing the plug to develop strength thus providing a hydraulic seal of the blowout zone.

Following confirmation that the blowing zone is sealed routine suspension operations with bridge plugs and cement would be carried out at the relief well location as per COGLA regulations. Consideration should be given in this operation for the possibility of re-entering the relief well should any further problems develop with the blowout zone.

If re-entry of the blowout well is feasible at this time it would be abandoned in a routine manner with bridge plugs and cement as per COGLA regulations. These operations would likely occur with a second drilling unit, as such they would be carried out concurrently with the abandonment of the relief well.

It is estimated that abandonment of the relief well will require approximately 2 days.

TABLE 4.3
ORIGINAL WELL vs RELIEF WELL
INPUT TIME COMPARISONS

ITEM	ORIGINAL WELL	RELIEF WELL
WELL PROFILE		
Measured Depth	3500 mRT	3646 mRT
True Vertical Depth	3500 mTVD	3500 mTVD
Surface Offset	0	750 m TVD
Kick Off Depth		800 m TVD
Build Rate		2.5 deg/30m
Drop Rate		2.5 deg/30m
Tangent Section Angle		23.1 deg
CASING PROFILE		
Mud Line	40 mRT	40 mRT
762 mm Shoe	200 mRT	200 mRT
508 mm Shoe	750 mRT	750 mRT
340 mm Shoe	2400 mRT	2400 mRT TVD or 2523 mRT MD
244 mm Shoe	3500 mRT	3450 mRT TVD or 3596 mRT MD
ROP SUMMARY		
914 mm Hole Section		10 m/hr
Pilot Hole	15 m/hr	No Pilot Hole
Hole Open	15 m/hr	
660 mm Hole Section		10 m/hr
Pilot Hole	10 m/hr	No Pilot Hole
Under Ream	10 m/hr	
445 mm Hole Section	10 m/hr	12.5 m/hr
311 mm Hole Section	10 m/hr	12.5 m/hr
216 mm Hole Section		8.0 m/hr
Connection Time	5 min	5 min

TABLE 4.3 Con't
ORIGINAL WELL vs RELIEF WELL
INPUT TIME COMPARISONS

ITEM	ORIGINAL WELL	RELIEF WELL
DIRECTIONAL DRILLING		
% of Hole Drilled	Oriented	50
% of Hole Drilled	Rotating	50
Mud Motor ROP Efficiency		100%
Oriented ROP Efficiency		80%
WIRELINE LOGGING		
BGT	914 & 660mm Hole	None
Induction/SP	Below 508mm Shoe	None
Neutron Density	Below 508mm Shoe	None
Formation Micro Scanner	Below 508mm Shoe	None
Sonic	Below 508mm Shoe	None
RFT	Below 508mm Shoe	None
Side Wall Cores	Below 508mm Shoe	None
Max Time Between cleanout trips	24 hours	N/A
PROXIMITY LOGGING		
Gyro Survey		508 and 340 mm Casing Strings 4, 8 Hours
Wellbore Detection		3 Runs, 340 and 244 mm csg point and 244 mm OH 4, 4, 16 hours
OPERATING EFFICIENCY		
Wait on Weather/Ice	None applied	None applied

TABLE 4.3 Con't
ORIGINAL WELL vs RELIEF WELL
INPUT TIME COMPARISONS

ITEM	ORIGINAL WELL	RELIEF WELL
PIPE HANDLING		
Run/Pull Riser	6 hours 660mm Hole Drilled With Riser	6 hours 660mm Hole Drilled With Riser
Make up Wellhead	2 hours	2 hours
Make up Guide base	2 hours	2 hours
Prep BOP Stack	10 hours	10 hours
Make up SS Hanger	1 hour	1 hour
Set SS Hanger	1 hour	1 hour
Set SS Pack-off	1 hour	1 hour
Round Trip	1 hour/305m	1 hour/305m
Time on Bank	2 hours	2 hours
Directional Trip Factor		110%
HOLE CONDITIONING		
Circulating up Samples Background Gas, Ect.		
660 mm Hole Section	1.5 hole vol./50m	None
445 mm Hole Section	1.5 hole vol./50m	None
311 mm Hole Section	1.5 hole vol./50m	None
216 mm Hole Section		None
Wiper Trip Interval	24 hours or 150 m above 340 mm casing 300 m below 340 mm casing	24 hours or 150 m above 340 mm casing 300 m below 340 mm casing
Wiper Trip Length	To last trip	To last trip
Circulate Prior to Trip	1.5 hole volumes	1.5 hole volumes

TABLE 4.4
ORIGINAL WELL vs RELIEF WELL
DRILLING TIME COMPARISONS

OPERATION	ORIGINAL WELL (DAYS TO TD)	RELIEF WELL (DAYS TO TD)
914mm Hole Section		
Drilling (Single Pass)	N/A	0.81
Pilot Hole	0.61	N/A
Hole Opening	0.53	N/A
Formation Evaluation	0.25	N/A
Casing & Cementing	1.22	1.22
Total	2.61	2.03
660mm Hole Section		
Drilling (Single Pass)	N/A	2.85
Pilot Hole	3.22	N/A
Under Reaming	3.04	N/A
Formation Evaluation	0.99	N/A
Wellbore Detection	N/A	0.17
Casing & Cementing	2.48	2.48
Total	9.73	5.50
445mm Hole Section		
Drilling	9.90	8.50
Formation Evaluation	2.14	N/A
Wellbore Detection	N/A	0.50
Casing & Cementing	2.24	2.41
Total	14.28	11.41
311mm Hole Section		
Drilling	7.61	5.44
Formation Evaluation	N/A	N/A
Wellbore Detection	N/A	0.83
Casing & Cementing	N/A	2.43
Total	7.61	8.70
216mm Hole Section *		
Drilling	N/A	0.28
Total Time	**34.23**	**27.92**

* 50m below last casing point, to intersect blowout wellbore

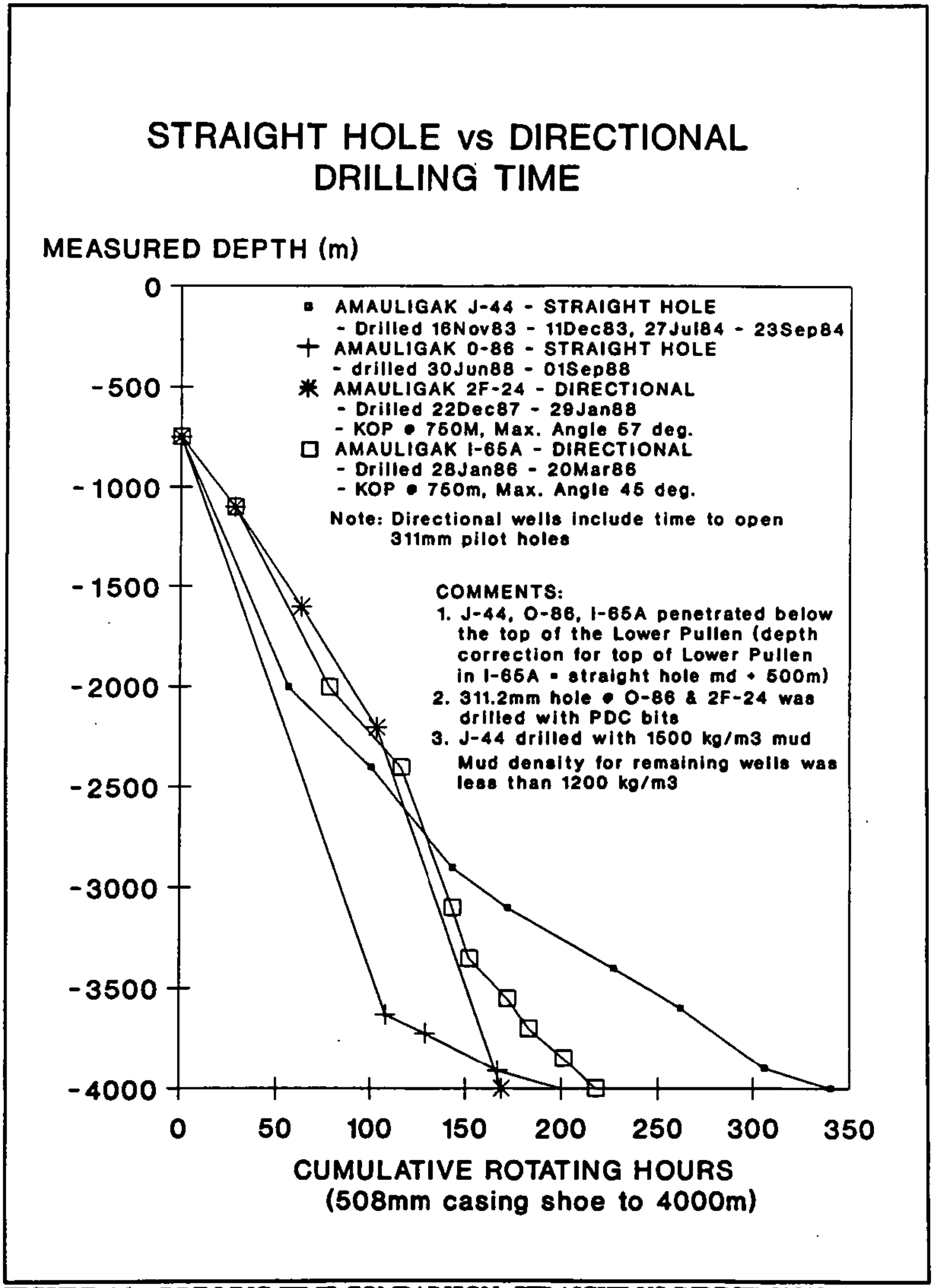


FIGURE 4.1 DRILLING TIME COMPARISON: STRAIGHT VS DIRECTIONAL

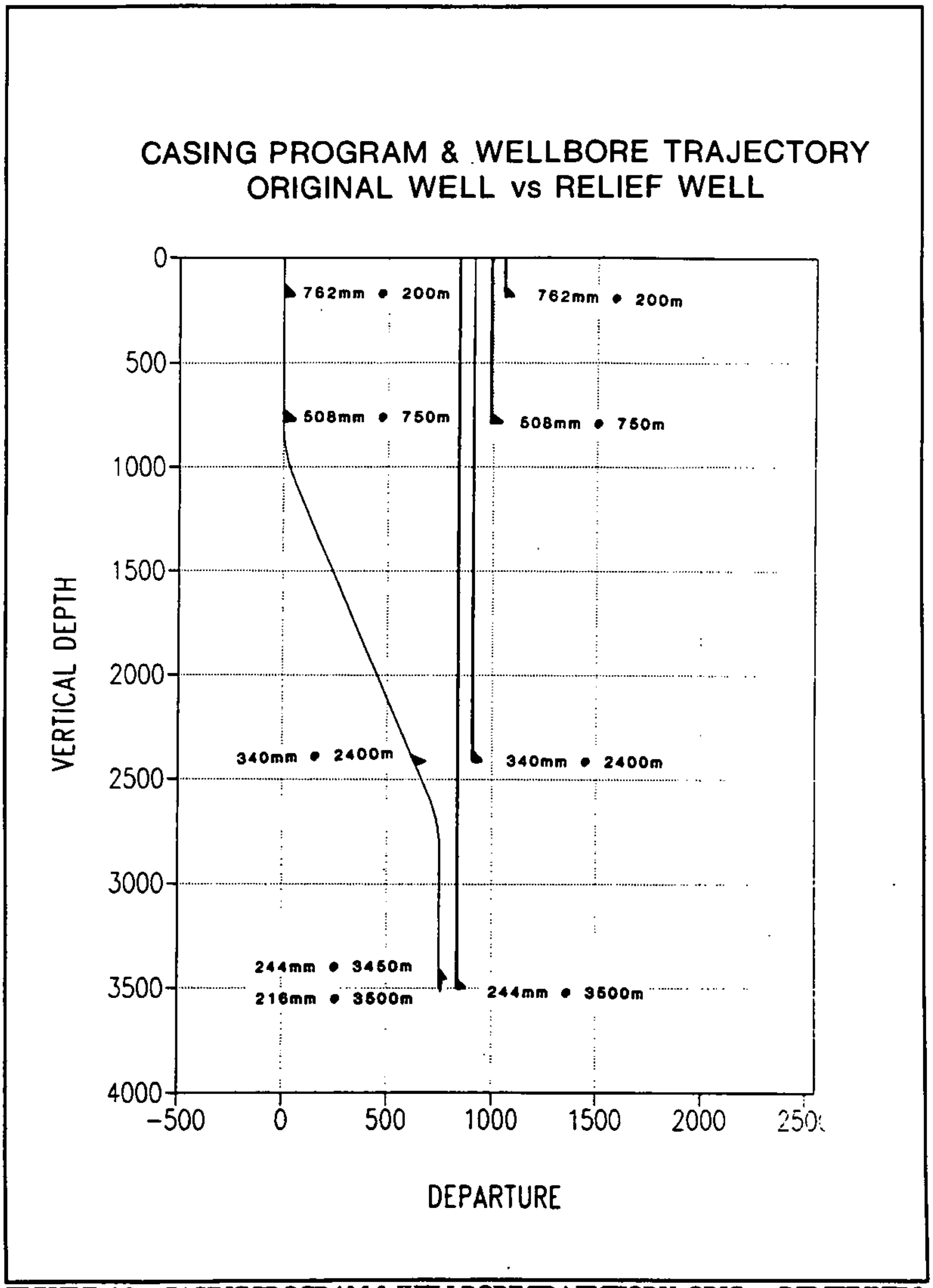


FIGURE 4.2 CASING PROGRAM & WELLBORE TRAJECTORY: ORIG. vs RELIEF WELL

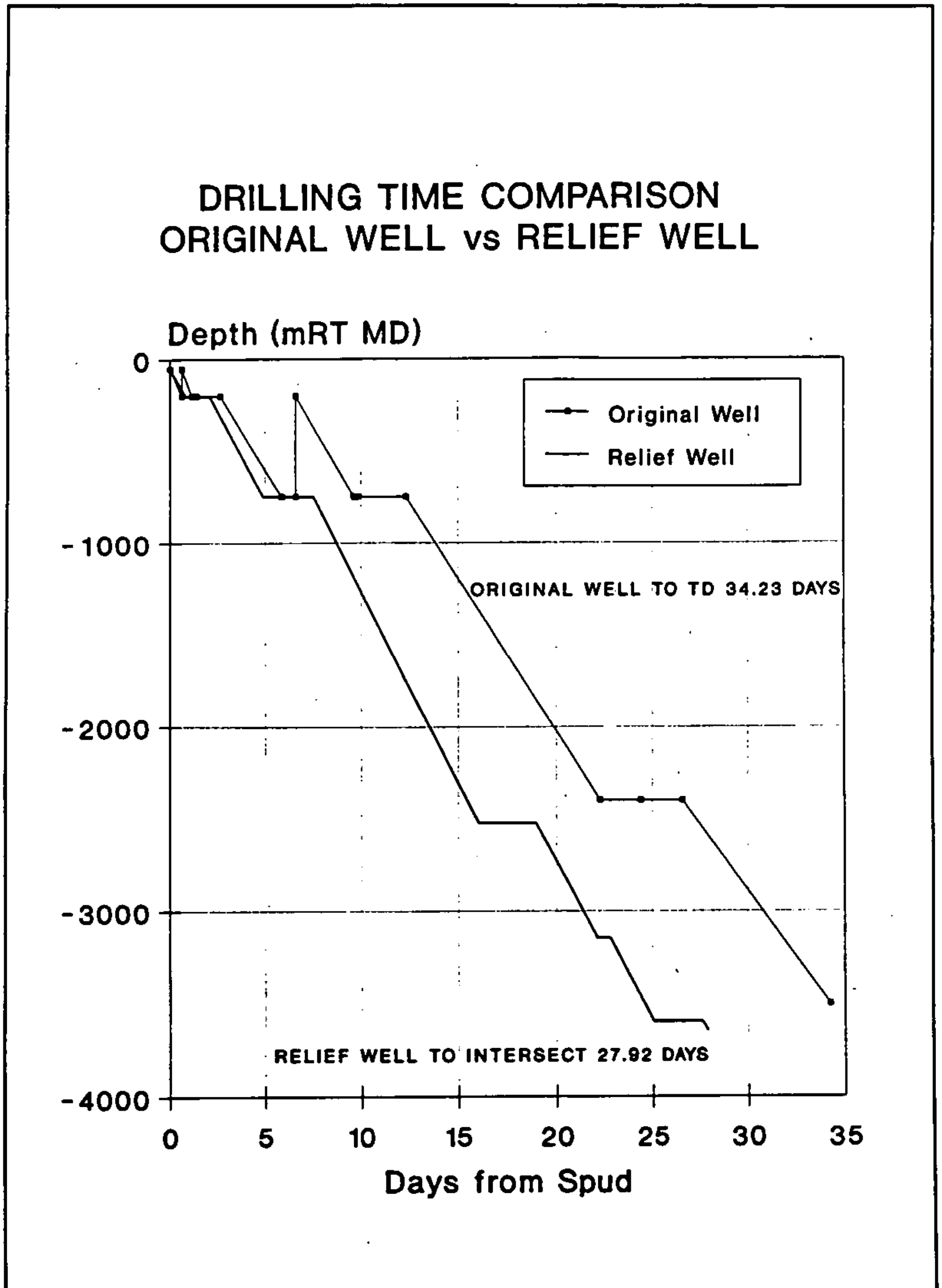


FIGURE 4.3 DRILLING TIME COMPARISON: ORIGINAL vs RELIEF WELL

REFERENCES

1 Buist, I., "Dispersion of Hydrocarbons in Air from Blowouts", Report to Gulf Canada, 1989.

2 Angle, R.P., "Plumes II - A Guideline for Plume Dispersion Calculations", a revision of the Alberta Environmental Model for Atmospheric Gas Dispersion.

3 ERCB, "Lodgepole Blowout Inquiry, Addendum to the Phase I Report", December 1984.

4 Applied Science Association, "Offshore Oil Spill Model".

5 Dome/Amoco Well Histories:
- Amoco et al Kingark J-44
- Dome et al Edlok N-56
- Dome et al Adlartok P-09
- Dome et al Nerlerk J-67
- Dome et al Arluk E-90
- Dome et al Siulik I-05
- Dome et al Havik B-41
- Dome et al Natiak O-44
- Dome et al Uviluk P-66
- Dome et al Aiverk 2I-45
- Dome et al Irkaluk B-35
- Gulf et al Pitsiulak A-05
- Gulf et al Amauligak I-44 & 2I-44
- Gulf et al Akpak P-35 & 2P-35
- Gulf et al Aagnerk E-56
- Gulf et al Amauligak O-86
- Gulf et al Immiugak N-50 & A-06
- Gulf et al Amauligak I-65

6 Chevron Frontier Development Division, "Beaufort Sea Pre-Development Program Drilling", Amauligak Joint Venture Proprietary Report.

7 Gulf Well Histories:
- Gulf et al Pitsiulak A-05
- Gulf et al Amauligak I-44 & 2I-44
- Gulf et al Akpak P-35 & 2P-35
- Gulf et al Aagnerk E-56

- Gulf et al Amauligak O-86
- Gulf et al Immiugak N-50 & A-06
- Gulf et al Amauligak I-65

8 Leraand, F., Wright, J., Zachery, M. and Thompson, B., "Relief Well Planning and Drilling for a North Sea Underground Blowout", SPE 65th Annual Technical Conference, New Orleans Lousiana, September 23-26, 1990.

9 Maduro, W. and Reynolds, J., "Enchova Blowout: Record Relief Well Time", SPE/IADC Drilling Conference, New Orleans Louisiana, February 28 - March 3, 1989.

10 Gust, D., "Drilling the Boundary Lake A6-20 Relief Well", CADE/CAODC Spring Drilling Conference, Calgary Alberta, April 21-23, 1987.

11 Amoco Canada Petroleum Co. Ltd., "1990 Relief Well Contingency Plan Beaufort Sea Operations", Proprietary Report.

12 Gulf Canada Resources Ltd., "Kulluk Drilling Program 1990-1992", Submission to the Environmental Impact Review Board, April, 1990.

13 Personal Communication with;
a) Dr. Bruce Thompson, Vector Magnetics Inc., Ithaca, New York
b) Mr. Bob Waters, Tensor Inc., Austin, Texas
c) Mr. Jack Gordyko, Scientific Drilling Controls, Calgary, Alberta

5.0 EQUIPMENT AND MATERIAL SUPPLY

5.1 Introduction

COGLA regulations require that all operators have contingency plans to ensure that the materials and equipment required to drill a relief well and kill a blowout are readily accessible to begin immediate operations. Typically each operator has maintained an inventory of drilling consumables in Tuktoyaktuk for that purpose. The specialized equipment which is not stored in the North, but required later in the relief well program, would have to be brought from southern locations. That includes high pressure pumps, specialized drilling tools and miscellaneous consumables.

This section outlines the infrastructure in place to move all materials and equipment to the relief well location, as well as the options available for storage, layout and support.

5.2 Transportation Options

5.2.1 Southern Locations to Tuktoyaktuk

Figure 5.1 outlines the options available to move goods north to Tuktoyaktuk. Dependent on the seasonal constraints, each piece of equipment would be moved by the most economical mode of transport providing that timing did not impact on the critical path for relief well drilling or well kill operations.

The location and availability of the required well kill equipment is controlled through service companies such as; Halliburton and Dowell Schlumberger. It is anticipated to take no more than 2 weeks to marshall the pumping and storage equipment for the well kill operation at Nisku, Alberta. An additional 4 to 14 days will be required to move these goods to Tuk dependent on season and routing (Figure 5.1). This places all heavy equipment in Tuk approximately 2 to 4 weeks after call-out.

Specialty drilling equipment or other rush items can be flown directly to Tuk in 2 days allowing for marshalling and transport.

5.2.2 Tuktoyaktuk to Location

Figure 5.2 is a flow chart outlining the options available for movement of equipment offshore, depending on season and weight. The prioritization of equipment movements using helicopters, supply vessels and/or barges will be done through an Emergency Response Team located in the north. Given the concurrent oilspill clean-up, relief well drilling and well kill preparations, it is anticipated to take 1 to 2 weeks to mobilize the well kill equipment to location and rig it up.

Therefore, from the time equipment is called out, arrives at location, is rigged up and ready for use, would be 5 weeks maximum. This is a conservative estimate and is within drilling time for a "typical relief well". This would indicate there should be no allowance for equipment mobilization in the overall time curve.

5.3 Equipment and Materials

5.3.1 Drilling

The worst case scenario from a supply point of view would be one where the blowing well was near T.D. and had used most of the consumables allotted for that well. Resupply for relief well drilling would come from either;

- a shore base (Tuk), or
- an offshore marine base (barge).

In these cases, the organizational period immediately following the blowout would be utilized to mobilize the essential consumables required for spud and subsequent operations. High priority would be given to a resupply operation, and within a 4 day time frame, a relief well rig could be supplied with the materials necessary to get operations underway. Subsequent resupply operations would not affect the drilling time line.

5.3.2 Well Kill Equipment Layout

Several options would be considered for how and where the kill equipment would be located. They would include:

- barge,
- supply vessel(s),
- relief well vessel,
- ice island,
- man made or sacrificial beach island.

In the case where an ice island was employed, ample space would be available close to the relief well site for rig up and tie-in of the well kill equipment, with minimal constraints on layout.

The case of a floating operation is somewhat more restrictive. A barge, supply vessel(s) or the relief well vessel would be the only options and of those, the barge would likely be preferred.

Considering the amount of equipment that would be stationed on the kill barge, the crew (30-40 people) needed to operate the equipment and maintain the fluids, as well as the movement of equipment to and from the barge, a crane, mooring capability and possibly accommodations would be desirable features for such a barge. Figure 5.3 would be a typical footprint of the kill equipment layout when utilizing a barge.

The most significant concern around using a barge for this operation would be stationkeeping. Above certain ice concentrations and velocities, it would be difficult to maintain a barge on location giving adequate support to ensure its safety and still support the drilling operation.

In the case where it was not favorable to use a barge, a supply vessel could be substituted. Obviously, the space limitations would restrict what could be placed on its deck. Figures 5.4 and 5.5 show a typical arrangement. These types of layouts rely on the relief well vessel to mix and supply the kill fluid to the pumping units located on the support vessel.

The least desirable of all options would be to locate the well kill equipment onboard the relief well vessel. This arrangement would be utilized in a situation where the support craft were not available to accept the kill equipment.

A drilling unit such as the Kulluk could, with some rearrangement, be able to accept and rig in this equipment. Vessels with less available deck space may not be able to do so. However, it is highly unlikely this option would be utilized.

5.4 Summary

Industry has carried out Beaufort Sea drilling operations for almost two decades, and in doing so have developed an infrastructure to transport personnel and cargo in a timely fashion to locations throughout the North. The need for an efficient logistical infrastructure has grown out of demands of the costly drilling operations where even small delays in transportation could litteraly cost tens of thousands of dollars. In the event of a blowout the logistics are in place to ensure that the required equipment and supplies are transported without delay.

TABLE 5.1
TRANSPORTATION ALTERNATIVES
NISKU TO TUKTOYAKTUK

ROAD TRANSPORT

- Available: mid-June to mid-October
  mid-January to mid-April
- 2 day service Nisku to Hay River
- 4 day service Nisku to Tuk
- 7 day service Houston to Tuk
- Utilize Dempster Highway
- Up to 60,000 lb payloads

RAIL SERVICE

- Nisku to Hay River for barge pick-up
- 7 day service Nisku to Hay River
- 21 day service Houston to Hay River

MARINE BARGE

- Hay River to Tuk via McKenzie River
- Available late June - early October
- 8 day service Hay River to Tuk
- Barges could be met and unloaded offshore, if necessary

AIR TRANSPORT

- Available all year round
- Regular passenger and freight service to Inuvik
- Charter direct to Tuk as required
- Available aircraft include 737 and Hercules transport

FLOWCHART FOR MOVING EQUIPMENT NORTH

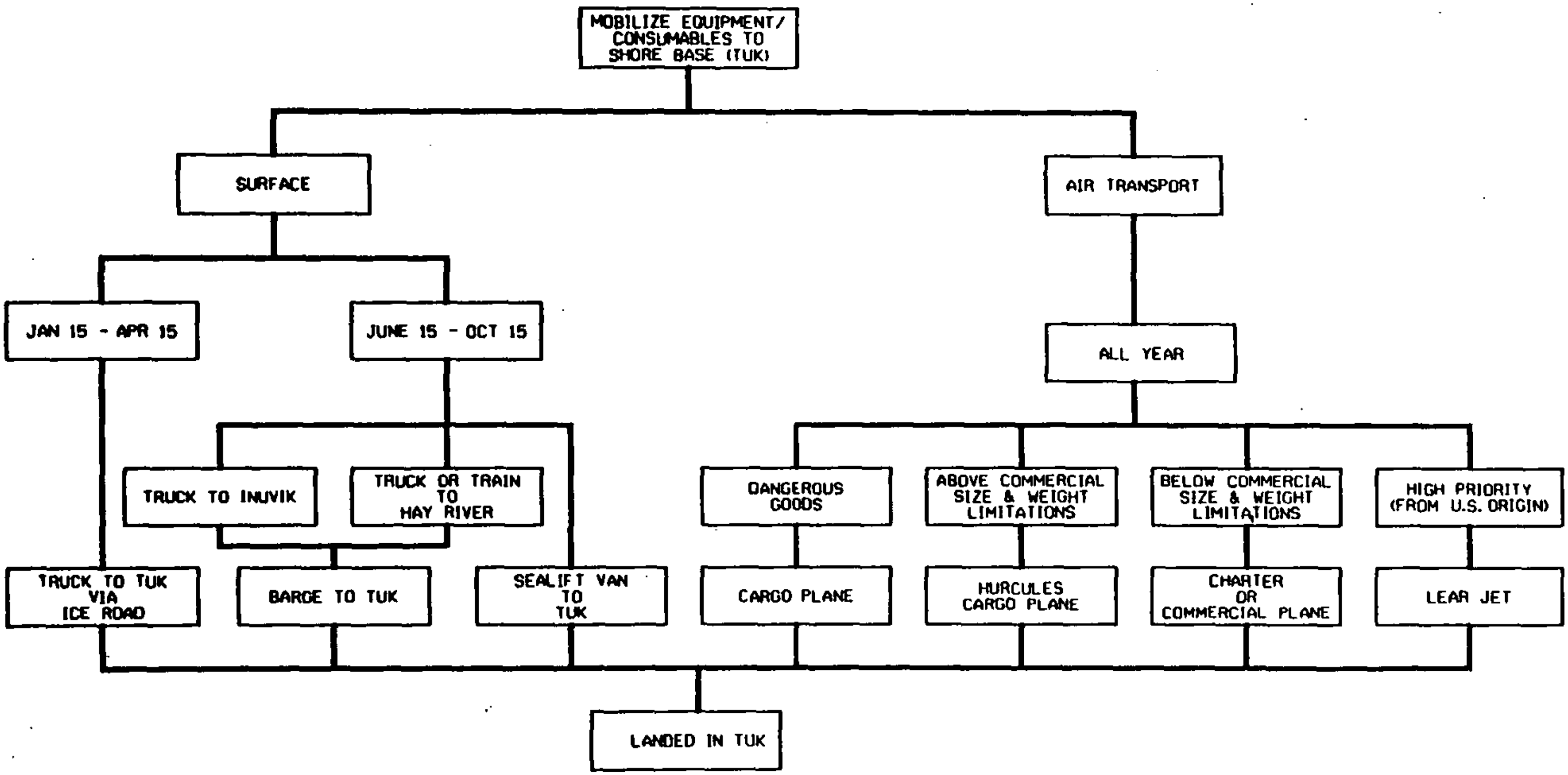
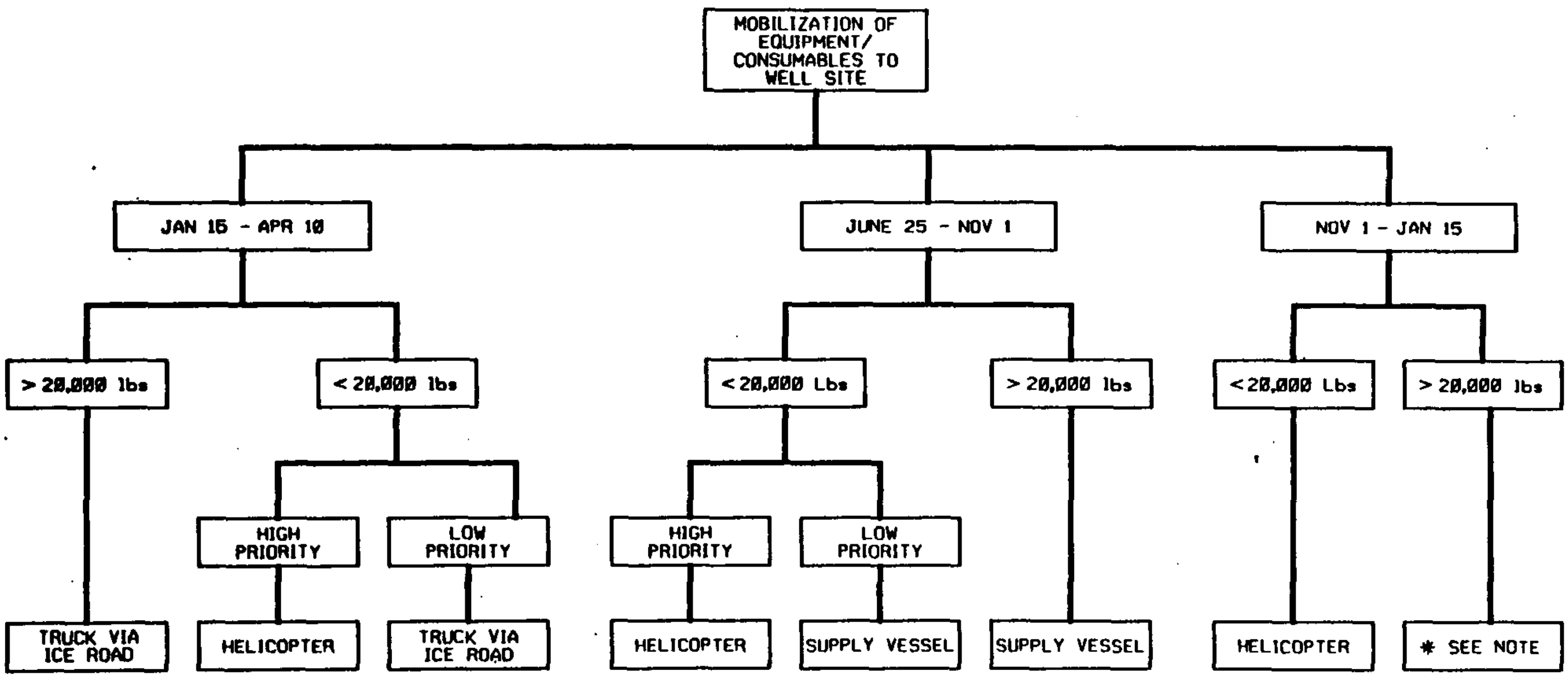


FIGURE 5.1 FLOW CHART FOR MOVING EQUIPMENT NORTH

FLOWCHART FOR MOVING EQUIPMENT TO LOCATION



* NOTE: COULD EITHER BE STAGED OFFSHORE OR AT McKINLEY BAY TO ALLOW LATE SEASON ACCESS

FIGURE 5.2 FLOWCHART FOR MOVING EQUIPMENT TO LOCATION

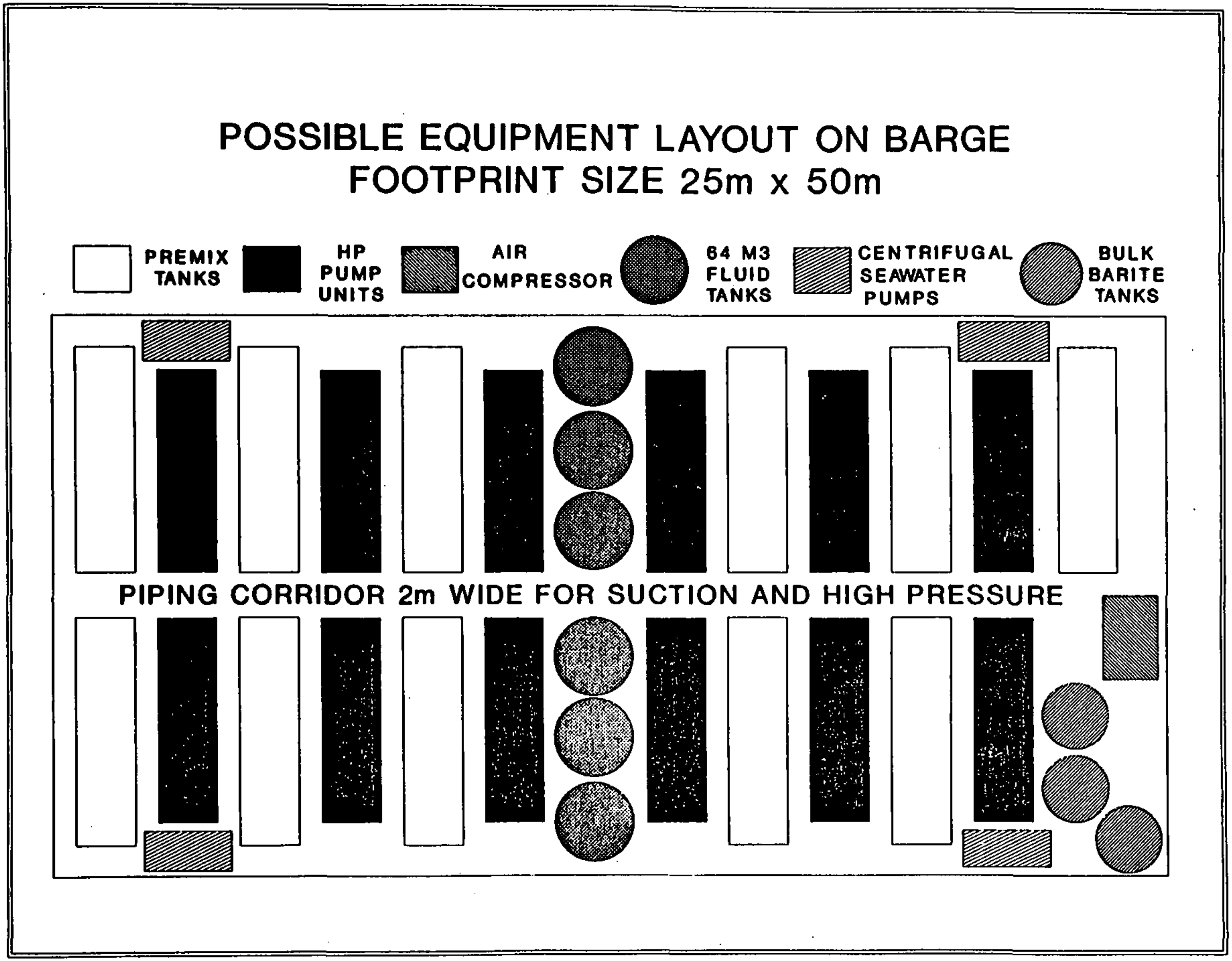
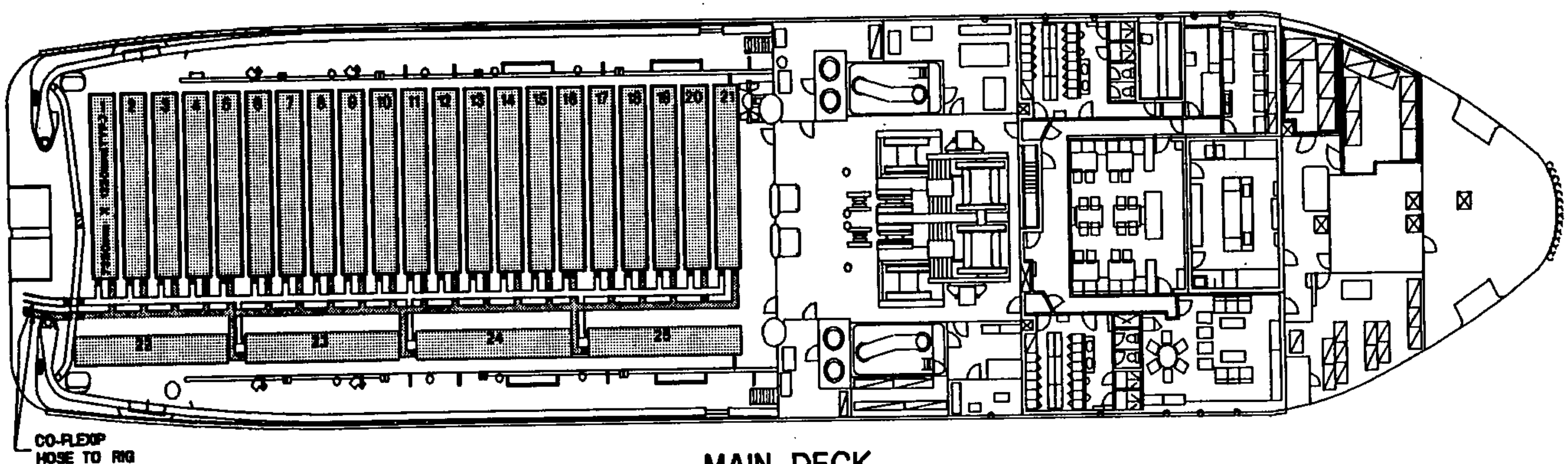


FIGURE 5.3 POSSIBLE EQUIPMENT LAYOUT ON A BARGE

"MISCAROO"

PROPOSED DECK LAYOUT FOR 594 HHP HALLIBURTON PUMPING UNITS



MAIN DECK

LEGEND

SUCTION MANIFOLD

DISCHARGE MANIFOLD

594 HHP PUMPING UNIT

 FIGURE 5.4 MISCAROO DECK LAYOUT FOR 594 HP PUMPING UNITS

"MISCAROO"

PROPOSED DECK LAYOUT FOR 1250 HHP DOWEL TURBINE PUMPING UNITS

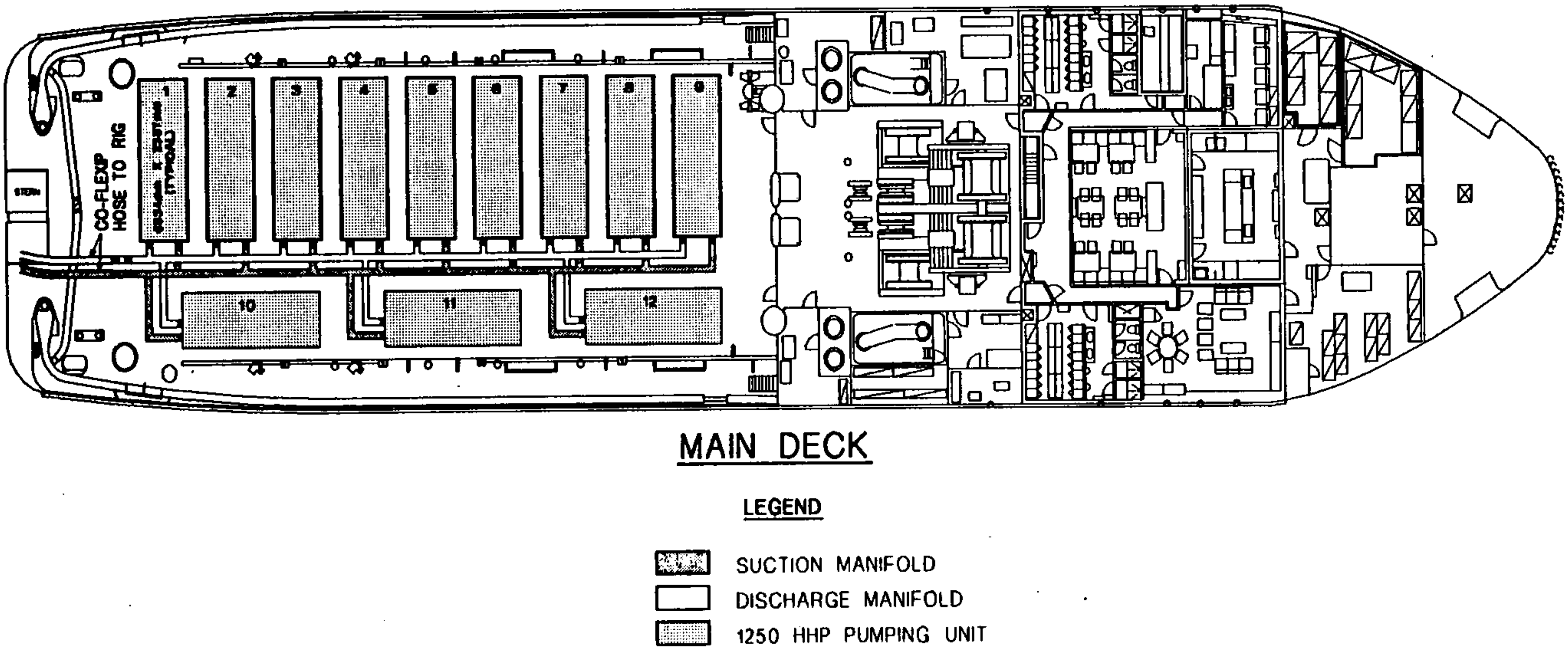


FIGURE 5.5 MISCAROO DECK LAYOUT FOR 1250 HP PUMPING UNITS

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6.0 END OF RISK DRILLING DATES

6.1 End of Risk Drilling Equation

Section 3, Drilling Systems and Capability, examined the environmental operating limitations of each Beaufort Sea drilling system and the time of year these conditions are expected to occur. The result of this analysis was the determination of the latest date that each drilling system could be expected to operate under emergency conditions, such as relief well drilling. It was assumed that all supporting resources available in the Beaufort would be committed to the relief well effort, in the unlikely event one should be required.

If this date is taken as the end of the operating season for emergency purposes, then the prudent end of risk drilling date can be determined by subtracting the amount of time required to bring a blowout under control from the end of operating season date. This end of risk drilling concept can be expressed by the following equation.

$$D_C = D_E - M - \frac{(0.8t+k)}{e}(1+c) \tag{6.1}$$

Where;

- D_C = Cut off date for risk drilling.
- D_E = End of operating season date, for emergency operations such as relief well drilling, in a year with average environmental conditions, with support measures taken to extend the season.
- M = Number of days required to mobilize and deploy the relief well drilling system which includes, where appropriate, time to moor up, and time to drill a glory hole.
- t = Number of trouble-free drilling days required to drill the original well from spud to TD. This would be based on the estimated time when the well was approved, but would be based on actual times as the well proceeds. The factor of 0.8 is based on the findings in Section 4.2, which concluded that the spud to TD time for a relief well should be approximately 80% of the spud to TD time of the original well.
- k = Number of days required to kill and abandon both wells.
- e = Anticipated operational efficiency factor for the relief well drilling system; determined by taking into account weather and ice factors.
- c = Contingency Time Factor, to ensure that there is sufficient time to drill a relief well, even during unfavourable years, and/or to account for other unscheduled events. This contingency factor is taken to be 15%, which is based on reasonable engineering judgement given that some extrapolation of operating experience was necessary to determine realistic end of season dates.

6.2 Drillship as a Relief Well Unit

In the case where a drillship is designated as the relief well drilling system (generally for another drillship or for the Kulluk), then the equation defined in Section 6.1 can be used as follows to determine the end of risk drilling date.

First the independent variables are determined on the basis of the work contained in the main body of this report (*Ref. Section 4 & Ref. Section 3.3.2*).

t	=	60 days (assumed)
k	=	3 days
D_E	=	December 31
e[1]	=	76%
M	=	14 days (emergency start-up plus glory hole time)
c	=	15%

By substituting these variables into equation 6.1 the end of risk drilling date (D_C) can be calculated. In this case the end of risk drilling date is October 1st.

In this example, the 91 days from October 1 to December 31 are accounted for as follows;
- 14 days to mobilize and moor the drillship and drill a glory hole,
- 48 days to drill the relief well from spud to TD,
- 3 days to kill and abandon the well,
- 16 days of anticipated downtime due to weather and ice,
- 10 days of contingency time as a safety factor.

Figure 6.1 depicts the effect of varying the length of the original well (t) on the end of risk drilling date while maintaining all of the other factors, except efficiency, constant at the above values. Operational efficiency is variable; it decreases as the season progresses into winter. Shorter drilling times result in relatively lower efficiency because the relief well is assumed to end on December 31 (in the case of the drillships) which means that the a 20 day well would be drilled entirely in December whereas a 50 day well would extend into November when operational efficiency is higher.

6.1 Efficiency is calculated by assuming the relief well finishes on D_E (e.g. Dec. 31 for a drillship) then factoring each day by the appropriate efficiency as given in Section 3 (varies during season) until the required relief well drilling time is achieved (i.e. $0.8t + k$). The required relief well drilling time divided by the total calender days consumed becomes the effective efficiency, e.

6.3 Kulluk as a Relief Well Unit

As described in Section 3, the Kulluk, with the support of four icebreakers, is capable of drilling at any time of the year in the transition zone. The Kulluk is expected to be able to operate with at least a 70% monthly average operating efficiency from late fall through to the end of January. It is this late fall and early winter period when the Kulluk would be operating as a relief well unit in support of a drillship, or itself.

In the winter months, from the beginning of February to the end of May, downtime due to ice incursions would be greatest. It is expected that the Kulluk would be able to operate an average of about 50% of the time during these months. If the Kulluk were working in a relief well support capacity during this period, it would normally be operating in relief well support of a bottom-founded unit, such as the Molikpaq, which has oil containment and disposal capability. Furthermore the Molikpaq, being a bottom founded structure, has a greater capacity to mitigate the effects of a blowout compared to a floating unit. The Molikpaq's oil containment, and disposal capabilities in conjunction with the increased likelihood of successful surface intervention temper the effects of the Kulluk's reduced operating efficiency over the winter months, and makes the Kulluk a possible relief well unit during the winter months in the transition zone.

Kulluk as Relief Well Unit for a Drillship
In the case where the Kulluk is designated as the relief well drilling system for a drillship, then D_E, would be conservatively chosen to be January 31. The equation defined in Section 6.1 can be used to determine the end of risk drilling date.

The independent variables are determined on the basis of the work contained in the main body of this report (*Ref. Section 4 & Ref. Section 3.3.1*) and are as follows;

t	=	60 days (assumed)
k	=	3 days
D_E	=	January 31
e	=	73%
M	=	10 days (emergency start-up plus glory hole time)
c	=	15%

By substituting these variables in to equation 6.1 the end of risk drilling date (D_C) can be calculated. In this case the end of risk drilling date is November 1st.

In this example, the 91 days from November 1 to January 31 are accounted for as follows:

- 10 days to mobilize and moor the Kulluk and drill a glory hole,
- 48 days to drill the relief well from spud to TD,
- 3 days to kill and abandon the well,
- 19 days of anticipated downtime due to weather and ice,
- 11 days of contingency time as a safety factor.

Figure 6.2 depicts the effect of varying the length of the original well (t) on the end of risk drilling date while maintaining all of the other factors, except efficiency, constant at the above values. The operational efficiency factor (e) is allowed to vary as described in the drillship example and footnote 6.1.

Kulluk as Relief Well Unit for Molikpaq in Transition Zone
There would be no risk drilling cut off date for the Molikpaq working in the transition zone, if its alternate relief well vessel was the Kulluk since the Kulluk offers year-round relief well capability for the Molikpaq.

6.4 Drillship and Kulluk When Not Severely Damaged by Blowout

As noted in Section 3, it is likely that the original drilling unit would survive a blowout and thus be able to drill its own relief well. This fact adds some conservatism to the End of Risk Drilling dates presented above because in all likelihood the mobilization time would be reduced by drilling the relief well with the original unit. Furthermore, in the case of the Kulluk drilling its own relief well (as opposed to using a drillship), the End of Drilling Season D_E, for the relief well unit increases from December 31st (drillship) to January 31st (Kulluk). A few possible scenarios are described below:

1) **Kulluk has a blowout and is undamaged:** In this case the Kulluk is able to begin relief well operations once relocated. It would take approximately 4 days to relocate the rig and drill a glory hole at the relief well site. Furthermore relief well drilling could continue until January 31st. Therefore an additional 37 days of relief well operations would be available compared to mobilizing and using a Drillship as a relief well unit.

2) **Drillship has a blowout and is undamaged:** Once relocated, the drillship would be able to begin immediate relief well operations. In this case it would take 4 days to relocate the drillship and drill the glory hole at the relief well site. This scenario would result in an additional 10 days of relief well drilling time compared to mobilizing a second drillship. If the time required was envisioned to extend beyond the drillship end of season, then the Kulluk could be mobilized to take over operations at an optimal time

(e.g. after setting a casing string). It would take approximately 3 days to "hand over" operations to the Kulluk. However the relief well season would be extended to January 31st and result in at least 18 additional relief well drilling days (average Kulluk operating days in January less 3 days to "hand over" operations) compared to a drillship relief well option.

3) **Kulluk has a blowout and sustains repairable damage:** Initially a drillship is mobilized to begin relief well operations. The Kulluk is repaired and takes over relief well operations from the drillship at a convenient point (e.g. 340mm casing depth). In this case the time savings will depend on the length of time to repair the Kulluk, as the efficiencies of the two units are different. Providing the Kulluk can take over by December 31st, at least 18 additional days would be available for relief well operations (average Kulluk operating days in January less 3 days to "hand over" operations) compared to the drillship relief well option.

In a real blowout situation, all possible countermeasures would be assessed. To assume that the original drilling unit is effectively destroyed is a conservative assumption, and for the Kulluk, has considerable impact on its end of risk drilling date.

6.5 SSDC/MAT as Relief Well Unit

SSDC/MAT as Relief Well Unit for Another System

The SSDC/MAT is a year-round drilling system, once mobilized. The SSDC/MAT's normal mobilization period is from July 1 to December 1. If the SSDC/MAT is the designated alternate relief well drilling unit, the end of risk drilling date would depend on the time of year and the mobilization time. (*Ref. Section 3.4.1*).

The SSDC/MAT could be mobilized from a stacked condition near Herschel Island to a location in the Canadian Beaufort Sea in 14 days. If the SSDC/MAT was operating at another well-site, it could be mobilized to a location in the Canadian Beaufort Sea in about 7 days.

Therefore, the end of risk drilling date, for a drilling unit with the SSDC/MAT as its designated alternate relief well drilling unit, would be about November 16 if the SSDC/MAT was in a stacked condition, and would be November 23 if the SSDC/MAT was in an operating condition. The exact dates should be determined on a case by case basis depending on the exact location and operating status of the SSDC.

SSDC/MAT as Relief Well Unit for Itself

As described in Section 3.4.1, the lengthy deck of the SSDC/MAT allowed it to be designed with its own relief well capability. Since the SSDC/MAT can be designated as its own alternate relief well drilling unit there is no end of risk drilling date for the SSDC/MAT.

6.6 Molikpaq as Relief Well Unit

The Molikpaq, like the SSDC/MAT, is a year-round drilling system, once mobilized. However, in most instances, the Molikpaq requires sandfill in its core and seabed preparation. These tasks are difficult to accomplish late in the season and so the Molikpaq would have limited capability as a relief well system. The use of the Molikpaq as a relief well unit would be examined on a case by case basis to determine its suitability, but in foreseeable cases there would be better alternates available.

6.7 Ice Island as Relief Well System

When considering the use of an Ice Island as a relief well drilling platform there are five milestone timing constraints which impact the end of risk drilling date D_e;

- the latest date that spray pumps can be mobilized,
- the latest date that island construction can start,
- the average date beyond which air temperatures preclude construction progress (April 19th),
- the latest date to commence mobilization of a relief well drilling rig,
- the date by which the island must be abandoned.

The latest date that spray pumps can be mobilized is dependent on the construction requirements of the island. The latest date that construction can start and still provide sufficient time to construct the island depends upon the water depth, construction rates, and whether stable rubble exists at the relief well location (*Ref. Section 3.5.2*). The average date that construction must be completed by, due to air temperatures, is conservatively estimated as April 19 (*Ref. Section 3.5.2*). The latest date that rig mobilization must commence is dependent upon the type and location of the rig chosen for drilling the relief well. The date by which the island must be abandoned has been conservatively set as July 19th (*Ref. Section 3.5.2*). These constraints are of critical significance in the determination of the end of risk drilling date for a site dependent on an ice island-based relief well.

Construction of Spray Ice Island

As described in Section 3.5.2, ice island construction can begin once the pumps are mobilized to the site. The pumps come in various sizes and can either be mounted on an icebreaker or set on the ice. Figure 6.3 illustrates the latest mobilization and construction start dates for the various pumps in different water depths. In almost all cases, on ice pumps will either be at the original well location or can be mobilized to the location at little cost. As such, in most cases pump mobilization time will not impact the determination of D_c - the end of risk drilling date. Only in the case where the island will be constructed using icebreaker mounted pumps are the pre-mobilization costs high and therefore mobilization unlikely. For the icebreaker mounted construction scenario, it is reasonable to add the pump mobilization time of 23 days to the island construction time.

Relief Well Rig Mobilization

Where an ice island is designated as the alternate relief well drilling system (generally for another ice island, a bottom-founded MODU, or a sacrificial beach island), the equation defined in Section 6.1 can be modified and used as shown in the example below to determine the latest date for mobilization of the relief well rig. Equation 6.1 must be modified to account for the fact that the island must be abandoned prior to break-up, this requires 10 to 14 days. The modified equation becomes:

$$D_C = D_E - M - \frac{(0.8t+k)}{e}(1+c) - B \qquad (6.2)$$

Where;

B = the number of days required to demobilize the drilling equipment and abandon the island,

D_E= the date the island must be abandoned, and
All other variables are as previously defined.

The various ice island relief possibilities are described in Section 3.5.2. The main difference between scenarios is the mobilization of the drilling rig. The basic drilling rig options and their corresponding mobilization time (*M*) are summarized as follows;

1) **Esso's Rig 2** would require 12 days to prepare (rig currently stacked in Tuk), 5 days to move rig from Tuk to location by trucks via ice road, and 8 days to rig-up. Total mobilization time and rig-up, *M*, is 25 days. Operations requiring the use of the Tuk to location ice road, must commence at least 17 days before the average May 28 ice road closure date, which means mobilization operations must begin no later than May 11.

2) **Non-Local Herc Rig** would require 17 days to mob from the South to Tuk via Hercules aircraft, 10 days to move the rig from Tuk to location by trucks via ice road, and 10 days

to rig-up. Total mobilization and rig-up time is 37 days. Operations requiring the use of the Tuk to location ice road, must commence at least 27 days before the average May 28 ice road closure date, which means mobilization operations must begin no later than May 1.

3) **Non-Local Land Rig** would require 17 days to mob from the South to Tuk by trucks via ice roads, 5 days to move rig from Tuk to location by trucks via ice road, and 8 days to rig-up. Total mobilization and rig-up time is 30 days. Operations requiring the use of the Inuvik to Tuk ice road, must commence at least 17 days before the average April 28 ice road closure date, which means mobilization operations must begin no later than April 11.

4) **Non-Local Helicopter Rig** would require 17 days to mob from the South to Tuk via Hercules aircraft, 5 days to move rig from Tuk to the helicopter staging site by trucks via ice road, 20 days to move rig and materials from staging site to location via helicopter, and 8 days to rig-up. Total mobilization and rig-up time is 50 days. If the ice road becomes a limiting factor then the mobilization can proceed by airlift.

The example below is one possible scenario which envisions the mobilization of a non-local land rig to the relief well island by ice road and the demobilization of the rig by barge in July. The variables (*Ref. Section 4 & Section 3.5.2*) in this instance are ;

t	=	60 days (assumed)
k	=	3 days
D_B	=	July 19
e[2]	=	100%
M	=	30 days
c	=	15%
B	=	10 days

Using equation 6.2 with these values results in a latest relief well mobilization date of April 11. As this is the same as the mobilization cut-off date described above, mobilization operations must begin no later than April 11. The results for the other potential relief well rig scenarios are summarized in Table 6.1.

6.2 In the case of an ice island, weather and ice do not delay drilling and so 100% operational drilling efficiency is realistic.

Also included in Table 6.1 is the date that the ice island must be finished so that the rig can be assembled. This date is determined by subtracting;

- the total drilling time ($[0.8t+k]/e]*[1+c]$), plus
- the time to assemble the rig, plus
- the time to demobilize the island, B

from the end of drilling date (D_E), which for ice islands in July 19[th].

TABLE 6.1
CRITICAL MOBILIZATION DATES FOR ICE ISLANDS

RELIEF WELL DRILLING RIG	SPRAY PUMP MOBILIZATION	ISLAND COMPLETION	BEGIN RELIEF WELL RIG MOBILIZATION
Esso's Rig 2	February 24	April 19	April 16
Non-local herc-rig	February 24	April 19	March 31
Non-local land rig	February 24	April 19	April 11
Non-local heli-rig	February 24	April 19	March 18
Note: These results are based on the assumptions described in the text (e.g. ice mounted pumps).			

Figure 6.4 depicts the effect of varying the length of the original well on the latest relief well rig mobilization date, for each of the potential drilling rigs.

Summary

This section has developed the methodology for establishing the critical dates that pertain to the use of an ice island as a relief well system. By meeting each of the critical dates for a specific location an Operator can extend the End of Risk Drilling Date (D_c). Figure 6.5 depicts the effects of varying the length of the original well on the critical dates, all other factors have been maintained at the same values as in the example above.

Referring to the example depicted in Figure 6.5; for a 60 day relief well, to be drilled with a non-local land rig, from an ice island platform in 10m of water, constructed with ice mounted pumps, initially the D_c will be February 24[th]. If the spray ice pumps are then mobilized on February 24[th], the D_c will become March 10[th], the date on which island construction must commence. If on March 10[th] island construction is started then D_c will become April 11[th], the date at which a non-local land rig must be mobilized to meet the latest possible acceptable relief well spud date. If mobilization of the rig is begun by April 11[th], and the island is completed, then D_c becomes May 11[th].

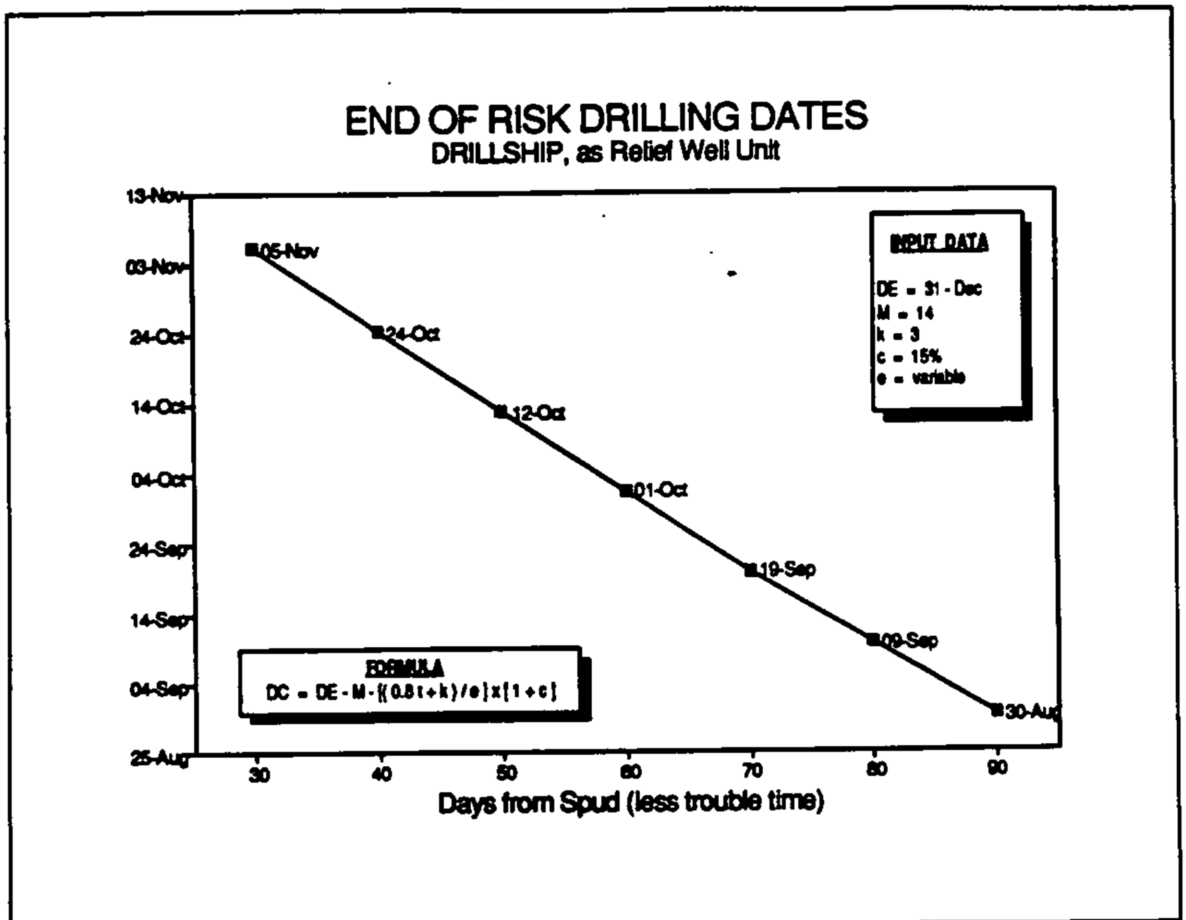


FIGURE 6.1 DRILLSHIP: END OF RISK DRILLING DAYS

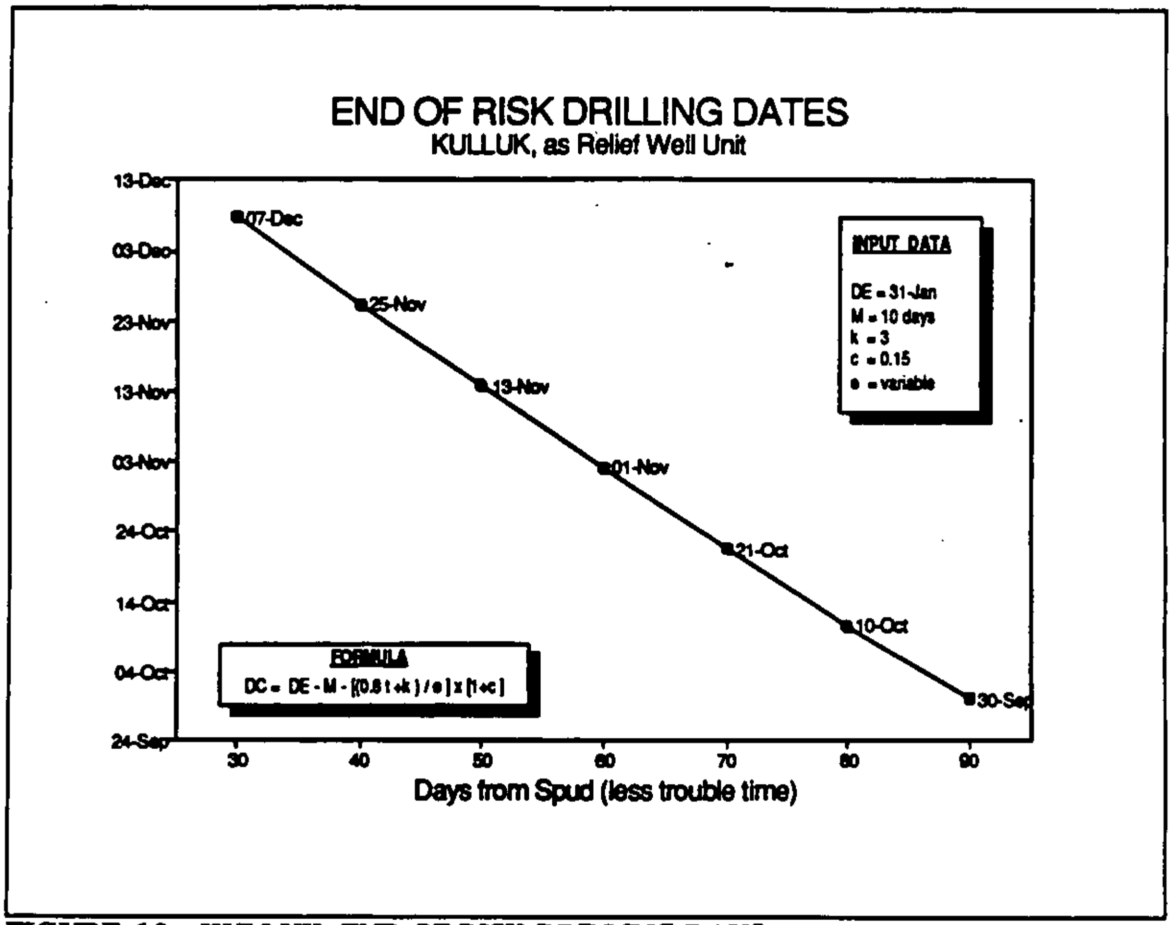


FIGURE 6.2 KULLUK: END OF RISK DRILLING DAYS

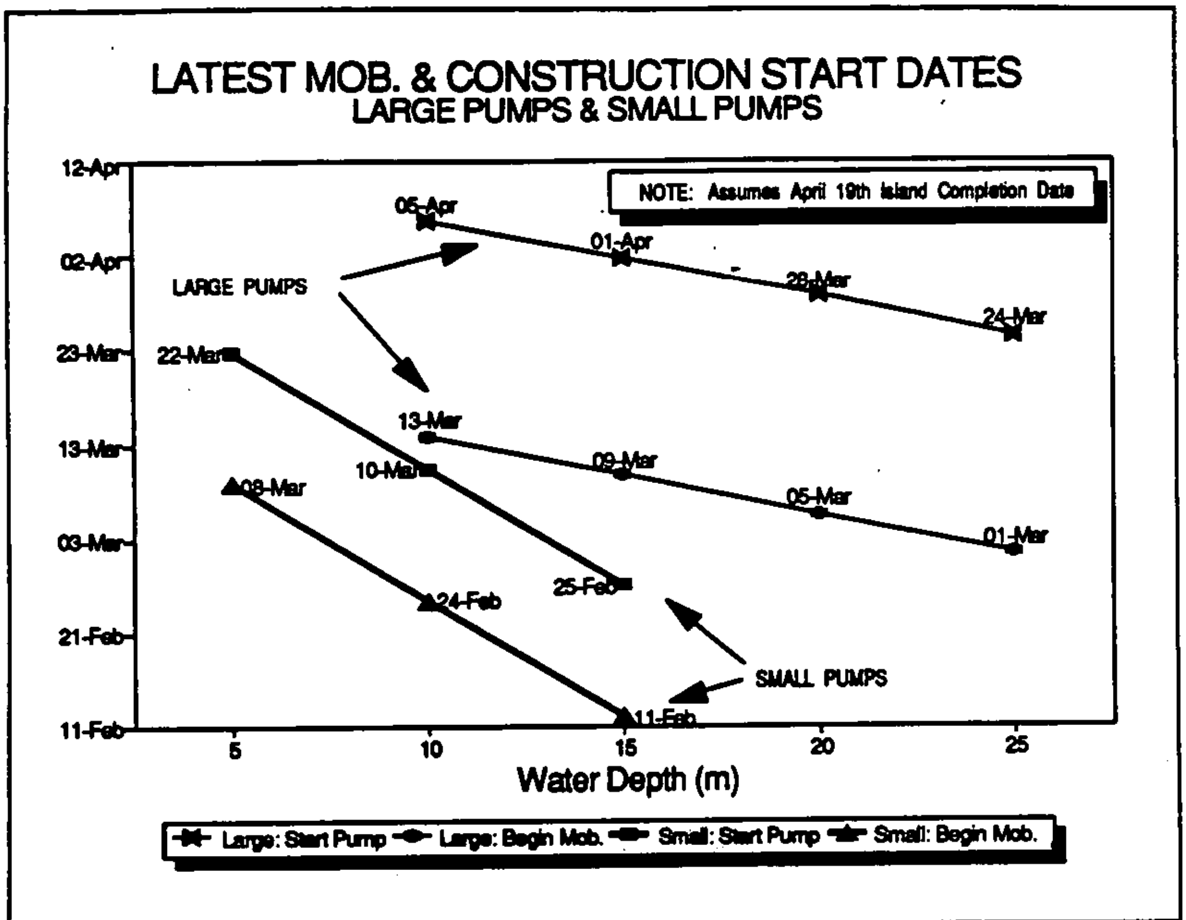


FIGURE 6.3 ICE ISLANDS: LATEST MOB. & CONSTRUCTION START DATES

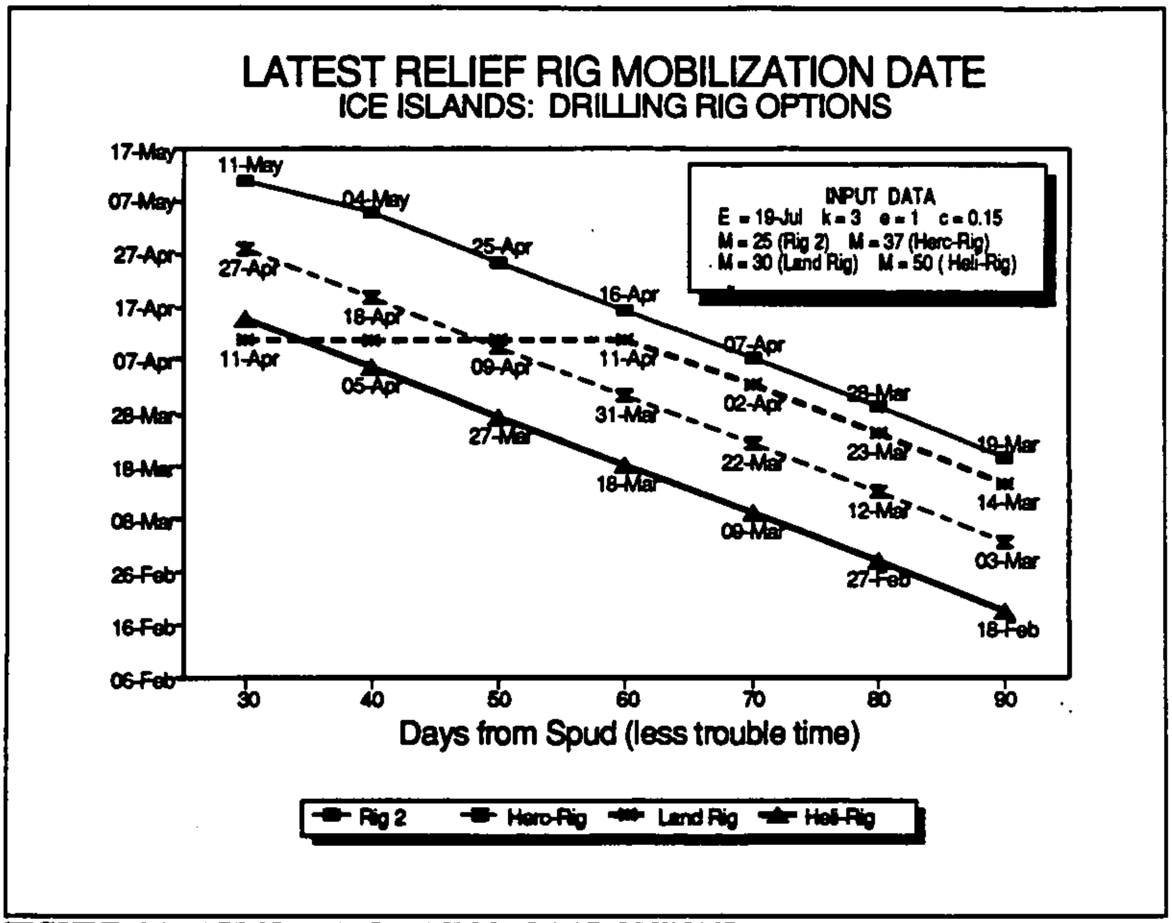


FIGURE 6.4 ICE ISLANDS: DRILLING RIG OPTIONS

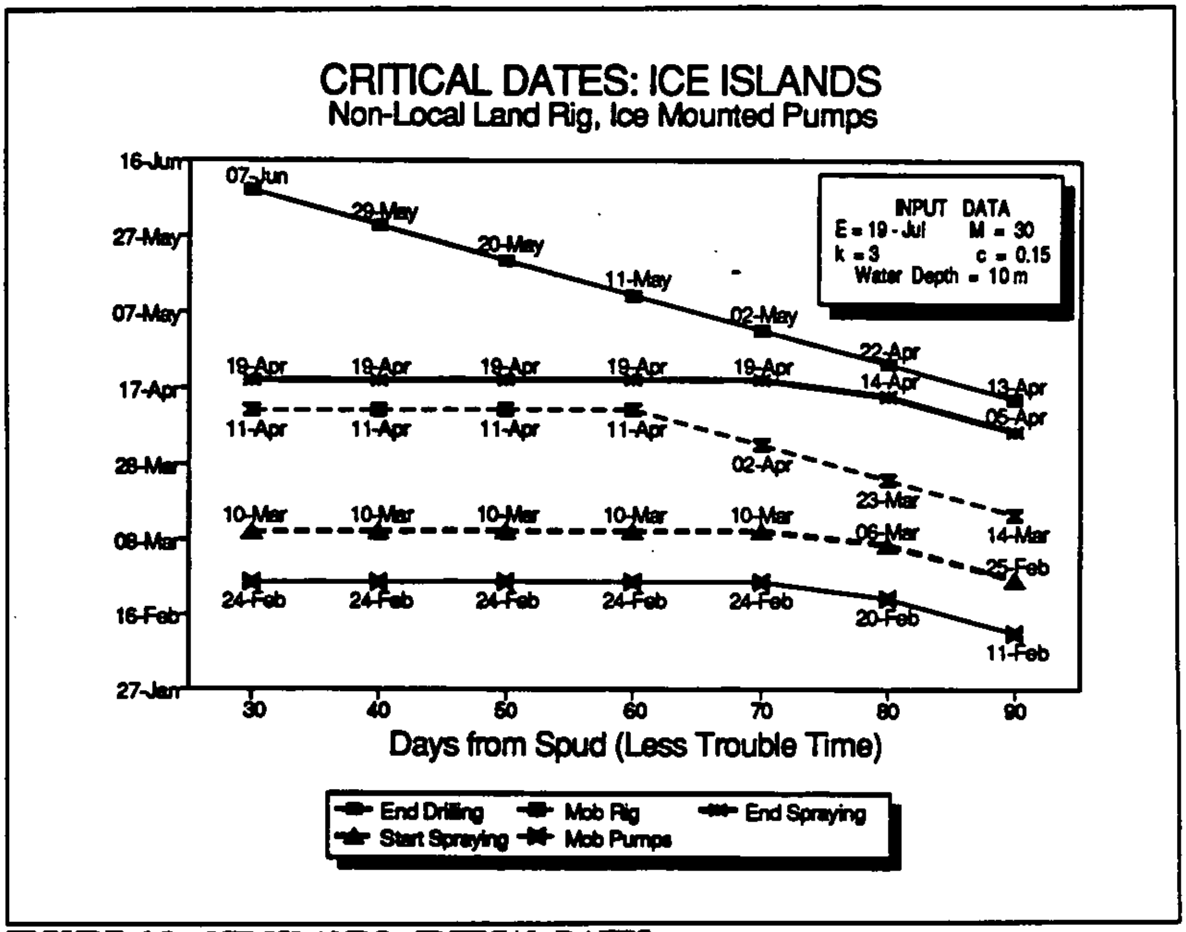


FIGURE 6.5 ICE ISLANDS: CRITICAL DATES

7.0 SUMMARY AND CONCLUSIONS

7.1 Background

Unlike operators in other offshore areas, Beaufort Sea operators must demonstrate "same season" relief well capability in order to gain drilling program approval. This requirement results primarily from the following considerations:

- Only a limited number of drilling units are capable of drilling a relief well in the Beaufort Sea. Non-Arctic rigs are unsuitable for drilling in ice conditions, and furthermore ice conditions around Alaska's North Slope would preclude mobilization of such a rig until the following summer. In most other offshore drilling areas there is a large number of rigs which could drill a relief well, and mobilization of these units is generally not restricted by weather or ice conditions.

- Floating Arctic drilling systems (i.e. the Kulluk or a Drillship) become less efficient as the winter progresses and ice conditions worsen. In the case of a drillship, ice conditions eventually become too severe for drilling activities to take place. Without a "same season" relief well contingency plan which takes into account the effective operating seasons of the available drilling units, a relief well could be delayed until the following summer. Although operational downtime is a normal part of all offshore drilling operations, the potential for extended downtime caused by sea ice is unique to the Beaufort and other Arctic seas.

- The Arctic is a unique environment in terms of its delicacy and unspoiled nature. Although all offshore areas are ecologically important, special consideration is given to Arctic waters.

As described in Section 2, the chance of requiring a relief well to kill an oil blowout is remote (about 1 in 18,000 for worldwide offshore wells). Despite the low probability it has been a policy of Canadian regulators to prohibit drilling into potential hydrocarbon zones, from a floating unit, after September 25th unless conditions were extremely favourable and the operator could demonstrate "same season" relief well capability. For fixed structures the September 25th date does not apply but the principle of requiring "same season" relief well capability is maintained.

7.2 Objective

The Beaufort Sea Steering Committee commissioned Task Group 6 to;

Determine the safe operating season for Beaufort Sea Drilling Systems.

This objective was accomplished by examining the relief well drilling capability of the existing Beaufort Sea drilling systems and developing a logical basis for establishing the end of risk drilling date.

7.3 Beaufort Drilling Systems

The Beaufort Sea presents a non-typical working environment for offshore drilling. Industry has responded to this challenge with several different types of drilling units each with their own relative advantages and disadvantages. This report identifies each of the units and describes their operating capability. Although all systems were examined, special emphasis was placed on the floating units and ice islands since these are the most likely candidates for relief well drilling. Bottom founded MODUs have year round capability as drilling units but their relief well capability is restricted by their installation requirements.

Floating systems can usually begin operations in June or early July and continue, if allowed, until ice conditions prevent drilling progress. Current regulatory practice generally prohibits the drilling of any potential hydrocarbon zone after September 25th and so this effectively sets the "end of risk drilling" date. Non-risk drilling can proceed beyond that date and it is this experience that has provided the operators with some insight as to the latest date a unit could operate under emergency, relief well circumstances. Unfortunately, there have not been enough late season drilling opportunities to provide a large database of drilling operations during this time of year. Generally drilling has stopped due to economic considerations or lack of non-risk drilling work, rather than the inability to continue operations. For this reason it is necessary to extrapolate the available experience to define reasonable end of operating seasons for the floating units. Examples of industry's experience are;

- The latest that a drillship has operated has been November 29, 1979. In 1979 there was less than half the icebreaker capability available today and ice management techniques were in early stages of development. Since 1979 there has been no reason to operate late in the season due to lack of non-risk drilling work and/or economic considerations.

- The Kulluk has operated until December 11th and stopped drilling for economic reasons rather than because of ice.

The absolute "end of drilling season" for a floating unit is not definitive. As ice conditions worsen drilling progress slows since the floating unit is forced to suspend operations more frequently. At some point drilling progress, under normal circumstances, is sufficiently slowed and ice support so expensive as to render further drilling uneconomic. In a relief well situation economics would not dictate the end of drilling. The relief well plan would include all available support necessary to ensure that the blowout could be controlled within the planned date. Even if unforseen events delayed the relief well, work would continue until the well was controlled or it was physically impossible and unsafe to make further progress. The two main considerations in determining the end of drilling season are;

- the ice conditions, and
- the operating efficiency at the end of the relief well operations.

Ice conditions are variable, both in a geographic sense and on a year to year basis. To account for geographic variations in ice conditions a specific drill site must be chosen. Example drill sites were chosen for both the Kulluk (North Amauligak) and the Drillships (South Kogyuk). These sites were chosen because they represent potential drill sites over the next few years. To account for year by year variations in ice conditions, ice data for the last ten years was analyzed and the corresponding downtime determined for each unit. This downtime was then averaged to determine average operational efficiency. Using average ice downtime was considered appropriate for this work because of the extreme nature of a blowout in the first place. If extreme ice conditions were used, the effect would be to combine two independent extreme events (extreme ice conditions and a blowout), which is normally avoided in design. Blowouts are independent of ice conditions and are usually the result of unexpected geological conditions or poor drilling practises.

For planning purposes a relief well drilling cut-off date was established based on the downtime analysis carried out by the Task group. For both the Kulluk and, more distinctly, the Drillships there is a rapid decrease in effective drilling days after certain dates (e.g. Figure 3.14). In the cases considered, this date was about December 31st for the drillships and January 31st for the Kulluk. Two important considerations with regard to the end of relief well date are:

- Drilling could continue past these end dates although at reduced efficiency rates. In the case of the Kulluk, drilling could continue throughout the winter, and in the case of a drillship, drilling could continue for an additional few weeks. In a relief well situation operations would proceed until the blowout was brought under control.

- Although efficiency is reduced towards the end of the relief well period, the majority of the relief well would be drilled in lighter ice conditions and thus at greater efficiency.

Ice islands present a unique form of Arctic drilling platform and offer winter relief well capability to all drilling units operating in the landfast ice zone. The restrictions on the use of an ice island relate to its construction and rig mobilization. Construction requires cold temperatures and stable ice cover which generally restricts ice island drilling to the landfast ice area. The construction scenario for a particular ice island depends on water depth, time of year, ice movements, and drilling rig. As these are all site specific considerations the suitability for using an ice island must be considered on a site by site basis. This report describes a methodology for determining the end of risk drilling date for a drilling unit whose relief well system is based on an ice island.

The other bottom founded MODUs, the SSDC/MAT and the Molikpaq, are year round drilling structures. In the case of the SSDC/MAT a relief well slot is provided at the forward end of the vessel and a fire-wall and water monitors are positioned to allow relief well drilling even if the original well is on fire. In some cases the Molikpaq would require the Kulluk to drill its relief well. As previously noted the Kulluk is capable of year round drilling although drilling in the midwinter would be at reduced efficiency. To mitigate the potential oil spill, the Molikpaq has built-in oil containment and disposal systems which are able to operate without personnel aboard. Furthermore, the likelihood of achieving a successful surface kill from a bottom founded MODU is enhanced in comparison to a floater. As previously noted, the emphasis of this work is on floating systems and more work may be required on a site specific basis to determine the end of risk drilling date for these bottom founded units.

7.4 Relief Well Drilling Operations

Two key factors with respect to relief well drilling operations are;

- the length of time required to drill the relief well, and
- the surface location of the relief well.

The surface location of the relief well can be influenced by;

- Oil in the vicinity of the relief well site,
- Blowout gas levels,
- Radiant heat and its effect on ice island construction,
- Anchor handling operations adjacent to damaged rig and potential fire, and
- Shallow gas hazards.

All of these considerations are addressed in this report and while important, were not critical to the success of a relief well.

To determine relief well drilling time, a computer simulation was used to compare the time to drill the original well with the time to drill its relief well. Historical records were used to calibrate the model. The result of this analysis was that a typical relief well should conservatively be completed within 80% of the drilling time it took to drill the original well.

Time for controlling the flow from the original well and abandoning both wells must also be allowed for. Times for kill and abandonment procedures were conservatively estimated at one day and two days respectively.

7.5 End of Risk Drilling Date

For drilling systems which use floaters or ice islands as their specified relief well unit, the end of risk drilling date can be expressed in terms of the formula developed in Section 6 and repeated below. If other bottom founded units are proposed as relief well units then each case must be examined on an individual basis.

$$D_C = D_E - M - \frac{(0.8t+k)}{e}(1+c) - [B] \tag{7.1}$$

Where;

- D_C = Cut off date for risk drilling.
- D_E = End of operating season date, for emergency operations such as relief well drilling, in a year with average environmental conditions, with support measures taken to extend the season. For an ice island it is the date that the island must be abandoned.
- M = Number of days required to mobilize and deploy the relief well drilling system which includes, where appropriate, time to moor up, and time to drill a glory hole.
- t = Number of trouble-free drilling days required to drill the original well from spud to TD. This would be based on the estimated time when the well was approved, but would be based on actual times as the well proceeds. The factor of 0.8 is based on the findings in Section 4.2, which concluded that the spud to TD time for a relief well should be approximately 80% of the spud to TD time of the original well.
- k = Number of days required to kill and abandon both wells.
- e = Anticipated operational efficiency factor for the relief well drilling system; determined by taking into account weather and ice factors.
- c = Contingency Time Factor, to ensure that there is sufficient time to drill a relief well, even during unfavourable years, and/or to account for other unscheduled events. This contingency factor is taken to be 15%, which is based on reasonable engineering judgement. A contingency factor of 5-15% is often added to the estimated length of time to drill a well, to account for any unscheduled events. This contingency factor is taken to be 15%, which is based on reasonable engineering judgement given that some extrapolation of operating experience was necessary to determine realistic end of season dates.
- $[B]$ = the number of days required to demobilize the drilling equipment and abandon the ice island. This term does not apply to floating units.

Example applications of this formula are provided in Section 6. The key steps in the application of this formula are:

1) The end of drilling season date (D_B)is estimated for the chosen relief well unit based on the units projected performance and the expected ice conditions at the site. To determine D_B, site specific ice data must be examined.

2) The number of days required to mobilize the relief well drilling unit (M) is then determined based on the location, status and type of unit.

3) If the relief well is being drilled from an ice island then the time required to demobilize the rig from the island (B) must be determined.

4) 80% of the projected drilling days (t) for the initial well plus the expected number of days to kill the original well and abandon both wells (k) is divided by the expected efficiency (e). Efficiency is a function of how late in the season the relief well is drilled and so this term in the equation would be the sum of several periods with each period having a distinct efficiency rate. The result of this calculation is the total time expected to mobilize a drilling system, drill the relief well, control the original well and abandon both wells given the expected ice conditions.

5) The result of step three is multiplied by some contingency factor to allow for drilling problems. Since the 80% time factor on original well drilling time is based on a conservative estimate the contingency factor should be modest. The task group recommends a contingency factor of 15%.

6) Finally the terms are subtracted to arrive at the cut off date for risk drilling (D_C).

This approach, although somewhat complicated, is supported by Industry and it is anticipated that as experience is gained the values for each of the terms can be estimated with increasing accuracy. Since this calculation is different for every potential drilling site, and every potential primary and relief well drilling unit combination, consideration was given to a simpler formula for floating units that would still encompass the general principles. In this regard the Task group examined the effect of simply reducing the estimated end of drilling for the relief well unit (D_B) such that it would, in general, include the efficiency (e) and contingency (c) factors. It was determined that by deducting 30 days the contingency and efficiency factors could be dropped and in most cases the resulting time "D_C" would be earlier. The simplified formula then becomes:

For Drillships

$$D_C = Dec\ 31^{st} - M - (0.8t+k) - 30 \tag{7.2}$$

For Kulluk

$$D_C = Jan\ 31^{st} - M - (0.8t+k) - 30 \tag{7.3}$$

7.6 Conclusions

1) Due to the site specific and equipment specific nature of each potential drilling program no single date or general formula can determine the end of risk drilling date for all situations.

2) A site and equipment specific methodology and formula was developed for determining the end of risk drilling date (*Equation 7.1*) for floaters and ice islands.

3) For regulatory purposes, COGLA recommends that the more rigorous methodology encompassed by *Equation 7.1* be approximated by *Equation 7.2* and *Equation 7.3* for drillships and the Kulluk respectively.

4) It was recommended by COGLA that the September 25th review date be retained for drillships and the Kulluk as a means of ensuring further safety. If the simplified formula predicts an earlier date, then a review shall be held prior to that date.

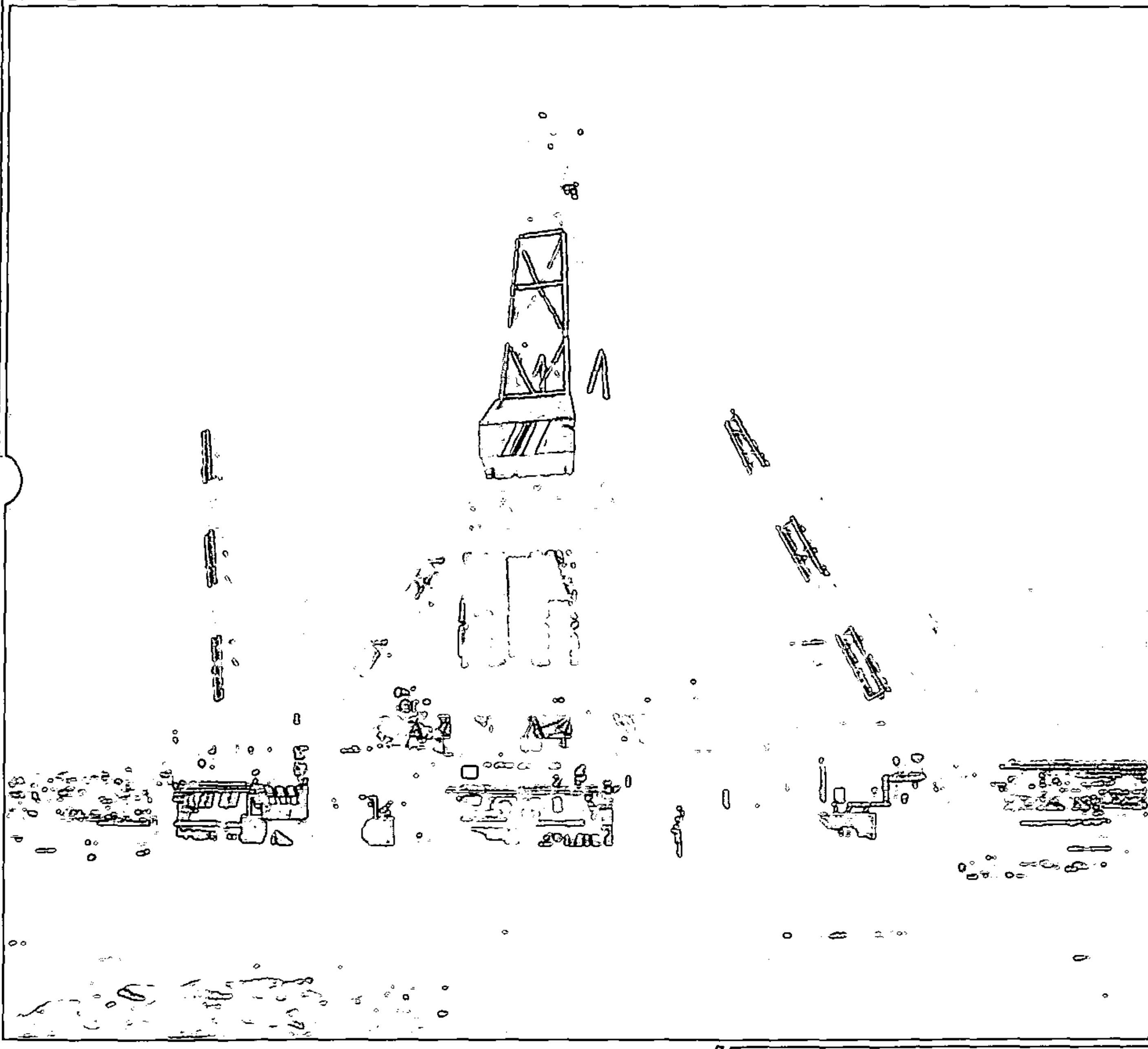
5) Drilling operations should be continually monitored in light of back-up units and support facilities as the program proceeds. Either the simplified or more detailed method can be used to monitor relief well contingency throughout the drilling program.

6) The drilling program for bottom founded MODUs should be evaluated on a case by case basis. There is no general methodology that can determine their end of risk drilling date. Effectively they are year round drilling structures and each operator must demonstrate relief well capability for each drilling program based on site specific and equipment specific considerations.

BeauDril

Kulluk

Conical Drilling Unit



Kulluk

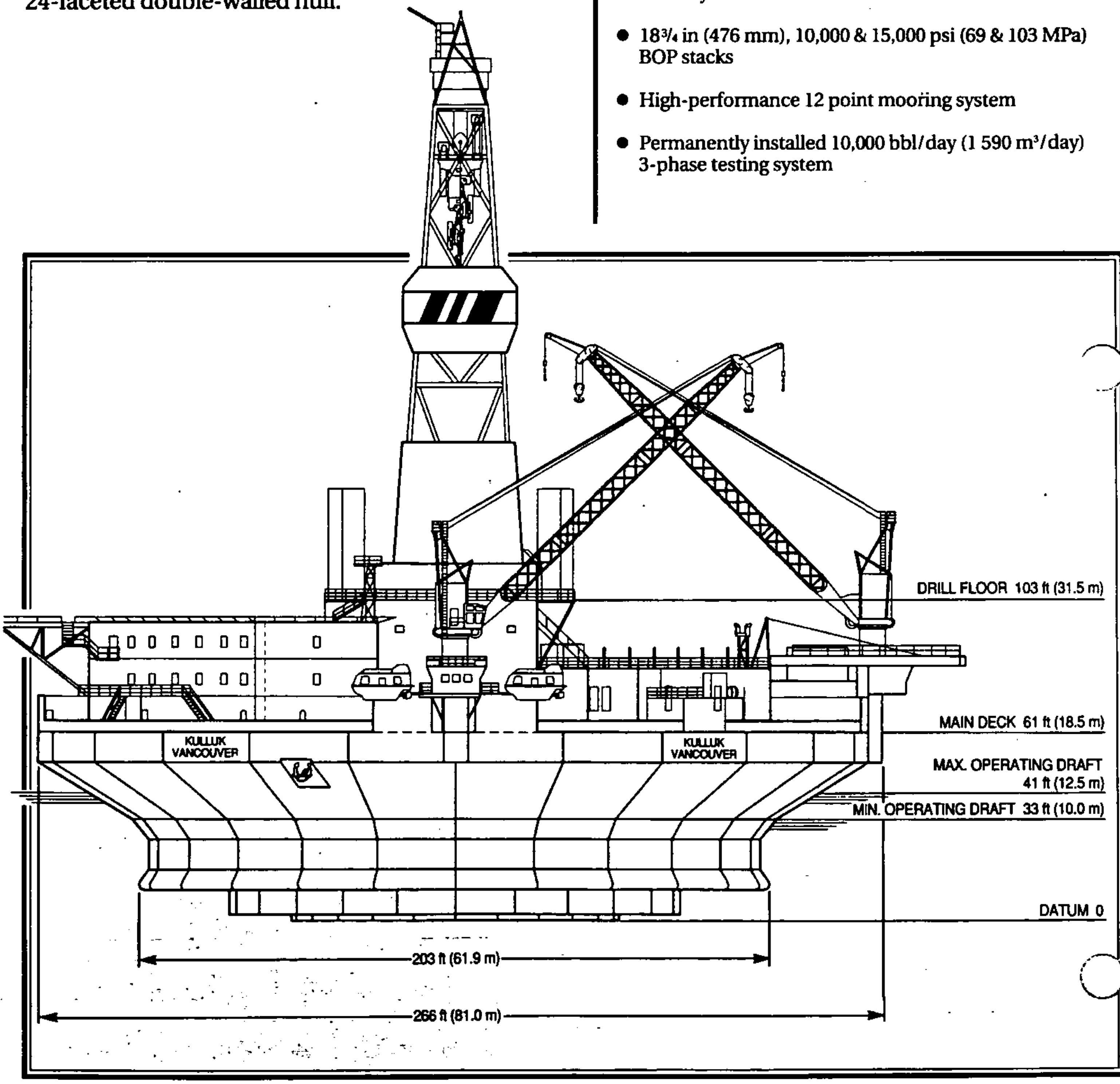
BeauDril

Kulluk is the first floating drilling vessel designed and constructed for extended season drilling operations in deep Arctic waters.

An improvement on the floating drillship concept, Kulluk is a conically shaped, ice strengthened floating drilling unit with a 24-faceted double-walled hull.

Key Features

- Unique, purpose-built conical Arctic Class IV hull de
- Operating water depth 60 to 600 ft (18.3 to 183 m), drilling depth up to 20,000 ft (6 096 m)
- Electrically driven Varco top drive drilling system
- 24 ft (7.3 m) diameter glory hole bit capable of drilling and setting a steel caisson 40 ft (12.2 m) into the seabed for ice scour protection
- Partially enclosed derrick
- 18¾ in (476 mm), 10,000 & 15,000 psi (69 & 103 MPa) BOP stacks
- High-performance 12 point mooring system
- Permanently installed 10,000 bbl/day (1 590 m^3/day) 3-phase testing system



Equipment

Drilling Equipment

Derrick
160 ft (44.8 m) Dreco dynamic with a 40 ft x 40 ft (12.2 m x 12.2 m) base, rated at 1,400,000 lb (623 000 daN) with 14 lines

Racking platform has capacity to hold 23,340 ft (7 115 m) of 5 in (127 mm) drill pipe plus bottom hole assembly

Drawworks
Ideco E-3000 electric drawworks complete with sand reel, Elmago model 7838 Baylor auxiliary brake, spinning and breakout catheads and three GE model 752 motors each rated at 1,000 hp (746 kW) continuous

Travelling Block
McKissick model 686, 650 ton (590 tonne) capacity with 7 sheaves grooved for 1⅝ in (41.3 mm) drilling line

Swivel
Ideco TL-500, 500 ton (454 tonne) capacity

Drill Pipe
20,000 ft (6 096 m) x 5 in (127 mm), 19.5 lb/ft (29 kg/m) with 4½ IF connections

Top Drive
Varco TDS-3 with one GE model 752 motor rated at 1,000 hp (746 kW) continuous and a 500 ton (454 tonne) hoisting capacity

Rotary Table
Ideco LR-495, 49.5 in (1 257 mm) driven by one GE model 752 motor, rated at 1,000 hp (746 kW) continuous, coupled to a two speed transmission

Drill String Compensator
NL Shaffer 18 ft (5.5 m) stroke 400,000 lb (178 000 daN) compensating capacity or a 1,000,000 lb (444 800 daN) locked capacity

Tensioner System
4 x 80,000 lb (35 600 daN) Western Gear riser tensioners, 48 ft (14.6 m) wireline travel with 1¾ in (44.5 mm) wire rope

6 x 16,000 lb (7 100 daN) Western Gear guideline/pod tensioners, 40 ft (12.2 m) wireline travel with ¾ in (19.1 mm) wire rope

Mud Pumps
2 x Ideco T1600 triplex, each driven by two GE model 752 motors rated at 1,000 hp (746 kW) continuous

Cementing Unit
Dowell owned R717 twin triplex powered by two GE model 752 motors each rated at 1,000 hp (746 kW) continuous, with 7,500 psi (52 MPa) and 10,500 psi (72 MPa) fluid ends

Rig Floor Pipe Handling System
Varco Iron Roughneck model IR-2000
Range: 2⅞ to 8 in (73 to 203 mm)

Mud Logging Room

Designed to accommodate equipment from any of the major mud logging companies. This room is an integral part of the rig and contains complete lab facilities

Testing Equipment

Complete testing system with a 10,000 BOPD (1 590 m^3/day) capacity consisting of: data header, choke manifold, steam heater, 3-phase separator, surge tank, water degasser, transfer pumps, and flare booms

Mud Conditioning Equipment

4 x Thule United VSM-120 shale shakers
1 x Brandt SR-3 desander
1 x Brandt SE-24 desilter
1 x Thule VSM-200 mud cleaner
1 x Wagner Sigma-100 centrifuge
1 x Sharples DM 40 000 centrifuge
2 x Burgess Magna-Vac vacuum degassers
2 x Alfa-Laval AX30 mud coolers

Subsea Equipment

BOP System
1 x NL Shaffer 18¾ in (476 mm), 10,000 psi (69 MPa) BOP stack with annular, 4 ram type preventors, and Vetco H-4 E connector

1 x NL Shaffer 18¾ in (476 mm), 15,000 psi (103 MPa) BOP stack with annular rated at 10,000 psi (69 MPa), 4 ram type preventors, and Vetco H-4 E x F connector

Lower Marine Riser Packages
2 x 18¾ in (476 mm) with 10,000 psi (69 MPa) Shaffer annular, Regan 24 in (610 mm) CR-1 pressure compensated lower ball joint and Vetco H-4E connector

BOP Cranes
2 x Hepburn main bridge cranes, 85 ton (77 tonne) capacity each with 10 ton (9.1 tonne) auxiliary hoists

30 in (762 mm) Marine Riser System
3 x hydraulic pin connectors; 2 x 36 in (914 mm) Cameron and 1 x 30 in (762 mm) Dril-Quip

1 x Regan 28 in (711 mm) CR-1 pressure compensated lower ball joint

30 in (762 mm) riser consisting of 1 in (25.4 mm) wall casing with Hunting Lynx 52S connectors

1 x Regan 28 in (711 mm) telescoping riser joint with 45 ft (13.7 m) stroke

1 x Regan 28 in (711 mm) DR-1 upper ball joint

1 x Regan KFDS 28 in (711 mm) diverter

21¼ in (540 mm) Marine Riser System
21¼ in (540 mm) Cameron RCK riser with 10,000 psi (69 MPa) choke and kill lines

2 x Cameron telescoping riser joints, 1 x 40 ft (12.2 m), and 1 x 50 ft (15.2 m) stroke

1 x Regan 24 in (610 mm) DR-1 upper ball joint

1 x Regan KFDS 24 in (610 mm) diverter

Glory Hole Bit
1 x Brown Tornado, 24 ft (7.3 m) diameter hydraulically operated with airlift discharge. Capable of drilling a glory hole 40 ft (12.2 m) into the seabed for ice scour protection

Power Generation

Prime Movers:
3 x Electro-Motive Diesel rated at 2,817 hp (2 100 kW) each

Emergency Power:
1 x GM Detroit diesel rated 873 hp (651 kW)

Cranes

3 x Liebherr, BOS 65/850, rated at 72 ton (65 tonne) at 30 ft (9.1 m)

Safety Equipment

4 x Whittaker 54-person survival craft; two on port, two on starboard

1 x Hurricane Model 700-D emergency rescue boat

2 x RFD inflatable escape slides

Helideck

Capacity for Sikorsky 61 or similar with fueling station

Accommodation

Bunks for 108 people, recreation room, sauna, galley with seating for 36, offices, and hospital

Classification

The unit has been designated as Arctic Class IV (by the Canadian Coast Guard) under Canadian Arctic Shipping Pollution Prevention Regulations, and as Ice Class 1AA by the American Bureau of Shipping.

Specifications

Owner:	BeauDril Limited
Flag:	Canadian
Rig Type:	Conical Drilling Unit (CDU)
Delivered:	1983
Rig Design:	Earl & Wright - Lavalin
Built By:	Mitsui Engineering and Shipbuilding, Japan

Dimensions

Diameter at main deck:	266 ft (81.0 m)
Diameter at pump deck:	196 ft (59.7 m)
Hull Depth:	61 ft (18.5 m)

Operations

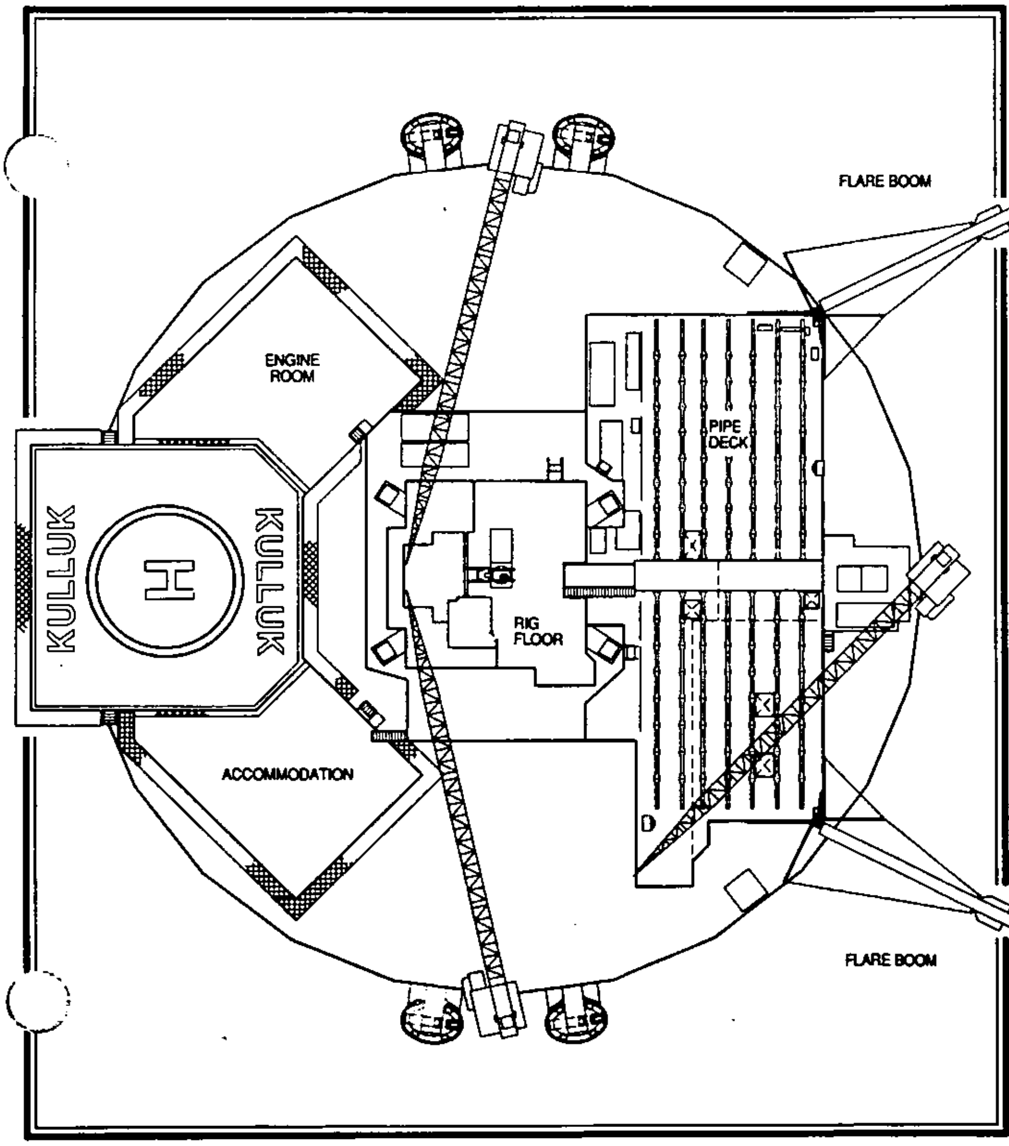
Draft (max. operating):	41 ft (12.5 m)
Draft (min. operating):	33 ft (10.0 m)
Draft (light ship):	26 ft (8.0 m)
Light Ship Displacement:	19,300 tons (17 510 tonnes)
Maximum Drilling Depth:	20,000 ft (6 096 m)
Operating Water Depth:	60 to 600 ft (18.3 to 183 m)

Variable Load

7,717 tons (7 000 tonnes)

Storage Capacities

Barite & cement bulk:	21,471 cf (608 m^3)
Liquid mud:	2,605 bbl (414 m^3)
Drill water:	4,227 bbl (672 m^3)
Fuel:	10,085 bbl (1 603 m^3)
Potable water:	1,961 bbl (312 m^3)
Ballast:	35,928 bbl (5 712 m^3)
Pipe & casing (pipe deck):	1,543 tons (1 400 tonnes)
Brine:	2,010 bbl (320 m^3)

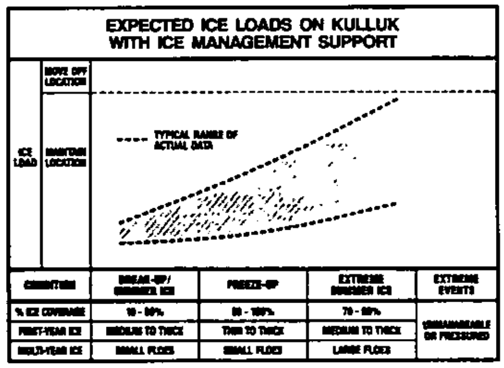


Operational Limits

Stationkeeping Conditions

Kulluk was built to operate in the ice infested waters of the Arctic offshore. The unit was developed to extend the drilling season available to more conventional floating vessels by enabling operations to be carried out through spring breakup conditions, the summer months, and well into the early winter period.

Kulluk was designed to maintain location in a drilling mode in moving first-year ice of 4 ft (1.2 m) thickness. With ice management support provided by BeauDril's Arctic Class IV icebreakers, the unit can maintain location in more severe conditions as shown below.



In terms of Kulluk's open water performance, the drilling unit was designed to maintain location in storm conditions associated with maximum wave heights of 18 ft (5.5 m) while drilling and 40 ft (12.2 m) while disconnected (assumed storm duration of 24 hrs).

If ice or open water storm conditions become more severe than those indicated, the unit's mooring system, which incorporates acoustic release devices, is disconnected from the anchors and the unit moves off location.

Kulluk Mooring System

The Kulluk's mooring system consists of twelve Hepburn winches located on the outboard side of the main deck. Anchor wires lead off the bottom of each winch drum inboard for approximately 55 ft (17 m). The wire is then redirected by a sheave, down through a hawse pipe to an underwater, ice protected, swivel fairlead. The wire travels from the fairlead directly under the hull to the anchor system on the seafloor.

Specifications

Anchor Winch

12 x Hepburn single-drum winches with a 287 ton (260 tonne) operating tension

Mooring Wires and Anchors

Anchors:

Various sizes & quantities of anchors are available for use. Exact anchor configuration to be provided once location and seafloor conditions are specified

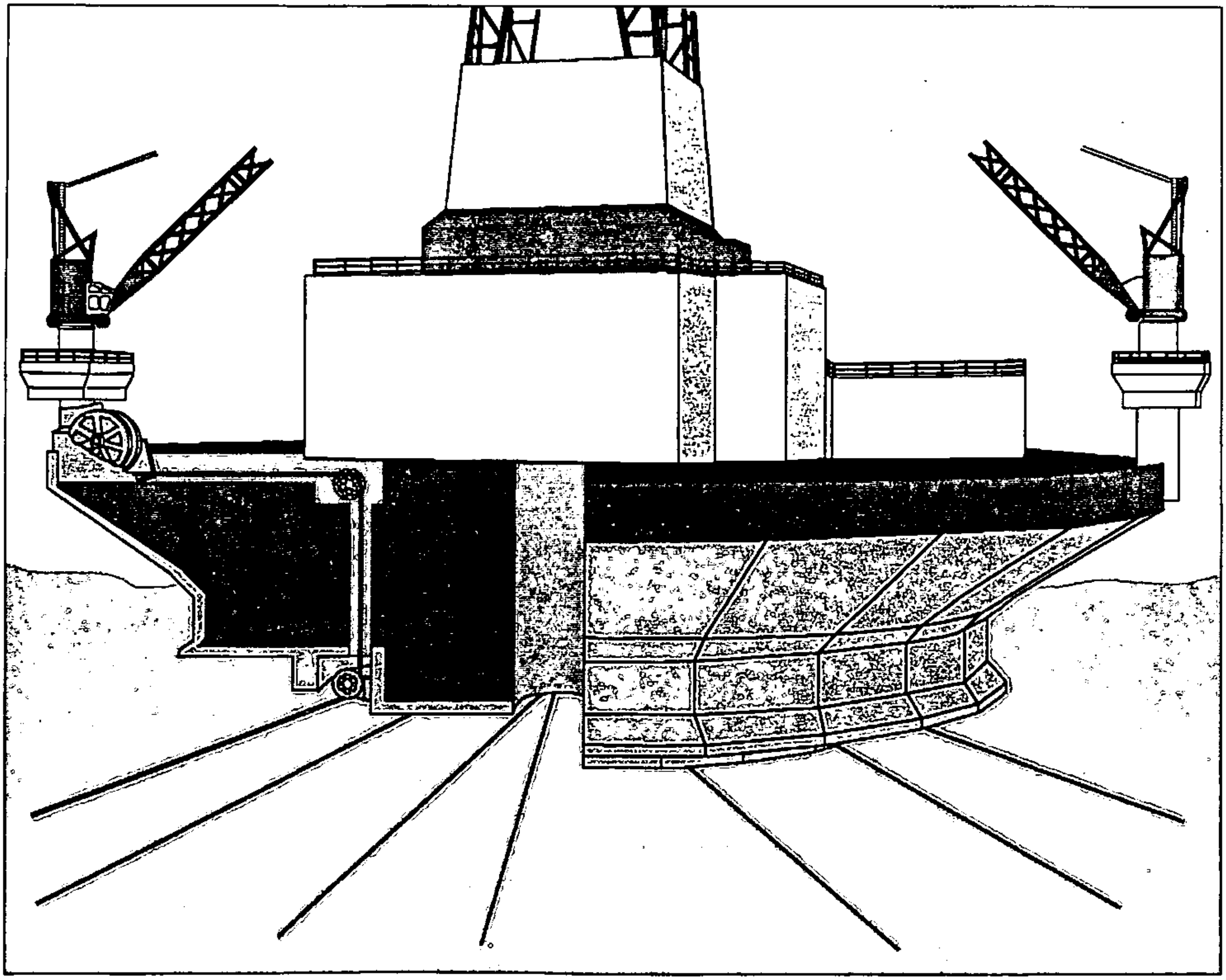
Wire ropes:

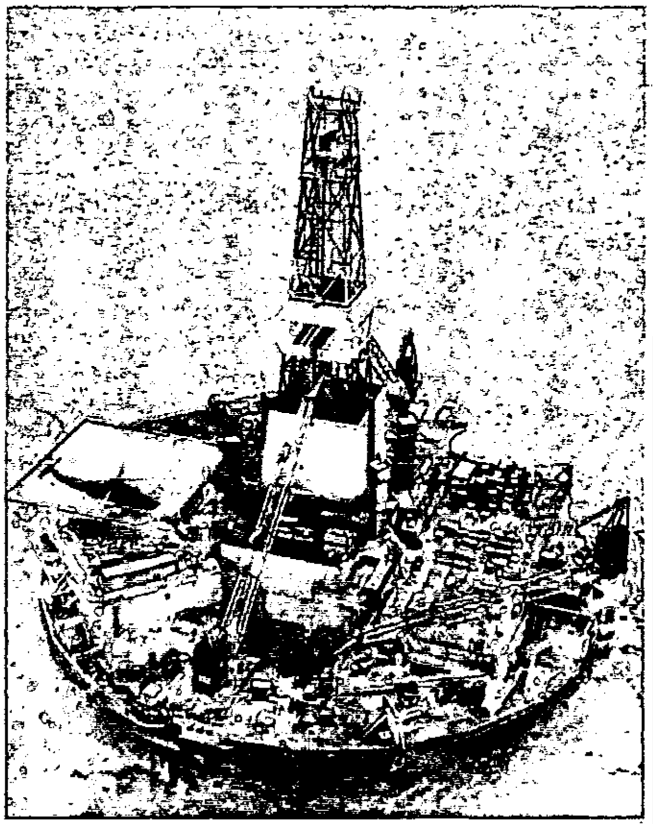
Each winch drum has capacity for 3,763 ft (1 147 m) of $3^1/_2$ in (88.9 mm), 573 ton (520 tonne) breaking strength wireline

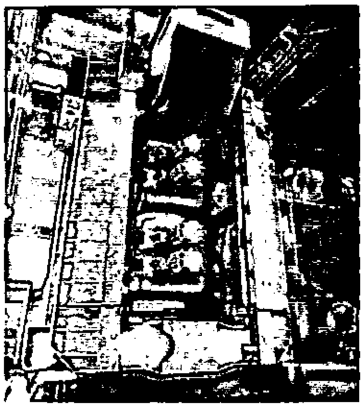
Anchor Release:

Each anchor wire contains a remote acoustic release (RAR) unit

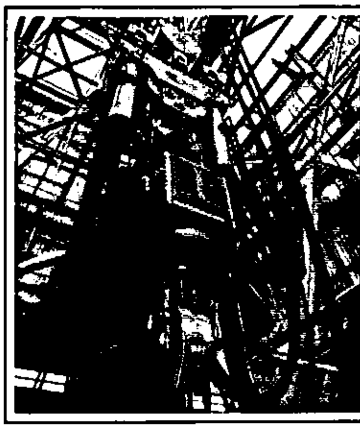
FOR MORE INFORMATION ABOUT KULLUK, CONTACT MANAGER, BEAUDRIL AT (403) 233-3030.



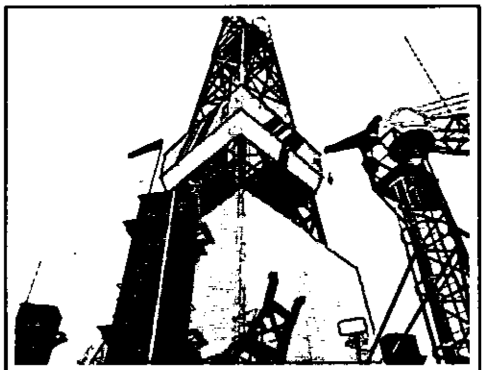




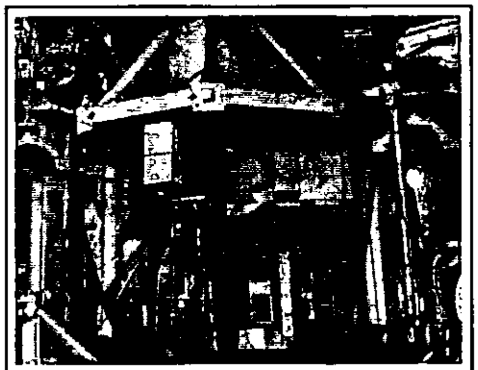
Two complete BOP systems



Varco TDS-3 top drive drilling system



Derrick enclosed to A-frame for harsh Arctic environment

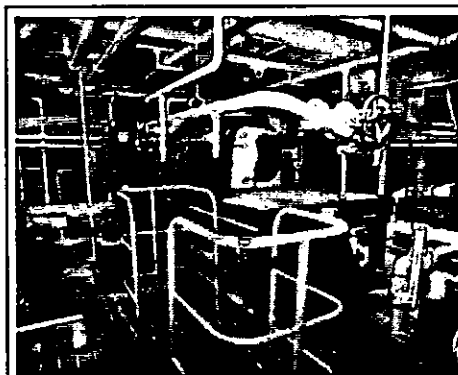


24 ft (7.3 m) diameter glory hole bit

Typical two man room in 108 man accommodation

Inside storage for drilling and rental tools

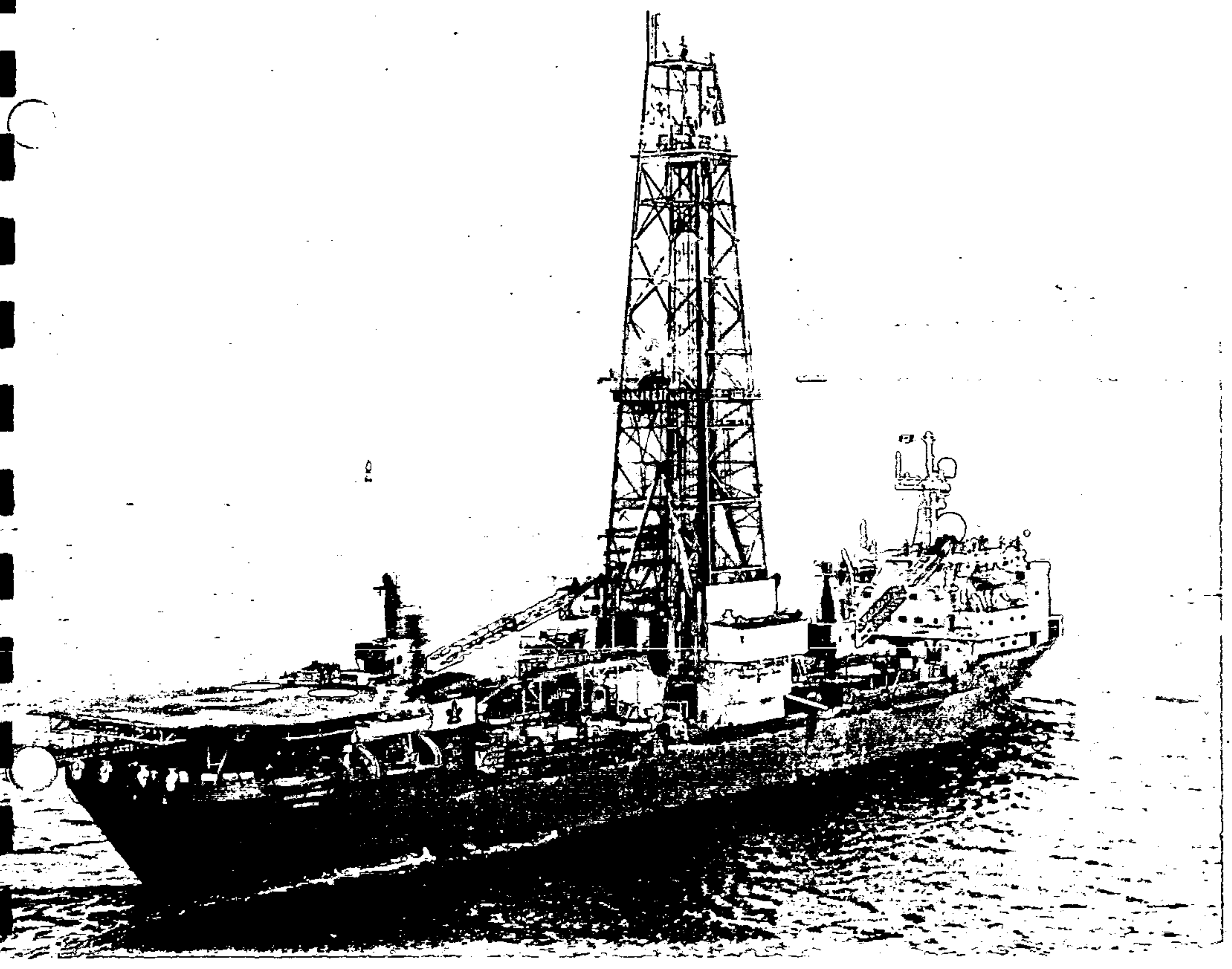
Pressurized mud logging room



Dual purpose barite recovery/solids control centrifuge

CANMAR EXPLORER III

Experience and Achievement in the Arctic Offshore



General Information

CANMAR EXPLORER III *is the largest drillship in the CANMAR fleet, developed for offshore oil and gas exploration in the Arctic regions of the world. The hull has been built to DNVIAI*IceA* specifications, is fully equipped for open water Arctic environmental conditions, and is classed by DNV.*

CANMAR EXPLORER III *has a rated drilling capacity of 6 000 metres in water depths up to 300 metres. The large storage capacity and most up-to-date drilling equipment enable the drillship to sustain long periods of uninterrupted service.*

The derrick has a 600 tonne gross nominal capacity and is equipped with advanced handling equipment for drill pipe, casing, tubing and B.O.P.s. A Varco TDS-3 top drive system provides state-of-the-art equipment for efficient drilling operations. Power is provided by a diesel electric system, consisting of five SACM AGO-V16-ESHR-240 turbocharged engines driving five AEG generators delivering a total of 12 000 KW at 6000V and 60HZ. The ship is propelled by four electric motors with a total output of 4 472 KW (6,000 HP) and five 1 350 KW (1,750 HP) thrusters.

All eight mooring lines are equipped with remote anchor release units. This special feature, in conjunction with the collapsible pawls installed on the drums, allows quick disconnection from the anchors, enabling the ship to withdraw from the drilling location quickly in the event of ice encroachment.

CANMAR EXPLORER III *has accommodation for 103 persons, and includes offices, a galley and mess room, a recreation area, and a four-bed hospital.*

Explorer III Specifications

CANMAR

PRINCIPAL DIMENSIONS

Length overall	149.25 m (489'-8")
Beam, main deck	23.79 m (78'-1")
Depth	12.50 m (41'-0")
Draft (max)	7.60 m (24'-7")
Displacement (max)	16 519 tonnes (16,260 tons)
Displacement (lightship)	9 299 tonnes (9,152 tons)
Variable load	7 220 tonnes (7,106 tons)
Water depth capacity	30 m-305 m (100'-1,000')
Helideck	*Sikorsky* S-61 or similar, plus refuelling system
Accommodation	Quarters for 103 persons, also recreation area and a 4-bed hospital

STORAGE CAPACITY

Bulk cement and mud (12 silos)	532 m³ (18 000 ft³)
Sack material	400 tonnes (440 tons)
Liquid mud	334 m³ (2 100 bbls.)
Fuel	3 397 m³ (897,300 U.S. gal)
Helifuel	23 m³ (6000 U.S. gal.)
Potable water	269 m³ (71,000 U.S. gal)
Drill Water	424 m³ (112,100 U.S. gal.)
Casing	697 tonnes (686 tons)
Drill Pipe	440 tonnes (433 tons)
Riser	110 tonnes (108 tons)

POWER PLANT

Main Engines	Five *SACM* AGOV16 250 kW (3 400 BHP)
AC Generators	Five *AEG* 3 000 kVA-6 000 VAC
DC Conversion	Eight *AEG* SCR's, 1,200 Amp @ 530 VDC
Harbour Generator	One *SACM* MGO V12,600 kW (800 HP), 440 VAC
Emergency Generator	One *Scania* 120 kW (160 HP), 440 VAC

PROPULSION

Main Propulsion	Four 1 120 kW (1,500 HP) motors, total continuous power 4 472 kW (6,000 HP). Two 3.96 m (13') variable pitch propellers
Thrusters	Five *LIPS* NV Model BP-176 tunnel-type thrusters driven by five *AEG* model AJ63055 motors at six KV, 1 350 kW (1,750 HP) each
Speed	Fourteen knots

ANCHOR SYSTEM

Mooring System	Eight point system with acoustic quick release modules on all eight lines. Four *Skagit* model *DMW-250* diesel driven double drum winches with collapsible pawls and 70 mm (2⅔") wires. Eight 6 500 kg (14,300 lbs) Bruce anchors

MAJOR DRILLING EQUIPMENT

Derrick	48.66 m, 13.61 x 10.97 m base (160', 44' x 36') 600 tonnes (665 tons) capacity. Designed for 160 km/h (100 mph) wind
Drawworks	*National Model* 1625-DE with *Baylor Elmagco* Model 7838 auxiliary brake
Top Drive	*Varco* TDS-3
Rotary Table	*National Model* C375 953 mm (37½")
Motion Compensator	*IHC* crown block heave compensator with 200 tonnes (220 tons) capacity and a 4.6 m (15') stroke
Mud Pumps	Two *National* Model 12P-160 pumps each driven by two AEG 800 HP DC motors
Solids Control	Three Derrick Flo-Line cleaners, *Pioneer* desander, *Brandt* scalping shaker, two *Swaco* desilters, *Wagner Sigma* 100 Centrifuge
Cement Pumps	One *Dowell* electric drive model TLO rated at 34.5 MPa (5,000 psi) One *Dowell* electric driven model TLO rated at 69.0 MPa (10,000 psi)
Drill String	6 000 m (20,000') 127 mm (5") drill pipes Grade E & G

B.O.P./RISER

Blowout Preventers	476 mm 69.0 MPa WP (18¾" 10,000 psi) system One NL *Shaffer* type LWS triple ram One NL *Shaffer* type LWS single ram One NL *Shaffer* double spherical, 34.5 MPa (5,000 psi) WP
Marine Riser	559 mm (22") *Vetco* riser with MR6C connectors c/w ball joint 69.0 MPa (10,000 psi) choke and kill lines
Telescopic Joint	*Vetco* 17 m (55') stroke
Diverter	*Regan* KFDS system
B.O.P. Control	*Koomey* Hydraulics control system
Choke Manifold	69.0 MPa (10,000 psi) system with Cameron auto choke

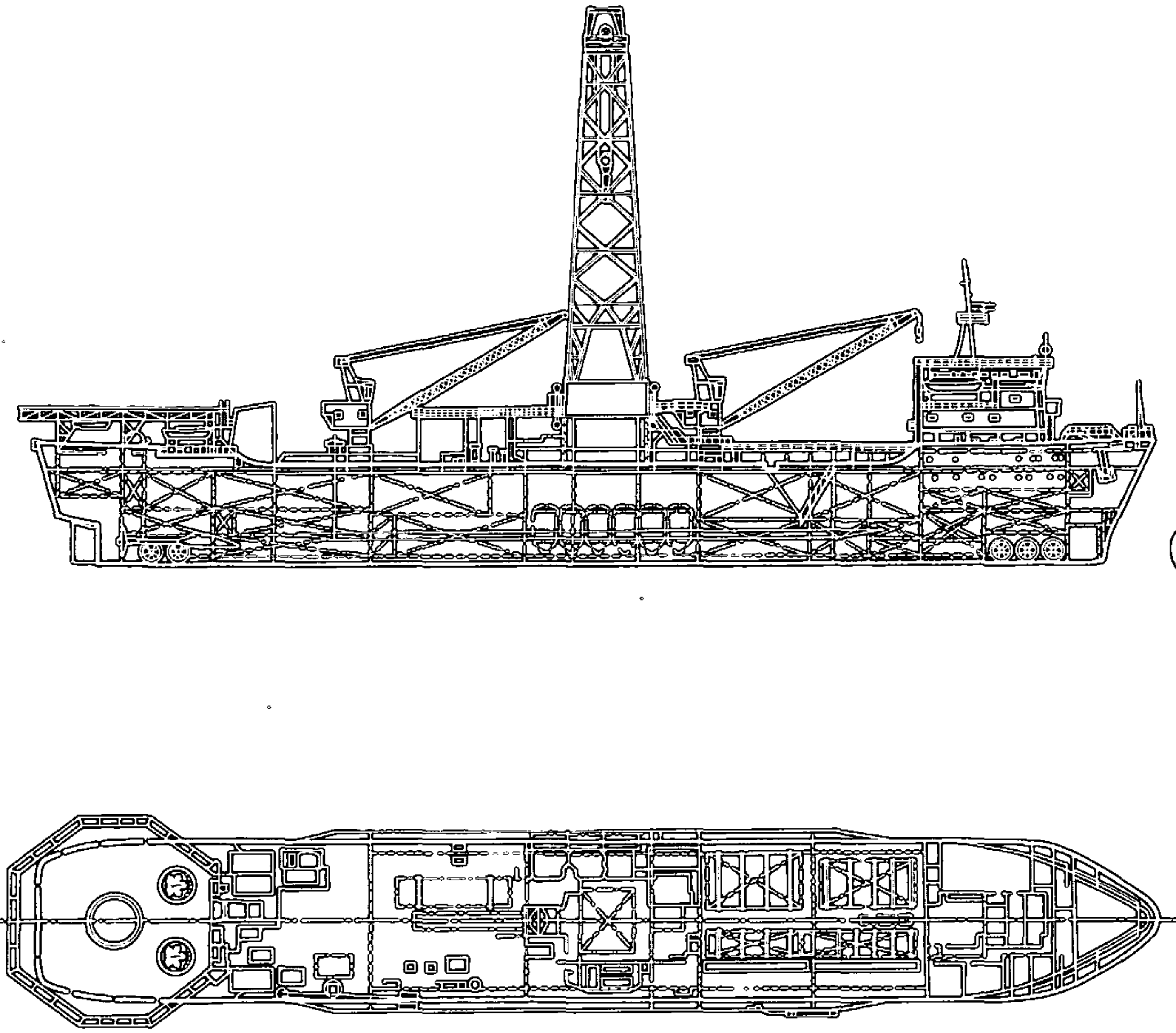
AUXILIARY EQUIPMENT

B.O.P. Handling System	Two 90 tonne (100 ton) capacity hydraulic trolley carts
Cranes	One *IHC* 28 m (90') 36 tonnes (40 tons) One *IHC* 28 m (90') 23 tonnes (25 tons) Both equipped with remote control
Pipe Racker	*Byron Jackson*
TV and Diving	T.V. system rated at 366 m (1 200') C.G. Doris with bell and guiding device and decompression chamber rated at 300 m (1,000')
Re-Entry	Acoustic long baseline navigation system

SPECIAL FEATURES

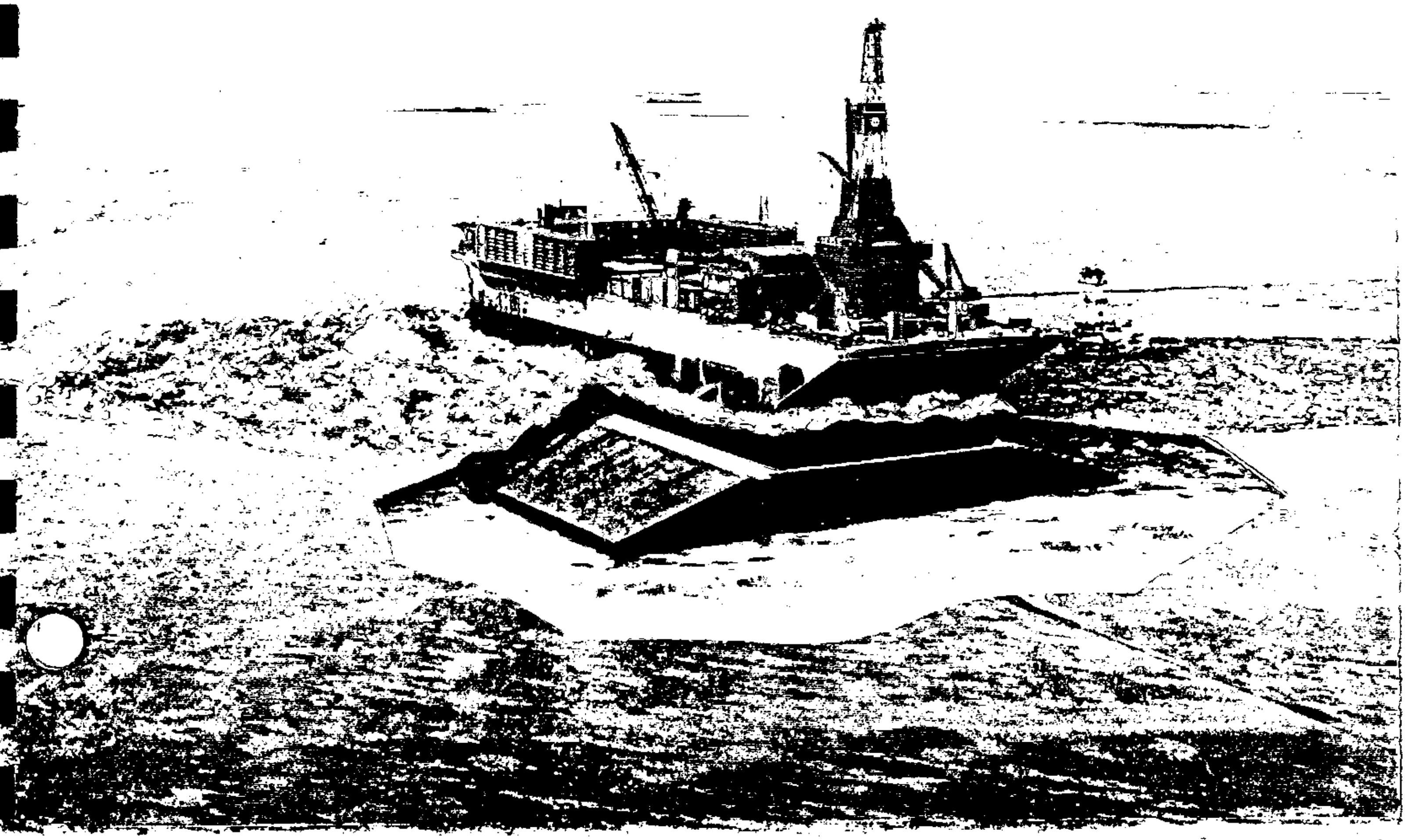
Ice Reinforcement	Hull reinforced to DNV1A1*IceA specification. Propulsion equipment meet DNV 1A1*Ice*B specification. Hull corresponds to Type C of Canadian Regulations.
Radar	Derrick Top for Ice Management

Explorer III



CANMAR SSDC/MAT

Experience and Achievement in the Arctic Offshore



General Information

SSDC/MAT Specifications

PRINCIPAL DIMENSIONS

Length overall	715'-6" (218.1m)
Length on waterline	551'-2" (168.0m)
Breadth overall	360'-11" (110.0m)
Depth	128'-7" (39.2m)
Design Draft	2[illegible]'-80' (7.6m-24.4m)
SSDC Topsides:	
Length	663'-11" (202.4m)
Breadth	173'-11" (53.0m)

STORAGE CAPACITY

Bulk barite (14 silos)	141,000 ft³ (3,990m³)
Bulk Cement:	
- Permafrost (4 silos)	40,300 ft³ (1,140m³)
Class "G" (2 silos)	20,[illegible] ft³ (5[illegible]m³)
Sack Storage area	8,6[illegible] ft² (805m²)
Liquid mud	2,100 bbls (334m³)
Fuel	1,446,500 U.S. gal (5,47[illegible]m³)
Heli fuel	[illegible] U.S. gal (22.7m³)
Potable water	29,000 U.S. gal (110m³)
Drill water	482,000 U.S. gal (1,825m³)
Casing	2,750 tons (2,500 tonnes)
Drill Pipe	275 tons (250 tonnes)

POWER PLANT

Main Engines	6 *Caterpillar* D-399 JWAC 746kW (1,000 HP)
AC Generators	6 *Kato* 6P5-3150, 1,050 kW 1,500 KVA-600 VAC
DC Conversion	4 *Ross Hill* SCR's-2,000 AMP @ 750VDC
Emergency Power	1 *Caterpillar* D-399 JWAC (1,000 HP) 746 kW 600 VAC

MAJOR DRILLING EQUIPMENT

Mast	*Dreco* cantilever 147' (44.8m) clear working height, 34' (10.36m) leg spread 650 tons (590 tonnes) gross nominal capacity.
Drawworks	*National Supply* model 1625-DE 3,000 HP (2,240 kW), driven by 2 GE752 R DC motors, with *Elmagco* Model 7838 brake
Rotary Table	*National Supply* Model C-495 49½" dia (1,2[illegible]mm) [illegible] gear drive driven by GE 752 R [illegible]
Mud Pumps	3 *National Supply* 12-P-160 triplex pumps rated at 1,600 HP (1,200kW) each driven by 2 GE 752-R DC motors
Solids Control	*Brandt* triple tandem shale shaker; *Brandt* model SE-12 desander; *[illegible]* tandem mud cleaner; *Wagner* Sigma 150 centrifuge; *Burgess* Magna-Vac degasser; Cuttings cleaning system
Drill String	22,000' (6,700m) 5" (127mm) Grade G drill pipe

B.O.P. EQUIPMENT

Low Pressure System	1 *Hydril* 20¾" (527mm) double ram, 3,000 psi (20.7 MPa); 1 *Hydril* 21¼" (540mm) annular preventer, 2,000 psi (13.8 MPa); *Vetco* LS riser system 24" (610mm) O.D.
High Pressure System	3 *Hydril* 13⅝" (346mm) single rams, 10,000 psi (69.0 MPa); 1 *Hydril* 13⅝" (346mm) annular preventer, 5,000 psi (34.5 MPa); *Vetco* MRF Riser System 18" (457mm) O.D. 10,000 psi (69.0 MPa)
Diverter	*Regan* KFDJ-500 system with 16" (406mm) duel vent lines
Accumulator	*Hydril* Valvcon 240 gal. (908 litre) capacity
Choke Manifold	10,000 psi (69.0 MPa) with *Wagner* auto choke

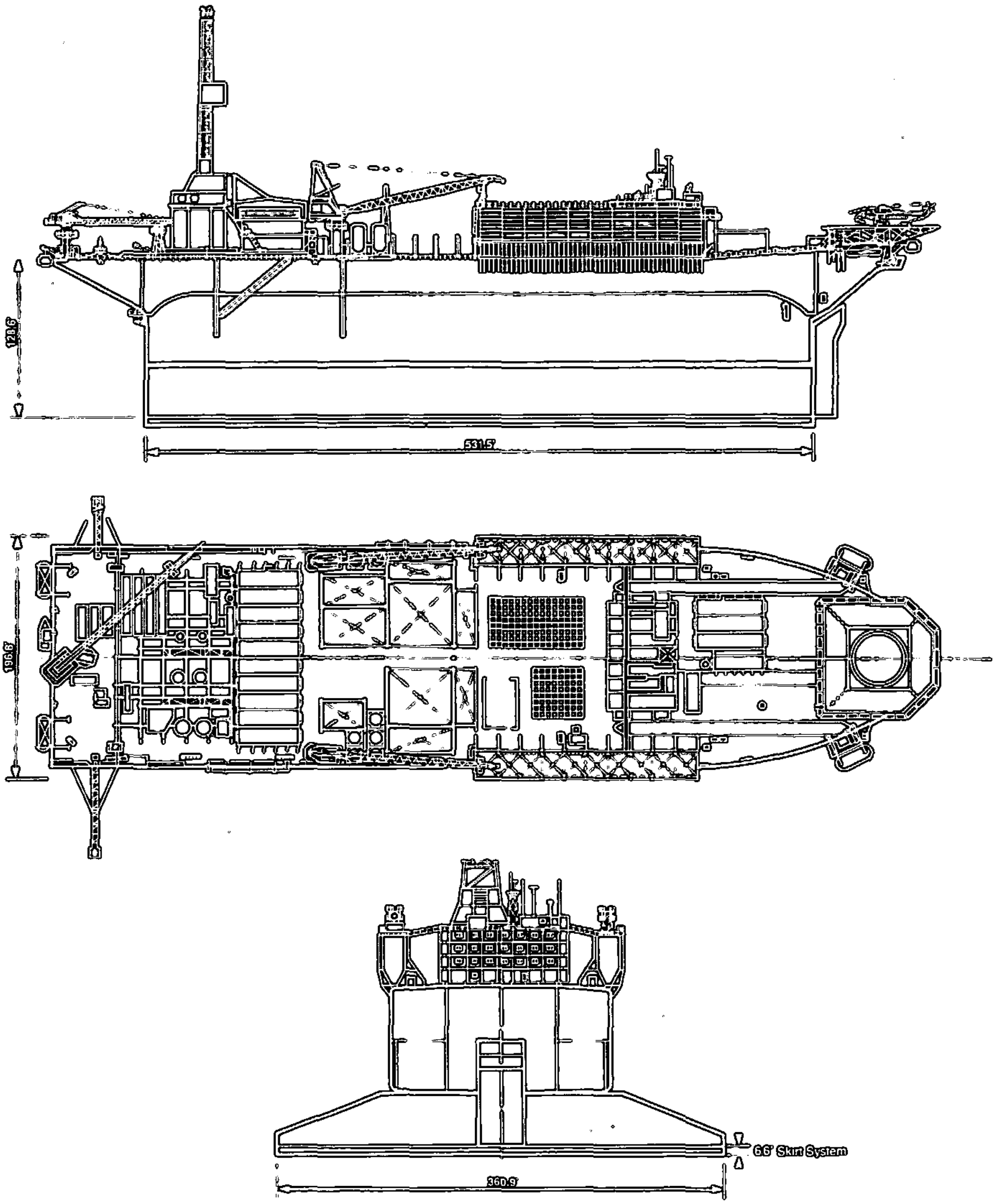
AUXILIARY EQUIPMENT

Bulk Transfer	2 low pressure air blowers; 2 [illegible] Vac [illegible]
Pipe Handling	1 *Metreco* model 33 lay down machine; Handles all sizes up to 42" (1,067mm) casing
Cranes and Forklift	2 *FMC* Link Belt 1500 max. capacity 62 tons (57 tonnes), 120' (36.6m); 1 *FMC* Link Belt 238A max. capacity 35 tons (32 tonnes), 120' (36.6m); 1 *FMC* Link Belt HSP 8022 22 tons (20 tonnes), rubber tired; 1 *Caterpillar* Model 930 forklift; 2 - 25 ton (22.8 tonne) B.O.P. cranes

SPECIAL FEATURES

Ice Reinforcement	SSDC reinforced with 3.3' (1m) thick concrete and extra supports
Skirt System	6.6' (2m) long box type skirts covering the total base of the system to provide sliding resistance in all soils
Instrumentation	Complete instrumentation for weather, ice and geotechnical information
Multi-well Drilling	Substructure can be skidded to drill from any 1 of the 4 moon pools available
Drilling Services	Dual pumping systems for water supply, fuel supply and ballast systems
Welding/Garage Facilities	Totally enclosed steel shop 41' x 25' x 15'-9" (12.5m x 7.6m x 4.8m)
Waste Incineration	*Atlas* Type Maxi 50-S
Helideck	Suitable for *Sikorsky* S 61N c/w fire fighting and refueling system
Accommodation	Quarters for 93 persons and 25 emergency beds, recreation room, dining room, offices and a hospital

SSDC/MAT



BeauDril

Molikpaq

Mobile Arctic Caisson

BeauDril

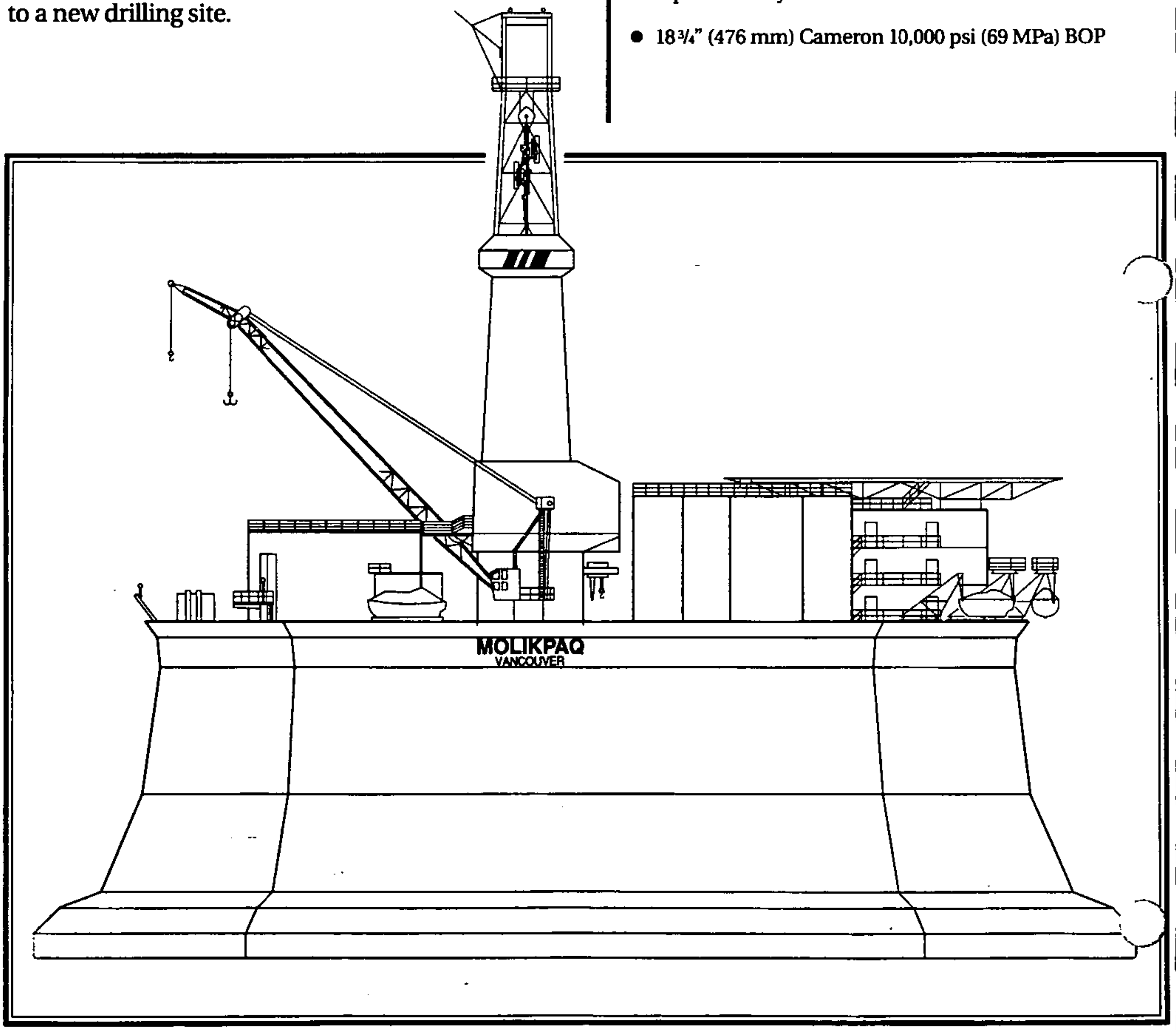
Molikpaq

Molikpaq is the first single piece deep water caisson vessel designed and constructed for bottom founded year round drilling operations in Arctic waters.

An extension of the caisson retained island concept, Molikpaq is designed to be ballasted down for drilling operations. The drill rig, support facilities, pipe barn and accommodations are supported on top of the operations deck in modules. Molikpaq is easily refloated after completion of one or more wells at a location, and towed to a new drilling site.

Key Features

- Operating water depth 26 to 130 ft (7.9 to 39.6 m), drilling depth up to 20,000 ft (6 096 m)
- Electrically driven Varco top drive drilling system
- Two drill cellars with space for four wells total
- Derrick enclosed to racking platform
- Enclosed heated pipe barn
- Extensive deck storage area
- Bulk silos with 59,000 ft³ (1 671 m³) capacity
- Permanently installed 10,000 bbl/day (1 590 m³/day) 3-phase test system
- 18¾" (476 mm) Cameron 10,000 psi (69 MPa) BOP



Equipment

Drilling Equipment

Derrick
147 ft (44.8 m) Dreco dynamic with a 30 ft x 30 ft (9.1 m x 9.1 m) base, rated at 1,000,000 lb (445 000 daN) with 12 lines

Racking platform has capacity to hold 19,845 ft (6 049 m) of 5 in (127 mm) drill pipe plus bottom hole assembly

Drawworks
Ideco E-3000 electric drawworks complete with sand reel and Elmago model 7838 Baylor auxiliary brake, spinning and breakout catheads and two GE model 752 motors each rated at 1,000 hp (746 kW) continuous

Travelling Block
Emsco model RA-60-6 unitized, 650 ton (590 tonne) capacity

Swivel
Ideco TL-500, 500 ton (454 tonne) capacity

Drill Pipe
20,000 ft (6096 m) x 5 in (127 mm), 19.5 lb/ft (29 kg/m) with 4½ IF connections

Catwalk Pipe Handling System
Hydraulically operated pick-up/lay-down trough, 4.5 ton (4.1 tonne) x 20 in (508 mm) capacity

Top Drive
Varco TDS-3 with one GE model 752 motor rated at 1,000 hp (746 kW) continuous and a 500 ton (454 tonne) hoisting capacity

Rotary Table
Ideco LR-495, 49½ in (1 257 mm) driven by one GE model 752 motor, rated at 1,000 hp (746 kW) continuous, coupled to a two speed transmission

Mud Pumps
2 x Ideco T1600 triplex, each pump driven by two GE model 752 motors rated at 1,000 hp (746 kW) continuous

Cementing Unit
Dowell owned R624 diesel powered twin triplex with 10,500 psi (72 MPa) and 7,500 psi (52 MPa) fluid ends

Rig Floor Pipe Handling System
Varco Iron Roughneck model IR 2000
Range: 2⅞ to 8 in (73 to 203 mm)

Enclosed Pipe Barn
56 ft (17.1 m) x 187 ft (57.0 m) x 44 ft (13.4 m) high enclosed heated space with 10 ton (9.1 tonne) overhead crane

Testing Equipment

Complete testing system with a 10,000 BOPD (1 590 m³/day) capacity consisting of: data header, choke manifold, diesel heater, 3-phase separator, surge tank, water degasser, transfer pumps, and flare booms

Mud Conditioning Equipment

4 x Thule United VSM-120 shale shakers
1 x Brandt SR-3 desander
1 x Brandt SE-24 desilter
1 x Thule VSM-200 mud cleaner
1 x Wagner Sigma-100 centrifuge
1 x Swaco vacuum degasser
2 x Alfa-Laval AM20 mud coolers

BOP Equipment

BOP System
1 x Cameron 18¾ in (476 mm), 10,000 psi (69 MPa) BOP stack with type "D" annular and 2 x "Double U" ram type preventors

Diverter
1 x Regan KFDJ 27½ in (699 mm) through bore

BOP Cranes
2 x 50 ton (45 tonne) Olympic cranes

Ballasting

6 x Peacock Desmi centrifugal pumps rated at 2,860 bbl/hr (455 m³/hr) at 43 psi (296 kPa)

Core Filling & Removal Equipment

The core is filled by a dredge through a 30 in (762 mm) floating hose

The core material is removed using a submersible pump.

Power Generation

Prime Movers:
4 x Caterpillar D399, 1,250 hp (930 kW) each

Emergency Power:
1 x Caterpillar D399, 1,115 hp (831 kW)

Cranes

3 x Liebherr BOS 65/850, 72 tons (65 tonnes) at 30 ft (9.1 m)

Safety Equipment

4 x Watercraft 50-person survival craft

1 x Hurricane Model 700-D emergency rescue boat

2 x RFD inflatable escape slides

Helideck

Capacity for Sikorsky 61 or similar with fueling station

Accommodation

Bunks for 104 people, recreation room, galley with seating for 30, offices, and hospital

Operational Limits

This monolithic caisson structure was designed to withstand the forces from both first and multi-year ice interactions. Molikpaq's deployment design is tailored to the ice and sea floor conditions at specific locations in either landfast or moving ice zones. The unit can withstand local ice pressures of 1,000 psi (6 895 kPa) and has been deployed in configurations to sustain global ice loads as high as 134,840 tons (1 200 MN).

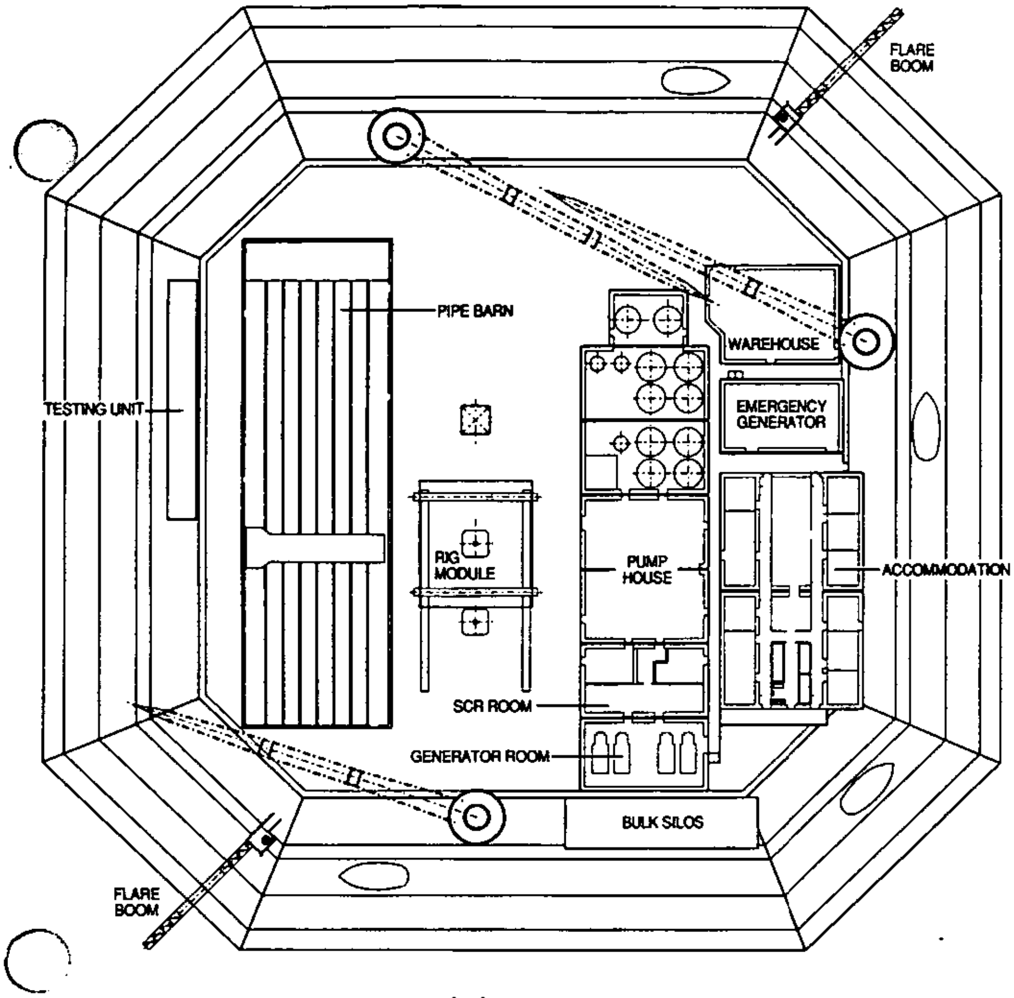
In terms of Molikpaq's open water performance, the unit has been designed to operate with no constraints from wave overtopping or spray in storm conditions associated with maximum wave heights of 40 ft (12.2 m).

Variable Load

14,065 tons (12 760 tonnes)

Storage Capacities

Barite & cement bulk:	75,965 cf (2 151 m³)
Liquid mud: (90% cap.)	2,209 bbl (351 m³)
Drill water:	451 bbl (71.7 m³)
Fuel (90% cap.):	32,399 bbl (5 151 m³)
Potable water:	500 bbl (79.5 m³)
Ballast:	504,060 bbl (80 138 m³)
Pipe & casing (pipebarn):	2,485 tons (2 254 tonnes)



Classification

The unit is classified by the American Bureau of Shipping as Ice Class 1AA. The ice belt in the caisson was designed to withstand local ice pressures of 1,000 psi (6 895 kPa).

Specifications

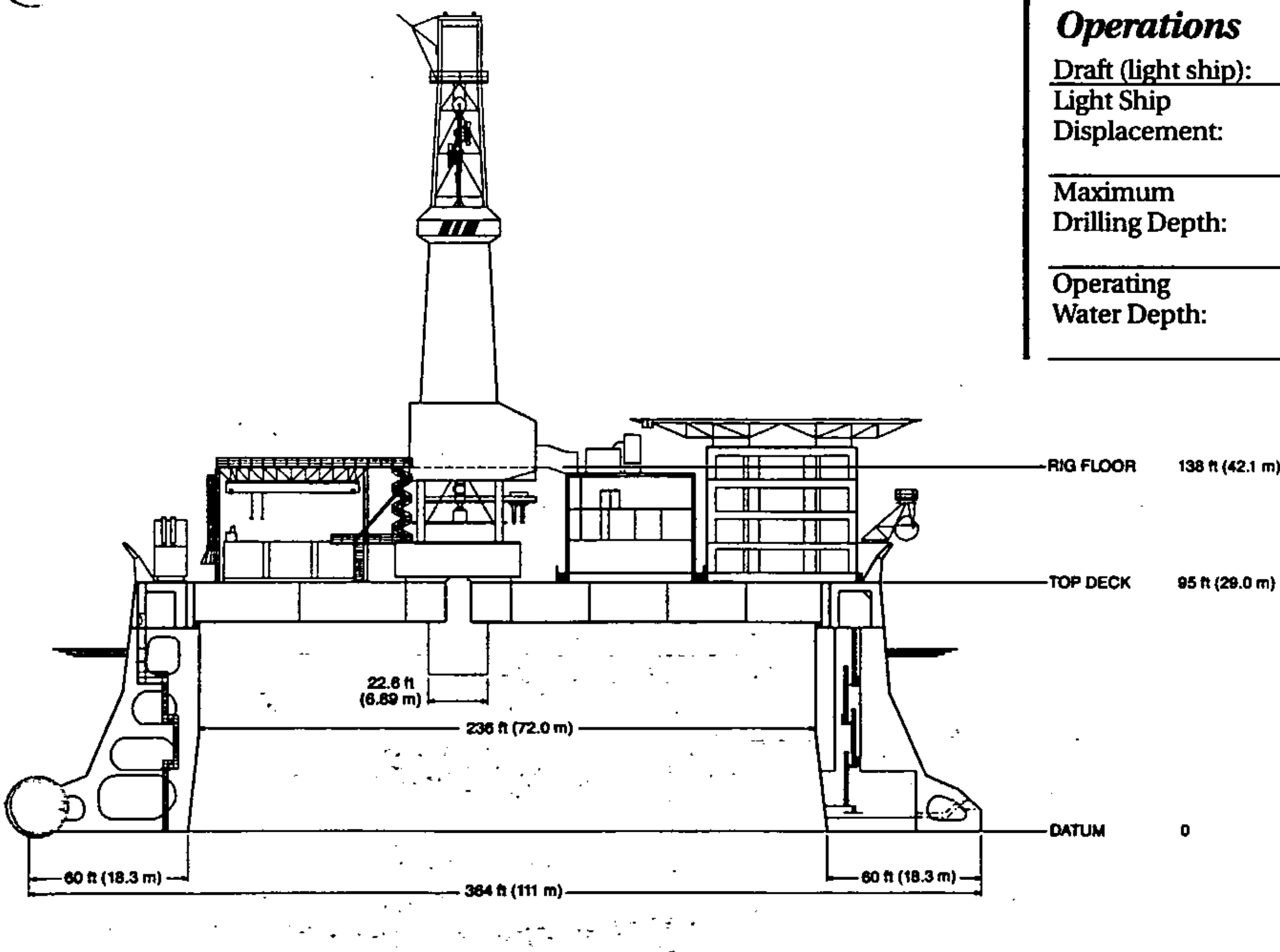
Owner:	BeauDril Limited
Flag:	Canadian
Rig Type:	Mobile Arctic Caisson (MAC)
Delivered:	Sept. 1984
Rig Design:	
Caisson:	Swan Wooster Engineering, Vancouver
Modules:	Tri-Ocean Engineering, Calgary
Built By:	IHI, Japan & Dominion Bridge, Canada

Dimensions

Base Dimensions:	364 ft x 364 ft (111 m x 111 m)
Deck Dimensions:	240 ft x 240 ft (73.1 m x 73.1 m)
Hull Depth:	95 ft (29.0 m)

Operations

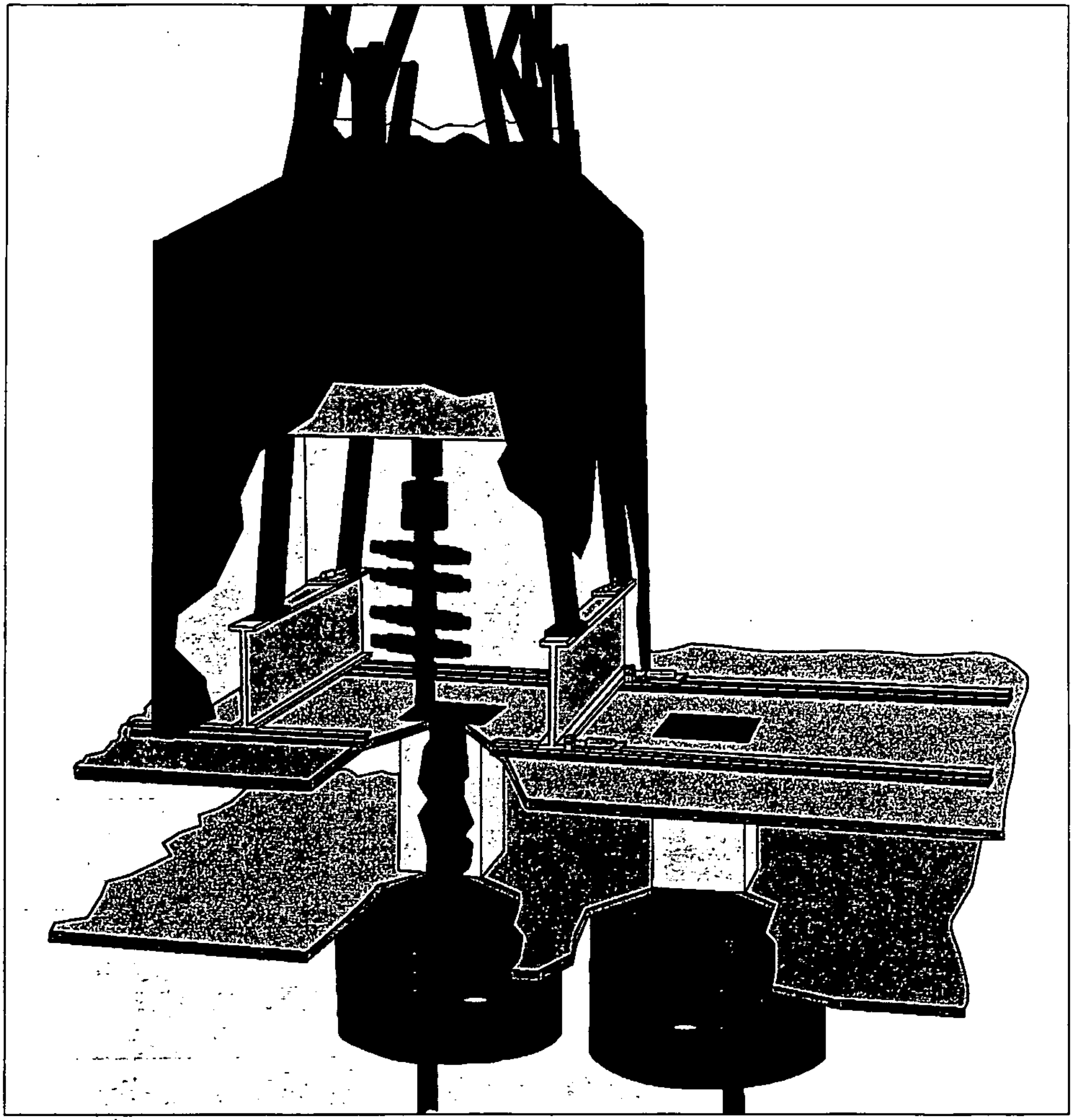
Draft (light ship):	17 ft (5.2 m)
Light Ship Displacement:	34,172 tons (31 000 tonnes)
Maximum Drilling Depth:	20,000 ft (6 096 m)
Operating Water Depth:	26 to 130 ft (7.9 to 39.6 m)

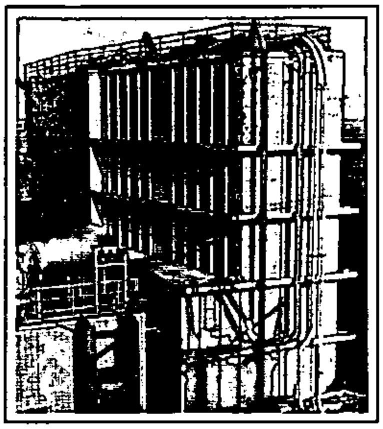


Molikpaq Rig Skidding System

Once Molikpaq is set down, drilling operations can begin in one of two moonpools which penetrate the operations and box girder decks to provide access to the drill cellars below. Two wells can be drilled diagonally opposite one another in each drill cellar. The rig can be skidded using four 150 ton (136 tonne) hydraulic jacks to facilitate movement to the four drilling slots.

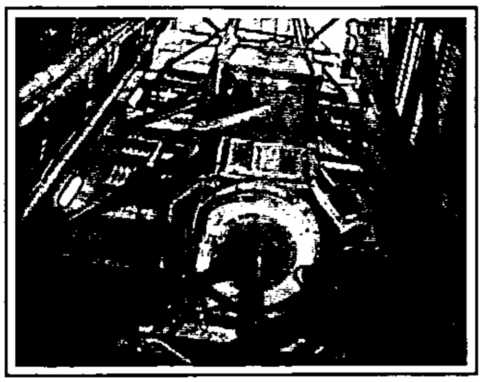
FOR MORE INFORMATION ABOUT MOLIKPAQ, CONTACT MANAGER, BEAUDRIL AT (403) 233-3030.



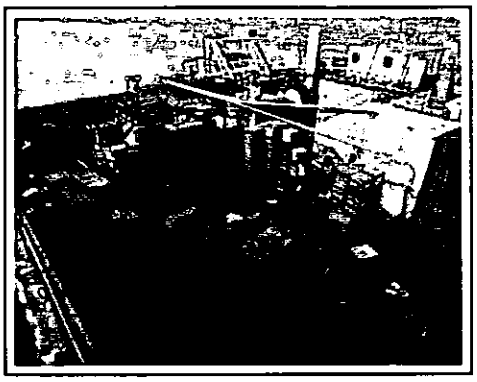


Bulk silos with 59,000 cf (1 671 m^3) capacity

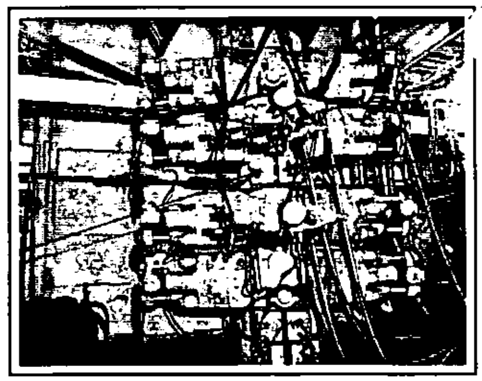
Enclosed derrick for harsh Arctic environment



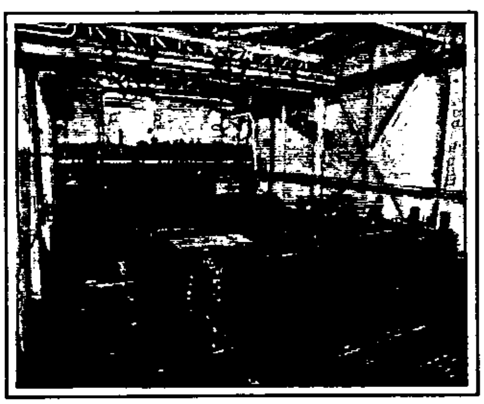
Varco TDS-3 top drive drilling system



Extensive deck storage area outside pipe barn

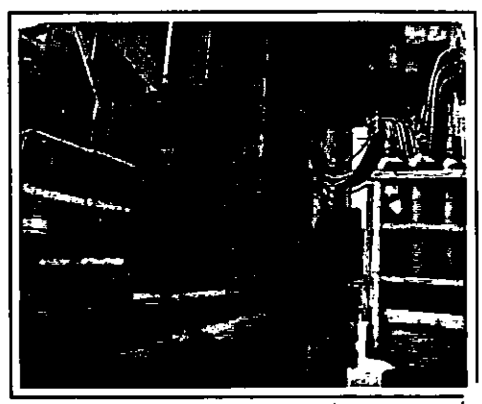


$18\frac{3}{4}$ in (476 mm) x 10,000 psi (69 MPa) one stack system



Enclosed pipe barn

Typical two man room in 104 man accommodation



Skiddable rig package for access to two drill cellars

GLOMAR BEAUFORT SEA I

GLOBAL MARINE DRILLING COMPANY

GENERAL DESCRIPTION

The GLOMAR BEAUFORT SEA I is a mobile offshore drilling unit designed specifically for year-round exploratory drilling in the harsh offshore arctic environments in water depths ranging from 35 to 55 feet. The drilling unit is classified by the American Bureau of Shipping as a ✠ A1 caisson drilling unit and is completely certified by the United States Coast Guard.

The GLOMAR BEAUFORT SEA I consists of six structural modules: a steel mud base, a center structure of honeycomb concrete referred to as the "Brick," two steel deck storage barges, the quarters unit and the drilling rig. Combined, these modules form a drilling unit which can be towed to, and ballasted down at, the drill site. When required, the unit can be deballasted, refloated and towed to another drill site. The deballasting and refloating operation can be accomplished within approximately 72 hours under normal conditions.

Modular Components

The steel mud base consists of a series of large tanks which can be flooded with sea water thereby providing ballast control during the lowering or refloating of the platform. Once on the bottom, the tanks are completely filled to obtain the maximum gravity load. The mud base is the means by which the ice loads are transmitted from the Brick to the foundation soil. A five foot deep grid, which extends beneath the base, penetrates the soils to provide further resistance to sliding.

The concrete Brick, connected to the steel mud base, is the main structural element which resists the large ice forces prevalent in the arctic. A Rubble Generation System utilizing high pressure "water cannons" provides additional protection against advancing ice. The system provides a high volume spray which produces a grounded ice berm around the platform creating passive protection from the ices forces. The Brick supports the two deck storage barges. Combined, the two deck barges provide a total of more than 79,000 square feet of deck space as well as internal areas for machinery spaces and storage for fuel and consumables.

The rig is completely self supporting and can operate without the resupply of major drilling consumables for periods of up to ten months. This freedom from resupply permits continuous drilling operations throughout the year in remote arctic regions.

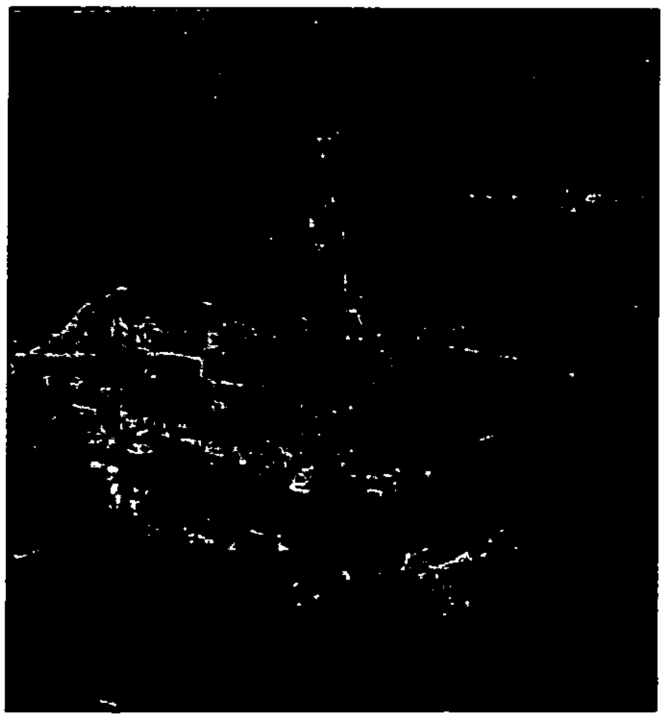
The starboard barge houses a survival shelter which is outfitted to support all crew members for a period of up to three days in the event of a major on-board emergency. The quarters are installed on the starboard barge. The drill rig and all drilling support equipment are located on the port barge.

Both the drill well located in the port barge and the service well located in the starboard barge run vertically through the barges, Brick and base. Multiple wells can be drilled at a single platform location.

The five story quarters structure can accommodate up to 92 personnel. The quarters structure also houses the machinery spaces on the main deck, three floors of staterooms, mess hall and recreational facilities. The control and communications rooms are located in the fifth level. The helicopter landing facility is located on top of the fifth level.

The drilling rig presently on board is a standard 2,000 horsepower land rig which has been modified to meet the USCG MODU regulations for offshore operations. The rig, located on the port barge, is complete with a power generation system independent from the power system which supplies the quarters, marine systems and survival shelter. The drilling rig is equipped to comply with environmental regulations.

Engineered to withstand the arctic environment and designed to drill multiple wells without resupply, the mobile GLOMAR BEAUFORT SEA I can accommodate drilling programs in the arctic regions in a cost effective and efficient manner.



On location in the Beaufort Sea

The GLOMAR BEAUFORT SEA I being towed to location.

Vessel Information

CLASSIFICATION: Certified by the USCG as a Mobile Offshore Drilling Unit (MODU). By ABS as a ✠ A1 caisson drilling unit.

DECK BARGES:
- LENGTH OVERALL: .... 290 ft. 6 in.
- WIDTH (for two barges): .... 274 ft.
- HEIGHT: .... 26 ft.

BRICK:
- LENGTH OVERALL: .... 234 ft.
- WIDTH: .... 234 ft.
- HEIGHT: .... 44 ft.

BASE:
- LENGTH OVERALL: .... 312 ft. 6 in.
- WIDTH: .... 295 ft.
- HEIGHT (not including 5 ft. skirts): .... 25 ft.

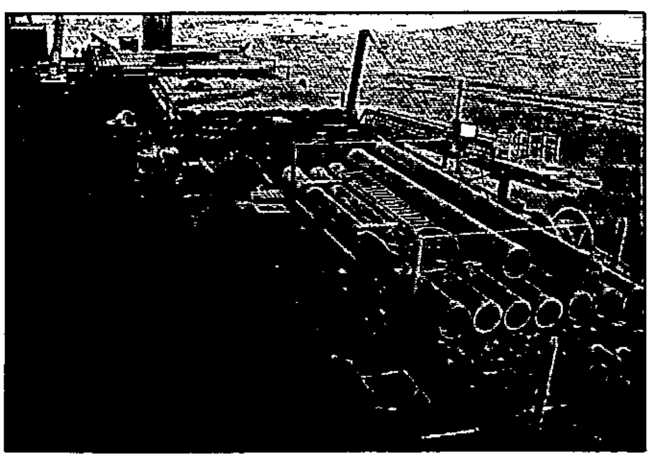
OVERALL DIMENSIONS:
- FROM BASELINE TO MAIN DECK: .... 95 ft.

HELIPORT: .... 73 ft. x 73 ft.
Designed to support an S-61 helicopter in accordance with USCG specifications.

ACCOMMODATIONS: Quarters for 92 personnel. Seven-bed Hospital. Galley, mess and recreational facilities.

DRILLING DEPTH: .... 25,000 ft.

OPERATING WATER DEPTH:
- MAXIMUM: .... 55 ft.
- MINIMUM: .... 35 ft.



Tubular storage area

Storage Capacities

SACKED MATERIALS:	2,000 sacks
BULK CEMENT:	9,000 cu. ft.
DRY BULK MUD:	27,000 cu. ft.
LIQUID MUD:	4,190 bbls.
DRILL WATER:	34,736 bbls.
FUEL OIL:	48,712 bbls.
CUTTINGS STORAGE:	4,000 bbls.
POTABLE WATER:	730 bbls.
TUBULAR STORAGE:	Three 10,000 ft. wells
SALTWATER BALLAST:	116,925 s. tons

Loading and Towing Data

OPEN OCEAN TOWS: Average Towing Speed 3.6 knots with two 22,000 IHP oceangoing tugs. Towing Draft: 32 feet (Navigational).
LOCATION TOWS: Equipment for location to location moves are site dependent.

Starboard Barge Power System

Provides power for quarters, marine systems and survival shelter.

Power Generation

Three CAT D379 diesel engines driving three 400 kw, Kato 480 volt AC generators.

Power Conversion

Two 1,000 kva, 480 volt/120 volt transformers. Three 480 volt motor control centers and distribution panels.

Port Barge Power System

Provides power for the drilling rig and drilling support equipment.

Power Generation

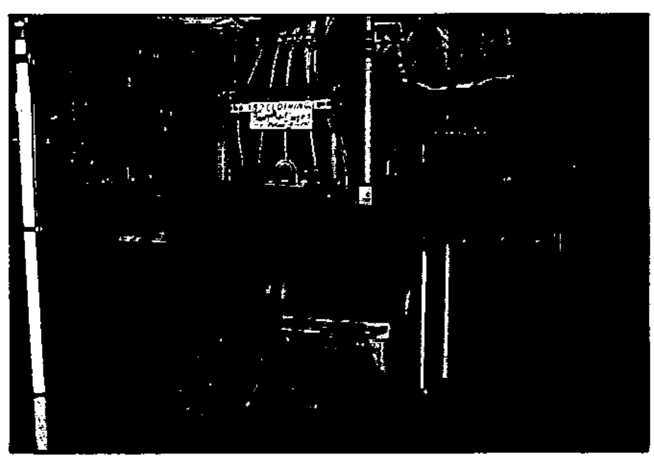
Four CAT D399 diesel engines driving four Kato 1,050 kw AC generators.

Power Conversion

Four Ross Hill SCR power conversion units.

Emergency Power

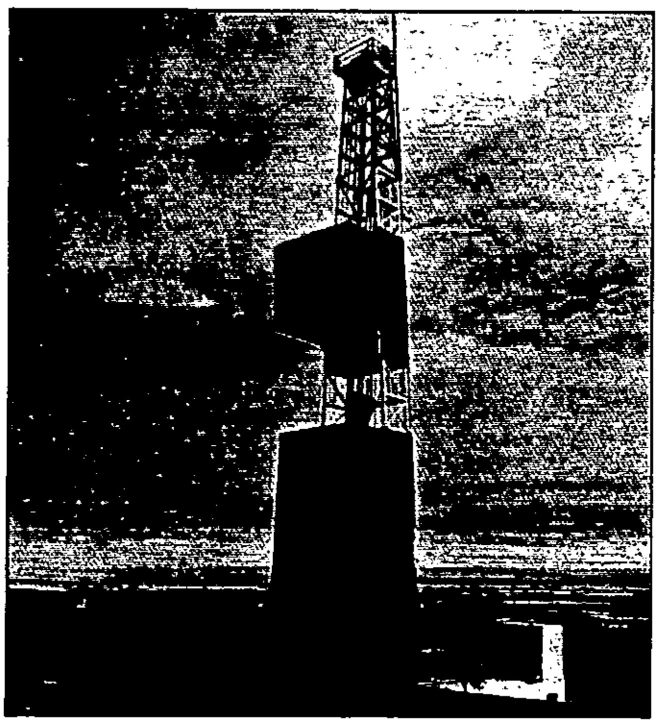
One CAT D379 diesel engine driving one Kato 400 kw generator.



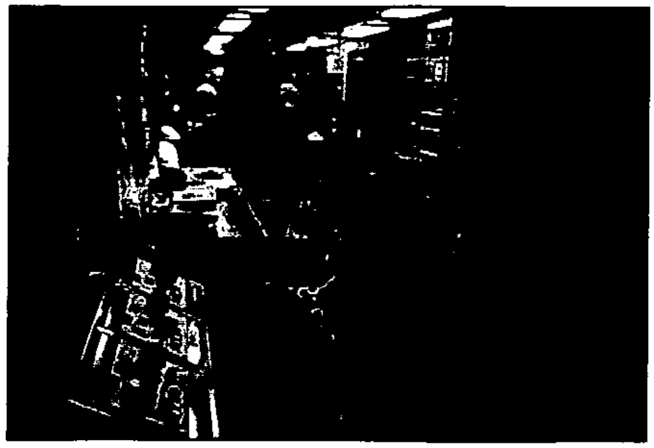
Kato generator

Drilling Equipment *

DRAWWORKS: OIME 2000E complete with Baylor-Elmagco 7838 electric auxiliary brake.
DRILLING LINE: 1-1/2 in. 6 x 19 extra improved plow IWRC 7,500 ft. arctic lube.
SANDLINE: 9/16 in. 6 x 7 20,000 ft.
DERRICK: Parco cantilevered mast with a hook load capacity of 1,250,000 lbs.
CROWN BLOCK: Parco crown block grooved for 1-1/2 in. line with 60 in. sheaves.
TRAVELING BLOCK AND HOOK: Ideco 535 ton block with 6 sheaves and Ideco 535 ton hook.
SWIVEL: Continental Emsco LB 400.
ROTARY TABLE: 37-1/2 in. Oilwell rotary table with 650-ton capacity.
KELLY SPINNER: International Tool A-6C.
WEIGHT INDICATOR: Martin-Decker E.
DRILL PIPE: 16,000 ft. 5 in. OD grade E and G; 1,085 ft. 5 in. OD hevi-wate.
DRILL COLLARS: Eighteen 6-1/2 in. OD and eighteen 8 in. OD.
IRON ROUGHNECK: Varco 2000.
MUD PUMPS: Two National Supply 12-P-160 triplex pumps.
MUD MIXING: Two Mission Magnum centrifugal pumps driven by 100-hp electric motors.
SHALE SHAKER: Dual tandem Brandt shakers mounted on sandtrap.
DESANDER: Two Brandt SRS-2 rated at 1,000 gpm each.
MUD CLEANER: Two Brandt mud cleaners rated at 400 gpm each.
DEGASSER: Swaco degasser rated at 1,000 gpm.
CEMENTING UNIT: Cementing unit with two diesel engines.



Winterized derrick

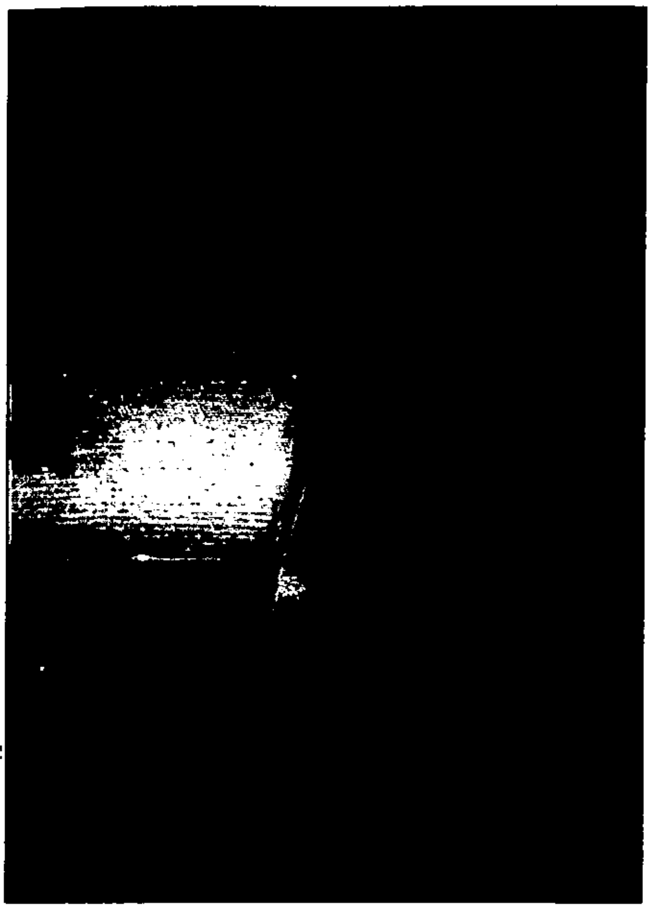


Control Room showing water cannon control console

Blowout Preventer Equipment *

BOP SYSTEM: Certified for H_2S service.
STACK SIZE/RATING: 13-5/8 in. 10,000 psi wp.
ANNULAR PREVENTER: One Cameron 13-5/8 in. 5,000 psi wp annular preventer.
RAM PREVENTERS: One Cameron single U ram preventer 13-5/8 in. and one Cameron double U 13-5/8 in. 10,000 psi wp ram preventer.
CHOKE AND KILL VALVES: Two 3-1/16 x 10,000 psi wp opening gate valves. One 3-1/16 x 10,000 psi check valve. One 3-1/16 x 10,000 psi hydraulic full opening gate valve. One 3-1/16 x 10,000 psi full opening gate valve.
BOP CONTROL SYSTEM: NL Shaffer 3,000 psi accumulator with electric hydraulic triplex pump, two air operated hydraulic pumps, hydraulic pump control panel on drill floor, one removed from drill floor and proper manifolding valves and regulators for functioning BOPs, HCR valve and diverter control.
CHOKE AND KILL MANIFOLD: 10,000 psi wp with two 3-1/16 hydraulic chokes with remote panels, one manual adjustable choke, full control opening 4 in. bypass.
DIVERTER SYSTEM: One 21-1/4 in. 2,000 psi wp annular diverter with one 21-1/4 in. 2,000 psi wp drill spool with two 10 in. outlets. Two 10 in. 300 psi wp hydraulic diverter ball valves and two 10 in. diverter lines.

**Rig is currently equipped with this drilling and blowout preventer equipment.*



Water cannon building ice berm

Water Spray System

One Gould deepwell turbine pump, 880 rpm, 21,500 gpm, 110 TDH driven by a CAT D399 diesel engine. Two Gould centrifugal pumps, 16 x 18, 10,600 gpm, driven by a CAT D399 diesel engine. Svenska skumslackning water cannons, 2,400 M^3 per hour, electric remote control operators, heated for long term arctic operations.

Brick Instrumentation

188 Altech strain gauges embedded in the concrete Brick. Two Validyne strain gauge readout panels.

Mooring System

Four-point mooring system with four 20,000 lb. anchors and four 3,000 foot 2-1/4 in., 6 x 37 IPS, IWRC wire lines.

Firefighting and Safety Equipment

Fire Main with 38 external and 34 internal stations. Halon system in engine room, paint locker, pump rooms, and water spray pump room. Deluge system and portable dry chemical and CO_2 fire extinguishers. Complete first aid facilities. Helicopter deck is equipped with foam fire fighting system, fuel tank jettisoning and rescue equipment.

Survival System

Two 54-man Whittaker, USCG approved, arctic capsules with launch system and four USCG approved arctic life rafts sufficient to accommodate all on-board personnel. Sufficient arctic survival suits and sleeping bags to supply all personnel. Integral survival shelter outfitted with arctic survival gear and provisions to support the entire crew for up to 3 days.

Communications Equipment

Single side band radio telephone; VHF marine radio telephone; VHF aircraft radio; sound-powered telephone system; helicopter homing beacon; listen/talk amplified PA system; dial telephone system; INMARSAT.

Auxiliary Equipment

WATER DISTILLATION SYSTEM: One 15,000 gpd reverse osmosis and three 2,400 gpd waste heat distillers.
WASTE TREATMENT: One Omnipure System certified to accommodate 100 persons and one Vent-O-Matic waste incinerator unit.
AIR COMPRESSORS: Two 60 cfm, Ingersoll-Rand 125 psi electric air compressors and one Ingersoll-Rand 17 cfm 125 psi diesel air compressor.
WELDING EQUIPMENT: One 400-amp Lincoln electric unit and one 300-amp portable diesel electric unit.
CRANES: One crawler crane with 120 ft. boom, rated at 100 tons, one wheeled crane with 91 ft. extended boom, rated at 18 tons and one pedestal crane with a 120 ft. boom rated at 100 tons.

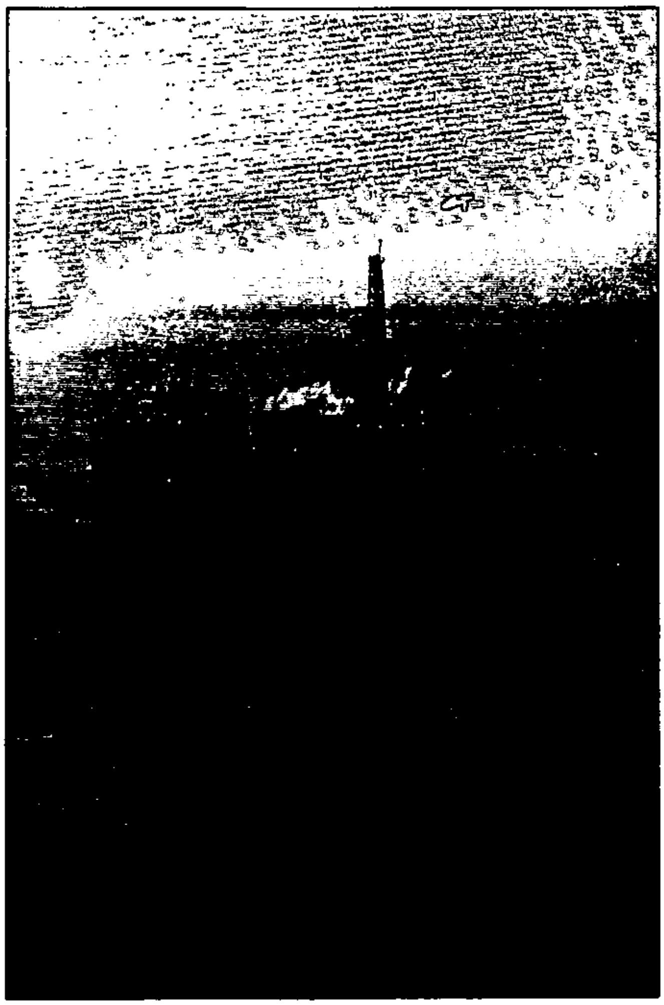
Pedestal crane with 120 foot boom

Environmental Control Equipment

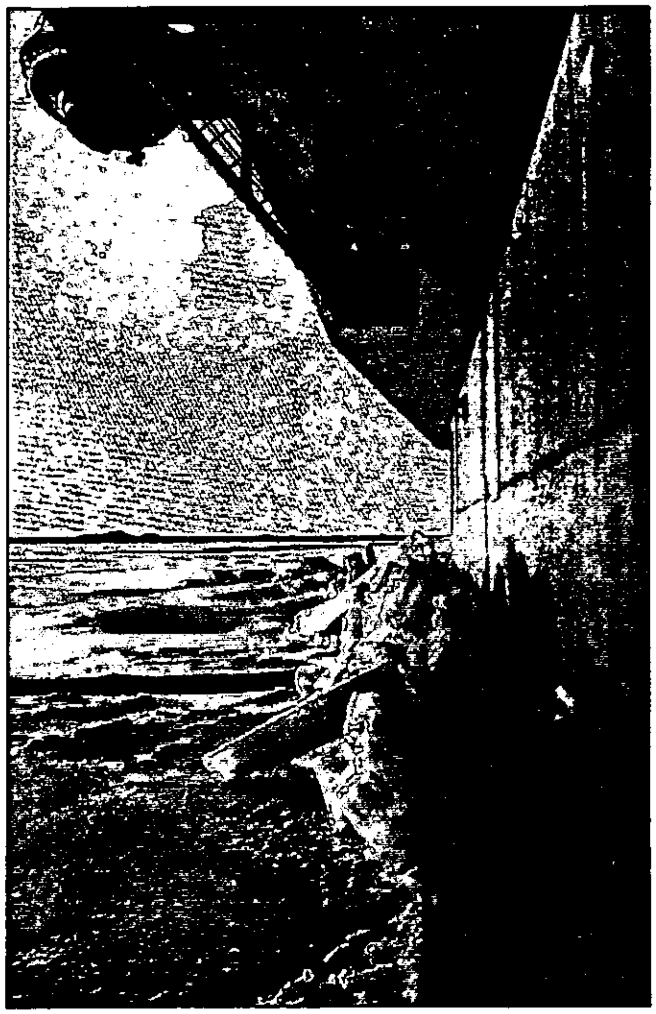
DRAIN SYSTEM: Every drain system can be diverted to the oily water separators to comply with environmental regulations.
OILY WATER SEPARATOR AND RECOVERY SYSTEM: Two Facet separators, 10 gpm capacity with fluid analyzer.
CUTTINGS TANKS: Four tanks with total storage capacity of 4,000 bbls.

The GLOMAR BEAUFORT SEA I is engineered to withstand the ice forces expected in the arctic without sustaining detrimental structural damage. The unit is also designed to resist sliding on the ocean floor. For additional protection against the arctic ice floes, the platform has been fitted with a Rubble Generation System (RGS) which produces a grounded rubble field. The ice barrier which is created around the platform provides passive protection from the advancing ice. The ice barrier is built by the water cannons spraying a water stream between 250 and 300 feet from the platform. As the water is sprayed, the droplets freeze in air and fall to the surface forming a grounded ice barrier which protects the rig.

The deck barges and the mud base of the GLOMAR BEAUFORT SEA I are constructed of steel. These components are not exposed to the severe ice loads. Concrete was used where ice loads do act against the structure. The concrete Brick provides the necessary strength and durability for minimum structure weight per unit of enclosed volume. The honeycomb design, particularly, contributes to the optimum strength to weight ratio required of a mobile rig capable of withstanding the ice loads.



Ice barrier built by the Rubble Generation System

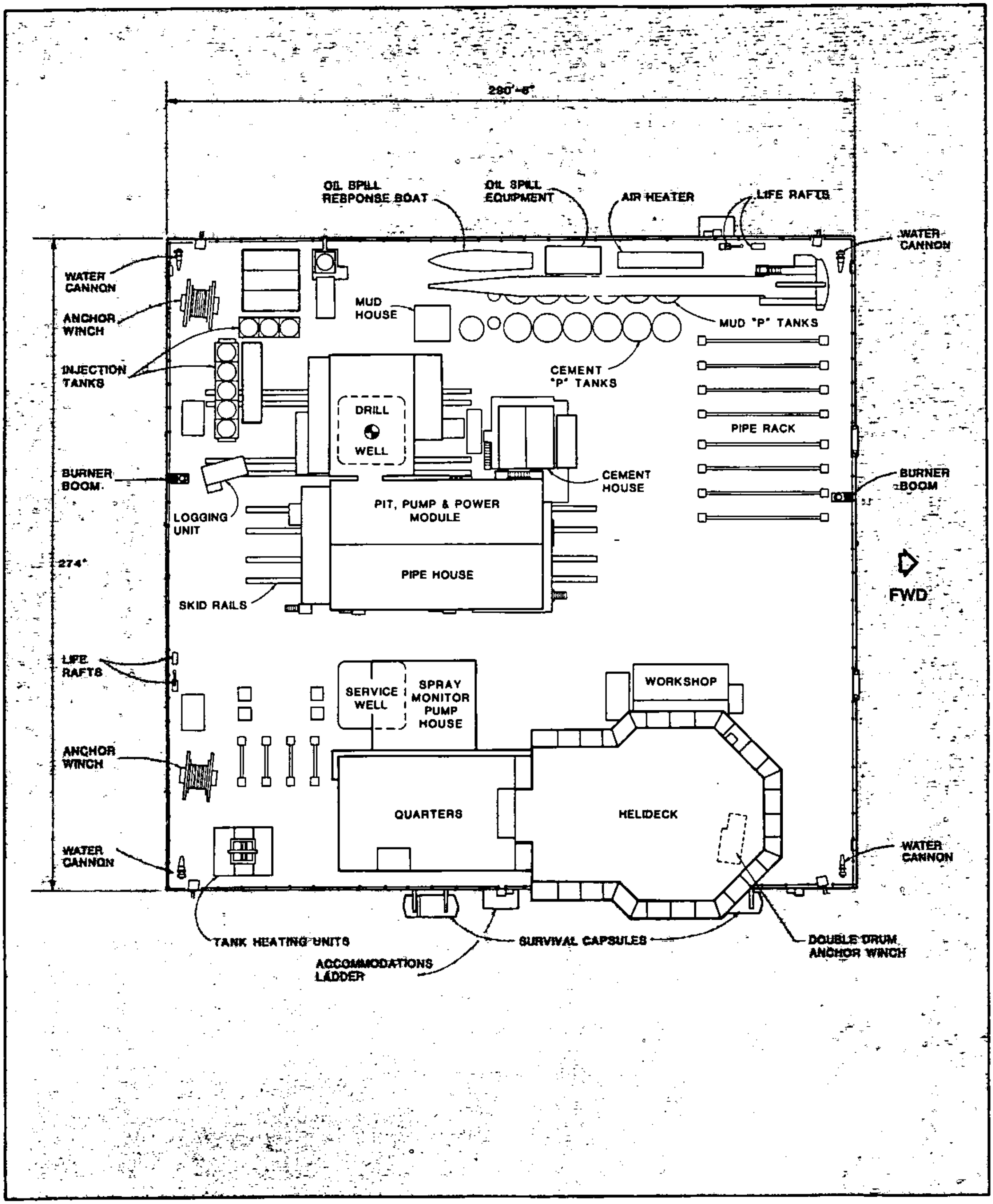


Ice build-up against side of Brick

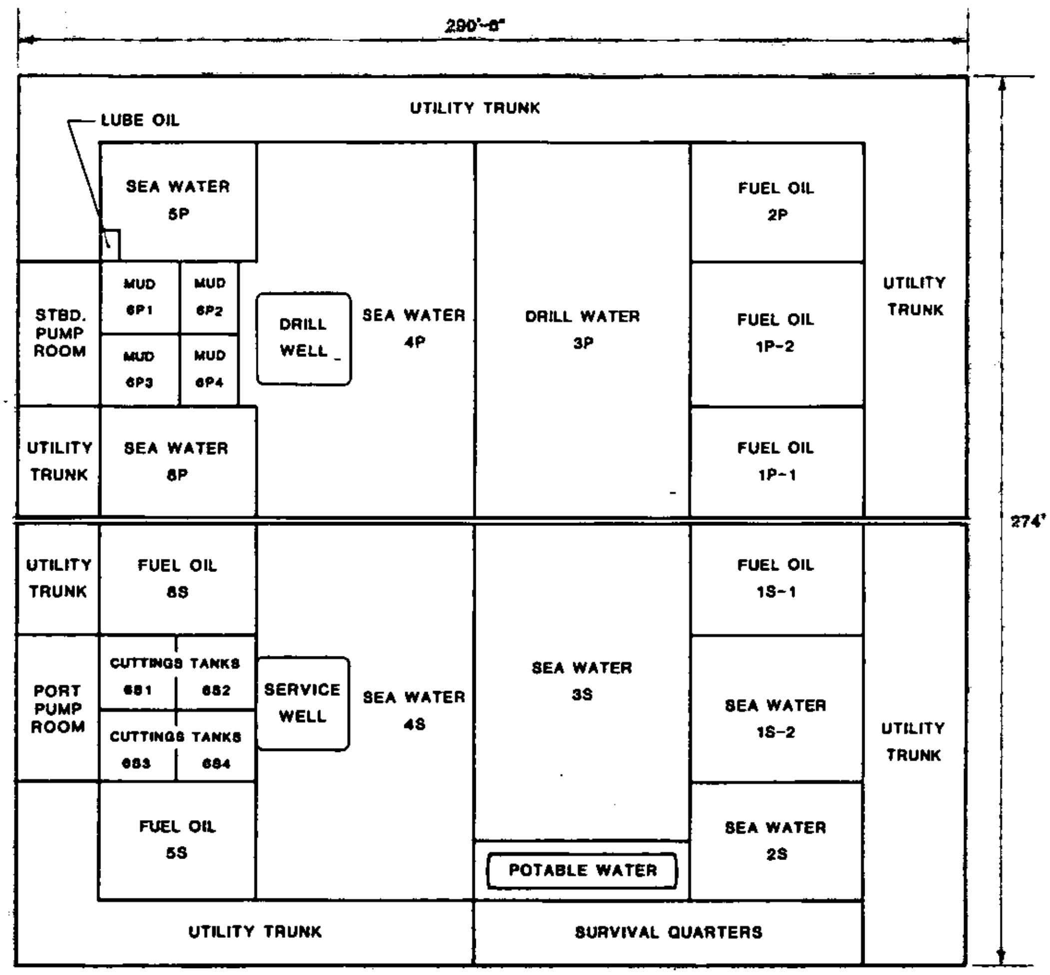
The concrete Brick consists of a field of honeycomb silos surrounded by an internal wall, a series of shear walls and an external wall. The silos are joined to each other by interconnecting walls. Thus the forces imposed on the structure by the ice are evenly distributed throughout the structure. The walls and silos are sandwiched between top and bottom slabs for additional structural stiffness thus forming internal tanks. Like the base, the tanks in the Brick are used solely for sea water ballast.

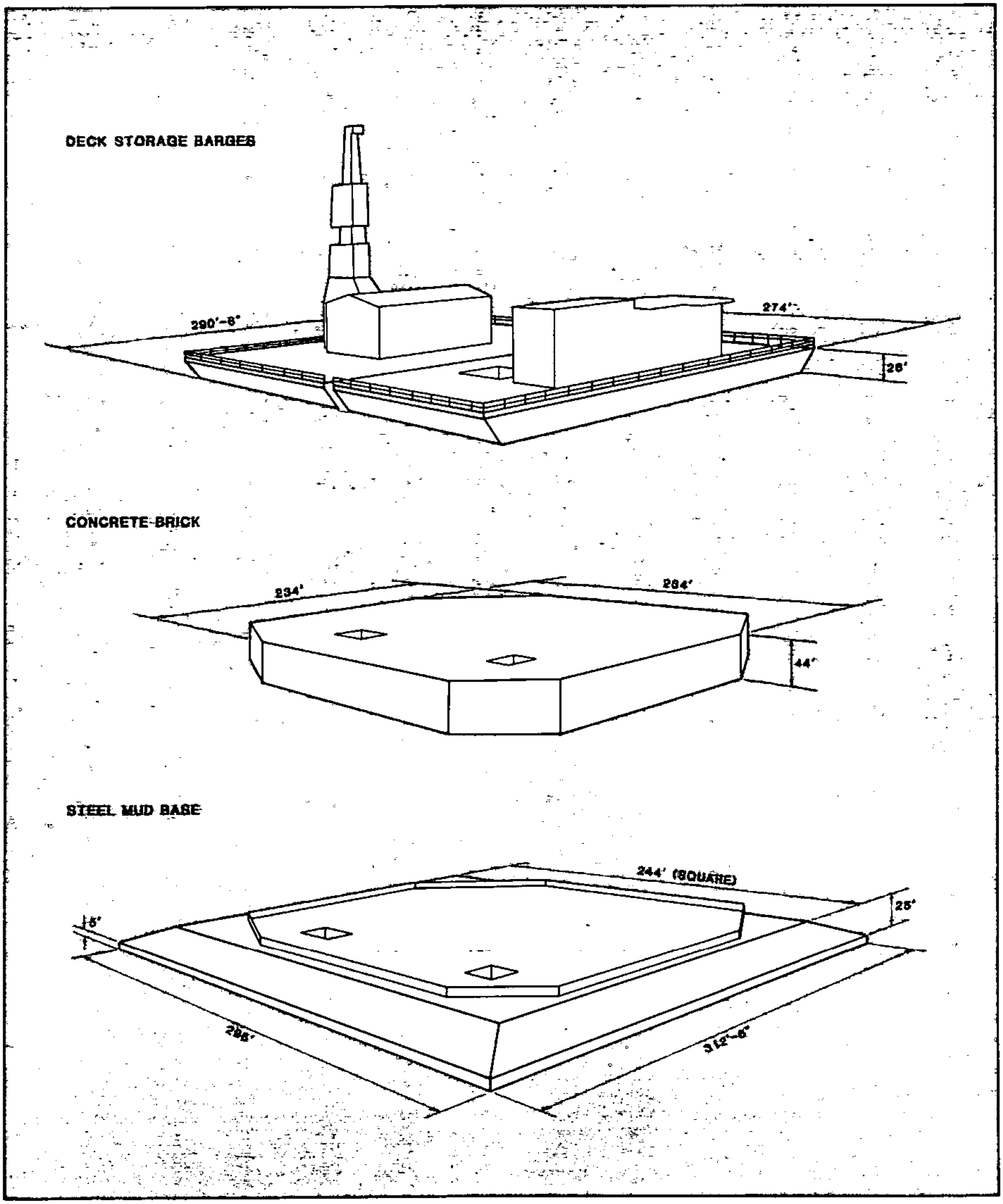
The design ice load for the GLOMAR BEAUFORT SEA I is as follows: global is 460 kips/foot and the local, acting over a 5 foot by 5 foot area, is 900 psi.

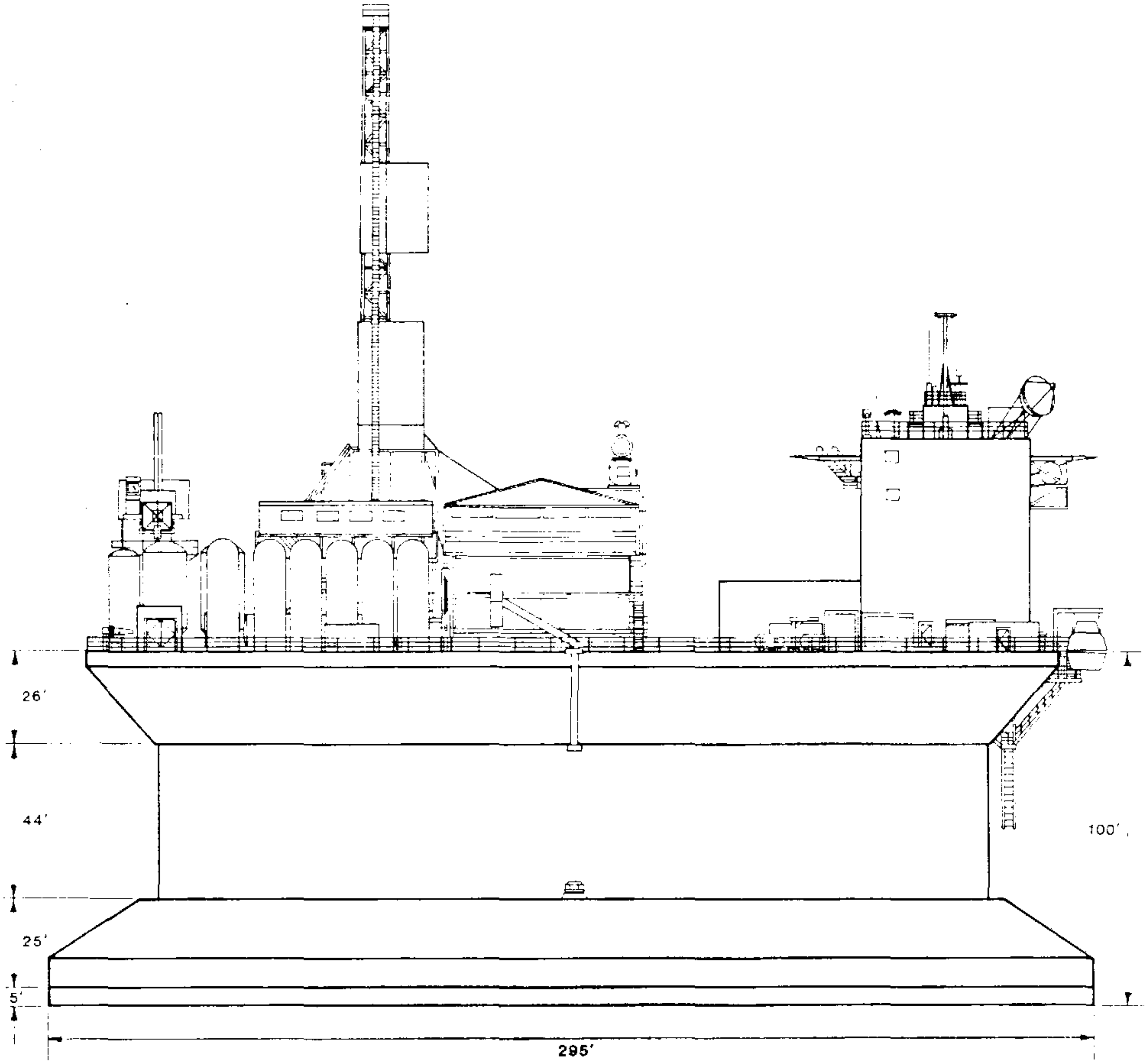
MAIN DECK LAYOUT



BARGE TANK LAYOUT




DECK STORAGE BARGES
26'
CONCRETE BRICK
234'
264'
44'
STEEL MUD BASE
244' (SQUARE)
25'
5'
312'-6"



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THE DESIGN, CONSTRUCTION AND VERIFICATION OF THE ANGASAK SPRAY ICE EXPLORATION ISLAND

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Calgary, Alberta, Canada

ABSTRACT

A spray ice exploration island was successfully completed during the 1986-87 winter in a water depth of 5.5 m in the Canadian Beaufort Sea. The island, Angasak L-03, was designed, built and operated by Esso Resources Canada Limited on behalf of Trillium Exploration Corporation and partners and represents the second successful use of a spray ice island for exploration. Success was measured in two ways:

i) Dollars saved by using ice as a construction material. Construction costs were halved when compared with the next cheapest material - dredged sand.
ii) The actual performance met or surpassed the expected performance.

This paper discusses the engineering aspects of the design, construction and verification of the island, and highlights some new and innovative engineering techniques used on this project.

INTRODUCTION

Canadian Beaufort Sea exploration drilling commenced in 1972 with the construction of a sand island in 3 m of water at Immerk. Since then, more than forty sand and gravel islands have been built. Since 1980, various drilling systems and caisson retained islands have been used in water depths greater than 14 m, but up until 1985, sand and gravel islands have been used exclusively in shallow water. In 1985, Amoco Production Company built the first spray ice exploration island at Mars, in 7.6 m of water in Harrison Bay (1). The island performed well and confirmed the favourable economics of using a spray ice island for exploratory drilling in shallow water. Spray ice islands offer several important advantages over sand islands. First, they are cheaper, especially if local borrow materials are not available. Second, spray ice is made from natural sea water, and is therefore environmentally attractive. Third, spray ice islands melt and disappear thereby relieving the operator of the removal task.

While Mars was the first spray ice exploration island, many previous structures have been built using spray ice. To date, four experimental islands, at least five protective barriers and over 3 relief well drilling pads have been built in the Beaufort Sea (1,2). In addition spray ice has been used by Panarctic to construct offshore floating drilling pads in the high Arctic.

Esso Resources Canada Limited and Exxon Production Research Company have been very active in spray ice technology. In 1978, Exxon built an ice island in 3.5 m of water using a combination of flooding and spraying techniques (3). In 1984, Esso and Exxon built a spray ice experimental island in 15 m of water in McKinley Bay and later the same year Esso built a relief well spray ice pad at Kadluk (4,5). The success of these projects prompted Esso to conduct a comprehensive series of research studies on the engineering properties of spray ice, including laboratory tests and a large-scale model test in Esso's wave basin. Exxon has also built two very large 20 m high protective spray ice barriers around the Concrete Island Drilling System (CIDS) from which a wealth of insitu and laboratory test data has been collected (6).

The Angasak ice island was designed and subsequently built and operated during the 1986-87 winter by Esso Resources Canada Limited on behalf of Trillium Exploration Corporation et al. The site is located in 5.5 m of water in the Canadian Beaufort Sea, approximately 1 km from shore and 5 km south-southeast of Cape Dalhousie (Figure 1).

Presented at the Seventh International Conference on
Offshore Mechanics and Arctic Engineering
Houston, Texas – February 7-12, 1988

DESIGN CRITERIA

Operational Design Criteria

The operational criteria for spray ice islands are similar to those for any offshore arctic island. The platform must allow a well to be drilled and tested within a certain time frame, risk exposure and budget. For this project the following criteria were used:

- o minimum drilling and testing period = 60 days
- o minimum surface working diameter = 135 m
- o average rig foundation pressure = 15 kPa
- o maximum sustained rig foundation pressure = 33 kPa
- o total lateral movement of the rig relative to seabed should not exceed 0.2 m
- o differential settlement between rig buildings should not exceed 0.25 m
- o total rig settlement should not exceed 1.00 m

Environmental Loads and Criteria

Angasak is located in a sheltered near-shore ice environment and as such individual ice excursions are generally less than 3 m and are due to thermal expansion of the ice sheet. An ice force of 1.5 MN/m was therefore selected for design.

A stable ice sheet is a prerequisite to constructing a spray ice island. Historical data on landfast ice conditions at the site showed that in 12 of the last 13 years, the Angasak site was "landfast" by November 27. Due to deterioration of the ice sheet in the spring the latest date for rig removal via ice road was determined to be May 1.

The primary geotechnical issue for the island design was seabed resistance to horizontal shear forces. A site investigation was conducted about 600 m west of the exploration site prior to construction and on the basis of these results an undrained shear strength of 15 kPa was selected for design. The probability of encountering stronger soil was considered very high and so a detailed evaluation of onsite seabed conditions was not carried out until after construction was completed. These results are presented later.

Spray Ice Properties

The primary spray ice criteria relevant to the design of an island are the strength, deformation and thermal properties.

Spray ice is deposited as a mixture of brine and ice crystals. After deposition, most of the brine either drains away, evaporates or freezes, depending on the environmental conditions and construction technique. In very cold conditions, spray ice can be deposited continuously and the resulting material properties are quite uniform with depth. Under warmer temperatures, however, the "spray and freeze" approach is usually adopted resulting in a very layered material. During the "freeze" phase the ice grains in the upper portion of each layer bond together producing a material similar to porous ice. In this paper, this material is referred to as strongly bonded spray ice (SBS).

The ice grains in the lower portion of the layer remain damp and unbonded until "aging" processes bond the adjacent ice grains together. It is believed that the aging processes are linked to pressure melting of the grains and convective heat transfer by brine migration. The subsequent accumulation of additional spray ice not only imposes a surcharge but also flushes the underlying layers with cool brine. These effects help to densify and bond the underlying "slushy" layers, creating a cohesive material which is referred to as weakly bonded spray ice (WBS).

Subsequently, some of the spray ice is submerged below sea level thereby becoming partly saturated with sea water. After submergence, the physical properties of the spray ice continue to change, as the spray ice comes to equilibrium with its new stress and temperature state. During this "curing" period it is not uncommon for spray ice structures to experience up to 0.5 m of settlement in the first 2 weeks after construction.

By the end of the curing period the spray ice has become a competent but spatially variable material. Above the water line, ambient winter Arctic air temperatures are well below the melting point of the slightly saline ice, thus maintaining it in a competent frozen state. Underwater spray ice temperatures are maintained at the freezing point of the pore fluid and since the pore water is more saline than the ice grains, the underwater spray ice remains thermally stable.

The material variability is derived mainly from different degrees of bonding between particles, which can range from weakly bonded spray ice to a well bonded dense polycrystalline ice-like material.

Since the saturated layers of "WBS" are the least bonded, they are also the weakest and most compressible parts of the island. Therefore, it is the properties of these layers that control the design.

During construction subvertical tension cracks form on the underside of the spray ice mound prior to grounding, and then on the upper surface of the island during and immediately after grounding. Very little is known about the underside cracks, but field observations (4) confirm that all cracks which form prior to, or at the time of grounding, and are subsequently buried by the island freeboard, remain inactive and do not impair the performance of the island.

The shear stress-shear strain curve for spray ice is generally characterized by a yield point below which small strain (ice-like) behaviour is observed and beyond which large strain (dilatant granular) behaviour is evident (Figure 2). The ultimate strength of spray ice is typically 1.5 to 2 times the yield strength (7,8). The yield strength has been selected as the design strength for this study.

The yield strength depends upon the failure mode under consideration. Shear resistance along horizontal planes is governed by the weaker WBS layers, while shear resistance along inclined planes is governed by the SBS layers.

The design yield strengths used in this project were obtained from laboratory triaxial tests conducted at representative strain rates and under appropriate drainage conditions (8). Using this technique the following design yield strengths were chosen.

- For horizontal shear planes the yield strength equals 0.7 times the vertical effective pressure.
- For inclined shear planes (above sea level) the yield strength equals 180 kPa.

The effective vertical pressure on a horizontal plane is the island is a function of the depth of the plane and the density (or buoyant density if submerged) of the overlying spray ice. The following densities were estimated from laboratory test data (8) and used for design:

Above sea level, density = 600 kg/m^3
Below sea level, buoyant density = -100 kg/m^3

The deformation behaviour of spray ice is dominated by creep (7). The best source of creep data comes from full-scale observations of previous structures (1,5,6). These data suggest that vertical strain rates of 0.01 per month can be expected.

The above experiences are based on islands that have not been thermally disturbed by heated buildings. The rig foundation used at Mars included a ventilated rig mat which maintained ice surface temperatures at or close to the ambient air temperature. At Angasak, however, a ventilated pad was not used and the heated rig buildings were placed on rig mats overlying insulation. Therefore the temperature of the spray ice beneath the rig was expected to slowly rise throughout the drilling program.

Field experience (6) and laboratory test data (8) suggest that creep rate is fairly insensitive to temperature provided the temperature does not exceed about -4°C. Based on this evidence, it was decided not to let the spray ice temperature in the freeboard exceed -4°C and to design for an average strain rate of 0.02 per month.

Horizontal elastic and creep deformation of the island were deemed to be insignificant for the design ice load scenario.

In computing insulation requirements to maintain temperatures below -4°C, the following spray ice thermal properties based on measured data for dense snow (9) were used.

Thermal Conductivity = 1.5 $Wm^{-1}\,K^{-1}$

Heat Capacity = 2.0 $KJ\,Kg^{-1}\,K^{-1}$

DESIGN ANALYSIS

Island Design

The minimum resistance of the island to horizontal ice forces was determined from consideration of three potentially critical failure planes which are described in Figure 3. Failure plane A was termed the "edge passive failure" mode and consideration of this failure mode determined the island freeboard. Failure plane B was termed the "spray ice simple shear failure" mode and analysis of this mechanism lead to a specification of freeboard and diameter. Failure plane C was termed the "seabed sliding failure" mode and consideration of this lead to a required diameter.

The island diameter required for the drilling operations was 135 m. However, as a safety precaution against edge failures a set-back distance of 12.5 m was selected and a minimum "grounded" diameter of 160 m was adopted for design.

The resistance per unit width of the edge of the spray ice island was determined from the limiting equilibrium theory for a cohesive material.

$$R_1 = \frac{\gamma H^2 g}{2} + 2CH \qquad (1)$$

where R_1 = the passive resistance of the edge of the island (KN/m)

γ = the density of the above water ice (Mg/m^3)

H = the island freeboard (m)

C = the yield strength of the ice (kPa)

g = acceration due to gravity (9.81 m/s^2)

The required resistance was a function of both the design ice force per unit width I, and the safety factor F_1, and was determined by the following equation:

$$R_1 = 1000 F_1 I \qquad (2)$$

The minimum safety factor against ice loads at this location was determined to be 1.5. This resulted in a minimum design freeboard of 6 m and after allowing for a loss of freeboard of 1 m due to creep, a design end-of-construction freeboard of 7 m was selected.

The minimum resistance of the island with respect to horizontal shear failure in the spray ice was controlled by the WBS layer with the lowest vertical effective pressure. The minimum design shear strength for a 6 m freeboard was therefore determined to be 21 kPa. Therefore, the critical horizontal shear failure mode for Angasak was sliding at the seabed which was characterized by a shear strength of 15 kPa. The factor of safety, F_2, against this mode of failure was determined from the following equation:

$$F_2 = \frac{0.0118 D^2}{I(D + 2w)}$$

where D is the required grounded diameter of the island and w is the width of the "fringe" of the island (Figure 3), which in this case was assumed to be 3 m.

Therefore for a safety factor of 1.5 and a maximum ice load of 1.5 MN/m, the required grounded diameter was 190 m, and given a set-back distance of 12.5 m, the allowable operating surface diameter was 165 m. The design island geometry is summarized in Figure 4.

Rig Foundation Design

The spray ice foundation beneath the rig structure had to provide an adequate bearing capacity for all dead and live loads and exhibit acceptable settlements. Since spray ice is visco-elastic, the allowable design bearing pressure was controlled by consideration of settlement rather than bearing capacity.

Using the design criteria and island geometry presented earlier, the rig settlement rate was calculated to be 0.24 m/month. Since this creep behaviour was based on cool (<-4°C) above water spray ice, it was decided to install sufficient insulation beneath the rig to keep temperatures below -4°C.

A thermal analysis was carried out and it was concluded that spray ice in the freeboard could be kept below -5°C by placing the rig mats on 0.1 m of styrofoam insulation and maintaining floor temperatures in the rig buildings to below -5°C, thereby eliminating the need for a costly ventilated foundation pad.

The spray ice was also vulnerable to thermal degradation around the well cellar and conductor. To alleviate this concern, a refrigeration system was designed to circulate cold (<-5°C) brine through the annulus between the outer 2 casing strings. A schematic of this arrangement is present in Figure 5.

The conductor/well cellar design for Angasak differed from that used at Mars Island (1) in that the conductor casing and well cellar were installed after, rather than during, island construction, thereby, facilitating island construction.

Construction Design

It was planned to build up the central core (i.e. the working area) of the island uniform layers of thickness 0.3 m to encourage even grounding of the ice platform and to minimize aerial variations in spray ice properties. Each layer was to be constructed using the "spray and freeze" approach. The duration of freezing was selected so that the freezing depth (and therefore the depth of bonded spray ice) extended to 80% of the layer thickness. This criteria was established to limit the percentage of WBS to less than 20% by volume and hence minimize subsequent creep of the island. Theoretical freezing time curves were developed as a function of air temperature and layer thickness and these formed the backbone of the quality control program.

The volume of the spray ice island as presented in Figure 4 was 356000 m^3. The design spray ice volume was 450000 m^3 which allowed for 25% material losses due to material landing outside the island perimeter. It was estimated that 4 spray pump units with a combined spray ice output of 40 m^3/min would be required to build the island in 30 days given average temperature conditions. Given the schedule restraints outlined earlier, this provided for a 30 day contingency for downtime due to warm weather and mechanical problems.

CONSTRUCTION

Four pumps were used for construction. Two were modified diesel powered single stage centrifugal pumps (8m^3/min) marine firefighting units mounted on skids. The pump discharge monitors were manually operated in both the vertical and horizontal planes by hand operated worm gear assemblies.

The other two pump arrangements were built specifically for spray ice operation and leased to Esso from Geotechnical Resources Ltd. The diesel powered single stage centrifugal pumps were rated at 11 m^3/min. These units were equipped with auto-sweep control panels that were used for setting and controlling monitor sweep in the horizontal plane.

Two manageable parameters, the quantity and quality of spray ice, were used to determine and establish the safety and acceptable integrity of the island and its operational acceptability respectively. It was assumed that the quantity could be easily managed. However, major changes in construction techniques were required to optimize production in light of unseasonably warm temperatures. During the construction period the project was subjected to unusually warm weather. For two-thirds of the entire construction time, which was 58 days, the air temperature was above -20°C (which is considered an upper bound temperature for effective spray ice production). The actual temperature and production records during construction are presented in Figure 5.

The warm conditions dictated the need for a procedure change. Early experimentation indicated that better production could be achieved using lifts of 0.05 to 0.1 m. Therefore the spraying time was reduced to 5 minutes, and freezing time curves were revised to reflect the decreased lift thickness. The bulk density of the freshly deposited spray ice was higher when the temperature was warmer, due to the higher unfrozen water contents. Prior to the island becoming grounded most of the unfrozen water did not drain, and eventually froze in place, thereby creating a denser and stronger spray ice than was produced in colder weather.

Spraying times were increased to 10 minutes when temperatures were low and winds were high. Spraying for a maximum of 15 minutes was done sporadically, just prior to pump moves with the intent that the area would not be returned to for a minimum of 10 hrs.

Freezing times were reduced considerably once the island was grounded because effective drainage took place and D-6 bulldozers worked the material exposing more area for natural convection. Use of the bulldozers was particularly effective when the air temperature was above -25°C. However, when air temperatures were below -25°C, better production was obtained by continuous spraying.

The design philosophy of building the island as evenly as possible, to eliminate differential cracking, was adhered to. The pumps were managed to best utilize the existing meteorological conditions. Occasionally, this required a build up of up to 1.0 m on one side due to sustained wind from one direction. However, the wind direction varied relatively evenly between east and west providing flexibility in pump location. No tension cracks were observed during construction within the 135 m core diameter of the island.

The average buildup rate for the 58 day program was 0.21 m/day ranging from 0.06 m/day to a maximum of 0.52 m/day. Spraying rates varied from 2500 m3/day to 14000m^3/day for a total of 398,000 m^3 of water pumped.

VERIFICATION

A comprehensive island and site investigation program was carried out at the end of construction to verify the acceptability of the island. The following parameters were measured and evaluated in terms of island stability.

- o island geometry
- o seabed strength

- o spray ice density
- o spray ice strength

A comparison of design and actual values for these parameters is presented in Table 1.

Four continuous boreholes, thirteen cone penetration tests and 70 thermal drillholes were advanced through the island into the seabed to evaluate spray ice and seabed properties. The seabed consisted of a loose silty sand, and provided a shear resistance of 18 kPa at the island seabed interface. The average bulk densities of the above and underwater spray ice were determined to be about 0.7 and -0.1 Mg/m^3 respectively. The percentage of WBS in the central core of the island was estimated to less than 5%, well below the design target of 20%. The thermal drill holes and CPTS did not encounter any discernable voids within the central core, either in the spray ice or at the seabed - spray ice interface. Spray ice strengths were determined from triaxial tests on samples and found to exceed the assumed design strength.

Given the above geometry and seabed and spray ice conditions the island was determined to have minimum safety factors of 2.0 and 3.0 against global and local edge failures respectively, and as such the island was deemed suitable for exploration activities.

PERFORMANCE MONITORING

A comprehensive performance monitoring program was carried out during the drilling of the well.

The monitoring program was both proactive and reactive. It was proactive in that performance data was collected during the early part of the winter and used to calibrate the design methodology adopted for later on in the winter when environment and drilling conditions were expected to be more critical. In this way, there was time if necessary to plan and execute remedial measures to improve stability. The monitoring program was also reactive in that data was collected to evaluate island stability in real time and so provide the basis for a stability alert program.

The following data were collected during the operation of the island.

1. Landfast ice movements
2. Landfast ice forces
3. Horizontal movement of the island (surface and subsurface)
4. Settlement of the island (surface and subsurface)
5. Spray ice temperatures beneath the substructure and around the conductor
6. Meteorological conditions

A comparison of design and actual performance is presented in Table 1.

The landfast ice force, horizontal island movement and critical spray ice temperatures were automatically recorded and "alarmed" and comprise the "trigger" criteria in the Stability Alert Program.

Two landfast ice movement stations were installed about 300 m to the north and east of the island. Data were collected twice per minute and telemetred to the island where they were stored on a disc and tape.

Nine ice pressure panels were installed symmetrically around the island at a distance of 175 m from island centre to measure ice pressures. The data was collected twice per minute and telemetred to the island and stored on tape or disc.

Horizontal movement of the island was measured using the following 3 techniques:

a) 3 Slope Indicators
b) 3 Inplace Inclinometers (IPIs)
c) Trigonometric Surveys

The slope indicators were read manually once per week, while the IPI's were recorded automatically twice per minute and stored on disc and tape. Trigonometric surveys were done once per month, using 3 shore based survey stations.

Island settlement was also manually monitored once per week using three Sondex casings and a surface level survey. The Sondex casings were installed in the same holes as the 3 slope indicators.

Six vertical and two horizontal thermistor strings were installed on the island. Two of the strings were tied into the "alert" DAS. One was installed vertically against the outside face of the conductor casing. The other was routed to various locations at floor level in the substructure. A second horizontal string was laid on the ice surface directly beneath the floor of the substructure. These sensors were used to ensure that the average ice temperature in the above water ice remained below -5°C.

The performance of the island exceeded all expectations. Drilling activities were completed without interruptions relating to the island. Effective control of air temperature in the rig substructure was maintained and spray ice temperatures remained well below -5°C except on two occasions, when small mud spills triggered temperature alarms around the well casing. These accidents were quickly cleaned up and had no adverse affect on the foundation performance.

Differential settlement was imperceptible across the rig foundation. Island settlement at the three settlement stations ranged from 0.15 to 0.2 m over the period February 5 to April 20, considerably less than the design value of 0.06m.

The performance of the island met or exceeded our expectations. This can be attributed to higher than expected densities which resulted from both a well executed construction strategy and warm weather during construction.

CONCLUSIONS

The Angasak spray ice island was successfully built and a wildcat well was drilled without incident. The cost of the ice island was less than half that of a sand island.

Unusually warm weather extended the construction period to 58 days, but also resulted in higher than expected densities, which in turn gave rise to better than expected performance. No uneven settlement of the rig was experienced and total island settlements were less than 0.2 m.

The following techniques were successfully tried for the first time at Angasak:

1. Use of bulldozers to enhance construction in warm weather.

2. Installation of a driven conductor casing at the end of construction.

3. Placement of the rig mats directly on the spray ice (without a "ventilated" rig mat).

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REFERENCES

1. Funegard, E.G., Nagel, R.H. and Olson, G.G., 1987. "Design and Construction of the Mars Ice Island", 6th International Symposium on OMAE, Houston.

2. Goff, R.D. and Masterson, D.M., 1986. "Construction of a Sprayed Ice Island for Exploration." 5th International Symposium and Exhibit on OMAE, Tokyo.

3. Prodanovic, A., 1986. "Man-made Ice Island Performance." 5th International Symposium and Exhibition on OMAE, Tokyo.

4. Kemp, T.S., 1984. "Grounded Ice Pads as Drilling Bases in the Beaufort Sea." Proceedings of IAHR, Hamburg.

5. Kemp, T.S., Foster, R.J. and Stevens, G.S., 1987. "Construction and Performance of the Kadluk 0-07 Sprayed Ice Pad." POAC, 1987.

6. Jahns, H.O. and Petrie, D.R., 1986. "CIDS Spray Ice Barrier." OTC Paper 5290, 18th Annual OTC.

7. Weaver, J.S. and McKeown, S., 1986. "Observations on the Strength Characteristics of Spray Ice." 5th International Symposium and Exhibit on OMAE, Tokyo.

8 Golder and Associates, 1984. "Laboratory Testing of Saturated Spray Ice." (Report to ERCL).

9. Mellor, M., 1977. "Engineering Properties of Snow." Journal of Glaciology, Vol. 19, No. 81.

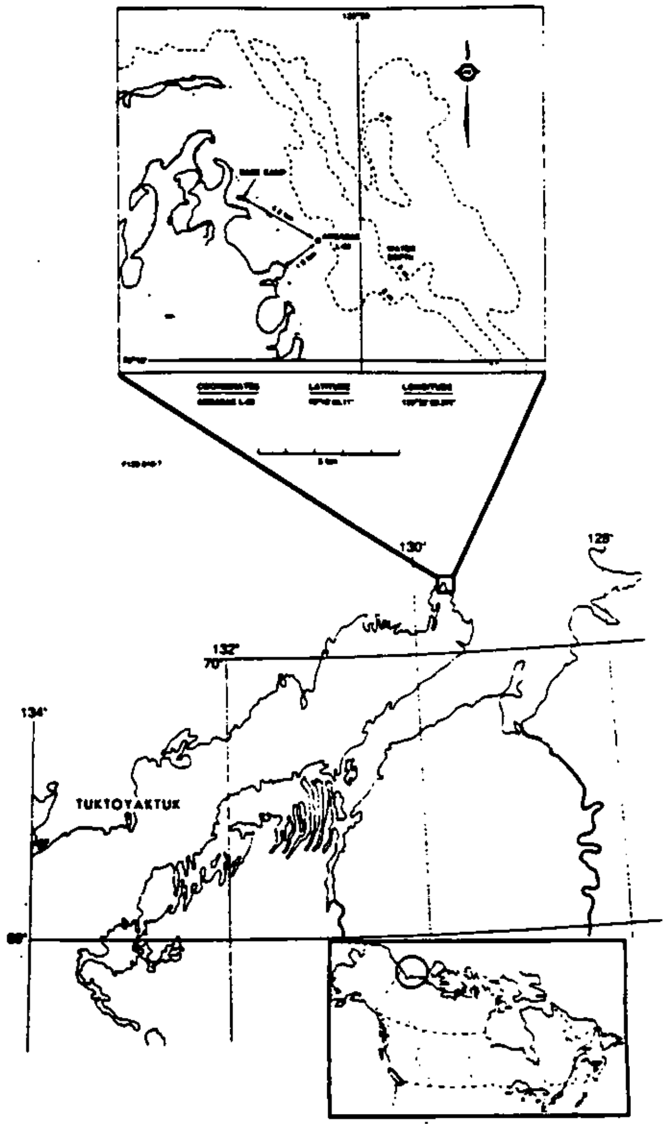

FIGURE 1 LOCATION OF ANGASAK L-03

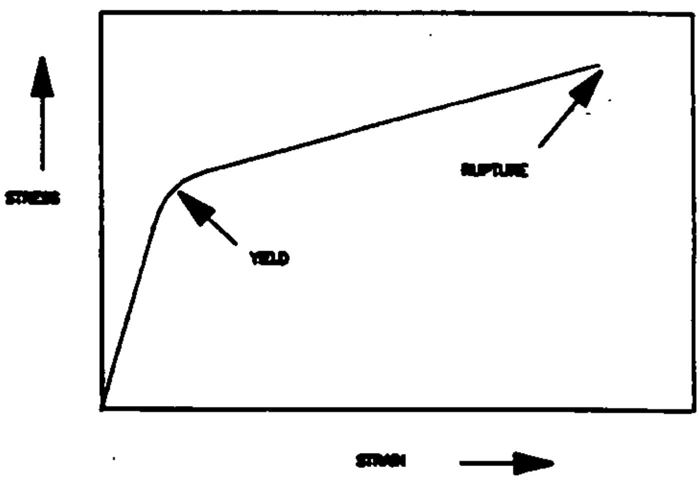

FIGURE 2 SIMPLIFIED STRESS-STRAIN CURVE FOR SPRAY ICE (NTS)

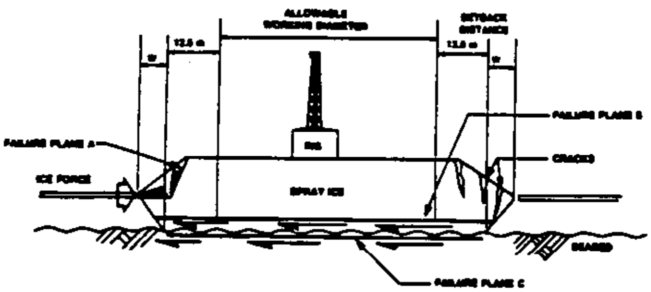

FIGURE 3 POTENTIAL FAILURE PLANES

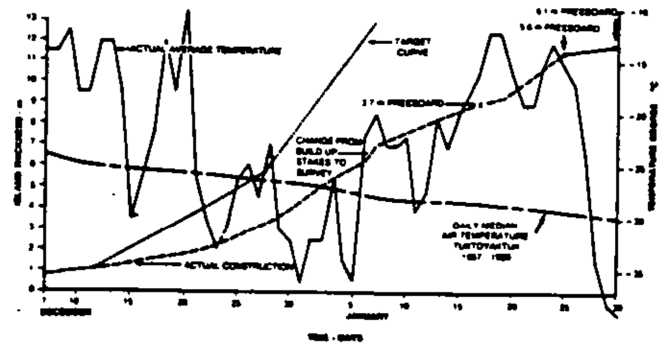

FIGURE 5 ANGASAK L-03 ISLAND
PRODUCTION & TEMPERATURE vs TIME

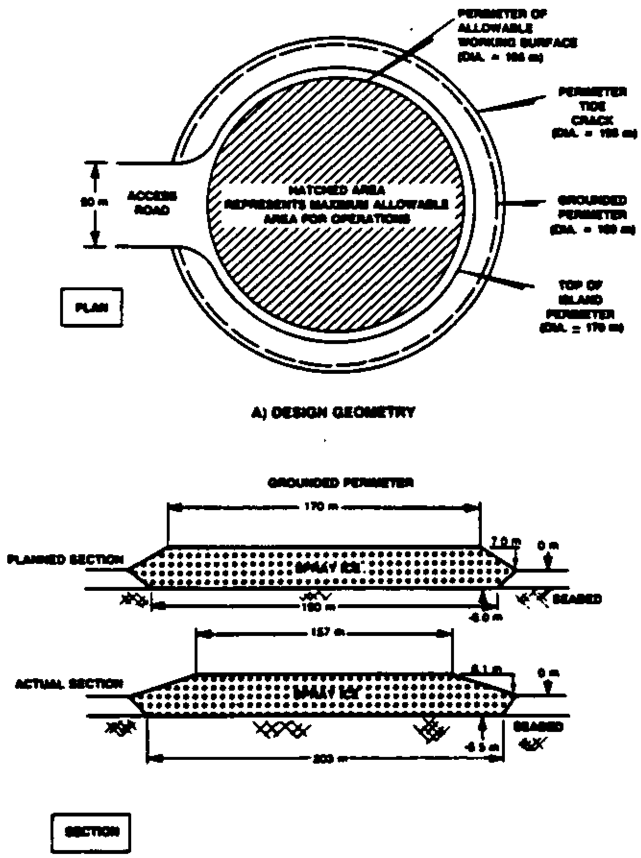

FIGURE 4 ANGASAK L-03 ISLAND GEOMETRY

PARAMETER	DESIGN VALUE	ACTUAL VALUE
ISLAND SEABED DIAMETER (m)	190	203
ISLAND FREEBOARD (m)	7.0	6.1
WATER DEPTH (m)	6.0	5.5
SEABED STRENGTH (kPa)	15	18
ABOVE WATER SPRAY ICE DENSITY (Mg/m^3)	0.6	0.7
UNDER WATER SPRAY ICE DENSITY (Mg/m^3)	−0.1	−0.1
MIN SPRAY ICE STRENGTH (kPa)	21	>23
PERCENTAGE OF WBS (%)	20	<5
SURFACE SETTLEMENT RATE (m/MONTH)	0.24	0.07
DIFFERENTIAL SETTLEMENT (m)	0.25	<0.05
AVE SPRAY ICE TEMP IN FREEBOARD (C)	−5	−11
MAX ICE FORCE (MN/m)	1.5	<0.2

TABLE 1 COMPARISON OF DESIGN AND ACTUAL DATA

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