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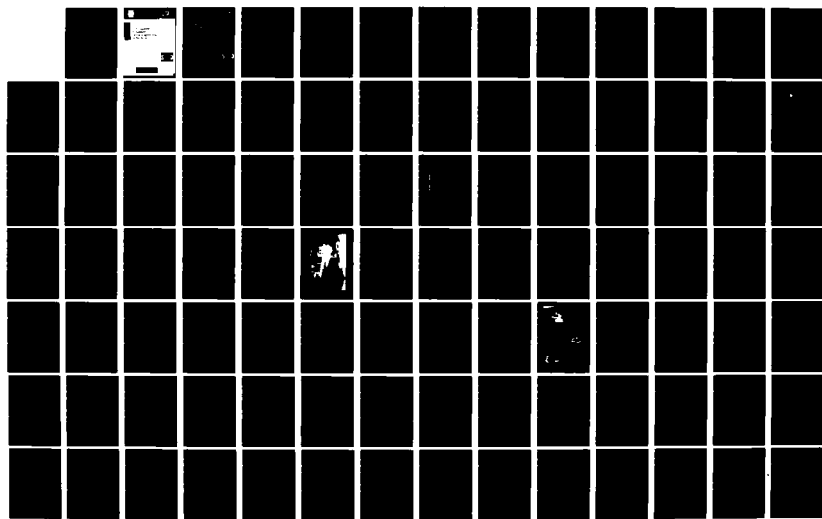
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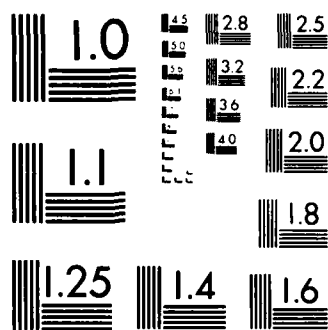
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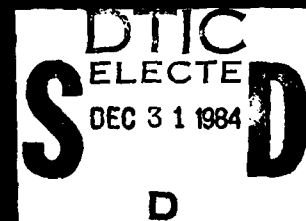


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U.S. Capability to Support Ocean Engineering in the Arctic

Committee on Assessment of Arctic Ocean
Engineering Support Capability
Marine Board
Commission on Engineering and Technical Systems
National Research Council



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Generally, the Arctic offshore regions of Alaska have low seismicity, but a few areas near the Seward Peninsula and in the Beaufort Sea have higher levels. Along the Aleutian Islands and in the southern Bering Sea, seismicity is very high, warranting long-term monitoring.

ENVIRONMENTAL CONCERNS

It is anticipated that continued oil and gas development in the Arctic will have an effect on its physical and biological

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Engineering Support Capability
Marine Board
Commission on Engineering and Technical Systems
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PREFACE

Many of the engineering problems and requirements particular to Arctic offshore and coastal resource development and production have been identified since 1980 in National Research Council (NRC) reports,¹ in a National Petroleum Council (NPC) report,² and in several federal government reports. However, the capability of the nation to respond to these engineering requirements, either by government or private-sector means, has not been assessed.

In response to the Marine Board's recognition of the need for such an assessment, the NRC appointed the Committee on Assessment of Arctic Ocean Engineering Support Capability to examine requirements for support of ocean engineering activity in the U.S. Arctic and the present national capability for providing this support. Deficiencies were to be identified and responsive alternatives were to be described.

Objectives and Scope of Study

For the purposes of this study, the Arctic offshore region is defined as that area north of the Alaska Peninsula and the Aleutian Islands. It is recognized that engineering capabilities applicable to this area often can be usable in other Arctic locations, and access to U.S. resources may also imply a need to operate outside of the area, e.g., maritime support in international and Canadian areas.

The committee was charged to undertake the following tasks:

- By use of recent National Research Council, National Petroleum Council, government reports, and selected

¹Engineering at the Ends of the Earth: Polar Ocean Technology for the 1980s (1979), Research in Sea Ice Mechanics (1981), Maritime Services to Support Polar Resource Development (1981), and Understanding the Arctic Sea Floor for Engineering Purposes (1982).

²U.S. Arctic Oil and Gas (December 1981).

additional committee assessments, consolidate and evaluate engineering requirements and research needed to support engineering development in the U.S. Arctic Ocean regions.

- Assess the available national capabilities (i.e., facilities, manpower, and organizational arrangements) to support Arctic engineering programs including an examination of data acquisition and analysis, laboratories and other engineering research entities, engineering and technical personnel, and logistics and support services; and identify the deficiencies.
- Develop a framework for government, industry, and academic programs and activities in Arctic ocean engineering that will best use the integrated capabilities of all.

In its discussions regarding the third task, the committee was aware of two concurrent government activities and actions that strongly influence the options for improving government coordination and cooperation in engineering-related Arctic ocean research and development. National Security Decision Directive No. 90, United States Arctic Policy, April 14, 1983,³ and the Arctic Research and Policy Act of 1984 (P.L. 98-373) both address government responsibilities and organization in the Arctic. The committee also noted that a dominant problem for government-industry cooperation is the lack of a focal point within the government where the industry research and development associations and joint ventures can plan and conduct programs in concert with the government. The committee did not suggest organizational changes. Such changes will be influenced by the pending report and analysis of the interagency committee in response to the National Security Directive as well as by the implementation of the Arctic Research and Policy Act of 1984. The act establishes an Interagency Arctic Research Policy Committee, which should do much to improve coordinated planning for both research and development. Organizational change usually follows such planning and subsequent program development.

The committee requested and received cooperation from all government agencies presently involved in Arctic work. Each agency contributed information about its objectives, responsibilities,

³The President of the United States, aware of the need to have general questions of U.S. Arctic policy resolved, has issued National Security Decision Directive No. 90 (April 14, 1983), which mandates a review of key problems in U.S. Arctic policy. The principles upon which the review will be conducted include protecting essential security interests, supporting sound and rational development, promoting scientific research, and promoting mutually beneficial international cooperation.

facilities, budget, and scope of ongoing and planned work. In addition, experts from several agencies provided technical and program presentations during the three committee meetings as well as at on-site meetings to brief the chairman on Navy Arctic research and Navy/National Oceanic and Atmospheric Administration sea ice forecasting services; these briefings were unclassified.

The report addresses, in Chapter 1, general engineering needs and resources regarding offshore operations, shipping operations, marine transportation systems, marine navigation systems, sea ice mechanics and ice forces, and geotechnics. Chapter 2 discusses problems and resources needed to address environmental concerns. Previous reports by the Marine Board have addressed some of these technical areas and concerns and have made specific technical recommendations for further work. Thus, this report highlights areas of important research, but does not attempt to provide details on specific projects for further study, nor does it attempt to judge the quality of past or current scientific investigations.

Chapters 3, 4, and 5 describe public and international issues, the objectives and capabilities of government agencies, and examples of joint industry research. Conclusions and recommendations follow the Executive Summary, which begins on page 1.

The study does not address the development and presentation of an action plan for the formulation and implementation of a national policy on Arctic development or research, although it does recognize that such a policy may influence the capability of industry and government to provide engineering-related data, information, and services. Furthermore, it does not address the engineering needs attendant upon national defense or security, although an enhancement of engineering-related research capability would likely enhance the nation's defense posture.

Improved materials for low temperature uses are needed and are under development for specific applications. The committee did not examine this area of technology in detail, as it does not appear to be limiting, i.e., technical alternatives for Arctic applications are available, but improvements may enhance economic choices.

Further, the study does not cast judgment on the adequacy of federal funding, but does assume that an intent to provide support for specific research and development of services will imply that sufficient financial support will follow. The committee study does note certain funding amounts have been provided for a program or area of activity only as indicators of this effort or an agency or organization. A complete list of specific research is not provided, since the committee was concerned with areas of engineering technology rather than specific projects.

In regard to the identification of needed research, the study focuses on engineering-related research, specifically, the acquisition, analysis, and dissemination of data needed to provide engineering criteria and guidelines and to establish requirements for design, construction, installation, operation, and maintenance of marine structures, facilities, and vessels.

The committee's analysis of engineering-related deficiencies focused on first-order problems affecting structural integrity and on safety of operations, and on preventing direct detrimental effects on the environment such as possible disturbances from sounds in the ocean from offshore operations or preventing or cleaning up oil spills. The possible indirect influence of human Arctic offshore activity on Arctic wildlife was not assessed, nor does the study deal with fish and wildlife questions that are also common to non-Arctic areas.

CONTENTS

EXECUTIVE SUMMARY.	1
CONCLUSIONS AND RECOMMENDATIONS.	7
INTRODUCTION	17
1. ENGINEERING CONCERNS	23
Offshore Operations, 23	
Shipping Operations, 32	
Sea Ice Mechanics and Ice Forces, 44	
Geotechnics, 59	
Industry Role in Engineering-Related Research, 68	
2. ENVIRONMENTAL CONCERNS	69
Offshore Operations, 69	
Oil Spills, Containment, and Cleanup, 73	
Environmental Data and Information, 75	
3. PUBLIC AND INTERNATIONAL ISSUES.	79
Major Political and Social Issues	
Affecting Development, 79	
Public Sector's Role in Arctic Development, 80	
Offshore Arctic Development in Canada, 82	
University Research and Education, 85	
4. GOVERNMENT OBJECTIVES AND CAPABILITIES	89
Resources and Roles of Federal Agencies, 90	
The Framework for Coordination of Technical	
Support and Services for Arctic Ocean Engineering, 113	
REFERENCES	119
APPENDIXES	125
A. Summary of Background Reports and Findings in	
Arctic Offshore Engineering, 125	
B. MarAd Analysis of Future Tanker and Other	
Commercial Ship Requirements and Related	
Technical Problems, 130	
C. Selected References on Acoustic Effects of OCS Oil	
and Gas Activities on Beaufort Sea Marine Mammals, 132	
D. Joint Government and Industry Arctic Programs, 135	

TABLES AND FIGURES

TABLE 1	U.S. Department of the Interior Offshore Leasing Schedule, 1979-1987	18
TABLE 2	Satellite Remote Sensing of the Polar Regions	26
TABLE 3	World Polar Icebreaker Fleet (Government Owned Vessels).	30
TABLE 4	Refrigerated Ice Basins in the World.	50
TABLE 5	Nonrefrigerated Ice Basins in the World	50
TABLE 6	Studies Conducted Under the Outer Continental Shelf Environmental Assessment Program.	76
TABLE 7	Data Analysis Capabilities of the Joint Ice Center.	92
TABLE 8	Summary of Government Activities Related to Arctic Ocean Engineering and Development	114
FIGURE 1	Alaska Subregions, Planning Areas, and Proposed OCS Lease Sales.	19
FIGURE 2	Models of Late Winter Ice Zonation	25
FIGURE 3	Prefabricated Oil Field Structure.	37
FIGURE 4	Trend and Projection for North Slope Sealift Barge Requirement.	39
FIGURE 5	Global Marine Development Corporation's Concrete Island Drilling System.	55
FIGURE 6	Floating Drilling Rig KULLUK	55
FIGURE 7	Stepped Pyramid Concept for Deep Water	55
FIGURE 8	Seasonal Movement of the Western Arctic Bowhead Whales	71

EXECUTIVE SUMMARY

The size of the Alaska Outer Continental Shelf (OCS) measures more than 1.8 million square kilometers around the state's nearly 11,000-kilometer coastline. It represents 74 percent of the total offshore area of the United States. The majority of this area, 1.2 million square kilometers, is north of the Alaska Peninsula. In a National Petroleum Council report (NPC, 1981) it is estimated that the undiscovered, potentially recoverable reserves in the basins north of the Aleutians are about 30 billion barrels oil equivalent.¹ Another study by the U.S. Geological Survey (USGS, 1981) gives a 21 billion barrel estimate for the same basins. Thus, perhaps as much as 25 to 30 percent of domestic undiscovered hydrocarbon recoverable reserves may come from these Arctic offshore areas.

The Arctic, however, is a harsh environment for man and machine. Its continued offshore and coastal resource development demands greater engineering support than do other parts of the world. The capability of government and industry to respond to these engineering requirements has not been assessed. In response to the Marine Board's recognition of the need for such an assessment, a committee was appointed by the National Research Council to conduct a study. This report represents the findings, conclusions, and recommendations of the Committee on Assessment of Arctic Ocean Engineering Support Capability.

ARCTIC RESOURCE DEVELOPMENT

Oil and gas exploration began in the Alaskan Arctic in 1901 when the U.S. Geological Survey (USGS) began surface assessments. In 1904,

¹Estimate is expressed in total hydrocarbons, billion barrels of oil equivalent (gas conversion 5.6 trillion cubic feet, TCF, per billion barrels), and is based on a "risked mean assessment" of responses by 17 organizations surveyed by the NPC.

oil seeps were found on what is now the National Petroleum Reserve in Alaska (NPRA), a 23.6-million-acre area. In conjunction with civilian drilling contractors, the U.S. Navy conducted geological mapping and exploratory drilling from 1923 through 1926 and extensively from 1944 through 1953. Nine noncommercial oil and gas fields were discovered.

In 1964, the state of Alaska began leasing land on the North Slope, and in 1968, the Prudhoe Bay oil field was discovered on state land east of the NPRA. Construction of the Trans-Alaska Pipeline System (TAPS) began in 1974 and was completed in 1977. Current throughput is 1.65 million barrels per day traveling at a speed of approximately 10 kilometers per hour, taking 5.5 days to travel from Prudhoe Bay to Valdez where it is taken by tankers to U.S. refineries. By the end of 1983, about 3 billion barrels of oil had been extracted.

In the Alaskan OCS north of the Aleutian Chain, as of May 1984, five federal lease sales have offered a total of just over 35 million acres for lease. Of this offered acreage, a total of 2.7 million acres were actually leased for \$3.8 billion. Leasing will continue with 8.5 million acres being considered for offering in a sale in 1984. Additional sales are tentatively planned through 1987 (see Table 1, page 18).

It is recognized that the Arctic area includes other resources, notably, minerals in shallow coastal waters and coal deposits onshore. Transport of these minerals will be required when the resources are developed. These resources are not, however, subject to the same development pressures as oil and gas. Engineering problems related to development, such as port and ship designs, can be resolved with existing methods in time to support eventual utilization of these resources.

ENGINEERING CONCERNS

The Arctic poses an engineering challenge to the development and maintenance of successful oil and gas operations seasonally and year-round. Ice is of primary concern for ships and offshore structures. The annual extent and variations in the sea ice cover, ice movement, the numbers and sizes of pressure ridges and multiyear ice floes and ice islands, as well as methodologies to estimate ice forces are among the factors that require continued data collection programs and experimental and theoretical research. Research on ice forces exerted on structures may result in large cost savings based on use of less conservative design criteria. New developments in such areas as ice surveillance systems, specialized equipment and instruments for ice data collection, model testing, and ice properties testing will be important in the support of future exploration, production, and shipping activities, as well as in oil spill control technology.

Commercial production of oil and gas in the U.S. Arctic at present consists of oil production from the Prudhoe Bay and Kuparuk fields and

gas production at Barrow. On the basis of reliable year-round operations, a pipeline across Alaska to an ice-free port was chosen over tanker movement through the Northwest Passage or through the Chukchi and Bering seas, as the means of transporting oil from the area. With the discovery of oil and the possibility of resource development in areas remote from the pipeline came a renewed interest in ice navigation for the support of development activity and future operations further offshore.

In 1969, the SS MANHATTAN, equipped with an icebreaking bow, made a successful transit of the Northwest Passage. In the 1970s, the U.S. Coast Guard continued to operate its WIND Class icebreakers to Nome and to the Bering Strait in winter ice. The delivery of two POLAR Class icebreakers allowed further study of ice navigation through joint industry and government programs that have been ongoing since 1979. In February 1981, the POLAR SEA completed a continuous icebreaking passage from Nome to Point Barrow, but was damaged on the return trip and had to winter in. U.S. information on and experience in year-round navigation in the Arctic oceans continues to be limited.

Tugs and barges are used almost exclusively to transport U.S. cargoes to the Bering, Chukchi, and Beaufort coastal areas because of the absence of deep-water ports north of the Kuskokwim Delta. The ability to use marine transportation to destinations on the Chukchi and Beaufort area depends on ice conditions. A new generation of specially designed vessels, as well as improved predictive information on ice conditions, will be required to respond to oil and gas exploration and development demands. Revolutionary new developments in icebreaker and ice transport vessels have been made in recent years, primarily by the Finnish shipyards, for use in Canada and the Soviet Union.

Expansion of Arctic resource development will create requirements for new and innovative transportation systems to carry products to distant markets. Successful operation requires careful design of the fleet to meet performance requirements. Designers need data describing the ice environment as well as an understanding of ship performance and reliability in ice. However, nontechnical barriers exist that are economic, regulatory, and environmental in nature.

At present, there is no plan for extension of U.S. Coast Guard search and rescue capability supporting marine or maritime operations in the Arctic region, apart from current helicopter services based on Kodiak or those operating from an icebreaker. Increased activity will require dependable and quick response coverage.

The need for highly accurate navigational systems has become a significant concern for Arctic offshore operators. Each of the available systems has limitations in polar regions. Commercial access to the Global Positioning System in 1987 is expected to resolve this problem.

Major advances in understanding the geotechnical nature of the Arctic seafloor have been made recently, but some phenomena, including subsea permafrost and overconsolidated silts, require special engineering solutions and further research.

Generally, the Arctic offshore regions of Alaska have low seismicity, but a few areas near the Seward Peninsula and in the Beaufort Sea have higher levels. Along the Aleutian Islands and in the southern Bering Sea, seismicity is very high, warranting long-term monitoring.

ENVIRONMENTAL CONCERNS

It is anticipated that continued oil and gas development in the Arctic will have an effect on its physical and biological environment. A subject of concern and controversy has been the potential effect that oil and gas activities may have on the region's fish, wildlife, and marine mammals, especially the bowhead whale, an endangered species. Such activities may cause noise disturbance and alter the coastline through causeway construction.

The possibility of a major oil spill and its effects represents one of the greatest environmental concerns. Government and industry have adopted some measures to mitigate the effects of an oil spill, but effective oil spill cleanup in broken ice remains a serious problem.

Three basic types of environmental information need to be developed further for Arctic operations: (1) baseline and monitoring information on wildlife demographics and behavior; (2) information on the hazards to structures posed by the environment; and (3) information on changes to the environment generated by industrial operations and structures. An extensive ongoing effort to collect information on the Arctic is the Outer Continental Shelf Environmental Assessment Program (OCSEAP), conducted by the National Oceanic and Atmospheric Administration (NOAA) for the Minerals Management Service (MMS). In addition, other projects are being conducted under the National Science Foundation's support, Sea Grant, and other environmental data are being acquired and analyzed by MMS and by industry on a site-specific basis.

PUBLIC AND INTERNATIONAL ISSUES

At present, the United States is evolving its Arctic policy through a current review of issues in U.S. Arctic policy ordered by a presidential directive. Key elements to be reviewed will be the protection of essential security interests, the support of sound and rational development, the promotion of scientific research, and the promotion of mutually beneficial international cooperation.¹ The

¹National Security Decision Directive No. 90, United States Arctic Policy, April 14, 1983.

Arctic Research and Policy Act enacted by Congress in 1984 (P.L. 98-373) provides the framework for planning and coordinating Arctic-related research. This report recommends that the Interagency Arctic Research Committee, which will be established in response to the act, be extended in its purview, by executive order, to encompass all government nondefense support of U.S. Arctic offshore and coastal development.

The federal government also needs to expand its already beneficial cooperative technical relationships with Canada. In addition, efforts to improve cooperation with the Soviet Union in several areas of Arctic technology should be encouraged.

The development of Arctic oil and gas resources by Canada has been of great interest to the United States as well as other countries. Canadian development has been particularly important in design and construction of Arctic offshore islands as well as marine and support systems.

Also, the significant advances made by the USSR in Arctic transport, with their essentially year-round capability, provide a potential source of technical background for possible U.S. maritime Arctic operation.

About 20 universities have engaged in ice, permafrost, and coastal Arctic research in recent years, while numerous others (up to 130) have conducted biological and ecological studies. University research and education are essential for a meaningful U.S. presence in the Arctic, since only the universities can produce new generations of Arctic researchers and engineers. Support of the universities is needed to allow them to train personnel and to produce graduates familiar with ice and other Arctic problems, as well as to assure the continuity of centers of excellence for Arctic research.

Arctic research is hampered by a lack of U.S. research vessels that can operate in ice-covered waters. Other data acquisition barriers also exist, such as the lack of a suitably equipped U.S. all-weather radar satellite covering the Arctic area. This situation will improve if the proposed European and Japanese synthetic aperture radar (SAR) satellites are launched and agreement is reached to establish a read-out station for them in Alaska.

GOVERNMENT OBJECTIVES AND CAPABILITIES

A significant capability for support of industrial and joint efforts in Arctic engineering exists within the federal government. Several federal agencies have a role in determining the use of ocean and coastal Arctic resources. Summaries of their missions and services are provided in Chapter 4. Certain barriers exist to the development of this capability. Budgetary constraints limit the objectives and services to some degree and inhibit long-term commitment. Improvements in coordination among the various agencies with Arctic programs are needed. A framework for encouraging this interagency coordination in research has been provided by the Arctic Research and Policy Act of 1984.

JOINT RESEARCH SPONSORSHIP AND PARTICIPATION

The logistics expense of conducting Arctic research is such that cost-sharing arrangements are often found. This is particularly true for collecting and analyzing information commonly needed by all operators. The critical aspects of making a joint program successful for all parties are multifold. A need must exist, and the information must have a value, in the view of each participant, that is commensurate with its cost; there must be flexibility in designing the program to meet the needs of each sponsor; and the effort must not violate antitrust laws when industrial organizations are involved. Joint projects may involve several organizations within industry as well as government and industry. Three joint programs are described in Appendix D.

CONCLUSIONS AND RECOMMENDATIONS

The committee, through its review of information provided by U.S. and Canadian industrial organizations and associations, government agencies, and universities, developed the following conclusions after its deliberations. The recommendations that follow the conclusions are not intended to relate to the conclusions on a direct one-for-one basis.

CONCLUSIONS

Engineering Concerns

1. The oil and gas industry has demonstrated safe drilling operations to a water depth of 30 meters¹ in a sea ice environment while employing bottom-founded platforms. Also, industry has indicated, through publications, research programs, and engineering analyses, that the technology is available to design, construct, and operate resource recovery systems in most of the Bering Sea and to water depths of as much as 100 meters in the Beaufort Sea.
2. Industry assessment of resource exploration and development capability in the Arctic is based, in part, on the experience gained from Canadian and U.S. operations as well as on numerous engineering and data gathering programs carried out under the auspices of the Alaska Oil and Gas Association (AOGA) and the Arctic Petroleum Operator's Association [Canada] (APOA). These activities are supplemented by individual company programs and other joint industry efforts. Government and academic groups have completed or have ongoing physical and environmental programs to

¹Dome Petroleum Ltd. has drilled to water depths of 30 meters, using their Single Steel Drilling Caisson (SSDC), in exploratory drilling operations during the winters of 1982-1983 and 1983-1984.

acquire and analyze data affecting engineering design and operations. Industry, government, and academia in the United States and internationally have generally adequate programs for the continued evolutionary development of materials technology and structural and process design needed to support prospective development. Additional ice, oceanographic, meteorologic, and sea-bottom sediments data will be needed to improve and optimize designs, to better plan and schedule offshore operations, and to improve design margins.

3. Improved understanding of sea ice behavior at different scales--over large areas (tens to hundreds of kilometers), intermediate (tens of meters of kilometers), and small areas (tens of centimeters)--is needed. However, the development of a rigorous comprehensive theory for the mechanical behavior of sea ice may not be forthcoming. Parts of this problem have been addressed and solved for specific cases on an engineering basis as needed. Long-term funding is required to provide a continuing and effective research basis for ice mechanics research.
4. Permafrost and other geotechnical phenomena present hazards to offshore platforms, and pipelines offshore and must be taken into account when evaluating the technical and economic feasibility of structures. The capability to make site-specific permafrost and geotechnical measurements is adequate.
5. Considerable seismic exploration survey data are available. The basic techniques used in temperate zones appear to be applicable, although the costs of Arctic operations are higher.
6. Most of the Arctic ocean areas, with the exception of those adjacent to the Alaska Peninsula and the Aleutian Islands, are not very active seismically, and earthquake-related effects do not control structural design in areas under development. The southern Bering Sea, however, is sufficiently close to the continental plate margin to be strongly influenced by seismic activity. Therefore, safety and structural economics could be enhanced by acquiring additional seismic data on the Alaska Peninsula and Aleutian Islands.
7. The lack of a suitably equipped U.S. all-weather radar satellite covering the Arctic area inhibits the collection of needed data to predict ice movements and their effects that are vital to Arctic development. Both long-range analysis and prediction and improved real-time information rely on such a satellite. Output from future European and Japanese synthetic aperture radar (SAR) satellites justify constructing a suitable read-out station in Alaska, the only location on U.S. soil where SAR satellite data can be intercepted from the Bering, Chukchi, and Beaufort seas. Even though the coverage from this satellite is limited by power constraints (8 minutes per 100-minute orbit), the establishment of an SAR receiving station in Alaska is of highest priority.

8. There is a need for a research vessel, either leased or as a new construction, to support scientific research; acquisition and analysis of engineering-related data concerning ice forces, characteristics, and mechanics, would also benefit from the availability of such a vessel. The National Science Foundation has commissioned the design of such a vessel, but construction remains uncertain. The committee was unable to identify clear requirements supporting the large investments for a new ship, but it was noted that the planning and initiation of some long-term research depends on guarantees of vessel availability over several years. At present, all ice-qualified research vessels are of foreign registry.
9. While the supply of Arctic-oriented college technical graduates appears to fall short of projected needs, industry is currently meeting the requirements by using the traditional disciplines with on-the-job training. Industry has the resources and technology to carry out exploration programs. However, in the event of significant Arctic discoveries there will be a shortage of Arctic-qualified engineers and technical personnel to support development engineering, construction, and production startup. Current indications are that industry is increasing support to university Arctic programs, reflecting recognition of this long-term need.
10. The capability exists to develop marine transportation systems, including port facilities, that may be required in the Arctic. Further development must be based on an industry analysis of needs for specific oil field development, field size, location, development time, and cost. Trafficability studies and terminal designs are a necessary input to this process. Field development time scales allow adequate lead time for developing specific associated transport systems.
11. The committee concurred with the engineering and technical recommendations of earlier studies concerning research related to Arctic ocean engineering and offshore development (referenced in Appendix A), with several exceptions. In regard to maritime services to support polar resource development (NRC, 1981a), the committee considers that test vessels, such as the small-to-medium-sized oil tanker and corresponding local terminal facility, are not needed and could be a costly way to develop special technical and economic data. In addition, the committee does not concur with the designation of a single agency responsible for implementing all government-supported activity related to Arctic ocean and offshore development. However, the committee does concur in a lead agency responsibility for coordination of planning, such as is stipulated by the recent Arctic Research and Policy Act for research planning.

12. It is observed that technical personnel working in Arctic research are cooperating effectively on a case-by-case basis; communications appear to be working well on an individual basis, as well as through seminars and conferences. The committee noted that cooperation in Arctic offshore development between the U.S. and Canadian engineering and technical communities has been vigorous and effective. This beneficial relationship has been encouraged through industrial associations, as well as through intergovernmental agreements. It is equally notable that there is little interagency coordination in the long-range planning of government research, logistics, and budgeting for Arctic offshore application. It is also noted that there is no government focal point for Arctic engineering-related research and technical support to encourage government-industry coordinated research and development.
13. Additional Arctic engineering laboratory test tank facilities are not needed. However, specialized facilities essential to training and education in universities will be required.
14. The needed research, such as in ice mechanics and ice dynamics, icebreaking techniques, subsea permafrost, and geotechnics, will require individualized field support facilities for each specific project.

Environmental Concerns

1. There is a need to address the potential effects of Arctic operations on marine wildlife in the area. The effect of man-made noise on Arctic wildlife is a major concern of Alaska natives, who rely on that wildlife for their subsistence or as a part of their culture. The number and intensity of noise sources will increase as exploration and development proceed. Continued research, such as that sponsored by the Minerals Management Service, is needed to determine the nature and extent of noise effects, whether additional mitigation measures are needed, and, if so, what measures should be applied.
2. There is broad recognition among industry, government, and environmental interests that there is a significant oil spill response capability in solid ice and open water conditions (limited by sea state). However, there is not a consensus by industry and federal, state, and local governments on the adequacy of oil spill technology in broken or newly formed ice. This lack of consensus is a current constraint on Arctic operations. Government research in this area has been significantly reduced. The Coast Guard continues to have primary responsibility for the coordination of government activities to protect the marine environment from pollution resulting from oil spills, including associated research on cleanup.

Public and International Issues Affecting Development

1. The primary cold region emphasis of the federal government has been on Antarctica and on polar defense needs, rather than on Arctic resource development, despite such programs as OCSEAP. Long-term Arctic research and development programs have largely disappeared from federal agency budgets, when the need for environmental and engineering data is expanding rapidly in the Arctic. The difficulty and amount of time required in the Arctic to get significant sets of environmental data or to conduct a series of engineering and scientific research studies cannot be overemphasized.

Government Objectives and Capabilities

1. Program planning coordination is needed among government agencies and desirable between government and industry to avoid duplication of costly programs.
2. There is a need for continued cooperative efforts between industry and the government agencies involved in the polar regions; this is particularly true in conduct of prelease studies and in the areas of common goals. The expense, time, and difficulty of Arctic research makes pooling of effort of major importance if engineers and scientists are to develop a realistic and effective understanding of the offshore Arctic environmental factors.
3. The shift of icebreaker funding away from the Coast Guard to "user" agencies may jeopardize long-term icebreaker support and has discouraged icebreaker technology development and future capability. This technology development is highly capital-intensive and has a very long lead time. The overall technology development may then become inadequate to meet future overall needs. This issue is exacerbated by the lack of ice-capable U.S. research vessels.
4. The Coast Guard currently does not have nor does it plan to have a designated Arctic search and rescue capability beyond helicopter service, based at Kodiak, which can use refueling locations on the Bering, Chukchi, and Beaufort coasts. The region presents special problems, and significant expansion of offshore activity may be expected to place new demands on the agency.

RECOMMENDATIONS

1. The Administration should put in place a process for assuring that Arctic offshore and coastal resources research and development programs of all federal agencies are an integral component of and consistent with overall policies, priorities, and national goals for the Arctic ocean regions. Acceptance at appropriate policy levels that integrated Arctic ocean research and development is a critical and identifiable element of national policy will facilitate the establishment of more realistic funding levels within the federal budgetary framework. This process has been initiated by National Security Decision Directive No. 90 (April 14, 1983).
2. The designation of a single lead agency responsibility for all nondefense government engineering and logistical support for Arctic marine activities does not appear to be feasible. The issues and jurisdiction responsibilities are too complex to permit this to be effective. A better approach could be an Arctic coordinating council of senior decision-making officials from the concerned agencies, including a representative from the Office of Management and Budget (OMB).

The Arctic Research and Policy Act of 1984 (P.L. 98-373), which was signed into law July 1984, provides the framework for an Interagency Arctic Research Policy Committee, which would provide guidance to agencies in planning, budgeting, and implementing Arctic research only; the National Science Foundation (NSF) is designated as the lead agency in this planning and coordination role. The coordinating council recommended in this report would focus on all government services and development activities directed to the Arctic offshore, and is not limited to research. It is noted that the "Interagency Arctic Research Policy Committee," set forth by the Act, will include all the interested operating, as well as research, agencies. Accordingly, the coordination recommended by this study might be accomplished by extending the functional responsibility of the "Interagency Arctic Research Policy Committee" by executive order, thus avoiding the creation of another committee.

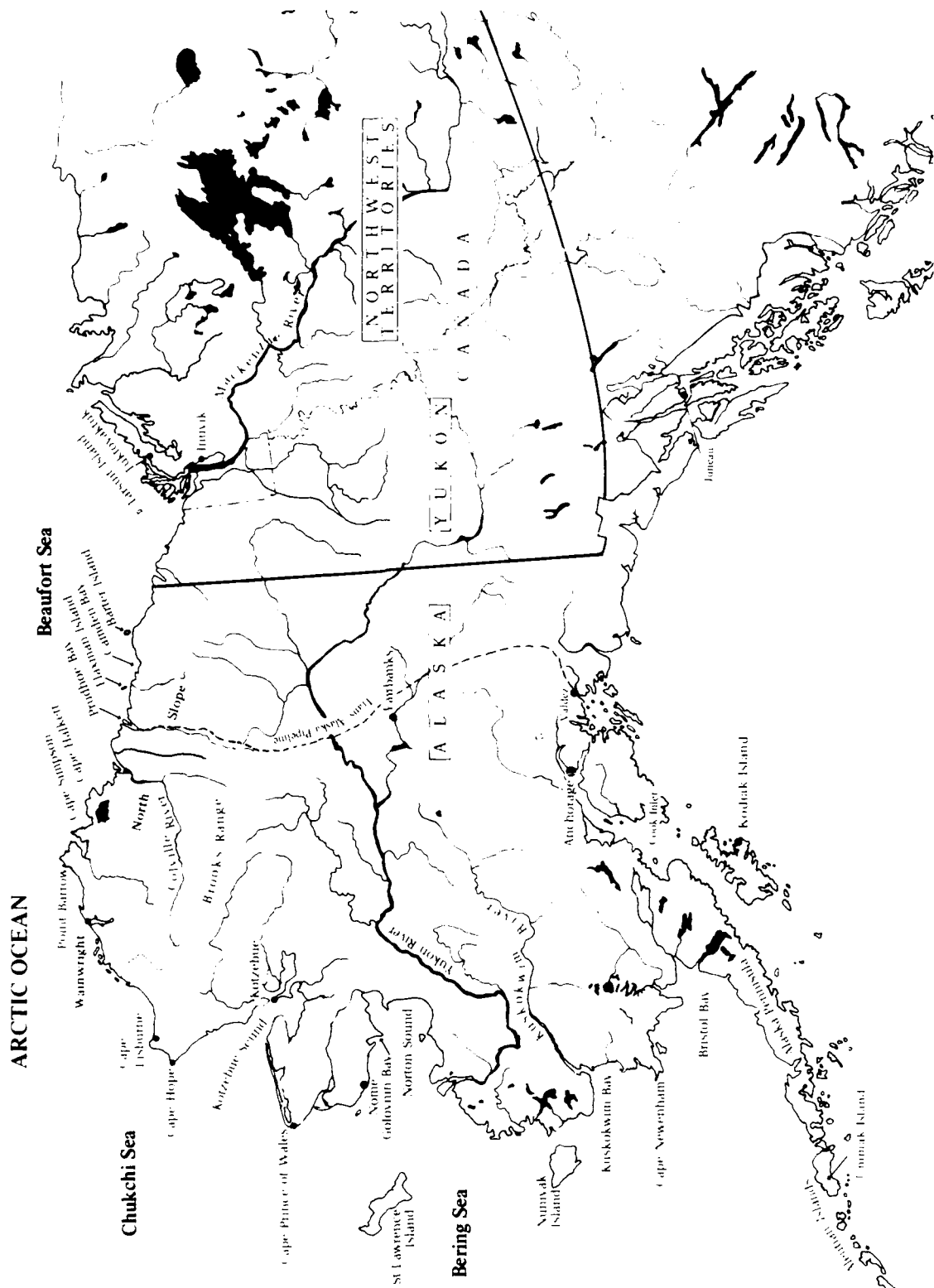
3. Areas for priority attention by the coordinating council are:
 - The development and establishment of a long-term data gathering and analysis system to support basic knowledge of ice, including oceanographic and climatic processes in the polar region. This should include a continuation of ocean-surface-positioned measuring systems as well as polar orbiting satellites and real-time read-out stations.

- The joint Navy-NOAA ice-forecasting activity should be supported with a view to expanding the type, accuracy, and timeliness of the ice coverage information available in support of industrial research activities in the Arctic region. The requirements for data on ice coverage and type will change as the development of the region increases or shifts.
 - A comprehensive review and dissemination of available data and analyses and continued research into the effects of humanly-induced noises on the living resources of the Arctic should be conducted. Results should be used to establish realistic noise limitations on systems development and operation.
 - Engineering development should also be continued with government support in the following areas:
 - Icebreaking for surface support systems;
 - Seismic monitoring for high-risk regions; and
 - Ice mechanics investigations, including research on the effects of ice forces on fixed structures, both in the laboratory and in the field, with long-term support.
4. The Coast Guard should be provided funds to replace the existing 40+-year-old icebreakers. Planning, authorization, and construction is a 7- to 10-year task that must be started well in advance of major Arctic development. These ships are needed for search and rescue, as well as for other Coast Guard missions. The construction and maintenance of icebreakers is a long-term, national security commitment of the government and it should not rely on construction initiatives by industry, which are based on short-term operational requirements.
 5. Special efforts should be made to expand use of existing federally funded vessels for research purposes in ice-covered U.S. Arctic waters. Only the U.S. Coast Guard (USCG) icebreakers fall in this category for use in the Arctic; however, these vessels have limited scientific capability and are dedicated to other missions. Therefore, a dedicated polar research vessel should be built or chartered.
 6. Further research on oil spill cleanup is necessary to evaluate the operational effectiveness of available technologies and to develop new technologies for severe ice conditions. The current level of government funding for planning, research, and development of spill response systems for the Arctic should be increased. The effort should be focused on achieving measurable criteria for

judging the extent and degree of cleanup to form a basis for agreement among all parties, including the oil industry, and federal, state, and local governments.

7. In view of the anticipated shortage of qualified personnel to support a major expansion of Arctic activity, it is recommended that both industry and government continue and expand support to universities for Arctic-related programs, including research, symposia, and technical courses or additions to courses. Through this action, focused graduate programs can be developed that will assist in providing competent engineers and scientists to resolve the development problems with the required Arctic offshore and ocean resources.

ALASKA AND NORTHWEST CANADA Geographical Locations of Reference



INTRODUCTION

Development of energy resources in the U.S. Arctic, north of the Alaska Peninsula and the Aleutian Islands, is of critical importance to the nation. This need raises concerns about the nation's governmental and industrial capability to provide the physical and personnel support for offshore ocean engineering, technical operations, and supporting research. Today, coastal oil resources at Prudhoe Bay account for over 17 percent (1.5 million barrels per day) of the oil produced from U.S. lands, and it is estimated that nearly a third of this reservoir is depleted.¹ The National Petroleum Council (NPC) estimates that the U.S. Arctic may encompass as much as 40 percent of the total undiscovered recoverable oil and gas resources remaining within the United States (NPC, 1981). The NPC's estimates also indicate that over 70 percent of this Arctic oil and gas potential may be offshore.

Six federal lease sales have been held since 1979 for Arctic offshore areas, including three in the Beaufort Sea and three in the Bering Sea. The lease areas listed in Table 1 are shown on Figure 1, which identifies subregions and planning areas.

Alaskan state land lease sales reflect similar actions and plans to move into offshore sectors. State submerged lands north of Prudhoe Bay and in the Flaxman Island/Canning River area were leased in 1982. A Beaufort Sea sector was leased in 1983 (sale #39), and two more Beaufort Sea sales are planned (1984 and 1987).

Several conditions, which also form the bases for judgments made in this report, are implied in state and federal government lease sale planning. They are as follows:

- Technology and practice are adequate to safely provide and operate the necessary facilities for acquiring and transporting Arctic offshore oil and gas as well as sand and

¹Source of estimates: U.S. Department of the Interior, Minerals Management Service, July 1984.

TABLE 1 U.S. Department of the Interior Offshore Leasing
Schedule, 1979-1987

Lease Date	Sale #	Area
1979	BF 71	Beaufort Sea (now called Diapir Field) Diapir Field (Beaufort Sea)
1982	57	Norton Basin (Bering Sea)
1983	70	St. George Basin (Bering Sea)
1984	83 87 -	Navarin Basin (Bering Sea) Diapir Field (Beaufort Sea) Diapir Field--sand and gravel (Beaufort Sea) (sale on hold)
1985	89 92 100 -	St. George Basin (Bering Sea) North Aleutian Basin (Bering Sea) Norton Basin (Bering Sea) Bering Sea--sand and gravel (sale on hold)
1986	107 97	Navarin Basin (Bering Sea) Diapir Field (Beaufort Sea)
1987	101 109	St. George Basin (Bering Sea) Barrow Arch (Chukchi Sea)

SOURCE: U.S. Department of the Interior, Final 5-year OCS Oil and Gas
Leasing Schedule, updated by Office of Information Services, May 24,
1984.

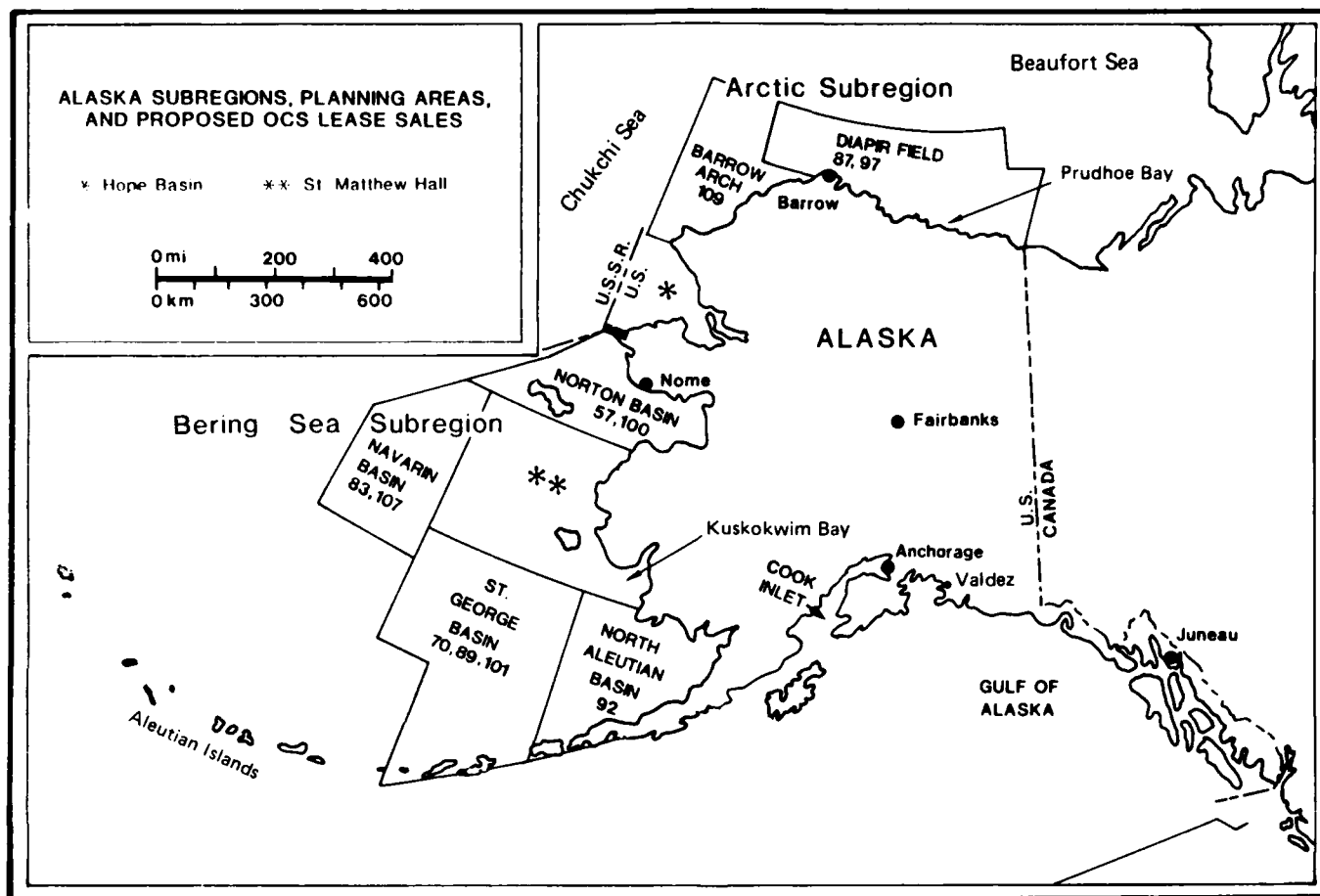


FIGURE 1 Subregions, planning areas, and proposed outer continental shelf lease sales.

SOURCE: U.S. Department of the Interior, Minerals Management Service.

gravel resources. Safety of personnel should be at least equivalent to operations in other U.S. offshore areas.

- Offshore operations can be responsive to public law and lease stipulations protecting ocean living resources, wildlife, and the environment.
- The schedule of leasing is not expected to be delayed or accelerated significantly by sudden world market changes or stresses.

While the development of energy resources in the U.S. Arctic ocean areas are the principal focus of Arctic engineering activities, the living resources of the Arctic seas are important to the nation. The Bering Sea contains one of the world's major ground fish resources, Alaska pollock. Other valuable fish caught are salmon, halibut, king and tanner crabs, Pacific cod, and sable fish. The optimum yield (an estimate based on biological data) for ground fish species in 1982 was 1.58 million metric tons. Until the Magnuson Fishery Conservation and Management Act was passed in 1976, almost the entire catch was by foreign vessels. The U.S. catch of ground fish from the area, originally less than 100 metric tons annually, reached approximately 110,000 metric tons in 1982.

Another Alaskan Arctic resource consists of hard minerals. Several minerals and metals are known to exist as placer deposits, usually at water depths less than 15 meters, along the Bering and Chukchi seacoasts. The resources include platinum, tin, chromium, tungsten, and gold.

Alaska's coal resources are perhaps equal to those of the rest of the United States, but only a small part of the coal is recoverable with present technology, and even less can be produced at a profit, according to a report by the National Research Council (NRC, 1980). Except for coal deposits in the North Slope Basin and near Point Hope, most Alaskan coal would be shipped by land routes or from ports on the Gulf of Alaska.

Since 1980, several studies and reports published by government agencies, the NRC, and the NPC have addressed broad issues of U.S. Arctic development, largely focusing on oil and gas resources. Appendix A summarizes the major, technically related findings and conclusions of these reports.

Three other government studies of Arctic problems are being conducted, one by the Coast Guard to assess the requirements for polar icebreaking service during 1985-2000, another by an interagency Arctic Policy Committee in response to an executive directive to review Arctic policy, and a third study by the U.S. Congress, Office of Technology Assessment (OTA). The OTA study assesses Arctic and deepwater oil and gas from technological and economic viewpoints. Although these studies were not published or available at the time the committee was completing its assessments, the agencies have been cooperative in discussing information that would be helpful to the committee.

The study of polar icebreaker requirements is being undertaken at the direction of the Office of Management and Budget (OMB), which has

charged an interagency policy committee (i.e., Department of Transportation, Coast Guard, Maritime Administration, Department of Defense, National Science Foundation, National Oceanic and Atmospheric Administration, and OMB) to develop an analysis of polar icebreaking requirements for the balance of the century, and to provide recommendations on how many polar icebreakers may be required and how they should be budgeted and developed. This study is to be completed in 1984. The Coast Guard is responsible for the conduct and coordination of the study, which will provide a forecast of industry and government requirements, an assessment of user alternatives, and development of financing recommendations.

The second major interagency Arctic-related study, now underway under State Department auspices, is a two-phase review project in response to the National Security Decision Directive No. 90, issued on April 14, 1983, which requested a report on ways to coordinate U.S. activities in the Arctic region with those of other countries bordering on the Arctic Ocean, and to identify federal services needed in the Arctic region over the next decade, including relative priorities.

ENGINEERING CONCERNS

Engineering to support successful operations in the Arctic must address ice, oceanographic, meteorological, and seafloor geological and seismic factors. The relative importance of each factor depends on the geographic area and the particular operation or structure of interest. For example, ice forces constitute the primary design influence for structures in the Beaufort Sea, although wave effects, such as spray and overtopping, are also a design consideration. On the other hand, waves and wave-borne ice comprise the primary design factors for production structures in the Navarin Basin.

The primary emphasis of this chapter is on ice and its effects on offshore structures and ships. A description of the ice environment includes statistical descriptions of ice feature occurrence, ice fracture characteristics, and ice movement. Ice mechanics addresses behavior of sea ice and ice features. Structure and ship configurations must be designed taking into account ice-structure or ice-ship interaction because ice loads and failure modes are structure-dependent. Geotechnical factors, or soils behavior, are also essential elements in the evaluation of structural performance. Final design is based on these technical factors and on user requirements for operating performance, assessment of acceptable risk and economics, and design codes and regulations.

This chapter addresses technical issues related to the environmental factors affecting offshore operations; shipping operations; sea ice mechanics and ice forces; and geotechnics. Requirements, existing resources, and gaps and deficiencies are described.

OFFSHORE OPERATIONS

Ice Cover, Weather, and Ice Features

Information on ice cover, weather, and ice features is needed to support icebreaker and over-ice transportation planning, to assist planning for open-water construction and supply operations, and to develop ice design criteria for fixed and floating structures.

Ice cover and weather information has been gathered by the U.S. Navy since the mid-1950s. During the last 10 years, these data have been used for prediction services for sealift operations in the U.S. Arctic and to support offshore exploration operations in the Canadian Arctic. More recently, emphasis has been placed on developing and improving ice surveillance and forecasting techniques for operational support.

Ice Cover

Ice cover, edge location, and ice concentration vary considerably both yearly and monthly. Information on these factors is required to plan operations that cannot operate in all types of ice concentrations. These would include conventional tug and barge supply operations, conventional dredging operations, floating drilling operations, and the movement of bottom-founded structures. Two types of information are needed: (1) historical data to assess the probability of successfully performing an operation and to help plan it, and (2) real-time data to assist the operation while it is continuing. Ice cover is characterized by extreme irregularities in thickness, particularly in the transition zone between the landfast and polar pack areas, where the ice is continually moving and deforming (see Figure 2). Significant seasonal and yearly variations in the ice cover also occur in the transition zone. Satellite imagery and photographic survey information has been used systematically to develop ice cover data in the Beaufort and Bering seas area since the 1970s.

Pressure Ridges

Both first-year and multiyear pressure ridges, an integral part of the regular ice cover, are recognized as being potentially hazardous ice formations. A knowledge of their size, geometry, and composition is needed when navigation is considered, because ridges are the principal impediments to the movement of vessels, and they obstruct over-ice transportation. Qualitative information on pressure ridges also is required to predict sea bottom gouging, which would affect subsea pipeline and production installations. Multiyear ridges also constitute a major design load for offshore structures.

Early work to obtain ridge height statistical data used conventional aerial stereo photogrammetric techniques to measure sail heights and employed upward-looking sonar measurements of keels by submarine. Sail height, location, and ridge orientation statistics currently are measured along representative "random" lines over large areas using aerial laser profilimeter techniques. Methods have been developed to estimate overall ridge thicknesses from sail height information. On-ice field measurements have been used to determine ridge composition.

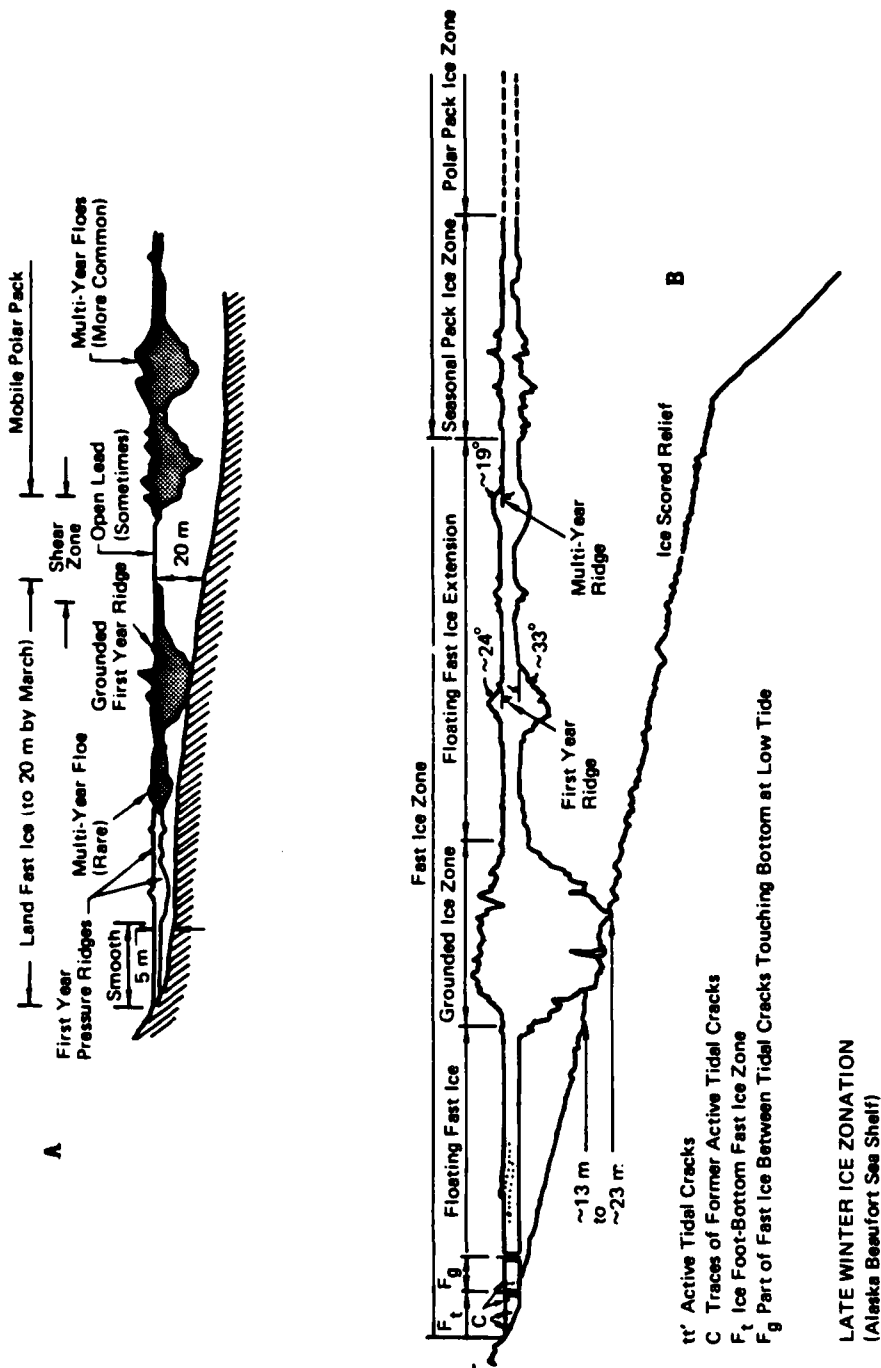


FIGURE 2 A and B: Models of cross-shelf ice zonation in the Beaufort Sea during winter.

SOURCES: A: Croasdale (1977); B: Kovacs and Sodhi (1981).

Limited information exists on ridge keel distributions. Some submarine profile data in deep water are available. Upward-looking, bottom-supported sonar sounders also have been developed for the measurement of keel geometries. These techniques, however, have not been used extensively.

Economical techniques to gather pressure ridge statistics (i.e., sail height, keel geometry, composition, orientation, and frequency) over large areas are needed. It would be desirable to have large quantities of data over large areas to assess geographic and temporal variations.

Ice Movements

Ice movements during all seasons are of interest in predicting the probability of encountering large ice features, defining ice loads, and assessing potential ice management concerns. Movements may occur throughout the year in the landfast, transition, and pack ice zones. Movements in the landfast ice zone, however, are smaller than those in the pack ice zone.

Large early season movements of both thin ice and 1-year-old ice have a major effect on floating drilling operations extended into the winter season. Once the ice sheet stabilizes, the landfast ice cover moves sporadically throughout the winter periods with movement increasing as its outer edges are approached. Much larger movements occur in the transition zone. During breakup much larger movements again occur, and during this period the concern about storm surges and ice ride-up is most acute.

Currently, limited measurements of midwinter ice movements are made in the landfast ice with bottom-anchored "wireline" measurement devices. Early season and breakup movements are measured using buoys. Low-cost techniques to measure movement accurately over large areas are needed for a better understanding of movements and for the development of more accurate modeling and prediction techniques.

Multiyear Floes

Multiyear ice floes, both when embedded in the ice sheet during winter and when floating free during the summer, constitute a major design load for bottom-founded and floating facilities.

Multiyear floe distribution frequencies and size statistics are obtained by airborne synthetic aperture radar (SAR) and side-looking airborne radar (SLAR) techniques, which can gather large quantities of data over large areas. Data on floe thicknesses have been obtained by on-ice drilling, impulse radar, electromagnetic sensors, and acoustic techniques. An improved thickness measuring technique, one that can obtain data at lower costs, is desired to provide a better statistical data base. Floe movement velocities during summer are measured by plotting SAR/SLAR data taken at daily intervals. Current work

indicates that multiyear floe velocities are correlated and highly responsive to wind velocities.

Improved systems are needed to monitor the size, paths, and velocities of multiyear floes into potential drilling areas. Also needed is an accurate model to predict multiyear floe velocities correlated with converted wind hindcasting techniques. It would be desirable to establish a real-time wind measurement network to determine accurate ground truth for such predictions.

Ice Islands

Although infrequent, ice island fragments are found in the Beaufort Sea region. These originate from the Ward Hunt Ice Shelf on Northern Ellesmere Island, become trapped in the polar pack, and are carried southward in the mean circulation. They usually remain in the polar pack, but fragments sometimes enter the Beaufort Gyre and on occasion ground in water as shallow as 14 meters. A comprehensive project to identify and track these ice features and study their properties as they move westward has been initiated at the University of Alaska and is sponsored by the Department of Energy. This activity is being conducted in cooperation with Canada's Department of Energy, Mines, and Resources.¹

Ice Forecasting

The AIDJEX² program has developed an ice model that has been adapted and modified by a number of offshore petroleum operators, as well as government agencies. One project known as WIEBS (Winter Ice Experiment, Beaufort Sea) involves the collection of data for early winter ice conditions and the theoretical development of a coarse-scale and fine-scale (100 kilometers) mathematical and computer model. Late-winter ice data are being added to this program. Other

¹Project is titled "Development of Quantitative Information on Arctic Ice Island and Sea Ice Movement and Mechanical Properties," (Department of Energy contract DE-AC21-83-MC20037).

²AIDJEX, the Arctic Ice Dynamics Joint Experiment, was conducted by the University of Washington under the sponsorship of the National Science Foundation, the Office of Naval Research, the National Aeronautical and Space Administration, and the U.S. Geological Survey. Field work on a pilot basis was done in 1972 and the main project was conducted in 1975 and 1976. The objective of AIDJEX was to seek a quantitative relationship between large-scale stress and strain fields in sea ice.

forecast models have been developed at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) (Hibler, 1979) and the Pacific Marine Environmental Laboratory.³ Improved ice forecasting techniques will be extremely important in the support of future exploration, production, and shipping activities. Work is underway by a number of petroleum operators to develop an ice model for predicting ice motion under summer and winter conditions. Dome Petroleum and Sohio have placed remote readout wind and current buoys to collect data for aiding model development. Future field programs will focus on gathering data for further testing, fine tuning, and modifying of the models to attain operational form. Drift models, similar to the iceberg drift models developed for the eastern Canadian petroleum areas, are under development for the movement of ice islands and large, multiyear floes in the Beaufort Sea.

Ice Surveillance Systems

Ship- and Aircraft-Mounted Radar Work is proceeding toward the development of accurate and reliable instrumentation for the detection and characterization of hazardous ice during summer operations in the Beaufort Sea. Marine radar placed in elevated positions on drilling islands and vessels has been used in Canada to provide ice detection capabilities. Other projects have used aircraft with SAR or SLAR as operational ice management tools.

Future research will focus on the provision of operational ice detection services for proposed icebreaking tankers and supply vessels. A lightweight SAR system mounted on vessel support aircraft is under development and is intended to lead to the production of a system optimized for airborne ice surveillance to support drilling and transportation operations.⁴

Development of an ice hazard detection system to be used on ships also is planned in Canada. This project will result in the development of advanced marine radar as well as supplementary systems including acoustic, passive microwave, infrared, and optical systems.

Buoys AIDJEX-supported contractors developed a satellite-interrogated buoy that provides position, meteorological, and oceanographic data. Presently, an Arctic basinwide operational network of buoys provides information on large-scale motion, deformation, and other features. These buoys serve as research as well as operational tools useful in

³Carol Pease, Pacific Marine Environmental Laboratory, Seattle, Washington, personal communication, June 1983.

⁴A 750 kg-SAR system, developed by Intera Technologies Inc., Houston, Texas, has been employed in such operations from a land base.

ice forecasting. Their continued technical improvement as well as the maintenance of an Arctic basinwide operational network is a relatively low cost undertaking that has high priority in an assessment of the National Research Council's Polar Research Board (NRC, 1983b).

Satellites Table 2 provides a list of remote-sensing satellites for Arctic coverage. Visible and infrared imagery from the polar-orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA) provides medium-resolution information on sea ice cover in cloudfree areas. All-weather, day/night synoptic information on ice concentration and on ice type (first-year versus old) is provided by passive-microwave imagery obtained by NASA's Nimbus-7. This spacecraft was launched in 1978 with a planned one-year lifetime. However, the radiometers are still providing good data, and they may continue operating into the mid-1980s. The next generation of microwave radiometers will fly aboard a series of Defense Meteorological Satellite Program (DMSP) spacecraft from 1986 into the early 1990s.

The altimeter aboard National Aeronautics and Space Administration's (NASA) Seasat provided high spatial resolution information on ice-margin position and sea ice roughness in 1978. In conjunction with data from wide-swath sensors, such as passive-microwave, altimeter data offer great promise for sea ice surveillance. Future altimetry missions include the U.S. Navy's Geosat (to be launched in 1985), the joint Navy/NASA/NOAA NROSS (in 1989), and the European Space Agency's (ESA) ERS-1 (in 1989).

No U.S. satellites are scheduled to carry a SAR during this decade. However, ESA's ERS-1 and Japan's ERS-1 will carry SARs. Since data rates from an SAR are too high for on-board storage, data must be transmitted as they are acquired. Consequently, NASA proposes to establish an SAR receiving station in Alaska to collect data from the Bering, Chukchi, and Beaufort seas. In conjunction with the ESA station at Kiruna, Sweden, and Prince Albert, Canada, this capability would provide the potential for all-Arctic coverage. It should be stressed, however, that power constraints limit total SAR coverage aboard ESA's ERS-1 to about 8 minutes per 100-minute orbit.

Availability and Assessment of Resources

U.S. resources for monitoring ice characteristics and developing theoretical prediction techniques consist of satellite-borne sensors and personnel from universities, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), the U.S. Navy's Joint Ice Center, and consulting firms that support industry. Several major oil companies also maintain significant in-house staffs for Arctic engineering research. These personnel have broad backgrounds in materials science, instrumental techniques, and offshore and ocean engineering.

TABLE 2 Satellite Remote Sensing of the Polar Regions

Mission	Sponsor	Sensors	Applications	Useful Lifetime/ Start Date	NASA Involvement
NIMBUS-5	NASA	Microwave Radiometer (MR)	Sea ice concentration	1973 through 1976	Sensor improvement. Data processing to geophysical parameters, and scientific analysis.
SEASAT	NASA	MR	Sea ice concentration	July to	Sensor improvement;
		Synthetic Aperture Radar (SAR)	High-resolution sea-ice imagery	October 1978	Development of techniques for processing and analyzing the data sets.
		Altimeter (ALT)	Sea ice extent and roughness; topography and extent of land ice		
NIMBUS-7	NASA	Scatterometer (SCAT)	Wind vectors over open ocean		
		MR	Sea ice concentration and type	1978-still operating	Data processing of geophysical parameters.
GEOSAT	U.S. NAVY	ALT	Sea ice extent and roughness; topography and extent of land ice	1985	Acquisition, processing and analysis of data over ice. Investigation of potential for deriving new ice products from ALT data.
DMSP (Defense Meteorological Satellite)	U.S. AIR FORCE/NAVY	MR	Sea ice concentration and type	1986 thru early 90s	Acquisition, processing, archival, distribution and analysis of data over ice.
ERS-1	EUROPEAN SPACE AGENCY	ALT SAR SCAT	As for Seasat	1989	Installation of a facility in Alaska to acquire SAR data; processing and analyzing these data.
NROSS	U.S. NAVY/NOAA	MR ALT SCAT	As for Seasat	1989	Process, archive, distribute and analyze ocean-surface winds. Process ice parameters from MR and ALT data.
ERS-1	JAPAN	SAR	As for Seasat	1990	Utilize Alaska SAR receiving station, as for ESA's ERS-1.
RADARSAT	CANADA	SAR	As for Seasat	1991	As above.

SOURCE: NASA, Earth Science and Applications Division.

Existing satellites, e.g., Landsat and NOAA's AVHRR⁵, provide valuable ice information on a historical basis, but their value to the Arctic offshore operator is limited by spatial accuracy limits (NOAA AVHRR), temporal coverage (Landsat), visibility restrictions, and time lag in obtaining data through normal processing procedures.

Important for the development of concepts to aid actual operations in the Beaufort Sea is the recognition that the edge of the ice pack is quite irregular, and differs significantly over time from the boundaries shown in the ice atlases. The same difference exists between images and atlases in regard to ice concentration. This is due to the fact that the satellite imagery is essentially synoptic, while the curves shown in the atlases result from statistical smoothing of many seasons of data, often obtained piecemeal. The satellite imagery provides observation of sea ice behavior over large areas in real-time that can be developed into dynamic rather than statistical models.

A better way of obtaining high-resolution information is to use SAR and SLAR. These radar systems have been investigated for their ability to provide identification, type discrimination, and high-resolution mapping of ice. Satellite-borne SAR and SLAR sensors can obtain wide-area information economically, which is invaluable for the study and prediction of large-scale sea ice behavior. SAR/SLAR flights are being used in the Beaufort Sea to support drilling operations and to assist in predicting ice conditions 24 hours in advance.

Gaps and Deficiencies

Design of offshore Arctic structures and ships requires an understanding of the Arctic environment that is sufficient to identify the most critical components. Based on this understanding, field measurements of parameters such as ice properties, ice feature occurrence, and ice movement are combined with analytical procedures to estimate design loads. In the Arctic, as in any other frontier area, the first generation of structures built will be based on conservative design procedures because of uncertainty. As experience is gained and additional data are collected during initial exploration, designs will be improved and optimized.

Presently, techniques and basic information exist to support the design of first-generation structures. Several systems have been designed and used successfully in the Arctic; however, additional environmental data are needed to improve and optimize second-generation systems. The data are being collected in research programs by industry, government, and academia and in conjunction with ongoing exploratory operations.

⁵AVHRR: Advanced Very High Resolution Radiometer.

An extensive historical data base exists for ice cover and ice characteristics in most areas of the Alaskan offshore Arctic. This data base consists of long-term historical observations (30 years or more) and more detailed information from satellite imagery during the last 10 years. In addition, a large quantity of area-specific data has been collected in the last 5 years from aerial photography, laser and SAR overflights, and on-the-ice studies. The primary need is to extend this data base to larger geographic areas and over a longer time period to assess annual differences. Concurrently, analytical studies should be performed to develop a quantitative understanding of near-shore ice movement in the Beaufort and Chukchi seas and ice movement in the Bering Sea during all seasons.

There are inadequate data to provide accurate and timely site-specific ice forecasts. These forecasts are used to assist summer and winter construction activities and exploratory drilling operations.

SHIPPING OPERATIONS

England's interest in trade routes to the Orient led to exploration of the North American Arctic in the sixteenth century. Numerous unsuccessful attempts to navigate the Northwest Passage followed. Finally, Roald Amundsen made the first successful transit of the Northwest Passage in 1903-1906. In terms of providing technical information for Arctic marine transportation, the most valuable transit occurred in 1969. Inspired by the discovery of oil at Prudhoe Bay, several oil companies converted a tanker, the SS MANHATTAN, and transited the Northwest Passage to test the feasibility of Arctic marine transportation.

Arctic marine operations have advanced more rapidly in other areas of the world than in North America because larger population centers in northern regions of Europe and the USSR have created more demand. Applications include freight transport, support of industrial activities, and support of mining. Since 1980, the Soviet Union has conducted year-round transportation (except at breakup) through the Kara Sea to various river ports (Makinen, 1983). The northern sea route from the western USSR through the Siberian and Chukchi seas is used for about 4 months of the year (mid-June to mid-October), and has been used for as long as 10 months. However, use of this route is costly and not completely riskfree, as illustrated by the ice entrapment of a Soviet fleet in late 1983.

The Soviet Arctic maritime capability continues to increase in numbers of vessels and experience with 15 polar-capable icebreakers, including 3 nuclear-powered and 34 seasonally operated vessels (see Table 3). One more BRESHNEV-class (formerly ARKTIKA) nuclear ship is soon to join the Soviet Arctic maritime fleet, and several more vessels are expected to be ordered from Finnish yards.

Oil and gas development in North America plays a primary role in nondefense Arctic marine transportation. Since the mid-1970s, an annual sealift operation has transported equipment and supplies to Prudhoe Bay to support development. All transportation to the north

TABLE 3. World Polar Icebreaker Fleet (Government Owned Vessels)

NATION	VESSEL/CLASS	BUILT	LENGTH (FT)	DRAFT (FT)	DISPLACEMENT (TONS)	TOTAL SHAFT HORSE POWER	POWER PLANT	ESTIMATED CONTINUOUS ICEBREAKING CAPABILITY (FT)
USSR	BRESHNEV SIBER	1975/77	446	36	23,460	75,000	NUCLEAR	8
USSR	LENIN	1959	439	34	19,240	44,000	NUCLEAR	6.5
USA	POLAR STAR POLAR SEA	1976/77	399	28	13,000	60,000 or 18,000	GAS TURBINE (GT) or DIESEL-ELECTRIC (DE)	6+
USSR	ERMAK CLASS (3 SHIPS)	1974-76	442	36	20,241	36,000	DE	6
JAPAN	SHIRASE	1982	440	30	11,418	30,000	DE	5
CANADA	LOUIS ST. LAURENT	1969	366	30	13,300	24,000	STEAM TURBO- ELECTRIC	4-5
USSR	MOSKVA CLASS (5 SHIPS)	1959-69	400	31	15,360	22,000	DE	4.5
USSR	KAPITAN DRAMITSYN CLASS (2 SHIPS)	1980/81	433	28	15,000	22,000	DE	4.5
USSR	KAPITAN SOROKIN CLASS (2 SHIPS)	1977/78	421	28	14,400	22,000	DE	4.5
USA	GLACIER	1955	310	28	8,800	21,000	DE	3.5
CANADA	MACDONALD	1960	315	28	9,160	15,000	DE	3.5
CANADA	RADISSON CLASS (3 SHIPS)	1978-82	316	24	8,055	13,600	DE	3.5
ARGENTINA	ALHIRANTE IRIZAR	1978	391	31	14,500	16,200	DE	3.5
W. GERMANY	POLARSTERN	1982	354	35	14,800	20,000	DIESEL	3.0
JAPAN	FUJI	1965	328	27	8,566	12,000	DE	3.5
CANADA	LABRADOR	1953	269	30	6,940	10,000	DE	3.0
USA	NORTHWIND WESTWIND	1944/45	269	26	7,500	10,000	DE	3.0

NOTE: This table does not include some 56 vessels (subarctic icebreakers) that are capable of icebreaking operations in seasonally ice-covered coastal seas and lakes outside the polar regions. These ships are owned by: Canada (2); Denmark (2); Finland (9); West Germany (1); Sweden (6); USA (1-MACKINAW); USSR (34); and East Germany (1).

SOURCE: U.S. Coast Guard, Ice Operations Division.

coast of Alaska occurs during the limited summer season (August-September).

Technology for construction and logistics support is available today. Ongoing work to improve vessel design and support services, such as forecasting, communications, and navigation, will lead to improved marine operations. The more demanding performance requirements for the remote Arctic development areas create questions regarding requirements and technology for surface transportation and marine navigation and transportation systems.

Marine Transportation Systems

Expansion of oil and gas exploration and production activities in Arctic waters will create requirements for new and innovative transportation systems. Commercial ships may be required for construction support, logistics support, and transport of oil and gas. Icebreaking and ice-strengthened tankers, icebreaking liquid natural gas carriers, and barges are among the transportation systems under consideration.

Selection and construction of a transportation system will be influenced by the size of oil fields, the cost to develop the fields, and the cost to develop the system. Technology is not perceived to be a constraint; construction technology is available and engineering capability is in place.

Planning for support vessels with heavy icebreaking capability is in much the same state of development as the system itself. The U.S. Coast Guard has no plans for the construction of icebreakers that would be dedicated to keeping sea lanes open for commercial traffic, and it recently announced plans to decommission one icebreaker. Several U.S. oil companies have assessed Canadian icebreaker designs, including a 150,000-horsepower, Arctic Class 10, Arctic Marine Locomotive that has been designed for Dome Petroleum Ltd. Development of icebreaking capability is expected to keep pace with the development of cargo-carrying vessels, since icebreakers will be an important part of the overall transportation system.

However, constraints of a nontechnical nature, i.e., economic and environmental, affect the development of a marine transportation system. In this regard, greatest emphasis has been placed upon the effects of potential oil spills and industrial operations (i.e., vessels, structures, and aircraft) on marine animals. Particular concern has focused on effects of ship noise on the food chain of Arctic marine mammals.

Ship Performance Requirements

Successful operation of an Arctic marine transportation system for oil and gas requires careful design of the fleet to meet performance requirements. Icebreaking or ice-strengthened tankers may be used to transport oil and gas from an offshore terminal in the Arctic with

storage facilities, which may be somewhat limited. Strict schedules for transit, loading, and off-loading must be met to avoid slowed or shut-in production. Predicting vessel performance is therefore more critical for oil and gas transport than for most cargo transport.

Designers require data describing the ice environment and an understanding of how ship characteristics, such as hull form and propulsion, relate to reliability and performance in ice. Ship performance criteria to be considered when designing Arctic ships include:

- Ship resistance, i.e., hull form, forebody shape, and stern shape; surface roughness; appendages; and resistance reduction techniques, such as air bubble and roll tanks;
- Ship powering, i.e., engines, transmission system, shafting, and propellers and ice guards;
- Hull structural integrity;
- Maneuverability; and
- Ice piloting and ice navigation.

The relationship between ship resistance, structural integrity, and available power will determine speed in ice. Design of the ship to meet expected ice conditions in the area of operation is critical. For example, numerous first-year ridges and rubble fields exist in the Alaskan Arctic. The forebody shape and hull forms should be designed to minimize resistance in these ice features and to reduce ice ingestion by the propellers.

Ship resistance in level ice is the most widely studied and understood resistance category. Unfortunately, other considerations usually govern ship resistance in the North American Arctic, such as resistance in ridge and rubble fields. Resistance must be predicted accurately for proper sizing of the ship power plant. While overpowering may be expensive and inefficient, underpowering could require the ship to ram on a frequent basis, leading to transit delays. Resistance in broken ice channels must also be evaluated if the transportation system involves icebreaker escorts and ice-strengthened tankers.

An important consideration in estimating resistance is the effect of pressure (or convergence) in the ice field. This pressure, which increases side friction and resistance, may be particularly important for icebreaking tankers because of their long straight hulls.

The ship powering system must be designed to provide sufficient power to overcome resistance. Propeller milling of broken ice pieces could also reduce propeller efficiency.

Hull structure design typically is governed by local pressure criteria based on ice impact loads. Numerous design guidelines are available worldwide, although most are based on empirical analysis and limited data. The ongoing trafficability programs with the Coast Guard's POLAR SEA are providing valuable data directed specifically at local design criteria (Appendix B and Appendix D, Case I).

Maneuverability in ice and ice piloting and navigation procedures will also affect ship performance. If accurate real-time data on ice

conditions are available, maneuverable ships may be able to reduce transit time and fuel consumption. In addition, better maneuverability will improve terminal connect and disconnect operational efficiency, even though icebreaker support will probably be available and required at terminals.

Interaction of vessel, terminal, and ice is also critical to successful operation of the overall marine transportation system. Repeated vessel transits could create rubble at a terminal located in a stable ice region. If the terminal is located in a dynamic ice area, such as the Navarin Basin, tanker weathervaning and dynamic ice effects on the ship-terminal system must be considered.

Cargo Transportation

Since the mid-1950s when the U.S. Navy last used self-propelled World War II LST-type vessels for the maintenance and resupply of Distant Early Warning (DEW) facilities in the Alaskan areas near the Bering, Chukchi, and Beaufort seas, tugs and barges have been used almost exclusively to transport cargoes to those regions. The lone exception is the M/V NORTH STAR III, a diesel-powered Victory ship, which the Bureau of Indian Affairs operates to provide cargo service to native villages in the Bering and Chukchi seas as far north as Point Barrow (Sea Use Council, 1983). A major reason for the transition from self-propelled vessels to tugs and barges is the absence of deepwater ports in the U.S. Arctic north of the Kuskokwim Delta. Conventional cargo vessels must anchor several miles offshore and lighter cargoes to shallow draft facilities or, in many instances, directly to the beach.

Navigation to destinations in the Chukchi and Beaufort seas is totally dependent on ice conditions. The normal operating season for vessels transitting from the Bering Sea through the Chukchi Sea and around Point Barrow into the Beaufort Sea is a period of 45 to 60 days beginning about August 1. Tugs and barges en route to the Arctic usually stop in the vicinity of Wainwright, where the heavy surge chain that is used in ocean towing is removed prior to proceeding through the ice and shallow waters, since it is not desirable to have the tow gear dragging the bottom during transit (Bogert, 1983).

The development of both onshore and offshore oil drilling and production activities resulted in an unprecedented requirement for the transportation of prefabricated modular components for petroleum gathering centers, pumping stations, water flood systems, and of other oil-field-related materials (Figure 3). Additionally, there were the basic materials and supplies necessary to sustain life that had to be transported to the North Slope. During the early stages of development (1968-1969), initial shipments moved in concert with military DEW line cargoes on a space-available basis. It was soon apparent that this arrangement was no longer satisfactory, and the oil companies contracted with major tug and barge operators for annual sealifts to the Beaufort Sea (Bogert, 1983).

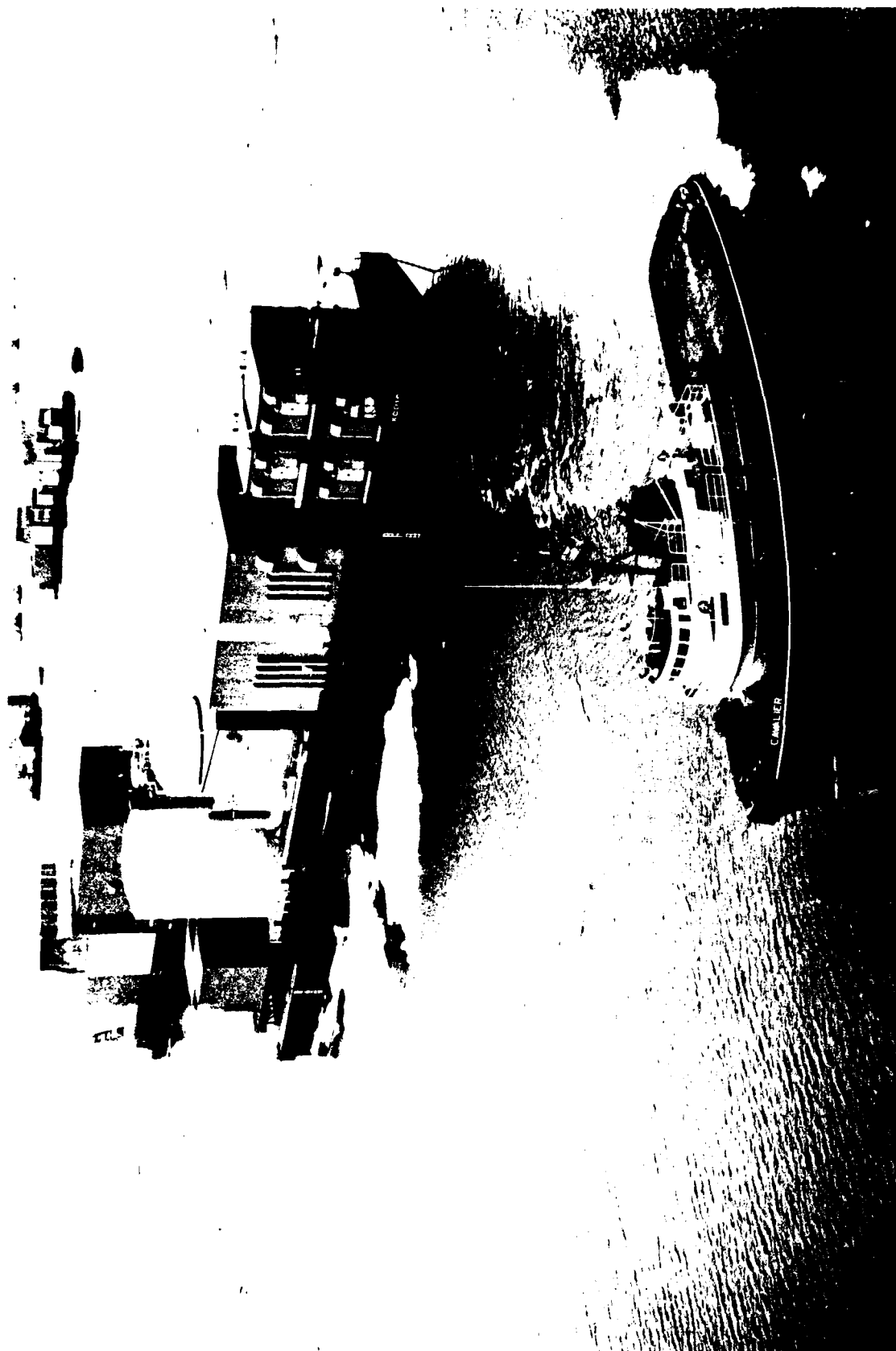


FIGURE 3 Transportation of prefabricated oil field structures, Crowley Maritime 1983 sealift.

SOURCE: Crowley Maritime Inc.

The number of vessels participating in annual sealifts may vary from as many as 43 barges and 29 tugs to as few as 2 barges and 2 tugs because of the cyclical nature of cargo tonnages, depending on lease sale timing and the development schedule for tracts purchased in a given lease sale (Figure 4).

A new generation of tugs, barges, rig supply vessels, shallow draft icebreakers, and air cushion vehicles will be required to respond to oil and gas exploration and development demands. The higher cost of Arctic offshore petroleum-related activities dictates that Arctic operating seasons be expanded to the maximum extent that technology will allow. Also, high construction costs and a short construction season further dictate that modular components be as large as can be safely transported to their respective Arctic sites; this large cargo in turn establishes the size of the equipment required to transport the units.

The only modern vessels designed for operating in the North American Arctic are Canadian icebreaking tugs, icebreaking supply vessels, and large (i.e., up to 20,000 DWT cargo capacity) ice-strengthened cargo barges that are capable of transporting dredges, derrick barges, rock barges, and caissons. Future requirements will include a new generation of vessels that will be larger and heavier and that will possess far greater horsepower than any equivalent U.S.-flag vessel in service today.

The technology and the industrial base for creating a new generation of supply vessels exist and can respond to the need as economics require.

Availability and Assessment of Resources

Until now it has been possible to deliver cargoes to the Arctic during each summer season with existing tug and barge fleets, and on only one occasion in recent decades--1975--has equipment become iced in until the following icefree season. Accelerating commercial development is causing the situation to change. Expansion of existing commitments and the surfacing of new shipping requirements will not only increase the volume of traffic but will require improved scheduling and reliability of delivery. This will place added emphasis on timeliness and accuracy of the range of environmental information.

Development and dissemination of accurate information on multiyear ice floes including such data as thickness, direction of drift, velocity, and any relationship to shorefast ice would assist vessels transitting the Bering, Chukchi, and Beaufort seas with plotting the safest and fastest routes through the ice. Present radar systems and twice daily air reconnaissance are inadequate because of the short range of radar and the frequent presence of ice fog.⁶ The

⁶Observation expressed by David Asplund, Racal-Decca Marine, Inc., Seattle, Washington, to Eugene Stearns, committee member, 1983.

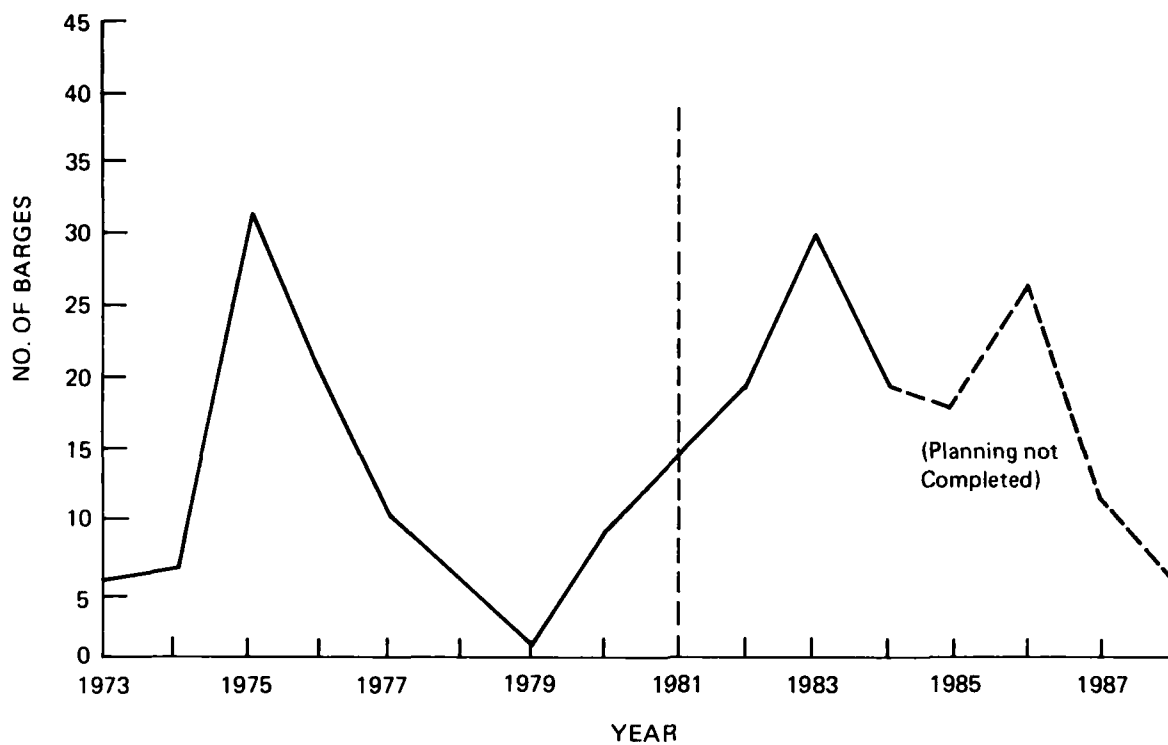


FIGURE 4 1973-1988 trend and projection for North Slope sealift barge requirement expressed in 400' x 100' barge equivalents. Discovery could change barge volume drastically in 1985, and following years.

establishment of a station in Alaska to receive imagery from the ESA's remote-sensing satellite, ERS-1, would be an enhancement. Such a system aided by SAR would greatly improve navigation in ice-covered seas (NASA, 1983).

At present there is no U.S. Coast Guard search and rescue capability supporting offshore operations in ice, other than that which can be supplied from the air by helicopters based at Kodiak, nor does the Coast Guard have plans for the initiation of such a service north of the Aleutian Islands. Increased activity in the Arctic on a year-round basis will result in a requirement for dependable and responsive search and rescue coverage.

The importance of Arctic gas and oil and their marine transportation is recognized by other countries. The USSR continues to add to its fleet of icebreakers, which is supplemented by transports strengthened for limited icebreaking, and other systems necessary to work in the Arctic. Many vessels in the Soviet icebreaker fleet were designed and built in Finland, which is currently the world leader in numbers of such ocean-going vessels produced. In Canada, Dome Petroleum, Gulf Canada Resources Ltd., and the government of Canada are sponsoring major programs to produce Arctic gas and oil and to transport these resources with icebreaking tankers. The Japanese have displayed very strong interest in obtaining and transporting Arctic oil, as demonstrated by their heavy investment in Dome's Arctic program and their participation in construction of advanced exploration drilling systems for Beaufort Sea use.

In the United States, the government, through the Maritime Administration's Arctic Shipping Program, has engaged in activities to develop data and basic technology necessary for commercial marine interests to make long-term commitments for the development of Arctic marine shipping systems, and specifically to promote the use of U.S.-built and -operated ships and facilities for processing and transporting Arctic gas and oil (NRC, 1981a). Appendix B summarizes the course and results of Arctic maritime research since the start of the exploratory voyages of the MANHATTAN. Recently, the Maritime Administration (MARAD) has focused its efforts on collecting year-round field data on ice conditions and ship performance requirements along possible tanker routes. Since no U.S. commercial icebreaking tanker vessel now exists, MARAD has used Coast Guard icebreakers for obtaining operational data.

MARAD has cosponsored these "trafficability" tests in the western Arctic in conjunction with the U.S. Coast Guard, the interagency Ship Structures Committee, the state of Alaska, the Canadian Ministry of Transport, 12 U.S. oil companies, and 1 U.S. shipyard. During a period of 5 years, the joint federal-state program has committed over \$3.1 million to these tests. Primary objectives are: (1) to demonstrate the feasibility of year-round tanker operations in the Arctic; (2) to collect data on the ice environment and features; and (3) to assess ship ice interactions. Concurrently, private industry has undertaken preliminary design studies for ships requiring

icebreaking capability for Arctic services. Current tests and those planned for the next few years by MARAD are oriented toward gathering additional environmental performance data north of the Bering Strait to contribute to the design of safe and efficient vessels.

Significant experience with icebreaking ships is available worldwide. Sources include Finland, which has developed extensive capability in ocean engineering and icebreaker design and construction, the MANHATTAN voyage, the U.S. Coast Guard Polar Class icebreakers, Finnish and Canadian icebreakers and merchant vessels, Soviet icebreakers and cargo operations, and marine transportation in the Baltic Sea. The use of existing data and experience to predict performance of the large tankers is an active area of Arctic marine research.

Estimates of ship resistance and maneuverability in ice are obtained by three methods: (1) theoretical predictions, (2) laboratory model tests, and (3) field measurements and instrumentation of existing vessels. Several analytical models for resistance in level ice have been calibrated with full-scale data. Ridge penetration models are also available, but have been verified to lesser degrees. Because of complicated hull-ice interactions, laboratory model tests are valuable to identify potential areas of concern and to focus full-scale measurement programs. However, additional field measurements would be particularly valuable to verify predictions of theoretical and laboratory models.

Gaps and Deficiencies

Icebreaking vessels have operated throughout the year in the western Soviet Union, the Canadian Arctic, and the Alaskan Arctic as far north as Point Barrow. Summer operations have become common in the Alaskan and Canadian Beaufort Sea. A major design and operational uncertainty is posed by extrapolating earlier experience to year-round tanker operations in the Arctic and to large increases in vessel size; icebreaking tankers will be 10 to 30 times larger than vessels currently operating in the Arctic.

The National Petroleum Council's report (NPC, 1981) states:

There is very reasonable expectation that ice-capable vessels can be built, powered, and operated to maintain reliable year-round rateable offtake from ports south of the Bering Strait.... Year-round tanker operation to ports north of the Bering Strait can probably be established, but reliability is uncertain.⁷

⁷The term rateable in this quotation indicates that there is, or will be, sufficient certainty of future delivery so that cargo rates can be assigned.

North of the Bering Strait, multiyear ice and more severe first-year ridges and rubble add to the vessel design and operational problems and to the need for technical information. Ongoing research programs in industry and government are directed at responding to this need. Continued funding of research programs aboard the U.S. Coast Guard Polar Class icebreakers north of the Bering Strait will permit the collection of valuable information. Improvements to theoretical models and additional model tests will also be required as leasing and exploration proceed. However, these requirements can be accommodated in present development schedules. Acquisition and analysis of long-term, wide-area data on ice characteristics and forces are major requirements for the development of models and design criteria.

In addition to the need for improvement of ship design, marine terminal operational reliability would be enhanced by refinement of ice design criteria and load estimation techniques and by the development of a numerical simulator to permit optimization of offloading and transportation operations and facilities (e.g., selection of shuttle tanker, fleet number and size, and support vessel requirements).

Marine Navigation Systems

The need for highly accurate navigational equipment has become a major priority for offshore marine operators who are engaged in support of oil and gas exploration in the Arctic. The following are options that are either available now or may be soon available:

- Satellite Navigation (Sat Nav)
- Loran C
- Loran C--Satellite (LORSAT)
- Omega
- Global Positioning System (GPS)

Each of the above systems has advantages and, with the exception of GPS, all appear to have limitations in polar application.

Satellite Navigation System The most widely used satellite system is Transit, a five-satellite system owned by the Navy; it first became operational in 1964 and was released for commercial use in 1967. The satellites are established at an altitude of 9,600 kilometers (6,000 miles) and orbit the earth every 107 minutes. Positions fixed from a satellite are usually accurate to 0.05 nautical mile. However, because of the fact that positions are only fixed when a satellite is in view, 90-minute time delays are experienced between fixes. Also, satellite signals are not continuous, and hours may go by before a fix is recorded.

Loran C There are 14 Loran C chains in the United States and overseas consisting of three to five land-based transmitting stations. Loran C's continuous transmission feature is especially popular with

mariners. Prescribed Loran C accuracy is better than 0.47 kilometers (0.25 nautical miles), 95 percent of the time. Less accuracy is achieved under other conditions, i.e., more noise. Accuracy diminishes outside the coverage area, but a number cannot be assigned.

In 1980, the Coast Guard sponsored a study concerning possible expansion of Loran C coverage to the Alaskan North Slope and other Arctic regions of Alaska. The recently completed assessment recommended no further expansion of Loran C for the North Slope and the Arctic Ocean. This was based upon a forecast of maritime user population expected to benefit from such an expansion, which indicated that potential marine traffic would continue to be seasonal and intermittent. Therefore, the Coast Guard has no present or immediate plans to provide for coverage or expansion of Loran C to the Arctic region north of Cape Prince of Wales.

Loran C--Satellite Navigation This integration of several navigation systems produces a navigation aid that takes advantage of the best traits of each system. One such system, LORSAT, combines Loran C and Satellite Navigation. Integration of the two systems allows operators to navigate in areas that heretofore were difficult when either system was used alone (Lawrence, 1983).

Omega The Omega system is a time-shared, continuous wave (CW) radio navigation system. Omega navigation relies on a very low frequency range possessing high propagation stability and low attenuation, which allows reception at great distances from transmitting stations. The system consists of eight transmitting stations and provides worldwide navigation in nearly all weather conditions. Accuracies of 1.6 to 3.2 kilometers (1 to 2 miles) may be realized from the Omega system. Using differential Omega, accuracy is possible to 1.4 kilometers (0.75 nautical miles). This system is scheduled to be phased out as the Global Positioning System becomes operational and available.

Global Positioning System (GPS) GPS is a U.S. Defense Department-developed satellite navigational system. It will be modified and, with two-dimensional capability, will be available for commercial use to 100-meter accuracy in 1987. Three-dimensional capability will follow in 1988. The system will consist of 18 satellites and 3 spares. The satellites will orbit at an altitude of 20,200 kilometers (10,900 nautical miles) in equally spaced sets of three, in six orbital planes. This configuration provides unobstructed radio contact with at least four satellites from any point on earth at all times. There will be no system cost to commercial users.

Summary

Navigation with precise accuracy in the Arctic is yet to be realized for routine marine operations. Most users and suppliers interviewed relative to the accuracy and reliability of existing

equipment readily admitted to system limitations. No one, however, wished to see Loran C phased out in areas where the service is available. Fishing industry and freight service operators with operations in the Aleutian Islands, Bristol Bay, and Bering Sea areas report that they need Loran C because of its continuous coverage. Primary reliance for the future must be placed on GPS since all other systems appear to have limited futures once GPS is in use. There is concern that the instrumentation need by GPS users may be expensive; this is a particular concern for the fishermen and native population.

SEA ICE MECHANICS AND ICE FORCES

Ice Mechanics

A major objective of theoretical ice mechanics is to provide the link between mechanical properties of ice and ice forces on structures. Significant progress has been made in ice mechanics research and ice force estimation in the past decade, as evidenced in the Proceedings of the Seventh International Port and Ocean Engineering Conference under Arctic Conditions (VTT, 1983). Nonetheless, considerable benefit could be derived by continuing a strong effort in ice research to develop a better understanding of the relationships that exist between small- and large-scale ice phenomena.

There are three physical scales or sizes of interest (S_1 , S_2 , and S_3) in which theoretical ice mechanics work is needed (Sackinger, 1980; NRC, 1981b; Mellor, 1983). The largest scale (S_1) applies over distances of tens of kilometers and is applicable to the large-scale deformation of pack ice. The ice forces of interest at this scale are the driving forces that act on individual ice floes or groups of floes that may contact a structure. The intermediate scale (S_2) consists of ice aggregates (e.g., first-year and multiyear ice ridges, ice rubble piles, and fragmented ice covers) with dimensions of the same order of magnitude as an offshore structure. The ice forces of interest at this scale are the global design forces for offshore structures. The smallest scale of interest (S_3) is of the order of tens of centimeters. At this scale, behavior of ice as a material is important. Stress-strain and failure criteria of different types of ice under varying conditions are of interest.

Ice mechanics on all three scales comes into play as ice moves against a structure. For example, consider a multiyear ice floe of over 300 meters in diameter, frozen into a much larger expanse of sea ice. When the floe or sheet moves against a structure, the structure must withstand the ice forces and cause the ice to fail. At the S_3 scale of interest, the material properties of the ice are the key items since these are the essential parameters in the analytical equations used to calculate both global ice forces and local (also called contact or punching) ice pressures. At the S_2 scale the actual failure mode of the sheet/floe is of interest. Crushing failure against vertical-sided structures, bending failure against

inclined surfaces, and mixed-mode failures as the floe moves into a rubble pile give rise to different ice loads. The S_1 scale brings into consideration other important questions, the most important of which is the actual driving force for the moving floe. It is not infinite, as often assumed. The floe will lose energy and momentum as it moves into contact with the structure, with or without a surrounding rubble field. The floe has weak zones. The ice sheet around the floe is not as thick as the floe, and it, too, has weak zones.

A major goal of ice mechanics research and analysis is to predict performance of engineering structures and ships in sea ice. All of these physical scales of interest and their interrelations must be understood, and achieving this understanding requires a combination of analytical, laboratory, and field programs. Analytical studies address all three scales of interest and bridge the gap between laboratory studies and field observations.

Laboratory sea ice mechanics studies can be classified into two general categories: (1) studies to determine mechanical properties of sea ice (i.e., ice properties tests); and (2) studies to evaluate ice-ice, ice-structure, and ice-ship interaction (i.e., model tests).

The objective of mechanical properties studies is to define the behavior of sea ice as a material. For example, tests are designed and conducted to determine tensile and compressive strength, stress-strain behavior, and yield criteria under different test conditions. Although laboratory tests of ice properties have been conducted for many years, a large scatter in test results is common. The principal causes of the diversity in results are often the lack of a description of ice sample characteristics and a lack of standardized test procedures. These deficiencies are recognized to varying degrees in current test programs, and improved reproducibility in test results is being achieved.

Model tests combine the knowledge of sea ice properties with large-scale ice, structure, or ship characteristics to evaluate ice modes and loads. The primary concern in all model tests is correct scaling of the properties of ice used in the model test. It is not possible to scale simultaneously all properties of the ice with present technology. Therefore, it is necessary to identify the failure mode of interest and to scale the appropriate properties.

Finally, field measurements of large-scale ice properties, ice features, and ice loads are required to verify the analytical and laboratory predictions.

Limited field data indicate that loads on full-scale structures may be less than predicted from analytical and laboratory studies. Three factors may contribute to this difference. First, mixed-load failures occur in the field but are difficult to evaluate quantitatively with theory or model tests. Second, large-scale defects in natural sea ice, typically not considered in small-scale tests, may cause ice failure at lower loads than predicted. Finally, the environmental driving forces in the field may be limited; for example, the natural driving force available to push a large ice

feature against a structure may be less than the load required to cause failure of the ice feature.

Analytical, Laboratory, and Field Requirements

The analytical resources needed to enhance the knowledge of theoretical ice mechanics consist mostly of personnel with broad backgrounds in materials science and solid mechanics. An understanding of the mechanical behavior of sea ice requires an integration of many of the topics that one would find in the engineering college catalogue of a major university--all applied to the same material. Sea ice behavior is very complex and depends on both ice type and loading conditions. The structure of sea ice is inhomogeneous, with large variations in crystal structure occurring over short distances. Ice is also anisotropic as a result of the shape and orientation of ice crystals. The qualitative nature of the mechanical behavior of ice is strongly dependent on the deformation process that creates the loading. Elastic, plastic, viscous, and brittle fracture material responses can all be observed within the realm of typical ice deformation processes. Properties vary by more than an order of magnitude depending on salinity, temperature, crystallography, and rate of loading. Sample size also may affect measured properties.

Thermal effects also are significant. A floating ice sheet represents a unique physical situation in that one entire surface is maintained at the freezing temperature while the other experiences large temperature excursions. The temperature distributions through the ice sheet thickness, that result from variations in conditions at the upper surface, give rise to a thermal-related distribution of mechanical properties.

The analytical models of sea ice behavior require ice properties data from laboratory tests. Results of laboratory tests of sea ice are strongly dependent on test procedures in all phases, including sample collection, sample storage, sample preparation, and testing. Detailed descriptions of sample characteristics and test conditions are required to interpret the data.

A laboratory involved in testing sea ice properties should have the following characteristics:

- Facilities to store ice samples at or below about -30°C .
- Equipment for sample preparation located in a cold room.
- Ideally a test machine located in a cold room, having a closed loop feedback system with multiaxial test capability.
- Experienced personnel involved in all phases of the test program.

Model testing uses laboratory ice with properties scaled in conjunction with the geometric scale of the model test. The purpose of model testing is to assess ice-ice, ice-structure, and ice-ship interaction. Model tests provide two types of information. First,

they provide qualitative description of ice failure mode and behavior. This qualitative information is valuable in evaluating new structure or ship configurations, particularly where a complicated ice failure mode is involved. The second type of information is quantitative measurements of forces on structures and resistance of ships to verify theoretical predictions.

In attempts to improve the scale properties of model ice, several types of model ice have been used. Saline ice, carbamide ice, and wax base model ice are most commonly used at the present time.⁸ Each type of model ice has advantages and disadvantages depending on the particular application.

Model ice properties are very critical to the success of the tests but are very sensitive to formation and curing procedures. Proper scaling of the most important ice parameters and homogeneous, reproducible model ice are required. As in the case of mechanical properties of sea ice, detailed documentation of model ice mechanical properties are required to interpret correctly the model test results.

The test basin must be large enough to minimize and control edge effects. The minimum acceptable size depends on the model scale, the type of structure being tested, and the physical properties of the model ice used. Large-scale tests are desirable to minimize scaling problems. However, large-scale modeling requires a more massive support structure or carriage to ensure adequate stiffness to withstand the forces exerted on the model. Large-scale testing is more costly and usually produces fewer data points per test ice sheet.

Field programs to determine mechanical properties can provide valuable information but are difficult and expensive to conduct. Numerous programs have provided useful information on ice characteristics such as temperature, salinity, and crystallography. However, in situ or in-the-field tests of mechanical properties are more difficult. Unless the programs are well-planned and carefully executed with good equipment, data can be meaningless and confusing.

Bulk properties of ice features such as rubble piles and multiyear floes and ridges are being studied. These data are required to correlate large-area data (S_1) to the ice forces on structures (S_2).

Full-scale observations in the field of ice failure modes and loads are essential to verify model test results. As with mechanical properties testing, programs that develop meaningful data are expensive and difficult to perform.

⁸Saline test ice is naturally grown ice that has been "doped" with salt. Carbamide is ice "doped" with urea. Wax ice is a synthetic molding material that can be used in a nonrefrigerated environment.

Availability and Assessment of Resources

Knowledge of theoretical sea ice mechanics has advanced greatly in recent years due to planning for oil and gas lease sales and exploration operations in the Canadian and Alaskan Arctic. Analytical models of ice dynamics, initially developed to study large-scale motions of the Arctic pack (see, for example, Hibler, 1979; Coon, 1980), have been refined. Current research efforts emphasize near-shore ice behavior.

Recent needs have been met by applying conventional engineering approaches to specific problems at the S_2 scale of interest. In this approach, the dominant ice behavior (failure mode) expected in a specific problem is defined and used to determine the type of material property measurements to be made and the type of mechanics model to be used. For example, elastic properties and analysis are used to predict the minimum vertical bearing capacity loads that floating ice sheets can support for short time periods. A viscous (creep) analysis might be used for ice loading that occurs over a long time period. Plastic limit analyses also have been used in some applications to estimate the maximum horizontal loads that can be applied by the ice. These types of applications typically use ice property data generated from the S_3 scale of interest to estimate S_2 properties and compute S_2 loads.

This approach is successful in the sense that useful engineering criteria are developed; however, it is time-consuming and somewhat wasteful of personnel and other engineering resources. In addition, the utility of the dominant failure mode approach tends to break down when complex failure processes (sometimes called mixed-mode failures) occur. The result is usually a tendency to overdesign because of an inadequate understanding of basic ice behavior. Present long-term research on theoretical ice mechanics emphasizes a more complete understanding of sea ice behavior to complement the short-term requirement for answers to specific engineering problems.

Laboratory facilities are limited in the United States for model testing and testing mechanical properties of ice. The first type of facility is for ice properties testing. The only industrial facility for ice properties testing is owned by Exxon Production Research Company (EPR) in Houston, Texas. EPR has performed several test programs with first-year and multiyear ice using closed loop equipment. They have published some results and offered others for sale. The facility is not generally available for private use.

CRREL, located in Hanover, New Hampshire, contains extensive facilities for storing and testing ice. The ice engineering facility with a test basin, a large flume, and a model testing area is addressed in the discussion of model testing. Existing equipment for ice properties testing includes a closed loop test machine with an environmental chamber for testing ice. Other test machines are located in cold rooms but are not presently outfitted with a closed loop feedback system. First priority for use of CRREL goes to government agencies, but academic participation is welcome; industrial use is an exception, but can be arranged when common interests are involved (see Appendix D).

At least three other high-quality facilities for ice mechanical properties testing exist outside of the Soviet Union. Both the National Research Council of Canada and ARCTEC Canada Limited operate laboratories in Ottawa; the latter is available for commercial testing. The third facility is owned by Hamburgische Schiffbau-Versuchsanstalt (HSVA) in Hamburg, Germany. All facilities have closed loop test machines, cold room facilities, and experienced personnel. Though limited in number, there appears to be a sufficient number of facilities worldwide for ice properties testing.

The second type of laboratory facility is for model testing of ice-ice, ice-structure, and ice-ship interactions. Three general types of model ice basins are in operation today--indoor refrigerated basins, an outdoor basin, and indoor basins using a wax-base model ice. Table 4 lists characteristics of existing refrigerated ice model basins in the world. Eleven basins have been constructed as of 1983. The first basin was constructed in 1955 in Leningrad. Refrigerated model test basins in the United States are at CRREL (government), Iowa Institute for Hydraulic Research (university), and ARCTEC, Inc. (commercial).

The number of basins has increased dramatically since 1970, reflecting the increased interest in offshore development of the Arctic. As indicated in Table 5, recent basins are typically larger to accommodate models of wide offshore structures at larger scales. Several other basins are presently under construction in the USSR, Canada, Japan, and West Germany.

The only existing outdoor basin is owned by ESSO Resources Canada in Calgary, Alberta. Its characteristics are shown in Table 5. The basin has been used since 1974 to study ice-structure and ice-ice interaction at large scale (about 1:10). The large basin has the advantage of being able to accommodate large-scale tests, but is subject to weather fluctuations. If a warm winter occurs, testing is limited.

Two model basins using a wax-base ice, called Mod Ice, are in operation in North America--one owned by ARCTEC, Inc., in Columbia, Maryland, and the other by ARCTEC Canada Ltd. in Calgary, Alberta (Table 5). Mod Ice is a proprietary wax-based material with some potential advantages at small model scales. However, as with saline and carbamide model ice, not all properties can be scaled simultaneously in correct ratios.

Gaps and Deficiencies

The engineering requirements for theoretical ice mechanics at the S_1 , S_2 , and S_3 levels of interest are generally associated with optimization and cost reduction. In most cases, questions of feasibility can be addressed with existing analytical methods.

Potentially available resources for theoretical ice mechanics work in the United States consist of university personnel, as well as professional personnel and facilities at CRREL and the U.S. Navy Ocean Systems Center, San Diego, California. The need for basic work in

TABLE 4 Refrigerated Ice Basins in the World

Year Built	Country	City	Owner	Size in Meters		
				Length	Width	Depth
1955	USSR	Leningrad	Arctic and Antarctic Research Institute	13.4	1.8	1.3
1969	Finland	Helsinki	Wärtsilä Icebreaking Model Basin	37.0	4.5	1.2
1971	Germany	Hamburg	Hamburg Ship Model Basin	30.0	6.0	1.2
1974	USA	Columbia, Maryland	ARCTEC, Inc.	30.5	3.7	1.8
1977	Canada	Kanata (Ottawa)	ARCTEC CANADA	30.5	4.9	1.5
1979	USA	Hanover, New Hampshire	Cold Regions Research and Engineering Laboratory (U.S. Army Corps of Engineers)	36.0	9.2	2.5
1981	USA	Iowa City, Iowa	Iowa Institute of Hydraulic Research	20.0	5.0	1.5
1981	Canada	Ottawa	National Research Council (Canada)	21.0	7.0	1.2
1981	Japan	Mitaka (Tokyo)	Ship Research Institute	30.0	6.0	1.2
1982	Japan	Tsu City	Nippon Kokan K.K.	20.0	6.0	1.8
1983	Finland	Helsinki	Wärtsilä Arctic Research Center	77.3	6.5	2.3

TABLE 5 Nonrefrigerated Ice Basins in the World

Year Built	Country	City	Owner	Size in Meters		
				Length	Width	Depth
<u>MODEL ICE</u>						
1981	Canada	Calgary, Alberta	ARCTEC CANADA	30.5	7.3	1.2
1982	USA	Columbia, Maryland	ARCTEC, Inc.	25.6	10.7	2.4
<u>OUTDOOR ICE BASIN</u>						
1973	Canada	Calgary	ESSO Resources Inc.	55.0	30.5	1.4/3

theoretical ice mechanics has been recognized in the literature, but the level of actual activity remains low (Morland, 1983; Ponter, et al., 1983). Progress in this work area is limited primarily by funding commitments rather than technical resources. Long-term funding commitments are necessary for substantial progress to be achieved. Time, on the order of 5 or 10 years, should be expected for significant contributions. Additional effort would then be required to apply the basic work to engineering problems.

Existing ice laboratories can support increased demand for small-scale ice properties testing. More data are required and test techniques have been identified that would provide good data, but test programs are expensive. At present, construction of new facilities has not been economically justified. Another limitation to the use of existing facilities is a lack of standardized test techniques that would facilitate data comparison among test programs.

Similarly, in the committee's view, existing model basin facilities seem adequate to meet near-term needs of offshore development. However, it is important to continue development of improved model test capabilities. Improved model ice materials capable of simultaneously scaling all properties would be valuable for studying multimodal failure. As with ice properties testing, comparison of data among model test programs is difficult because of a lack of standardized procedures for testing model ice properties.

The primary information gap is a limited supply of full-scale measurements with which to verify laboratory test results. Analytical studies, model tests, and field measurements have been performed to design and operate the first generation of Arctic structures. A second generation of structures for deeper water is being developed. Several measurement programs around structures and on icebreakers are currently underway or planned in the Arctic. There, field data will provide useful feedback for evaluating and improving laboratory tests used in evaluating future designs.

Ice Loading on Structures

Ice loadings on structures are both local and global. The local loads may be generated under impact from a moving ice feature or from the sustained force of surrounding ice acting through a "hard point" bearing on a local area. The crushing strength of the ice is very significantly affected by the area of contact in relation to the thickness of the ice feature. This is due to the two- and three-dimensional confinement of the "hard point." For larger contact areas, the increase in the number of homogeneities, such as fractures and brine inclusions in the volume of ice under stress, reduces the effective strength. The local loads are also affected by the strain rate, the temperature of the ice, and the salinity.

Curves have been developed giving the apparent ice strengths versus contact area, recognizing the variables involved. For very small areas, the varying pressure may be up to three times the uniaxial compressive strength of the ice. Such local loads, ranging

up to 8.3-11.0 MPa (1,200-1,600 psi) and more, produce high flexural and shear loads on the peripheral walls, which could lead to buckling of frames in steel-skinned structures or punching shear in concrete walls unless they have been properly designed to resist such forces. Considerable effort is being devoted to the design and testing of various walls.

The design of the internal structure of the platform must also consider these local loads, since they can produce very high compressive and membrane shear forces in the diaphragms (walls or frames) supporting the peripheral ice wall.

Global ice forces are those acting on the structure as a whole. The structure must withstand forces in the winter generated by the slowly moving ice fields that may contain ridges embedded in multiyear floes. Structures must also resist the impact of a multiyear floe in a summer ice invasion, in which the floe transmits high kinetic energy forces to the structure over a period of a few seconds. This short-burst energy must be absorbed primarily by the crushing of the ice, although other mechanisms such as the far-field creep strain and compliance of the structure in soil strain may limit the maximum force.

A number of sophisticated configurations have been developed to induce ice failure, including upward-breaking cones, hour-glass configurations, and monotowers with conical collars. These appear, on the basis of model tests and engineering analyses, to reduce the maximum ice forces exerted on the structure. However, this reduction may be inhibited by adfreeze (adhesion by freezing) or the jamming of a large multiyear ridge against the throat of the structure. Therefore, consideration has to be given to extreme event loads, as well as to the wide range of forces that may be developed by the various ice scenarios. Fortunately, the maximum force exerted on the structure by a large ice expanse may be restricted by natural limits to the driving force of the ice pack-ice sheet that is acting against the critical ice feature.

The effect of these extreme loads on structures is to produce both lateral (sliding) forces and overturning (tilting) moments that must be transmitted through the structure to the soil, and then be resisted by the soil in shear and bearing. This action is discussed later in this chapter (see Geotechnics).

Global forces, especially those occasioned by the impact of floes and ridges, may be centric or eccentric. They may act normal to the peripheral wall or at an angle to it. Recent studies show that these eccentric and inclined forces may be more demanding than centric loadings, since they produce torsional forces in the structure and the foundation soils.

The philosophy of Arctic structures design is in evolution. It appears that a philosophy similar to that employed in earthquake engineering is most appropriate, namely to design for elastic behavior under normal operating loads that have a reasonable probability of occurrence during the service life. For extreme events, ductility and failure mode should be considered. Progressive collapse should be

prevented, while damage and displacement can be accepted, provided it involves no loss of life or risk of an oil spill.

Both industry and government need more information on the return periods and properties of the larger ice features to permit a statistical evaluation and a rational semiprobabilistic approach to design. Research on large ice features and the forces they can exert on structures may result in significant cost savings.

At present, companies that operate or plan to operate in the Arctic offshore, as well as Arctic engineering firms, base their design methodologies on established procedures such as the limit state or the working stress approach (API, 1982).⁹ Such methods have provisions for including statistical information relative to sea ice through specification of recurrence intervals. However, currently there are no widely accepted industrial design practices that set forth sea ice force criteria. In general, industry-developed practices for risk-based local and global ice force criteria are desirable, provided that such practices would allow new technology to be included in the design criteria, with little time delay. Use of such practices would require considerable knowledge about the statistical variability of the ice environment to receive wide acceptance. The current data base of ice failure mechanisms and ice strength measurements, although sufficient to support the design of certain structures, is insufficient to establish generalized ice criteria of the type commonly specified in an industry design practice. However, this data base is expanding and evolving yearly through industry and government studies that will extend the data base available for the development of an industrial design practice.

Availability and Assessment of Resources

An area of engineering concern is the superstructure icing of drilling rigs and vessels to the point that operations can become critical and may even require curtailment. This is more of a problem with floating and semisubmersible drilling units than with bottom-founded platforms. Experiences in the Alaska Outer Continental Shelf Region make it obvious that superstructure icing is a risk in the central and southern Bering Sea area under certain weather conditions. Rigs must be designed to accommodate excessive ice loads resulting from superstructure icing.

⁹American Concrete Institute's consensus standard, Proposed State-of-the-Art Report on Offshore Concrete Structures for the Arctic, ACI committee 357, Jal N. Birdy, chairman (Brian Watt Associates, Houston, Texas); report is in review and scheduled for late 1985 initial draft publication.

Most of the planning for exploratory drilling and production in the Beaufort and Chukchi seas is based on the use of fixed structures, founded on the seafloor. In shallow waters, up to 15 to 20 meters deep, gravel islands with slope protection have been adopted. Beyond that depth, concrete caisson-retained islands have been proposed. One such island, Tarsuit, in the Canadian Beaufort Sea, has been completed and the exploratory drilling program successfully executed in the Canadian Beaufort Sea. A second island concept utilizes a steel caisson ring as a means of containing and protecting the sand and gravel. This was emplaced in the summer of 1983 in the Canadian Beaufort Sea for Esso Resources Canada, Ltd. A third platform, used in Canadian waters, the single steel drilling caisson, SSDC-1, consists of the midbody of a very large crude carrier (VLCC), seated on an underwater embankment and protected by an artificially generated rubble pile of ice. Another caisson-type structure, Global Marine Development Company's Concrete Island Drilling System (CIDS) (Figure 5) was constructed in Japan, towed to the Alaskan Arctic and in August 1984 was emplaced 9 miles from shore, 115 miles northeast of Prudhoe Bay. Gulf Canada's mobile Arctic caisson was also built in Japan for emplacement in the Beaufort Sea during the summer of 1984.

For deeper water and extended service, the current trend in planning for the Chukchi and Beaufort seas is toward full caissons, either vertically sided or truncated cones, seated on the seafloor or on an underwater embankment of sand and gravel. Intensive effort and advanced engineering have been directed into a number of these concepts.

Several innovative structural concepts have been offered as being workable for exploration systems in waters out to 50- to 65-meter depths in the Beaufort Sea (see Figures 5, 6, and 7). For the most part, these include gravity-type mobile structures designed to break and split oncoming ice. Even though these structures are very heavy and therefore very resistant to ice forces, the fact remains that such structures, as built, will require conservative design criteria, critical design review, laboratory tests of scale models, and performance monitoring in the field. In the Canadian Beaufort Sea, Gulf Resources Canada Ltd. operated a floating drilling caisson, Kulluk, in 1983.

Planning for production platforms in the Beaufort and Chukchi seas generally appears to be based on gravel islands to 15 meters, caisson-retained islands to 30 meters, and full caissons or conical structures beyond that depth, although full caissons, e.g., concrete islands, may be used in preference to other systems in water as shallow as 20 meters. Extensive use will be made of modular processing units to minimize the offshore labor hookup.

For the Bering Sea, most sites are accessible for exploration drilling by conventional semisubmersible or jack-up rigs in the open

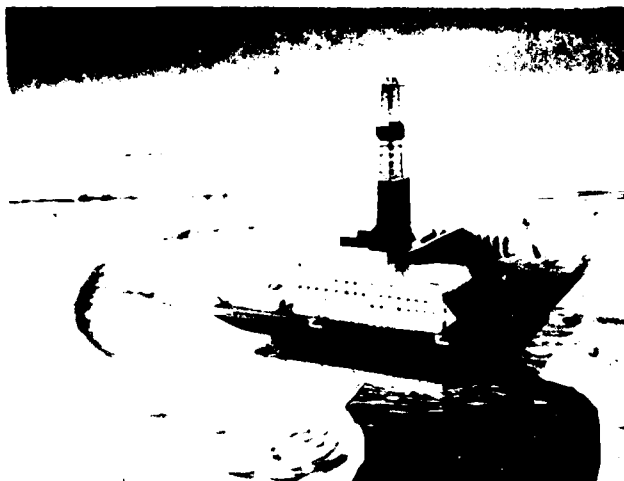


FIGURE 5 Global Marine Development Corporation's concrete island drilling system (CIDS).

SOURCE: Global Marine Development Corporation.

FIGURE 6 Floating drilling rig KULLUK.

SOURCE: Gulf Resources Canada, Ltd.

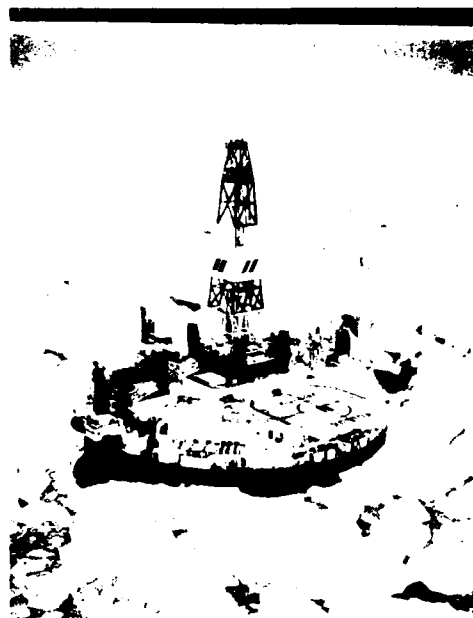


FIGURE 7 Stepped pyramid concept for deep water.

SOURCE: Committee on Assessment of Arctic Ocean Engineering Support Capability.

water during the summer season. Production structures will either be steel jacket structures, similar to those in Cook Inlet, or bottom-founded gravity-base structures similar to those in the North Sea. Concrete islands or caisson-type structures may be used in Norton Sound. Monotowers with icebreaking conical collars may be favored to reduce the overturning moments caused by winter ice. In the Navarin Basin especially, offshore oil storage may be required, and the structures will probably be similar to those emplaced in the North Sea.

The use of full caissons, supporting fully integrated decks, with all process and drilling equipment installed, hooked up, and tested, appears economically advantageous with almost all construction and assembly carried out in warm-water areas such as Japan, Korea, or Puget Sound, Washington. One example of such integrated construction is the "stepped pyramid" concept for deep water shown in Figure 7. Another example is the cone-shaped drilling platform, Arctic Cone Exploration Structure (ACES), developed for Exxon, Shell, and Chevron by Brian Watt Associates.

Based on various industry-sponsored conceptual development studies to date, Arctic offshore production terminals will most likely bear a remarkable similarity to Arctic oil production structures or be reasonable extensions of existing production terminal technology. The Alaskan Arctic ocean environment does not present a unique problem for the design of moorings.

The structural materials being considered include heavily stiffened steel and prestressed reinforced concrete. Sand and gravel will be used to increase ballast weight where needed. A review and discussion of current technology and proposed projects in the application of concrete structures to the Arctic was held at the International Workshop on the Performance of Offshore Concrete Structure in the Arctic Environment on March 1-2, 1983, at the National Bureau of Standards, U.S. Department of Commerce. Proceedings of this workshop have been published (NBS, 1983).

The offshore industry has had many years of experience of engineering and using many structures in a wide variety of sea states. Storms in the Bering Sea are not significantly different, if at all, from storms in the North Sea and the Gulf of Alaska, except that the combination of ice and storms accentuates the potential for damage to coastal and some offshore structures. Short steep waves are common under storm conditions in Norton Sound, which is characterized by extensive shallow water areas. This environment could be particularly hazardous to barge and small ship transportation. Such conditions accentuate the need for accurate and timely weather and sea state forecasting covering the Bering Sea areas as development progresses.

Ports and Terminals--Bering Sea

The construction difficulties posed by the terrain along the Bering Sea, the lack of land transportation interties, and the short ice season for most of the area make the use of tankers appear to be

the most promising option for transporting oil from the Alaskan west coast along the Bering Sea.

Although icebreaking tankers have been proposed by several companies, the capital cost of a fleet of specialized tankers that would only operate a small percentage of the time in the icebreaking mode would make this option uneconomical. The most probable scenario would be the use of conventional tankers operating from a trans-shipment terminal at a location in the Aleutian Islands, such as Unimak Island.

As ice conditions in the Bering Sea are not particularly severe during most of the year, tanker transport using conventional craft could transport crude in the Bering except for a short period of time. Some storage capacity would be required offshore for well sites remote from the shore. Storage onshore for locations relatively close to shore would be feasible. The onshore storage facilities would be designed to high standards such as those at Valdez, Alaska, to assure against environmental damage.

Present engineering plans include the use of tankers that would be double hulled and would not use contaminated ballast water. With side-looking radar reconnaissance, the probability of collision with ice and damage to a large tanker should be low. Local damage to a hull would release environmentally safe ballast water.

Gaps and Deficiencies

There is a significant lack of data and information about the distribution and properties of large multiyear floes. This important information often establishes design limits for extreme structural loadings. Ice floes may contain embedded ridges, which make an evaluation of floe forces even more complex. Data on floe size, thickness, velocity, spatial and corporal distribution, internal fracture planes, and surficial ice strength (especially the external 1 to 2 meters that have been in contact with the sea), are needed so that a reasonable assessment can be made of the force they can exert on a structure. Similar information is needed for the properties of thick multiyear ridges and ice island fragments.

A statistical problem exists since most floes are only a few hundred meters in diameter, but rare ones with masses that are orders of magnitude greater than common floes, have been sighted and have been 5,000 to 10,000 meters in diameter.

A most critical question is whether the work in ice mechanics (i.e., the S_3 tests) can be reliably extrapolated to the ice features acting on the structures (S_2 scale). There are indications from field observations that the actual forces experienced on the S_2 scale are significantly less than those that can be computed from the available data on small-scale specimens.

Many of these questions have been raised in previous reports on Arctic ocean structures, and they are being addressed in research reports by universities, professional organizations, government, and

especially industry (NRC, 1981b). A more complete effort at data collection, directed at the extreme ice features such as multiyear floes and ridges and ice island fragments, will hasten the safe and economical development of Arctic ocean resources.

Meanwhile, structural research and development continues on improved materials and designs to resist these ice forces. Among the important areas identified (NBS, 1983) are the following:

- o Punching shear in concrete walls. Some industry-sponsored programs are investigating the use of multiaxial reinforcement and sandwich-wall (hybrid) steel-concrete construction. The National Bureau of Standards is planning a research project on this subject in the form of a joint government-industry study extending over a period of several years.¹⁰
- o Ice abrasion of concrete. Industry is investigating the actual performance of concrete and steel structures in sea ice environments, such as the Baltic Sea, and is conducting extensive laboratory testing.
- o Sea ice structure-soil dynamic interaction is being analyzed and evaluated through university research sponsored by industry.
- o Freeze-thaw of saturated concrete near the waterline has been extensively investigated under joint industry research programs.
- o Development of economical steels and welding technology to prevent brittle fracture under impact at low temperature has been carried out by the steel industry, particularly in Japan.
- o Pipeline burial techniques suitable to the Arctic have been investigated under joint industry programs. Burial in water depths less than 50 meters appears necessary to prevent damage from deep-keeled ridges. Similar efforts have been addressed to the pipeline crossing of the coastline, where permafrost degradation and thermokarst¹¹ erosion might occur.

Needed research and development for structures include repair techniques for concrete and steel structures at low temperatures, improved structural means for distributing high local forces through the internal structure and thence into the sea floor, and the development of high-capacity moorings for floating vessels under sea ice conditions.

¹⁰Refer to Dr. H. L. Lew, National Bureau of Standards, Construction Safety Group, Washington, D.C. 20234.

¹¹Thermokarst: settling or caving of the ground from the melting of ground ice.

Icing and Ships

The accumulation of large quantities of ice and attendant loss of stability is a major hazard to the operations of fishing vessels in northern waters and is also a safety concern in the design and use of floating platforms. The northern Pacific environment and especially that of the Bering Sea, as well as the Gulf of Alaska, present the most stringent structural icing problem, which is a threat to the U.S. fishing and crabbing industry operating in Alaskan waters. The most serious conditions prevail in areas where the air temperature is below the freezing point of seawater (about -1.8°C), the sea-surface temperature is below 5°C , and the wind is in excess of 20 knots. While there are icing standards promulgated in several nations, particularly Japan and the United Kingdom, as well as by the International Maritime Organization¹² (IMO), no such operational standard exists in the United States. The Fishing Systems Panel (MS-11) of the Marine Systems Committee, Society of Naval Architects and Marine Engineers (SNAME), has sponsored a study to identify associated actions needed to enhance understanding, such as the acquisition and analysis of icing reports, models or full-scale tests of various hulls and structures, and analyses of the risks associated with atmospheric icing. The SNAME panel's work, which is in report preparation, should contribute to adoption of criteria for use in the design of U.S. fishing vessels.

GEOTECHNICS

Seafloor Soils and Soil Mechanics

Obtaining geotechnical data, especially in the shear ice zone, is a particularly difficult challenge which is confronted by several problems such as: (1) acquiring a platform capable of working in moving broken ice, (2) assuring adequate logistical support, and (3) obtaining relatively undisturbed samples in such critical soil strata as partially ice-bonded sands, overconsolidated silts, and gas-charged silty clays. These silts and silty clays appear to be highly anisotropic.¹³ In situ measurements currently appear to be the best means. One new technique, i.e., electrical resistivity measurements, is being explored.

¹²Formerly IMCO, the Intergovernmental Maritime Consultative Organization.

¹³Anisotropic: exhibiting properties (e.g., resistance) that have different values when measured along axes in different directions.

Advances in understanding the special geotechnical nature of the Arctic sea floor (NRC, 1982b) have been made in the past 5 years. At the same time, some phenomena have achieved new importance and concern.

The increased design forces associated with rare events may require the soil to accept very large forces (of the order of 100,000 metric tons) in lateral strain, accompanied by significant bearing loads under the overturning moment. The moment may be offset by configuring the structure with an inclined face so that the reaction is directed downward. While adfreeze may inhibit the effectiveness of this design in winter, the design concept may be effective for critical summer ice floe impact situations.

The structure-soil interaction may be very complex because Arctic seafloor soils may have major property changes with depth at locations where overconsolidated Pleistocene soils have received little additional sediment during the Holocene period. At these locations, failure by sliding may take place in shallow strata near the seafloor, where the soil has been reworked by ice gouging, or it may take place at some depth where a plane of silt has been weakened by water and possibly by gas influx from thawing permafrost below.

The installation of mechanical means to transfer shear, such as skirts or spuds, may be adversely affected by intermediate near-surface layers of overconsolidated silt, that are extremely difficult to dredge or penetrate mechanically. However, they appear to break up readily under the action of high-pressure water jetting. Further research on these phenomena is needed; some is underway in universities. Penetration of these layers may require the use of high-pressure jets along with other methods.¹⁴ The interaction of both jet water and mechanical impact and vibration on overconsolidated silts is not well understood, and improvements in knowledge of compound penetration techniques may have cost benefits.

The main difficulty with overconsolidated silt involves characterizing a design strength for sliding resistance, as partial drainage takes place during most in situ tests and during full-scale field loading.

The alternatives of artificial freezing or artificial drainage of these silts and silty clay layers are being proposed. Concurrently, related questions arise such as: How will silts whose high water content is saline behave under artificial freezing? Will the ice lenses and brine pockets be small and discontinuous or so large as to pose a serious plane of weakness? and Will drainage by wicks or sand drains be effective?

¹⁴Only some of the Alaskan silts have a low enough plasticity to be easily erodable. Jetting can also have adverse effects; dead-weight loading or mechanical impact may be preferred alternate techniques.

Stabilization of weak sea floors is being carried out in Japan, using cement-mixing and lime-mixing techniques. Sand injection methods have also been used in similar soils on shore. These may have applicability for production platforms in areas with weak surficial soils. The low ambient temperature (-1° to -2°C) must be taken into account. In Japan, at the request of Global Marine Development, tests have shown that satisfactory strength has been demonstrated at -1°C .

An early recognized problem, transfer of heat from a cluster of production wells, which causes large-scale thawing of permafrost and thaw subsidence under the structure, can probably be countered by well operational control techniques and refrigeration combined with the use of insulation. Data confirming this should be available soon from on-shore experience in the Prudhoe Bay area.

Engineering responses to other concerns, such as wave and ice erosion of slopes and bottom scouring, appear to be within the province and capability of industry or can be resolved with further research.

Ice gouging of the seafloor in the shear zone is a design consideration for a platform that may be 100 to 150 meters in diameter and may be spanning across many gouges, of different ages, depths, and degrees of refilling. Industry is working on various means to establish a satisfactory interface and contact for seafloor-founded structures. The "simple" solution of stripping and filling with sand and gravel turns out not to be entirely simple, as practical matters make the screeding of such an embankment to close tolerances extremely difficult. The experience with Dome Petroleum's SSDC-1 drilling vessel in the Canadian Beaufort has demonstrated the need for supplemental means of underbase filling. Reportedly, attempts to screed the underbase embankment to an acceptable tolerance proved impracticable in the open sea, despite the use of very modern, sophisticated dredging equipment. The structure was therefore temporarily seated on three pads (concrete plus a polyurethane cushion), and sand was slurried underneath the structure using a system patented in The Netherlands. A similar experience is reported for the barge-mounted saltwater treatment plant for the Prudhoe Bay waterflood project.

To resist extreme ice events such as thick multiyear floes, deep-keeled ridges, and ice island fragments, embankments and berms are often proposed to be constructed to absorb the kinetic energy of these large ice features by forcing a ploughing action. Embankments may extend close to or above sea level, in which case protection against wave erosion will be necessary, or embankments may terminate in a berm 10 to 15 meters below sea level. The resistance offered to the ice ploughing action is largely determined by the passive resistance of embankment soil and by the surcharge of soil pushed up ahead of the ice. Of apparently less importance are friction of the ice on the soil and lifting of the ice feature.

If smaller caissons are placed on the embankment to retain sand fill while acting to prevent wave erosion (the caisson-retained

island concept), then a sufficient depth of material must be piled behind the caisson to prevent a local upward failure of passive resistance.

Other potential concepts for retention of embankments include reinforced earth concepts and both conventional and novel sand cells made of fabric, membrane, or steel, filled with sand, gravel, or weak concrete.

Offshore Permafrost

Offshore ice-bonded permafrost affects petroleum operations in most of the same technical areas as onshore permafrost: pipeline settlement, thaw subsidence around wells, foundation deformation, seismic record interpretation, hindrance of excavation, and thermal-hydraulic erosion along the seacoast. However, offshore permafrost differs significantly from that onshore. Nearshore, water depth is the controlling influence on seafloor temperatures. In water depths greater than about 2 meters, there is no active layer, and the top of the ice-bonded permafrost is usually tens of meters below the seafloor¹⁵; pore water salinity affects permafrost thawing temperature and makes the thermal, mechanical, and electrical properties of the ice-bearing soil highly temperature dependent. Offshore permafrost is relatively warm and undergoing long-term degradation from above and below, and its distribution is dependent on recent shoreline history and the presence of overlying low-permeability soil layers. Because of pore water salinity, the standard definition of permafrost based on 0°C is not very useful, so in the following discussion, "permafrost" only refers to ice-bearing soil, which may or may not be bonded.

Research areas that merit further work and data acquisition include phase behavior of saline pore water; salt transfer in thawed and freezing soil; mechanical, thermal, and electrical soil properties; permafrost distribution, lithology, and temperature; data for surface and seafloor heat balance calculations; in-place condition of artificial fill material used in islands and causeways; numerical modeling for heat and salt transfer; soil/structure thermal and mechanical interaction modeling for wells, pipelines, and process facilities; frost heave; excavation methods; and coastal erosion. The proceedings of the Fourth International Conference on Permafrost (NRC, 1983a) provide a collection of research papers describing much of the knowledge on this subject.

¹⁵In some areas of overconsolidated sediments, the permafrost horizon may be within a few meters of the sea floor, as has been observed over a significant area in the Beaufort Sea where depth to bonded permafrost is less than 10 meters.

Availability and Assessment of Resources

Several oil companies interested in the Arctic offshore are conducting in-house research programs. There are numerous consulting companies with a range of analysis, laboratory, and field capabilities. Few U.S. universities conduct research or provide training in cold regions geotechnical engineering. Academic research that is done, such as by the University of Alaska, is funded by both government agencies and industry. Limited academic research is conducted at the University of California at Berkeley, Thayer School of Engineering at Dartmouth College, University of Washington, and the Massachusetts Institute of Technology, the latter under an industry grant from Sohio. CRREL, the U.S. Geological Survey (USGS), and the Minerals Management Service (MMS) are the major government organizations investigating offshore permafrost. Canada and the USSR also support offshore permafrost research.

Equipment, facilities, and trained personnel are generally available to perform the required engineering, as economic circumstances warrant. The research and engineering efforts undertaken for the Trans-Alaska Pipeline System and the Alaskan Natural Gas Transportation System underscore industry's ability to undertake large, comprehensive efforts. Several universities are interested in and capable of performing useful research and can become more involved as funding is made available.

Offshore-related work in the Beaufort Sea to depths of 20 meters has primarily been an extension of offshore experience from other areas of the world. Work in depths of less than 10 meters is primarily an extension of onshore experience. Training of personnel has tended to be on-the-job, typical of work in a developing technology. Technology advances have usually been keyed to acquisition of laboratory and field data, with the latter being costly to obtain.

The technical literature contains many recent publications that address most of the research areas identified. However, in almost every area, more data will be needed for both regional and site-specific design considerations. In most situations, it should be feasible to design for permafrost problems, but with existing information such designs may be overly conservative and could place additional financial burden on high-cost Arctic projects. Improved knowledge of offshore permafrost behavior and its interaction with offshore systems will lead to improved designs.

Gaps and Deficiencies

Although limited, there is technical literature on the phase behavior of seawater (Ono, 1972) and saline pore water (Page and Iskander, 1978). Salt transfer processes in permafrost have also been investigated (Lachenbruch and Marshall, 1977; Swift et al., 1983).

Limited data exist on frozen soil mechanical properties (Ogata et al., 1982; Sego et al., 1982), but industry has proprietary programs underway to develop additional data on frozen soil strengths and thermal properties. All soil properties depend on ice content, which is difficult to measure directly.

Information regarding the distribution of offshore permafrost is evolving (Miller and Bruggers, 1980; Sellman and Chamberlain, 1980; Osterkamp and Harrison, 1982), but few data on thickness exist, and the seaward extent of permafrost has not yet been determined. Increased information of this type would be useful for prelease sale costing of production scenarios, but is not believed essential until site-specific production centers and preferred pipeline right-of-ways are known, at which time industry would carry out the required detailed permafrost surveys.

Methods exist to acquire permafrost cores and log permafrost formations, but improved methods are needed to obtain better data quality. Advances in electromagnetic methods to map the top and bottom of permafrost are being made (Rosenberg and Hoekstra, 1982; Corwin, 1983), but additional work in this technical area would be useful, especially to aid in the selection of optimum subsea pipeline corridors and in the design of well completions.

Several heat transfer models have been developed for freezing and thawing soils (O'Neil, 1983), some of which include convection. None, however, rigorously includes salt transfer processes or the effects of a seawater layer. Improved models would be useful, especially for pipeline design. Measurements of some meteorological data, such as longwave and shortwave radiation and snow depth and density, needed for input to these models are relatively limited.

The technology for dealing with frost heave is rapidly evolving as a result of chilled gas pipeline work in both the United States and Canada. Additional research is needed to extend the developing technology into saline soil environments. Such work may be helpful in limiting costly engineering solutions to mitigate frost heave or to design foundations and facilities that can accommodate heaving soil. Saline pore water can significantly reduce heave (Chamberlain, 1983).

Some analyses of permafrost engineering problems for offshore petroleum development have been published (Scher, 1982; Heuer et al., 1983; Mitchell et al., 1983), but much more remains proprietary. Extensive efforts are underway for both exploration and production.

The preceding discussion is a brief summary of research that has been carried out to develop information on offshore permafrost. Most of the available publications date from work carried out in the past five years, which is indicative of the frontier nature of this work. To support the continued rapid development of technology, increased efforts are needed to catalogue the increasing amount of available data, to standardize terminology and data collection procedures, to publish updated maps of environmental data, to develop better instruments and techniques for in situ and remote data collection, and to translate pertinent foreign publications, especially those in Russian.

A process for exchange of information on permafrost-related research and technology is provided by national and international conferences sponsored by professional organizations, government agencies, and universities. A major international conference is held every 5 years; the most recent was the Fourth International Conference on Permafrost at the University of Alaska, Fairbanks, July 17-22, 1983 (NRC, 1983a) under the sponsorship of the National Research Council's Polar Research Board.

Exploration Seismology

Many types of geologic and geophysical information are used to develop an integrated interpretation of the hydrocarbon potential and to prepare an economic evaluation of an offshore basin. One of the key tools used in this process is seismic data that can provide the exploration seismologist with acoustic cross sections of the subsurface. Industry requires such data to carry out basin and prospect evaluations before lease sales, selection of optimum drillsites for exploration wells, and detailed evaluations of resource prospects during production development. The amount of seismic data required in these phases of activity varies, depending on basic structural complexity and on the degree of economic risk an oil company is willing to accept.

Availability and Assessment of Resources

An extensive seismic data base exists for most of the Arctic basins. For example, it is estimated that about 50,000 line kilometers (30,000 line miles) of seismic data exist for the Beaufort Sea. Additional data are being obtained each year. Numerous geophysical contractors are or have been engaged in seismic data acquisition programs in Arctic areas. Western Geophysical Corporation, for example, has four survey ships operating in the area. These contractors have several years of experience and have developed marine equipment and methods suited for Arctic and cold weather duty.

Data acquisition by geophysical crews in the Arctic offshore relies primarily on standard procedures that are carried out in open water, with little, if any, floating sea ice present. Ice is absent in the Bering Sea from 5 months in the northern regions to 10 months, or more, in the St. George Basin (just north of the Aleutians). Consequently, there is no practical seasonal limitation to significant seismic exploration in the Bering Sea. However, the open water time becomes less favorable in the Chukchi Sea, and is still worse in the Beaufort Sea.

Typically, offshore geophysical crews in the Beaufort Sea, north of Alaska, average 20 days a year to conduct seismic surveys using boats. This time is often reduced by 1 or 2 days due to passage of

bowhead whales. Boats are usually left overwinter at Prudhoe Bay since transit to and from the Beaufort Sea would reduce their availability for data acquisition service. Nonetheless, the quantity of data could be increased, at additional cost, by increasing the seismic survey fleet and survey capability. However, it is estimated that it costs \$5 million a year to operate and overwinter a seismic survey boat in the Beaufort Sea. Thus, the daily cost for data acquisition approximates \$250,000 per day--more than eight times the cost for exploration surveys in warmer oceans. Arctic seismic costs can be even higher if survey programs are conducted on short notice.

Although Arctic seismic boats are usually ice strengthened, the technical requirements imposed for operating the seismic sources (usually airguns) and maintaining proper geometry for the seismic cables essentially preclude operations in ice-infested waters. Hence, the overall open water period is reduced to the average 20-day period noted previously. It is not believed to be cost-effective to attempt to extend technology to conduct surveys in ice-infested waters. Costs using open water techniques, though large, are acceptable. Moreover, geophysical contractors have personnel and equipment available (and can readily expand their effort) to carry out the marine programs required by industry in the brief Arctic summers. Existing techniques are believed adequate to provide data for future lease sales well into the early part of the next century, although increasing water depths usually implies briefer open water periods. Consequently, deeper water seismic data acquisition programs may require large efforts concentrated in "good" ice years.

Offshore seismic exploration also is carried out using land seismology methods that have been adapted to work on stable ice, once it has grown to about 1-2 meters thick. Surveys from the stable ice also are costly, but have provided an effective way to augment data acquired by seismic boats. On-ice surveys typically employ a caterpillar train containing the crew quarters, and recording instruments, vibrator seismic sources, and seismic cables that are deployed and retrieved as in normal land operations.

Much of industry's current interests (and government leasing programs) lie in the shear zone, where the ice is always moving. In the lease areas that are deepest and farthest from shore, there may be little or no time in the year free from significant ice cover (4 tenths area coverage or greater). Therefore, technology must be developed for operations in these areas.

Once seismic data are obtained, several processing steps are required to produce final seismic sections for subsequent interpretation. To an extent, the existence of permafrost requires a refinement in normal processing, but the combination of more than a decade of exploration experience (both seismic and interpretation) has yielded methods to correct for permafrost effects.

Gaps and Deficiencies

Exploration seismic technology is well developed and has been proven applicable to the Arctic offshore. Nonconventional approaches (e.g., submarine seismic profiling or the use of drifting ice floes as source and array platforms) may be proven feasible, but are not likely to receive industry endorsement or funding until feasibility is established. However, cost tradeoffs among various existing methods can be made and industry is prepared to pay for the data it needs. Further, it is felt that seismic data processing techniques, applicable to non-Arctic areas, coupled with established methods to correct data for permafrost seismic velocity effects, are suitable for producing state-of-the-art seismic cross sections of the subsurface.

Seismicity

Generally, the deep Arctic regions of Alaska have relatively low seismicity. A region of moderate activity does exist in the Camden Bay area near the Canadian border and offshore of the Seward Peninsula. The two basins in the southern Bering Sea are regions of relatively high seismic activity.

The active plate margin south of the Aleutian Islands is far enough away to attenuate much of the high-frequency components in the St. George Basin and, to a lesser extent, those components in the North Aleutian Basin. However, ancient subduction zones exist north of the Aleutian Islands, and smaller but much closer events are possible.

Structures in these areas may be surrounded on rare occasions by ice rubble. The interaction of structure, ice, water, and soil under earthquake conditions recently has been addressed in an analytical research program at the University of California at Berkeley. The results are strongly dependent on the condition of the ice rubble at the time (i.e., mushy or strongly frozen) and the soil (i.e., medium clay or sand). However, evaluation of a number of combinations shows that the phenomena probably will not control the design in most cases.

Gaps and Deficiencies

Offshore development of areas near the Alaska Peninsula and the Aleutian Islands, which are adjacent to an active plate, may be subject to severe seismic conditions. A network of seismic sensors, telemetered to Sand Point, Alaska, provides a record of seismic events valuable to engineering development planning. Data from this sensor and recording system are analyzed by the Lamont-Doherty Geological Observatory, as part of a program supported by the U.S. Department of Energy. This data acquisition and analysis system was formerly part of a larger system in the Outer Continental Shelf Environmental Assessment Program (OCSEAP), under NOAA and U.S. Department of the Interior sponsorship. There is no long-term government commitment to the continuation of this important program.

INDUSTRY ROLE IN ENGINEERING-RELATED RESEARCH

This chapter has noted the role of industry, universities, and government in undertaking research that directly influences or supports engineering, including joint endeavors. More of the activity within academe and government is discussed in later chapters--in regard to environmental concerns in Chapter 2 and to government capabilities in Chapter 4.

In comparison to government and university research, industry research activities are more difficult to identify or quantify. Nearly all of the major petroleum companies engaged in U.S. Arctic offshore development have engineering research or analysis sections committed to resolution of Arctic offshore problems in ice mechanics and soils and their relationship to structural design, as well as to the acquisition of environmental data. In many cases Arctic work is being done by general engineering groups in other sections of the same organizations where the numbers of engineers, scientists, and technical personnel involved often exceed the numbers of those in organizations specifically committed to Arctic projects. If the consulting and design engineering and small organization specialists were added to the probable total of the engineering researchers in major companies, the committee estimates that professional personnel, in the order of 1,000, are now engaged in U.S. research and development work for those technical areas discussed in this section.¹⁶ The joint industry and joint industry/university/government work, while large in committed funds and technically valuable, is still a minority of all industrial research activity. The competitive and rapidly changing character of the research products encourage the single-organization, proprietary approach to research, despite the flexibility offered by joint industry projects sponsored by members of the Arctic Oil and Gas Association (AOGA).

AOGA has administered more than 260 projects since its first project in 1968 and has expended over \$55 million in their support since inception. Nearly \$8 million of research costs occurred in 1983 and over \$14 million was expended in 1982.

¹⁶Because of the proprietary interests involved and the breadth of interpretation of Arctic-related engineering and research and development, no attempt was made by the committee to derive precise estimates of the numbers of engineering and technical personnel. The range stated above is intended to be only generally indicative of the degree of industry activity in Arctic ocean engineering-related research and development.

ENVIRONMENTAL CONCERNS

OFFSHORE OPERATIONS

Three types of environmental information need to be developed for Arctic operations. The first type is baseline and monitoring information on the numbers, distribution, habitats, and behavior of Arctic wildlife, particularly marine mammals. The Minerals Management Service (MMS) and the National Oceanic Atmospheric Administration (NOAA) are responding to this need through OCSEAP, which is discussed later in this chapter. In addition, NOAA, through the Sea Grant Program, and the National Science Foundation have sponsored significant environmental research and assessments in the second category of information, which addresses the environmentally generated hazards to structures (discussed in Chapter 1). It is the third category of information, the "first order" effects¹ of industrial operations and structures on the environment, which is discussed in this chapter; this information is probably the least well developed.

Scientific research has concentrated on understanding basic biological and physical processes. Industry and university research has concentrated on understanding how to protect offshore and coastal structures from damage or destruction and to provide personnel safety (U.S. Department of the Interior, 1982b). There has been less interdisciplinary synthesis which would assess environmental information required to reduce the environmental impacts of industrial activities in the Arctic.

A major environmental concern related to engineering and development in the Beaufort Sea is the bowhead whale. From April to

¹"First order" effects are those physical changes that could result from engineering activities and technical operations in offshore areas, such as noise generation, oil spillage, Arctic or possible coastal modification caused by changes in currents or wave action following emplacement of structures.

June, these whales migrate northward from the Bering Sea through the eastern Chukchi Sea and cross the Beaufort Sea eastward to their summer feeding grounds in the Amundsen Gulf Area. From August through October, the bowheads usually migrate westward into the Chukchi Sea, through the Bering Strait, and into the Bering Sea. During this seasonal cycle, the whales pass through or near areas under or proposed for resource development (see Figure 8).

The National Marine Fisheries Service, which is responsible for managing the bowhead whale, stated, "Noise disturbance or oil spills that cause bowhead whales to abandon traditional wintering areas, alter migration routes, or interfere with feeding, mating, or breeding would be likely to jeopardize the continued existence of the endangered bowhead whale" (NOAA, 1983). The federal Endangered Species Act requires that federal agencies ensure that such jeopardy does not occur.

In 1979, because of these concerns, the state of Alaska and the U.S. Department of the Interior imposed seasonal drilling restrictions on all leases to be awarded in the 1979 Joint Federal/State Beaufort Sea Lease Sale. This decision allowed oil companies to drill exploratory wells only from November 1 through March 31 each year with the possibility of extensions up to May 15 at some locations.

In 1982, the restrictions were revised to prohibit drilling operations in major hydrocarbon-bearing formations during periods of broken ice until oil industry lessees adequately demonstrated the capability to clean up spilled oil in broken ice. In addition, the 1982 revised restrictions required a complete shutdown of drilling operations from May 15 to October 31 in major hydrocarbon-bearing formations outside the Beaufort Sea barrier islands. Inside the barrier islands, drilling was halted from May 15 until the sea was free of ice, usually in mid-July, and during the fall whale migration.

Four oil companies participated in oil spill cleanup demonstrations in February 1983 and, based on the state of Alaska evaluation of results, the state restrictions on exploratory drilling were partially relaxed to allow year-round drilling inside the barrier islands and a 9.5-month drilling season outside the islands (State of Alaska, 1984). While stating that an adequate cleanup capability exists if exploratory wells are drilled from a gravel or natural island or an approved platform, the state requires the lessee to submit and receive approval of an Oil Discharge Contingency Plan, to participate in a state-approved 5-year research and development program to improve cleanup effectiveness during broken ice periods, and to train drilling personnel in well control techniques. Further, year-round drilling within the barrier islands can be done only if the lessee participates in a whale monitoring program designed to assess the influence of the drilling operation on bowhead whale behavior. Outside the barrier islands, drilling above the threshold² level

²The threshold depth is a point above which major accumulations of hydrocarbons are not likely. This depth will be determined on a case by-case basis by the Division of Oil and Gas (state of Alaska) after consultation with the Alaska Oil and Gas Conservation Commission and, when appropriate, the Minerals Management Service.

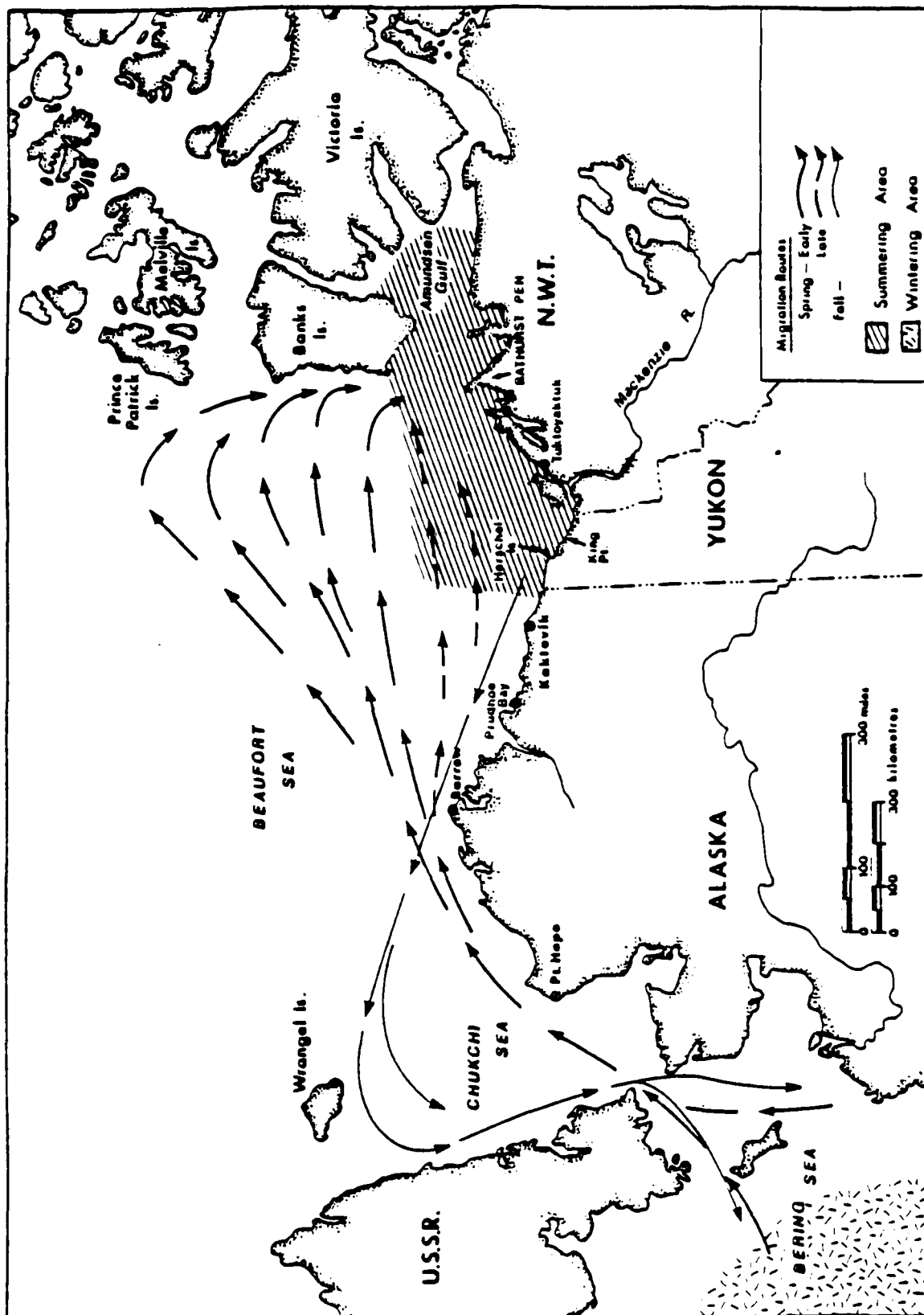


FIGURE 8 Generalized pattern of seasonal movement of the western Arctic population of bowhead whales.

SOURCE: LGL Ecological Research Associates, Inc., 1983.

will be prohibited only when whales are migrating through or near the area, but drilling below the threshold depth will be prohibited from August 15 through November 1, or until the whale migration has ended (providing the lessee participates in a state-approved whale monitoring program).

Effect of Operationally Generated Noise

The Beaufort Sea and its shore areas provide habitats for many wildlife species, including polar bears, seals, fish, caribou, and birds. This wildlife depends heavily on the brief but very productive open water season in the summer when there is a rapid growth in the food supply. The Inupiat (Eskimo) people, who are the native people of the North Slope, depend heavily on Arctic wildlife and have made a special case for the harvest of the bowhead whale.

Hydrocarbon development in the Arctic will introduce both stationary sources of noise, such as dredging equipment, drillships, and drilling activity on artificial islands, and mobile sources of noise such as supply vessels, icebreakers, and aircraft. Noise from these sources may propagate for long distances in the underwater environment (Gales, 1982).

Underwater sound is the by-product of normal marine operations and has the potential for affecting whales (Fraker et al., 1981). It also may affect other marine animals, such as seals and sea lions (Gales, 1982). In addition, noise may indirectly affect hunting by native Alaskans if it displaces animals from normal migratory routes into less accessible areas.

Marine animals may hear the sounds of offshore oil and gas operations out to distances as far as 185 kilometers (100 nautical miles) or more, depending on the oceanographic conditions. Available information indicates that noise may cause flight responses, physiological stress, and masking of signals used by marine animals for communication, location of food, and avoidance of environmental hazards (Fraker et al., 1981; Gales, 1982; U.S. Department of the Interior, 1982a).

One response to this concern is to design and construct drilling platforms and vessels for reduced sound emissions. Since some or all of these alternatives are expensive, it is desirable to establish the noise levels at which significant behavioral changes may occur so that unnecessary noise reduction efforts can be avoided. Unfortunately, those levels are largely unknown and will remain difficult to predict (MMS, 1983). It is an even more formidable task to establish cause and effect relationships between noise and animal behavior because of the problems in setting up experiments in the field (Mansfield, 1983). Arctic marine mammals are hard to locate, isolate, and observe. Stress effects are difficult to study in any animal, and are especially so in large whales (Richardson et al., 1983).

Consequently, much of the available information on reactions of such mammals to noise is anecdotal and inferential in nature. For

example, researchers have inferred that seemingly minor changes in overt behavior may be manifestations of internal stress (Richardson et al., 1983). Low-flying aircraft and high-performance boats appear to have the greatest effect on whales. Restricting the altitude for aircraft is one measure that mitigates the problem. A collection of references on the acoustic effect of outer continental shelf (OCS) oil and gas activities on marine mammals in the Beaufort Sea is presented in Appendix C.

The Outer Continental Shelf Lands Act (OCSLA) provides sufficient authority to establish noise standards. Section 21(b) of that act provides that the Secretary of the Department of the Interior shall require use of the best available and safest technologies for drilling and production operations (43 USC 1347(b)). In addition, Section 5 of that act gives the secretary broad authority to promulgate regulations necessary to conserve the natural resources of the OCS (43 USC 1334(a)). Similar authority to protect Arctic wildlife is provided by the Endangered Species Act and the Marine Mammal Protection Act (16 USC 1540(f); 16 USC 1382(a)).

OIL SPILLS, CONTAINMENT, AND CLEANUP

Statistical evidence points to a reduction in oil spills over the past 10 years (Lanfear and Amstutz, 1983). A recent comprehensive study of offshore oil spills that have occurred over the last 25 years has concluded, however, that "accidents will occur in future offshore operations despite the most determined efforts that can, and should be, made to prevent them" (Gulf Research, 1981). Consequently, it is necessary to prepare for such spills by developing oil spill containment and cleanup equipment. The best planning and the most modern safety techniques cannot ensure that accidental oil spills will not occur. Thus there is a definite need for oil spill contingency plans and response systems for Alaskan waters. The severest test of these plans and response systems will be in the Arctic regions of Alaska, specifically in the Beaufort and Chukchi seas.

Developing Spill Response Systems

OCS Order No. 7 requires inspections and reports, spill containment, cleanup equipment, materials, contingency plans, and personnel training. The MMS and the U.S. Coast Guard have a memorandum of understanding stating that the U.S. Coast Guard will review the adequacy of oil spill contingency plans submitted to the MMS. The Coast Guard has the overall responsibility to coordinate environmental protection action such as oil spill cleanup, in the Arctic waters, as well as in all U.S. offshore areas.

Oil Spill Response for Arctic Regions

The annual growth and decay cycle of the Arctic sea ice produces a changing ice arrangement and form throughout the year, which in turn requires the use of various response strategies and techniques should an oil spill occur. In describing the applicable spill response techniques, it is convenient to divide the yearly cycle into three specific ice conditions which may be encountered, and three overall response strategies that apply. These three spill conditions are summarized as follows:

- o Thick, stable, level ice. A release of oil beneath or on the surface of thick, stable, level ice results in a degree of containment on the rough upper surface or in the undulating under surface. In addition, the thick ice provides a working platform for spill response. The primary response strategy is direct disposal through in situ burning, skimming, and pumping.
- o Dynamic broken ice. A release of oil in broken ice presents the most difficult technical problem. At high concentrations (5-8 oktas, or 6 to 10 tenths),³ the ice may confine the oil in thick patches such that in situ burning is possible. At lower ice concentrations the oil layer may be too thin for combustion and the ice will hamper mechanical recovery attempts. However, industry in the United States and Canada has developed fire containment booms that can contain oil for in situ burning under these conditions. Research and engineering is underway to extend operational capabilities of such booms.
- o Open water. A response effort must be exclusively marine-based and oriented toward concentrating and recovering the oil from the surface of the water. Oil spills in some light ice conditions can be treated in a fashion similar to open water spills. The containment booms for in situ burning may also be applied under these conditions.

Arctic Oil Spill Response Capability

An oil spill response for oil on solid, level ice using state-of-the-art techniques for in situ burning could be highly successful, removing at least 70 percent of the oil from the ice and water. However, additional research is necessary to develop surveillance techniques for oil under ice, and careful planning,

³An okta is a measurement of ice cover; 1 okta means one-eighth of the area is ice covered. More recently, ice coverage descriptions have been expressed in tenths.

including an evaluation of the entire oil spill response system, will be required to provide adequate logistical support for the response effort.

The adequacy of oil spill response in broken ice in the Arctic has been debated for several years. Lack of agreement on the adequacy has prompted the state of Alaska and the U.S. Department of the Interior to restrict exploratory drilling in the Alaskan Beaufort Sea during periods of broken ice through the imposition of lease sale stipulations, beginning with the Joint State/Federal Beaufort Sea Lease Sale held in December 1979. The proponents of the restrictions argued that the risk to the environment of a large oil spill during exploratory operations is too high in periods of broken ice when cleanup effectiveness is lower and the biological activity is higher. The opponents of the restrictions argued that the risk of a large oil spill is extremely low, it could be cleaned up, and a spill would not result in long-term environmental harm.

During 1983, several oil companies met with representatives of the MMS, U.S. Coast Guard, Alaska Departments of Environmental Conservation and Natural Resources, and the North Slope Borough to define the areas of concern relative to spill response capabilities in broken ice and to design tests to meet the demonstration requirements of the lease sale stipulations. These tests were conducted by the industry and witnessed by the agency personnel during the summer of 1983 (S.L. Ross, 1983 a,b). The results of the demonstration have been reviewed by the state of Alaska, and some reduction in drilling restrictions has resulted, as noted earlier in this chapter. Further research will be required by the state for those companies wishing to explore in state offshore waters. Meanwhile, the lack of consensus on the effectiveness of response persists.

Overall response effectiveness using available techniques and equipment in light ice and open water conditions is highly dependent on the specific spill scenario, e.g., size of spill, type of oil, remoteness of location, and weather conditions.

ENVIRONMENTAL DATA AND INFORMATION

The Outer Continental Shelf Environmental Assessment Program (OCSEAP), conducted by NOAA for the MMS, is a major, multidisciplined, long-term attempt to collect information in the Arctic. Data and information produced by this program are used in leasing decisions of Alaskan offshore lease sales. The program, begun in 1975, is probably the largest undertaking of this kind ever attempted in the United States, involving at its peak in 1977 and 1978 more than 100 individual projects at about 30 institutions and an annual budget of over \$20 million. The program continues at a reduced level of about \$11 million in fiscal year 1984. The types of studies undertaken are summarized in Table 6.

It is not possible to summarize the findings of the program in a few paragraphs. These findings are contained in several synthesis

TABLE 6 Studies Conducted Under the Outer Continental Shelf
Environmental Assessment Program

Study	Objectives	Study Elements
Contaminants	Establish a chemical baseline	Light and heavy hydrocarbons Heavy metals
Environmental Hazards	Determine hazards to drill ships, platforms and pipelines and accident probability due to these hazards	Seismicity/volcanicity Seafloor instabilities, etc. Waves (extreme events) Sea ice morphology and dynamics Sea ice properties Ice islands Ice gouging of the ocean floor Subsea permafrost/clathrates Storm surges
Contaminant Pathways	Determine the transport, weathering, and dispersion of spilled oil and other contaminants	Wind-driven surface circulation Ocean currents Oil-ice interactions and transport Weathering and transformation Contaminant trajectories and dispersion
Biota at Risk	Determine what biological resources could be at risk from oil spills or other contaminants	Distribution and population dynamics Birds Mammals Littoral biota, benthos, and plankton Ecosystems Vulnerable habitats Food web relations of key species
Hydrocarbon and Development Effects	Determine the actual effect of spilled oil and other disturbances on individual species and systems	Effects on individual species (bioassays) Effects on ecosystems in selected areas

volumes, one for each lease sale that has occurred, and in the Environmental Impact Statements (EIS's) written by the MMS for each sale. Two sales took place in the Beaufort Sea prior to 1984. The environmental assessment for the sales is particularly relevant in the context of this report (NOAA, 1978, 1981). The EIS's also include technology and development scenarios, and an assessment of socioeconomic impacts. OCSEAP has attempted to relate its findings to environmental stipulations imposed on the lessees by the federal government (University of Alaska, 1979). Such issues include:

- Limitations as the result of extreme ice hazards;
- Monitoring of potential ice hazards;
- Biologically sensitive areas;
- Siting of industrial facilities and activities;
- Restriction of exploratory drilling period;
- Restrictions on borrow removal (e.g., sand, gravel);
- Restrictions on artificial islands and causeways;
- Deposition of formation water, drilling muds, and solid wastes;
- Oil spills, countermeasures, and contingency plans;
- Freshwater supply for industrial activities;
- Aircraft and noise disturbance;
- Duration of lease period; and
- Long-term monitoring and assessment.

Of the five study areas in Table 6, the least program emphasis and resources have been applied to the environmental hazards area. Hazard studies have been deemphasized by OCSEAP over the last few years, since they supposedly fall under the mandate of other government agencies or of industry. Apart from some marine geological studies sponsored by the U.S. Geological Survey, little work is done on the major subtopics of sea ice and subsea permafrost by other agencies. However, industry studies in this area are proprietary and not in the public domain, although they are usually made available after some time has passed. The need for such studies involving industry, government agencies, and universities has been pointed out in several recent reports by the National Research Council (NRC, 1981b) and the National Petroleum Council (NPC, 1981).

One area of environmental hazard under study within OCSEAP is modeling and statistically analyzing storm surges in the Beaufort Sea. Such surges are of particular concern in view of the low coastline and the potential for severe damage caused by ice movement and ride-up.

Studies of contaminant pathways are receiving attention from OCSEAP and constitute the major part of research. Biota at risk and hydrocarbon and development effects also continue to be studied by OCSEAP, the latter through cooperative arrangements with the Canadian Baffin Island Oil Spill (BIOS) Project.

Other Arctic offshore related environmental studies have been undertaken, such as PROBES (Processes and Resources of the Bering Sea Shelf) and other projects sponsored by the National Science Foundation

and NOAA. These programs are noted later in the report in conjunction with a review of government Arctic offshore activity (Chapter 4).

Gaps and Deficiencies

There are insufficient data to establish noise levels for design purposes. In particular, the frequency and level of acceptable noise have to be established through the study of animal behavior. However, this goal may not be achievable, and present research in the area will have to be assessed for its contribution to improvement in defining noise parameters that affect the marine wildlife considered important to the needs of the local population.

Similarly, oil spill response effectiveness does not have a generally agreed upon set of standards on which effectiveness judgments can be made. Overall subjective measures of response effectiveness such as "good," "adequate," or "has potential" are inadequate to achieve agreement among all relevant parties.

OCSEAP has been a major step forward in establishing the environmental baselines to be used in understanding and developing the Arctic. The Arctic is, however, a large area, and its changing environment must be viewed on a continuous basis to establish true baselines and tests. The program must be continual, reviewed, and adjusted to reevaluate emerging concerns and to analyze the considerable mass of acquired data. Moreover, correlation of the wide variety of studies within OCSEAP is a continuing problem.

PUBLIC AND INTERNATIONAL ISSUES

MAJOR POLITICAL AND SOCIAL ISSUES AFFECTING DEVELOPMENT

Economic, political, legal, and diplomatic uncertainties add to the list of factors that increase the risk of operating in the Arctic. A number of economic and political problems and questions, such as those listed below, impinge on the way in which engineering needs may be addressed. How these political issues and problems affect the approach and timing of efforts to close gaps in knowledge for engineering purposes, as identified in this report, is difficult to estimate. The problems are:

- What must be done to implement the principles of National Security Decision Directive No. 90¹ so that the United States will have an effective overall Arctic policy?
- What are the appropriate relationships between public and private sectors in the development of the Arctic?
- What are the appropriate relationships between the U.S. government and the state of Alaska on the question of developing the resources of the Alaskan Arctic, along with the associated concerns of environmental protection and the needs of the native peoples?
- How will problems be resolved between the United States and Canada on a substantial range of Arctic problems? In particular, how will the following problems be resolved:
 - Role of the Arctic in overall U.S.-Canadian relations;
 - Delimitation of several disputed boundaries;
 - Question of transportation rights through Arctic waters;
 - Role of pipelines; and
 - Role of third parties such as Japan in the U.S.-Canadian relationship?
- What are the implications of the U.S.-USSR relationship in regard to broad security questions, legal theory, scientific

¹See footnote #3 in the Preface.

and technological data sharing, and the uncertain location of the U.S.-Russian Convention Line of 1867 in the Navarin Basin.

U.S. Arctic Policy

According to many observers knowledgeable in polar affairs, the United States has never adequately addressed Arctic policy. While jurists in Canada and the USSR deny that the sector theory² is law, it is widely recognized that both countries see themselves as having a "preferential" regime in the Arctic (Johnston, 1981). Yet if a substantial percentage of U.S. oil reserves is located in the Arctic, critics argue that the United States should develop a concept that would allow it to articulate a broader level of concern. Some commentators suggest a national Arctic policy, a governmental commitment that allows the goals of both the private and public sector to be advanced but with the oversight that the public interest requires (Conant, 1983).

A useful reminder of the areas of government responsibilities has been provided by the National Academy of Sciences: (1) resource development; (2) stewardship of the land; (3) cultural well-being; (4) defense and national security; and (5) support of scientific research (NRC, 1982a). The current level of investment in science in relation to development needs has been low. For example, the fiscal year 1983 Arctic research budget of the National Science Foundation was about \$14.5 million (National Science Foundation, 1983), even though in comparison, each mile of the Trans-Alaska Pipeline System (TAPS) cost more than \$10 million.

Recently, there has been considerable discussion regarding the Arctic Research and Policy Act of 1984. While the Act does provide an organizational framework for research planning and does recognize U.S. Arctic interests, it does not state a general U.S. commitment in the Arctic that would assist in responding to the broader concerns affecting the nation's engineering and development needs, such as communications, navigation, and search and rescue.

PUBLIC SECTOR'S ROLE IN ARCTIC DEVELOPMENT

Federal-State Relationships

In recent years new problems have emerged in the relationship between the federal government and the people and government of

²Each country bordering the Arctic has sovereign-like powers within pie-shaped sectors from the two outer edges of its southern territory to the North Pole.

Alaska. There are a number of disputes that affect the level and cost of engineering support. The first is the concern of Alaskans that oil development will affect the region's fisheries (Young, 1977).

The potential impact of development on the subsistence economy and culture of the native population is also a matter of serious concern to the state. In addition, Alaska has an ongoing territorial dispute with the federal government in the Beaufort Sea concerning the method of delimitation of the territorial sea which could cloud the title to offshore tracts already under lease. The state also is an interested party in the U.S.-Canadian boundary dispute in the Beaufort Sea.

U.S.-Canadian Relations

The area north of the continental land mass represents principally a portion of Canadian national territory to which the United States and others have never fully acceded. This is the reason for the strenuous response of Canada, in the form of the Arctic Water Pollution Prevention Act of 1970, to the voyage of the MANHATTAN.

The U.S.-Canadian boundary in the Beaufort Sea is not the only boundary in dispute between the United States and Canada, but it will be a difficult one to solve because of the possibility of finding resources in the region. However, it is unlikely that this boundary question will be resolved until the Atlantic boundary dispute, now before the International Court of Justice, is also resolved.

How the resources extracted get to market from the high north is also a subject of considerable controversy. As the MANHATTAN voyage demonstrated, Canada is concerned over the possibility of opening up the Northwest Passage to commercial shipping. In addition to the sovereignty question, concerns with problems of pollution control, overall environmental effects, transportation safety, and who will provide support services, such as weather and sea ice prediction and icebreaker support, are related issues for resolutions. The question of which is more desirable, transportation by ship or pipeline, will be heavily case-oriented in the analysis, depending on the size and location of the field as well as other factors. Further, whether the pipeline will be purely national, such as TAPS, a parallel gas line, a purely Canadian polar gas project (Kanstinen, 1981), or a jointly developed Alaskan Natural Gas Transportation System (ANGTS) are also salient questions.

Finally, Arctic resource management must also consider the interest of parties other than the United States and Canada. It is conceivable that Canada or the United States may wish to ship energy products across each other's claimed areas to third parties.

Soviet Union and Arctic Resource Development

No survey of Arctic development problems can be complete without a brief discussion of the USSR's position. The Soviet Union is the

major Arctic power. It has a larger population living above the Arctic circle than any other nation, has tried "enclosing" the Arctic by various legal devices such as historic bays and closed seas, has been conducting a large volume of Arctic scientific and engineering research, and has had disputes with neighbors on sovereignty and access questions.

Two potential problems must be mentioned because of their possible effect on the level of Arctic activity. The first is the uncertainty of the location of the boundary line between the United States and the USSR in the Navarin Basin, where geological indicators point to the possible existence of oil. Joint discussions of resource development in the Arctic will take place in an atmosphere of political competition, which has become more strident. The Soviet Union has always been sensitive to Arctic issues.

In the second problem area, Arctic science, cooperation between the United States and the USSR has been sporadic. Even so, both nations have a broad base of common interests in the exchange of engineering-related research data and information in such areas as ice mechanics, icebreaker operations, soil mechanics, and materials and metallurgy related to Arctic environments, as well as in weather forecasting.

OFFSHORE ARCTIC DEVELOPMENT IN CANADA

The United States, United Kingdom, and Norway have enacted statutes claiming exclusive jurisdiction over their continental shelves. Canada does not have a continental shelf act extending Canadian law to the continental margin but does exercise control over the offshore through several acts (Johnston, 1981). However, as a nation voting for and signing the 1982 United Nations Law of the Sea Treaty, when the treaty comes into force Canada presumably will be guided in jurisdictional claims by treaty obligations concerning the delimitation of the continental shelf, the enforcement of a 200-mile economic zone, the special status of ice-covered areas, and the rights of transit passage through straits.

In Canada, the federal government and the provinces of Newfoundland, Labrador, Nova Scotia, and British Columbia claim jurisdiction over the continental shelf resources and exercise varying degrees of regulatory control over offshore drilling activities.

In the Arctic, responsibility for management of oil activities has been clarified by the passage of legislation in 1982 that created the Canada Oil and Gas Lands Administration (COGLA). This law, in concert with the 1979 Oil and Gas Proclamation and Conservation Act, establishes the legal and administrative framework under which oil activities in frontier areas are governed. It required the renegotiation of all interests in Canadian lands.

The development of oil and gas resources by Canadian companies in the Arctic has been of intense interest to commercial developers. Canadian developers have established the technical lead in offshore

island design and construction, and in the design and operation of several marine and land transportation support systems. Canadian affiliates of several U.S. oil companies have participated in the Beaufort Sea, Melville Island, and Eastern Canadian operations with significant benefit to U.S. planning and engineering for Alaskan development. U.S.-Canadian cooperative efforts are fundamental to minimizing risk to personnel and the environment as well as to ensuring the economic success of northern ventures for both countries.

Canadian industry has established several technical research and planning associations, having organizational interties between various offshore area developments. With few exceptions, these intraindustry organizations are not supported by direct governmental funding. Descriptions of the associations follow.

Canadian Arctic Petroleum Operators' Association (APOA) APOA was formed in 1970 by a group of petroleum companies operating in the Canadian Arctic to promote joint research in the Arctic and to provide liaison between industry, government, and universities on Arctic research related to petroleum development. Most APOA research has been directed to obtain engineering and environmental data and to develop operating techniques and equipment to meet the unique conditions of the Arctic. In 1983 about \$7 million (Can.) in projects were committed. In some cases the results of APOA research projects are released to the general public immediately, while some reports are protected up to 5 years.

Other Canadian Petroleum Industry Associations The Offshore Operators Division of the Canadian Petroleum Association (CPA) includes many of the members of APOA. The former East Coast Petroleum Operators Association (EPOA) merged with the CPA's Offshore Operators Division in 1984. APOA and EPOA have jointly engaged in safety-related investigations, such as the Offshore Safety Task Force in 1982, to review and evaluate the petroleum industry's offshore safety practices and capabilities, covering the topics of lifesaving and rescue equipment, marine emergency training and offshore safety. Much of Canada's offshore oil spill research until 1980 was conducted by individual companies, universities, and the government. With the expansion of offshore drilling, both industry and government concern for the environmental effects of a potential oil spill increased. In 1980, this concern induced APOA/EPOA members to form the Canadian Offshore Oil Spill Research Association (COOSRA) and undertake 26 research projects in a 4-year, \$5 million investigation of spill countermeasures. Results and reports are available to the public.³

³APOA, EPOA, and COOSRA project reports are available from Pallister Resource Management Ltd., 105, 4116 64th Avenue S.E., Calgary, Alberta, Canada T2C 2B3.

The Baffin Island Oil Spill (BIOS) Project is closely related to the mission and program of COOSRA. BIOS, which is conducted under the Environmental Protection Service of the Department of the Environment (Canada), was initiated in 1979 as a \$5 million (Can.) interdisciplinary and international project (Canada, United Kingdom, United States, and Norway). Oil spill experiments were conducted in a group of bays near Cape Hart on the northern tip of Baffin Island. These tests produced baseline data, determined the effects of dispersants, and assessed the effectiveness of mechanical cleanup devices and beach cleaning methods.⁴

Another program, the Eastern Arctic Marine Environmental Studies (EAMES), was initiated in anticipation of proposed oil and gas exploration and is managed jointly by government and industry. Its study area included marine sectors adjacent to Baffin Island, where research was conducted from 1976 to 1980.

Canadian Environmental Studies Revolving Funds (ESRF) The Canada Oil and Gas Act, March 1982, established ESRF "to finance the environmental and social studies needed to assist decisionmaking on oil and gas activity in the Canada lands." The funds are obtained by levies on petroleum companies holding oil and gas interests in Canada lands. There are two funds, one each for northern and southern Canada. The Northern Fund, affecting the Beaufort Sea and other Arctic areas, is administered by the Department of Indian Affairs and Northern Development (DIAND), and may have a budget maximum limitation of \$15 million (Can.). Research priorities are established by the minister of DIAND each year, and study proposals are invited from "individuals, companies, universities, private interest groups, oil and gas companies, or federal and provincial agencies." Studies must be regional or national in scope, "be supplementary or complementary to ongoing government programs, and be clearly targeted to the needs of the oil and gas industry and their regulators." Research results will be published and made public.

Association of Canadian Universities for Northern Studies Thirty-three Canadian universities conduct research on northern problems and have banded together to enhance their common interests. More than 650 faculty members report that their research involves northern problems. Moreover, scientific training grants are available, and

⁴BIOS reports can be obtained from BIOS Project Office, Environmental Protection Service, #804, 9942 108 Street, Edmonton, Alberta, Canada T5K 2J5.

northern field study facilities exist. Canadian scholarships in the northern studies area provide a source of valued data and expertise.⁵

UNIVERSITY RESEARCH AND EDUCATION

About 20 U.S. universities have conducted ice permafrost and coastal research in Alaska and its adjacent waters, while others have done biological and ecological studies. Much of this research is relevant to Arctic ocean engineering and some deals with engineering problems directly. Sea ice problems, in particular, have been the domain of university researchers (e.g., AIDJEX) and most of the nation's expertise on large-scale geophysical problems associated with sea ice resides in universities. The same can probably be stated for other fields that generate information needed in engineering designs and operations.

Topics of study include geophysical hazards such as land and subsea permafrost, ice mechanics and strengths, ice gouging, waves, tides and currents, and earthquakes. A number of projects have examined sea ice interaction with structures, including that occurring during an earthquake. University research in these areas is an integral part of the nation's efforts in Arctic ocean engineering, now and in the future, but poses some special program planning problems, such as assurance of adequate field support and long-term funding. At the same time, new opportunities for university and industry collaborative research appear to be emerging.

The University of Alaska awards advanced degrees in Arctic engineering, and the University of California at Berkeley conducts a graduate course in polar ocean engineering. A number of "short courses" and "seminars" have been conducted by various universities. These have been supplemented by specially dedicated Arctic-related seminars at the technical meetings of professional societies.

Industry grants to universities have been made recently to initiate ice research, to provide test facilities that complement industrial capability, and to attract and develop the technical and professional personnel needed in the next decade. For example, an ice testing program has been funded at the Thayer School of Engineering, Dartmouth College, and the interaction of concrete and steel structures, foundations, and ice floes and other environmental forces are being assessed at the Massachusetts Institute of Technology.⁶

⁵Occasional papers on northern problems are available from the Association at: 130 Albert Street, Suite 1915, Ottawa, Canada K1P5G4.

⁶The structure-ice interaction research, sponsored by Sohio, is being conducted at the Massachusetts Institute of Technology, Center for Scientific Excellence and Ocean Engineering, under the direction of Prof. Charles C. Ladd.

As discussed in Chapter 1, the most critical need is not for additional test facilities but to provide, on a continuing basis, personnel familiar with Arctic engineering problems. More efficient use of existing facilities, such as promoting sabbaticals and student research at CRREL, would assist this goal.

Shore-Based Logistics Logistics are expensive in the Arctic. Moreover, adequate logistics are often not available commercially. Aircraft, including helicopters, can usually be chartered, but few of these aircraft have the high-precision navigational systems that allow repeated occupation of the same oceanographic stations on the sea ice, for example. Hotel accommodations are available at Barrow, Prudhoe Bay, and at other locations, but there are no laboratories, libraries, computers, or other facilities available at these sites. Any comprehensive research program will need access to such facilities as well as field and logistic support. The Arctic Research and Policy Act of 1984 recognizes the need for improved logistical coordination and support of research, and this function has been identified as one of the duties of the new Interagency Arctic Research Policy Committee.

Ships There is a lack of research vessels that can operate in ice-covered waters. It is noteworthy that, unlike in other nations having major interests, coastal areas, and ocean resources in the Arctic, there is only one dedicated U.S. polar research vessel, other than Coast Guard ships, that can operate in ice-infested seas. This is the research vessel ALPHA HELIX, which is operated by the University of Alaska for the National Science Foundation. It is the only ice-strengthened ship in the University National Oceanographic Laboratories System (UNOLS) fleet.

Coast Guard icebreakers are available during limited periods, but they have inadequate laboratory space and accommodation, and moreover, often are diverted for other missions. In addition, some NOAA vessels can operate in ice, however, their capability is more limited than ALPHA HELIX. Leases of foreign vessels, if available, do not constitute a long-term commitment to Arctic research, but represent a stop-gap measure at best. The area between nearshore regions that can be covered by small boats and deeper waters in which the icebreakers have collected information is presently a data void along most of the shores of Alaska.

Education

Personnel requirements for U.S. oil and gas exploration and production during the period 1979-1990 have been compiled by the National Petroleum Council (NPC, 1979). While there is a sufficient number of personnel available today, the number of graduates expected to be produced in the long term by universities falls substantially short of projected requirements. The report states that oil and gas

industry employers have limited their hirings mainly to graduates with advanced degrees. At the same time, insufficient funds for faculty and student support have led to a decline in the graduate programs of some schools, or eroding the quality of graduate education, in which research plays a major part.

Recent developments, such as Sohio's grant to MIT for Arctic research, indicate industry's recognition of this problem. However, long-term funding of graduate level education and research continues to be a concern in assuring an adequate infusion of technical personnel and capability in Arctic engineering.

Professional societies have had a major role in fostering education in Arctic Ocean engineering technologies, particularly in advancing the information base available to trained engineers.⁷

⁷Examples are the special sessions on Arctic offshore technology held at the Offshore Technology Conference in 1984; the Arctic Offshore Short Course-1984, sponsored by the American Society of Civil Engineers (ASCE); a specialty conference of the ASCE, "Civil Engineering in the Arctic," scheduled for 1985; the Marine Technology Society's Spilhaus Symposium on "Arctic Engineering for the 21st Century," to be held in October 1984; and the American Society of Mechanical Engineer's Conference on "Offshore Mechanics and Arctic Engineering," held in 1984 and scheduled again for 1985. There have been similar meetings in Canada and Europe, several of which were conducted under the auspices of the International Association for Engineers.

US CAPABILITY TO SUPPORT OCEAN ENGINEERING IN THE
ARCTIC(U) NATIONAL RESEARCH COUNCIL WASHINGTON DC
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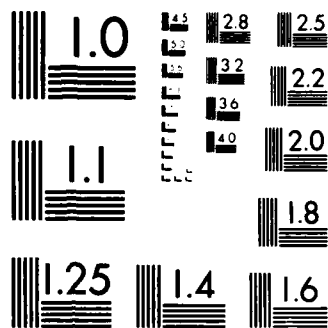
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GOVERNMENT OBJECTIVES AND CAPABILITIES

Various federal agencies carry out the government's role in the development of capabilities that support and enhance engineering activities essential to the use of ocean and coastal resources in the Arctic. Theoretically, no federal agency should be involved in an undertaking that does not stem from a legislative or executive base. This section discusses these mandates and their interpretation, programs that have been undertaken, and the commitments made to continuation or expansion of activity.

The national government's broad roles concerning the ocean may be stated as follows:

- Provide and operate a navy for national security. The other services' missions also affect the Arctic offshore and coastal activities, e.g., research conducted by the Army Corps of Engineers and activities undertaken by the Air Force to provide communications services.
- Enunciate national policies concerning the marine interests of the United States.
- Foster exploration, development, and use of the oceans and their resources, including environmental protection thereof, through establishment of appropriate financial, legal, regulatory, enforcement, and advisory institutions and measures to ensure maximum multiple use for the benefit of the United States.
- Promote description and prediction of the ocean environment.
- Initiate, support, and encourage programs of education, training, and research.

Historically, the federal government, sometimes in coordination with the states, has provided river, harbor, and ocean navigational capability; environmental data collection, sampling, and analysis; salvage; oceanographic science; education; and seafloor inspection for

civil purposes. These historic services are embodied in statute and executive directives.

The last few decades have seen significant federal ocean-related technology achievements primarily influencing engineering operations in the Arctic, through Navy undersea technology and NASA, Air Force, and NOAA satellite technology.

The federal government role as a sponsor of basic research in the United States is clear, but the level of support and the priorities or emphasis in various fields fluctuates and is both a congressional and executive issue each year. Federal support for development, including applied research, is unclear and a difficult matter involving level of support and even policy questions as to whether or not each endeavor is or should be a federal role or responsibility. Functions that fall in the unclear policy area regarding the appropriate supporting entity, private or government, are protection of coastal property from environmental forces, icebreaking, oil spill and pollution cleanup, oceanographic and meteorological information and data collection, and certification of some personnel and types of equipment.

The following is a discussion of the role, program, and commitment of each agency that provides resources for the development of Arctic offshore technical capabilities.

RESOURCES AND ROLES OF FEDERAL AGENCIES

U.S. Department of Defense

U.S. Navy

The Navy objective is simply stated: Be able to operate at anytime, at any depth, at any place in or on the oceans of the earth. The Navy has no legislative constraints, except that it may not provide weather forecasts to the continental United States unless the local commander decides that not to do so would endanger or threaten human life. Administrative directions prohibit the Navy from competing against private available services. The real constraints are mostly budgetary limitations and concerns about the handling of classified information and technology transfer to potential adversaries.

The Office of Naval Research (ONR) has served as the focus of Arctic research for the Navy, and the Arctic program objective is to stimulate and manage research that keeps pace with Navy operational needs and will close technology gaps. These technology deficiencies include knowledge of sea ice characteristics and dynamics, acoustic propagation loss, ambient noise, volume reverberation, ice scattering, ocean frontal and mixed layer dynamics, weather, Arctic geophysics, sediment distribution, and acoustic stratigraphy.

A major ONR activity has been the marginal ice zone experiment (MIZEX). The objective of this multinational effort is to understand

the interaction of ice and the atmosphere in the decaying ice margin at the southern extremity of the seasonal sea ice. While most of MIZEX has been in the Greenland Sea, a smaller parallel project was undertaken in the Bering Sea in 1983.

In addition, the Navy has sponsored work since 1975 at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); support has averaged about \$250,000 annually for ice modeling, drift observations, ice mechanics, and acoustics.

The Navy's Arctic-related research in basic areas has ranged from \$4 million to \$8 million over the past decade; 80 percent of this support goes to contractors, which are largely universities and oceanographic organizations.

Applied research in Arctic-related projects, which has received increasing emphasis since 1982 and is currently funded at \$2 million a year, largely supports in-house work at the Naval Oceans Systems Center, San Diego, California, and, to a lesser degree, university research. This research investment is expected to remain at this approximate level for several years.

Research vessels with icebreaking capability for Arctic work would be of interest to Navy investigators, possibly, for 60 to 90 days out of the year. Research vessels, such as Norway's POLAR BJORN or West Germany's POLAR STERN, are available from foreign sources. However, the demand for research vessel lease time is increasing, posing the real probability of a shortage of such vessels in a few years.

Joint Ice Center

The Joint Ice Center (JIC), which is operated by both NOAA and the Navy at Suitland, Maryland, generates ice analyses and forecasts for commercial and government shipping and barge operations in U.S. Arctic ocean areas. JIC integrates ground observations with satellite-derived image interpretations which are operationally available from the National Environmental Satellite Data and Information Service (NESDIS), NASA, and USAF. Ice forecasts are prepared using guidance material from the National Meteorological Center (NMC) and the Navy's Fleet Numerical Oceanography Center.

NESDIS provides several resources to the JIC: data from satellite sensors, funding at approximately \$40,000 a year, and one staff person. The Navy staff numbers about 18; NOAA's National Weather Service provides one staff person.

Table 7 lists the parameters and range of JIC's analysis capabilities for its categories. The Navy recognizes the need for improvement in the precision and timeliness of ice coverage that could result from the use of digital techniques rather than the present reliance on qualitative evaluation of ice conditions, which is derived indirectly from wind and meteorological information and other inferences.

TABLE 7 Data Analysis Capabilities of the Joint Ice Center

Parameter	<u>Environmental Conditions</u>		Reconnaissance
	Cloud Free	Cloud Covered	
	<u>Location (km)--range of accuracy</u>		
Ice Edge	5-10*	25-100 km	1
Icebergs	5-10*	None	1
	<u>Tenths of area covered</u>		
Concentration	5	3	1
	<u>Size</u>		
Ice Islands	5-10* km	None	20 m
Leads/Polynyas	1-4* km	25 km	10 m
	<u>Conditions observed</u>		
Ridging/Keeling	None	None	Frequency of ridging
Ice Motion	Directions and velocity from drifting buoys		None

*In limited areas due to lack of local area coverage or high-resolution picture transmission coverage.

NOTE: Age estimated as new, young, first-year, or old; thickness estimated as thin, medium, thick, first-year, or old.

SOURCE: Joint Ice Center.

U.S. Air Force

The U.S. Air Force operates Distant Early Warning (DEW) sites in Alaska and the Canadian Arctic. Ship and barge supply of these sites has been the major maritime operation north of Cape Prince of Wales until the recent oil development in the Beaufort Sea and North Slope area.

The Air Force Arctic Research Program deals only with atmospheric research, particularly concerning the Arctic ionosphere, and how to predict its changes and to assess the effects of these changes on Air Force communication and surveillance in the Arctic.

The Air Force has operational responsibility for the Global Positioning System (GPS). As was noted in the discussion of marine navigational systems in Chapter 1, the Air Force has made a commitment to provide GPS for use by other government agencies and civilian offshore operations beginning in 1987.

U.S. Army Corps of Engineers

In regard to its defense-related mission, the Corps of Engineers (COE) has no legislative constraints. However, the River and Harbor Act of 1899 and the Clean Water Act of 1977 add civil responsibilities in regulating certain construction and filling activities in U.S. waters, including coastal waters, rivers, streams, and some wetlands. Any regulated activity in these areas must be preceded by a permit from the Corps, specifically from the District office in Anchorage for Alaskan operations.

The focus of COE ocean engineering activities and research is in support of military requirements. However, the Corps has recognized the need for and value of joint research and development (R&D) in support of Navy needs and with civil research projects where the COE has unique facilities and staff capabilities which are not in competition with civilian laboratories and where such research would enhance the capabilities and expertise of the Corps. The Shell Oil Company/Corps of Engineers Sea Ice Mechanics program is illustrative of such a mutually beneficial arrangement and is discussed in Appendix D.

Cold Regions Research and Engineering Laboratory (CRREL) This specialty laboratory is operated by the COE and focuses on geophysics and engineering for military operations and construction in the world's cold regions. It supports the civil works responsibilities of the Corps concerning winter navigational problems. Much of the laboratory's work is applicable to the civilian sector. The CRREL staff numbers about 275, including more than 100 engineers and scientists.

The laboratory has a large library that, in conjunction with the Library of Congress, has access to the world literature on the science and engineering of the cold regions. Other CRREL facilities include 26 cold rooms, a large model basin for testing ships and structures in ice, a refrigerated flume, refrigerated hydraulic model facilities, and a wide variety of specially designed equipment developed for dealing with snow, ice, and frozen ground problems. A new building, which is under construction, will permit large-scale experiments on problems of ground freezing. However, CRREL's most valuable asset is its varied and experienced technical staff. It also provides opportunities in the academic field for professors on sabbatical leave and for thesis work by graduate students.

CRREL has a long and distinguished record of work on problems related to the science and engineering of the polar oceans, beginning with its initial study of the engineering mechanics of sea ice (the Joint Services Sea Ice Physics Program, Labrador and Greenland 1955-57). Frequently, CRREL's work in the polar oceans has focused on problems caused by the presence of ice--sea ice, ice islands and icebergs, snow cover, and subsea permafrost.

With few exceptions, CRREL research on polar ocean problems has been funded by other government organizations and agencies, including the Department of Energy, the Minerals Management Service, NASA, National Science Foundation, NOAA, U.S. Air Force, U.S. Coast Guard, U.S. Geological Survey, and the U.S. Navy. In addition, private organizations--Shell Oil Company, Exxon, and Sohio--have supported ice research programs at CRREL through joint and individual projects.

Defense Mapping Agency

The Defense Mapping Agency (DMA) provides coastal, harbor, and approach charts of the Arctic coasts of North America, Eurasia, Greenland, Iceland, and offshore islands in response to military and civil sector requirements. The Department of Defense Nautical Chart Library, maintained by DMA, is the repository of all available foreign charts of the region. DMA also is responsible for tracking satellites.

U.S. Department of Transportation

U.S. Coast Guard

The legislative requirements for the Coast Guard, in addition to enforcement of laws and treaties, are derived from an extensive set of acts which direct responsibility such as providing icebreaking services, maintaining aids to navigation, providing search and rescue services, protecting fishing resources, and undertaking remedial

action in the case of oil pollution. Many of these requirements focus on functions under Arctic environmental conditions. Coast Guard responsibilities, which are related to Arctic activities, are set forth in the following public laws:

- Federal Water Pollution Control Act (1972);
- Ports and Waterways Safety Act (1972);
- Deep Water Ports Act (1975);
- Clean Air Act (1977);
- Outer Continental Shelf Lands Act Amendment (1978);
- Ports and Tanker Vessel Safety Act (1979); and
- Title 14, USC--which includes requirements related to icebreaking, aids to navigation, persons or vessels in distress, services to other agencies and states, and to assist the operation of commerce.

The Coast Guard traditionally has operated in the Arctic to support the resupply and logistical operations for the Department of Defense's facilities. It has also served as standby for search and rescue and has placed navigational aids at selected North Slope locations. Support of the scientific and oceanographic activities of other agencies has included the Maritime Administration's trafficability studies and the Department of the Interior's marine mammal surveys.

The Coast Guard has the only U.S.-owned icebreaking capability.¹ The six-vessel icebreaking fleet includes two Wind Class icebreakers and the GLACIER, which are aged and soon will need to be replaced or to undergo major renovation. NORTHWIND and WESTWIND were built in the mid-1940s and GLACIER was built in 1955. The Coast Guard estimates 2-3 years are required for the design process and 4 years

¹Coast Guard ice operations are conducted by medium-endurance, all-weather icebreakers, of which one is ice-capable; patrol boats; and one ice-capable cutter (USCGC STORIS); ice-capable large buoy tenders; and ice-capable auxiliary general icebreakers, of which there are five: POLAR SEA, POLAR STAR, NORTHWIND, WESTWIND, and GLACIER. USCGC STORIS and the large buoy tenders are limited generally to ice thicknesses of less than 0.65 meters (2 feet). The POLAR Class is capable of year-round operation north of the Aleutians and along the North Slope. The WIND Class and GLACIER have a marginal capability to operate north of the Bering Strait in winter.

are required to build new ships. If the planning and budgeting time were added to the complete authorization and construction process, as much as 10 years may be needed before a new icebreaker could be available. The U.S. Coast Guard policy regarding replacement and upgrading of the fleet will be influenced by the results of an interagency study to be completed in 1984.

In the Arctic environment--which imposes high operational costs--icebreaking, as well as other traditional services, such as search and rescue, safety, and navigational aids, face increasingly more difficult budgetary constraints. The Coast Guard's missions in the Arctic, their present activity, and capabilities are summarized below.

Enforcement of Laws and Treaties (ELT) The Coast Guard has not yet needed to use its potential capability north of the Aleutians. POLAR and WIND Class breakers provide the potential for undertaking this mission in ice-covered waters.

Search and Rescue (SAR) The Coast Guard has the capability to conduct SAR on non-ice-covered waters north of the Aleutians. USCGC STORIS and large buoy tenders have conducted SAR on ice-covered waters, though their icebreaking is limited. The SAR demand on ice-covered waters is presently minimal. The five auxiliary general icebreakers can serve as SAR standby platforms when operating north of the Aleutians; their polar operational capability is extended by use of two helicopters (HH-52's). Arctic SAR capability for ice-covered waters, when icebreakers are not operating in the area, is dependent on twin-engine helicopter service (presently 3 HH-3 helicopters) operating from Kodiak Island and refueling at such locations as Barrow. Helicopter range is 300 miles from the fuel depot; however, 15 percent of the Bering Sea, an area along the U.S.-USSR border, cannot be reached.

"Domestic" Icebreaking The Coast Guard does not have domestic icebreaking capability over most of the Alaskan coastline because of the deep draft of its breakers (POLAR Class and WIND Class--8.53m [28 ft.], GLACIER--7.92m [26 ft.]). No domestic icebreaking has been conducted north of the Aleutians since the Prudhoe Bay sealifts of the 1970s.

Scientific Operations Polar icebreakers serve as the operating platforms that federal agencies may use for Arctic research. Examples include:

- Trafficability study for the Maritime Administration, Department of Transportation, feasibility of western Arctic year-round marine transportation system;
- Western Arctic marine mammal surveys, for the Department of the Interior's Minerals Management Service and NOAA;

- Topographic studies and acoustical research, for the Department of Defense; and
- Studies of the marginal ice zone for NOAA.

Humanitarian Services Because of the availability of dependable air service to outlying areas north of the Aleutians, no demand exists for ship transportation for humanitarian services, although the POLAR and WIND Class breakers possess the capabilities to render assistance, should it be needed.

Pollution Response The POLAR and WIND Class breakers and GLACIER have served as research platforms for Coast Guard projects in Arctic marine pollution response. These breakers could serve as staging platforms for responding to pollution incidents.

Navigation The Navy-operated NAVSAT (navigation satellite)² is now used for position fixing and, in addition, a helicopter aids in determining ice conditions, existence of leads, and other factors affecting the course and operation of Coast Guard cutters. Recent installation of an automatic picture transmission (APT) satellite image receiver/processor on POLAR SEA and POLAR STAR enables these ships to receive near-real-time satellite imagery showing ice conditions.

As noted earlier, there is no Coast Guard plan to extend Loran C navigation service in the Arctic to the Chukchi and Beaufort seas since GSP service is anticipated.

Funding of Icebreaker Facilities and Services

Icebreaker service in support of other agencies is fully reimbursable; user agencies fund both fixed and operating costs for the polar icebreaker fleet. The Memoranda of Agreement between the Coast Guard and other polar icebreaker "user agencies," which govern reimbursement, state the following:

The Coast Guard will plan and fund icebreaker acquisition, construction, and improvement (capital improvement) projects. This type of project will include icebreaker replacements and major rehabilitation and renovation work costing, in general, over \$125,000 per project.

²The Coast Guard will use the NAVSTAR (navigation satellite, timing and ranging)/GPS (global positioning system) when the system becomes available in the late 1980s.

Support Required by Increased Offshore Development

Pollution Response The U.S. Coast Guard responsibility covers all U.S. ocean areas including U.S. Arctic waters. Under a Memorandum of Understanding with the MMS, prior to approval of OCS Exploration Development Plans, the Coast Guard reviews oil spill contingency plans submitted by industry and advises MMS as to their adequacy. The contingency plans must provide an industry response capability that adequately addresses the risk presented by the drilling activity.

Research and Development in Arctic Oil Spill Behavior The objective of a group of projects is to understand and predict the behavior and movement of oil spills in an Arctic environment, particularly in the offshore regions of the Beaufort Sea. This work is being carried out primarily at the Coast Guard R&D Center, Groton, Connecticut. An environmental atlas for the North Slope region, including information on general oceanography and meteorology of the region, is being prepared. The information will be used to develop models for predicting oil spill behavior (e.g., spreading, vertical migration, and weathering) and oil spill movement in Prudhoe Bay and coastal areas of the Beaufort Sea. Projects that focus on oil spill detection and surveillance techniques applied to the Arctic environment, defining the extent of contamination, and monitoring the subsequent movement of the spill have been proposed for fiscal year 1985.

Research and Development in Arctic Oil Spill Countermeasures and Cleanup Technology This project comprises cooperative research with other agencies and organizations, such as Canadian AMOP (Arctic Marine Oilspill Program) and Alaska Clean Seas (ACS) and involves test and development of Arctic oil spill countermeasures and cleanup equipment. The project emphasis is on understanding the latest technology available to meet Coast Guard spill response monitoring and contingency planning responsibilities.

Maritime Administration

Maritime Administration (MARAD) activities and interests have included, for more than five years, an assessment of the risks and feasibility of Arctic maritime transportation systems; this activity, including early studies, is described in Appendix B. There are no legislative constraints to undertaking these areas of study:

- Environmental assessment--knowledge of the ice condition severity;
- Ship design standards--for hull resistance, power requirements, structural loadings, maneuverability, and propeller design;

- Operation criteria--navigational ability in ice-infested waters;
- Shipping systems and ports supporting Arctic transportation; and
- Financing incentives.

MARAD has provided funding for the Coast Guard's two POLAR Class icebreakers for use in two trafficability tests in the Bering and Chukchi seas. Icebreakers have served as platforms to collect data on ice characteristics and ship performance. Tests have been conducted with the cooperation of the Canadian Ministry of Transport and with the participation of interested industry groups and federal and state agencies.

U.S. Department of Commerce

National Oceanic and Atmospheric Administration (NOAA)

Those National Oceanic and Atmospheric Administration (NOAA) activities and programs which are Arctic-related are largely joint endeavors with one or more agencies. The Outer Continental Shelf Environmental and Assessment Program (OCSEAP) has been undertaken in collaboration with the Departments of the Interior and Energy. The interagency environmental assessment program, of which OCSEAP is a part, and the operational and environmental informational services are discussed later in this chapter in the context of interagency activities.

There are no legislative constraints to NOAA's activities in Arctic offshore support. The agency has a specific legislative offshore responsibility for mapping and charting U.S. waters, weather services, and fisheries management. NOAA serves as the government operating agent for satellite-based environmental data for civilian use. Several of its services, such as weather information and forecasting, have been examined as a potential user-fee-supported activity. In this regard, transfer of some functions or services to the private sector remains an issue. Meanwhile, in 1983, NOAA's first Regional Service Center went into operation in Seattle, Washington, and a second office was opened at Anchorage in July 1984. These Regional Ocean Service Centers were established as a focus for NOAA's oceanographic and atmospheric information services and products for local and commercial needs.

NOAA research has been undertaken in the following topical areas:

- Climate and meteorology: NOAA maintains an observatory at Barrow, Alaska, which is one of four worldwide sites to monitor the atmospheric constituents important for climate

change (part of the global monitoring network of the World Meteorological Organization, WMO). NOAA's National Weather Service (NWS) in Alaska undertakes research regarding local climatic and oceanographic phenomena. In addition, NOAA's Environmental Research Laboratories are active in Arctic cyclone development and remote sensing of sea ice.

- Atmospheric research: NOAA and the National Science Foundation provide funding for the international study of Arctic haze at the University of Rhode Island. NOAA also conducts research as part of this program.
- Sea ice phenomena and forecasting: Investigation of the distribution and trajectories of ice flows in the Bering Sea near Norton Sound have been supported by a NOAA project which employs the capabilities of NOAA's Pacific Marine Environmental Laboratory and a contractor, Flow Research Corporation. Other ice studies address the effects of the accretion of ice on structures and the characteristics of trajectories of oil spills under ice. NOAA is sponsoring studies by the University of Alaska that seek to describe accurately ice phenomena, particularly regarding ice breakup and coverage in Norton Sound.
- Arctic oceanography and biology: NOAA's Office of Marine Mammals carries out studies related to marine mammal and endangered species in the northwest region of the Alaskan Arctic, often in conjunction with the University of Alaska. These studies concentrate on bowhead whale research and monitoring of the Inupiat bowhead whale hunts. Recently, a Canadian observer has participated in these studies. NOAA's Sea Grant program also provides numerous awards to universities and other research agencies concerning development of Arctic marine living and natural resources.

The following NOAA studies in progress are examples of projects to evaluate the effect of Alaskan offshore development on marine life:

- Life history studies of bowhead whales in the U.S. and Canadian Beaufort Sea.
- Population dynamics, behavior, physiology, and fisheries interaction of the northern fur seal, in the Bering Sea and north.
- Bering Sea ecosystem analysis (marine mammals).
- Incidental catch of Dall's porpoise and other marine mammals in the Japanese salmon mothership high-seas gillnet fishery.

Studies have been planned, but are not funded, to assess the movements and behavior of gray, white, bowhead, hump back, and killer whales in

relation to ice, human activities, and other short-term changing environmental conditions; and determining the acoustic response and propagation of sound in the presence of migrating and feeding whales.

The potential marine biological resources for the Alaskan Arctic area are difficult to evaluate because the status of most stocks is not known, or at least not well understood. The principal concerns for marine mammals are twofold: (1) loss of individuals from already dwindling or endangered populations, and (2) loss or reduction of other resources, such as food or habitat, which may limit the growth of the marine mammal populations. Most large whales in the Bering Sea and Arctic region are considered endangered or threatened, and any adverse actions upon these populations might be irreversible.

National Environmental Satellite Data and Information Service

(NESDIS) This NOAA service supplies imagery data, data collection, and platform location services from two polar orbiters (NOAA 7 and 8). NOAA estimates that 5 to 10 percent of the useful output of the polar orbiting satellites is Arctic-related. Ice edges (0.8-kilometer resolution),³ coverage (percent concentration), and estimates of age (thickness) are derived from this data base.

The satellite data collection capability provides both direct and simultaneous transmission of data received from surface platforms and data storage for later transmission to the ground station at Toulouse, France. The data collection capability has been employed primarily in research-type activities, although Exxon and others have used it operationally. Position locations (accuracy: 1-3 kilometers) are provided by processing the received data from at least two transmissions from a surface platform.

The polar orbiters will be replaced as needed up through 1989. Funding has been planned, but not yet approved, for replacement in the 1990s with satellites carrying an Advanced Microwave Sounding Unit (AMSU) which would provide somewhat lower resolution but would have all-weather coverage. In addition, as noted in Table 2, Chapter 1, page 30, unclassified data will be available in 1986 from the Defense Meteorological Satellite Program (DMSP), which will have military satellites carrying a special sensor microwave imager (SSMI) capable of sensing edges and coverage. This imager will also provide a direct estimate of ice age through the phenomena of ice emissivity change.

NESDIS is closely coupled to the Navy's Remote Ocean Sensing Satellite (NROSS). The Navy will equip and launch NROSS in 1989 with NESDIS having access to data providing microwave all-weather ice surveillance capability.

³NOAA's 0.8-kilometer resolution imagery is useful only in cloud-free scenes. NASA all-weather passive microwave satellite data is provided to the Joint Ice Center by the Navy's Fleet Numerical Oceanography Center in a 60-kilometer resolution format.

After 1985, NOAA-NESDIS will become part of a shared data processing network with the Air Force and Navy. Interconnected by high-speed data links (1.3 megabits per second), the three agencies will distribute responsibility for processing as follows:

- NESDIS (Suitland, Maryland)--atmospheric soundings;
- Air Force--imagery (visual and IR);
- NAVY (Monterey, California)--marine data (e.g., sea surface temperatures).

NESDIS has no independent plans to expand communication or navigation services in the area.

U.S. Department of the Interior

Minerals Management Service

The Minerals Management Service (MMS), established in 1982 from several existing divisions of the U.S. Geological Survey, the Bureau of Land Management, and other Interior offices, is the focus of government activity dealing with development of the Outer Continental Shelf (OCS), one of the major programs being the oil and gas leasing program. Early in 1981, the schedule for leasing was revised to speed up the process and to advance the timing of development for the offshore areas having the greatest potential; several Alaskan Arctic offshore areas were affected by this acceleration in lease plans.

There are no specific legislative constraints on the MMS, and the MMS has pursued developmental research in response to the anticipated data and informational needs to support its role in the administration of leases as specified by the Outer Continental Lands Act. Joint government/industry and interagency research programs have been encouraged and have been implemented, such as the sea ice mechanics studies at CRREL (with participation by Shell Oil), and OCSEAP, which was initiated in 1973 in conjunction with NOAA. Information from the latter studies is used in oil spill trajectory analysis, environmental impact statements, and departmental decision documents, as noted earlier. Since 1973, OCSEAP funding by MMS for projects on the Alaskan OCS has been over \$200 million or 50 percent of the OCSEAP total budget.

Research for Engineering Applications in the Arctic. The Technology Assessment and Research (TA&R) Program of the MMS supports, in conjunction with industry and educational institutions, the following research directed toward the Arctic environment: (1) structural materials for Arctic operations, (2) mechanical properties of sea ice, (3) ice forces against structures, (4) behavior of concrete offshore structures in cold regions, and (5) superstructure icing data collection and analysis.

The Arctic-related studies sponsored by the MMS in 1984 are as follows:

Research under contract to industry or consultant:

- Technology Assessment for OCS Oil and Gas Operations in the Arctic Ocean
- Arctic Underwater Structural Inspection
- Southern Bering Sea Production System Study (joint project with industry)
- Evaluation of Structural Concepts for Norton Sound (joint project with industry)

Research being conducted by the National Bureau of Standards under MMS support:

- Structural Materials for Arctic Operations
- Behavior of Concrete Offshore Structures in the Arctic (joint project with industry and Canadian government)
- Reliability of Gravel Mat Foundations for Arctic Gravity Structures

Research being conducted by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory:

- Mechanical Properties of Multiyear Sea Ice (joint project with industry)
- Environmental Effects of Wellhead Removal by Explosives
- Development and Testing of an Ice Stress Sensor
- Engineering Properties of Subsea Permafrost
- Assessment of Structural Icing
- Superstructure Icing Data Collection and Analysis (joint project with industry)

Research being conducted by University of Alaska:

- Ice Forces Against Arctic Structures

Research being conducted by Woods Hole Oceanographic Institution:

- Seafloor Seismic Data Study (joint project with industry and the Department of Energy-Sandia)

Research being conducted by Clarkson College of Technology.

- Deicing and Prevention of Ice Formation on Offshore Drilling Platforms

The nature of the TA&R Program is twofold. First, technology assessments are conducted to determine, analyze, and compare state-of-the-art practice and knowledge, and to identify technology gaps or possible improvements for further study. Second, research studies are conducted to quantify the applicability of technologies to MMS operational needs and to provide needed information that is not available from industry or other agencies.

The MMS has provided partial funding for an expansion of the oil spill containment and cleanup equipment testing facility at Leonardo, New Jersey, which is jointly administered (with the Coast Guard). This facility, the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT), can withstand significant ice cover forces and the effects of operating during below-freezing conditions. The OHMSETT facility began oil and ice equipment testing in early 1984. The test tank is 203 meters long, 20 meters wide, and 2.4 meters deep, allowing testing of full-scale equipment in a variety of ice and oil conditions without risk to the environment.

Endangered Species During the past 5 years, the MMS has conducted an aerial survey of the bowhead whales in the Beaufort Sea to ascertain their movements and abundance. Another investigation has focused on beluga whales in the coastal waters of Alaska with an emphasis on the effects of noise disturbances upon them. Other, closely related studies include: (1) computer simulation of the probability of endangered species interacting with an oil spill, (2) possible effects of acoustic stimuli on bowhead whales, (3) the effect of noise on gray whales, and (4) the development of satellite-linked methods for tagging and tracking large cetaceans.

U.S. Geological Survey

Since 1982, after reorganization of the Department of the Interior's offshore activities, the U.S. Geological Survey (USGS) marine programs have been redirected to basic research on the OCS, including geotechnical investigations in the following categories.

- Regional Geologic Framework The goals of this program include the regional understanding of geologic conditions, tectonics, and evolution of the Continental Shelf. The identification of basins and the geologic setting conducive to energy and hard mineral formation continue to be the research aims of the USGS. Beaufort Sea and Chukchi Sea information are undergoing this analysis. Future

investigations are aimed at surveys of known, but inadequately mapped basins, or unsurveyed areas on the continental slope, rise, and deepwater areas.

- Mineral Resources Based on the previous program element, the USGS continues oil and gas studies of the OCS, but not on sale-by-sale basis as before. Basin analysis for petroleum prospects (including unconventional resources such as gas hydrates), source rock identification, and similar topical oil and gas projects continue. Several studies performed earlier on sand and gravel resources in the Beaufort Sea and Norton Sound are being used by MMS as guidelines in leasing those resources. There are no immediate plans to continue studies of hard mineral deposits in Arctic waters. Resource estimates for onshore and offshore oil, based on a regional scheme, will continue to be prepared.
- Geologic Processes Several studies, conducted in the past under the umbrella of environmental geology, continue⁴:
 - Geologic framework and resources assessment of the Beaufort and Chukchi seas;
 - Environmental geologic studies of the Beaufort and Chukchi seas;
 - Geologic framework and resource assessment of the Bering Sea area;
 - Geology and resource assessment of the northern Bering Sea;
 - Resource and geo-environmental assessment of Aleutian ridge and shelf; and
 - Alaskan marine micropaleontology.

With respect to the Arctic, topics such as shallow faulting, sedimentation/erosion/sediment transport, modification of shorelines and shoals and their agents (including freeze-thaw cycles, thermal erosion), offshore permafrost, and ice gouges, continue to be of current interest. The number of active Arctic projects have declined, however, as funds have contracted. Present activities in the Beaufort Sea concentrate on sea ice as a geological agent of the past and on recent sedimentary and geomorphic processes. A principal geotechnical concern is how to determine the stability and

⁴This list of 1983 projects includes projects specifically designated for Arctic portions of the U.S.-Alaskan waters, i.e., north of the Aleutians.

shear resistance of offshore Arctic silts, but no activity has been currently funded by the USGS.

- Other Activities. Onshore, coastal studies, and environmental rehabilitation investigations in the National Petroleum Reserve in Alaska (NPRA), as well as some permafrost research continue. In regard to sea ice, development of remote sensing techniques using data from radars and microwave radiometers continue for the Arctic ocean application.

Facilities The USGS operates two oceangoing vessels, the SP LEE and the POLARIS II, for marine geological and geophysical surveys. The SP LEE has spent several years in gathering deep seismic reflection data in the Arctic seas, including the Beaufort Sea. There are no plans at present to send the LEE or the POLARIS II to the Arctic region; neither vessel is capable of operations in ice-infested waters.

A coastal vessel dedicated to research in the Beaufort Sea, the KARLUK, has been gathering geophysical data in the Beaufort Sea, this activity was supported by OCSEAP through fiscal year 1983. Instrumentation used on or deployed from the vessels include CDP seismics, shallow seismics, echo sounders/bottom profilers, sonars, current meters, coring devices, and geotechnical instruments.

There are no laboratory facilities in the USGS dedicated to cold-regions research. Approximately 8 technical persons are engaged in the conduct or administration ongoing of Arctic research. Short-term efforts involving the North Slope studies of federal reserve areas on the North Slope boost USGS Arctic study activity to perhaps 15 persons a year in 1984 and 1985.

Cooperative Efforts Negotiations are underway to set up a cooperative research effort in the Beaufort Sea with the Geological Survey of Canada. The aim of this cooperation is to conduct joint surveys for the comprehensive understanding of the geology of the Beaufort Shelf, and to investigate sedimentation history and ice-scour regimes.

Department of the Interior, Other Arctic Activities

Bureau of Indian Affairs (BIA) The BIA assists the aboriginal Alaskan natives in protecting and ensuring their benefits from trust assets, including consideration for the native interests in hunting, gathering, and fishing rights, including bowhead whales.

Fish and Wildlife Service (FWS) The FWS conducts scientific research on polar bear, walrus, and migratory birds in the Alaskan Arctic. Such research is carried out under the authority of the Marine Mammal Protection Act of 1962; the Circumpolar Agreement on the Conservation of Polar Bears; and the U.S.-USSR Convention on the Conservation of Migratory Birds and their Environment. In accordance with the Fishery

Conservation and Management Act of 1976, which established a 200-mile fishery conservation zone, FWS is represented on fishery management councils. It also takes action to protect threatened and endangered species under the Endangered Species Act of 1973.

The FWS's scientific research program has emphasized the ecological effects of human activities related to development and exploitation of the marine environment on marine wildlife and ecosystems. These effects relate particularly to the habitats and populations of polar bears, walrus, caribou, anadromous fish, migratory birds, and species appearing on the U.S. list of threatened and endangered species.

U.S. Department of Energy

There are no legislative constraints to the Department of Energy's (DOE) mission of maximizing the energy supply from the U.S. Arctic while giving consideration to environmental needs and foreign policy concerns. U.S. Arctic energy-related policies and actions are closely linked with those of Canada, including joint research conducted in the Canadian Arctic.

DOE Arctic and Offshore Research Program The objective of DOE's Arctic and offshore research program is to reduce the technical and economical uncertainties in the development and production of Arctic oil and gas resources in Alaska and the Bering, Chukchi, and Beaufort seas. This program involves three major functional areas:

- Ice characterization, including laboratory and field analysis of multiyear ice, ice island movement analysis, laboratory analysis of ice accretion and structure. Contractors and other supporting agencies: University of Alaska, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), U.S. Geological Survey (USGS).
- Seafloor/soils research, including seafloor scouring and gouging, frost heave pipeline analysis, permafrost evaluations, and acceleration/velocity of seafloor movement/structure. Contractors and other supporting agencies: CRREL, USGS, Sandia National Laboratories.
- Program management, including data base development and technology transfer, is administered by the Department of Energy, Morgantown Energy Technology Center.

National Aeronautics and Space Administration

The objective of NASA's program related to Arctic development is to understand the physical characteristics and interrelationships of the ice cover and the upper atmosphere. Knowledge of the ice cover is of most relevance to this study. Here, the goal is to use spaceborne sensors to determine characteristics of the polar ice cover, and to understand how these are influenced by and in turn influence the atmosphere and ocean. The three primary sensors for this work are microwave radiometers, providing coarse-resolution imagery with a swath width of the order 1,000 kilometers; synthetic aperture radar (SAR) providing high-resolution imagery with a swath width of approximately 100 kilometers; and the radar altimeter--providing detailed information only along the subsatellite track.

NASA's program is focused on improving its ability to translate passive-microwave and SAR measurements rapidly and accurately into scientifically useful geophysical parameters, i.e., sea ice extent, concentration, type; velocity, and the sizes, shapes and distributions of ice floes and leads.

Past, present, and planned satellite missions relevant to research in polar regions were summarized in Table 2, Chapter 1. The possibility of adding a capability for real-time processing of ERS-1 data has been raised and, although not presently assured in budgeting, is receiving serious consideration by NOAA. The detail planning for the Alaskan receiving facility is underway by NASA, but completion funding before fiscal year 1986 is uncertain.

The NOAA weather satellites and LANDSAT were not included in Table 2. These satellites provide sea ice imagery at optical and infrared wavelengths. Spatial resolution is of order 1-4 kilometers for weather satellites and a few tens of meters for LANDSAT. Infrared imagery can be obtained at night, but no information can be obtained through a cloud cover. The high-resolution LANDSAT imagery can be extremely useful over ice, but arrangements have to be made to switch the sensors on over the area of interest.

National Science Foundation

The National Science Foundation (NSF) supports programs of fundamental research in and on the Arctic. This research includes projects throughout the entire (non-Soviet) Arctic, including Alaska, Greenland, Canada, Svalbard, and the Arctic Ocean.

The National Science Foundation has, since 1971, maintained the Arctic Research Program in its Division of Polar Programs (DPP) as one component of its overall Arctic research effort. DPP sponsors both small single-investigator research projects and large multi-investigator and multidiscipline research programs such as the Greenland Ice Sheet Program (GISP) and Processes and Resources of the Bering Sea Shelf (PROBES). PROBES has been one of the major marine ecosystem programs for U.S. Arctic ocean areas; it is coordinated and

managed by the University of Alaska. Additional research, applicable to the Arctic offshore, may be sponsored by other NSF divisions.

The NSF's Arctic Research Program's objective is to support the more complex and important Arctic research into problems that require an interdisciplinary approach for resolution. Areas of special interest include:

- Mechanisms of energy transfer between the magnetosphere, the ionosphere, and the neutral atmosphere;
- The role of the Arctic Basin in influencing climate;
- Interactions of the Arctic and subarctic areas with the global ocean system;
- Sea ice occurrence and behavior in coastal waters;
- History of climatic changes as revealed in the study of ice cores obtained at depth in the Greenland ice sheet;
- Permafrost properties and characteristics; and
- Structure, function, and regulation of Arctic terrestrial and marine ecosystems.

The foundation also manages the nation's Antarctic Program. The budget for this program is a separate additional appropriation of funds to the NSF that cannot be comingled with funds appropriated for the NSF's regular budget. As a consequence, there can be no conflict or competition for NSF support of research between Arctic and Antarctic locations.

U.S. Department of State

Responsibility for national participation in international activities related to the Arctic is lodged in the U.S. Department of State. The Department of State has three basic responsibilities in the Arctic: (1) definition and implementation, through appropriate negotiations, of the international interests and responsibilities of the United States in the Arctic; (2) facilitating the execution by other federal agencies of their mission responsibilities, requirements, and activities throughout the Arctic when these have international ramifications; and (3) negotiation of Arctic maritime boundaries.

In pursuit of the first two of these responsibilities, the department negotiates, or assists in the negotiation of, suitable agreements and arrangements with friendly circumpolar states and other countries (notably the NATO group) whose commitments include the Arctic. Cooperation with Denmark concerning U.S. scientific research

in Greenland is informal and close. Periodic meetings with Canada in two informal forums provided useful exchanges of information on Arctic research (led by NSF) and developmental activities (led by State) and seek mutually beneficial areas for cooperation. A scientific and technical agreement with the USSR in 1972 formed the basis for several programs; most only marginally deal with the Arctic, if at all. It did result, among other things, in several visits by U.S. scientists to Soviet drift stations in the Arctic. Such useful activities could be revived if a thaw in bilateral relations were to occur.

Environmental Protection Agency

U.S. environmental protection laws administered by the Environmental Protection Agency (EPA) have important implications for any resource developments in the Arctic. In particular, the Clear Air Act, the Clean Water Act, and the Marine Protection Research and Sanctuaries Act affect offshore oil and gas development as well as related onshore and offshore support activities. EPA also has a interest in preserving the environmental integrity of global commons areas as directed by Executive Order 12114.

EPA is involved in international negotiations and meetings of experts held pursuant to two major international marine pollution agreements relevant to the Arctic: the London Ocean Dumping Convention,⁵ and the MARPOL '78 Protocol.

Government Interagency Programs in Environmental Assessment

In addition to projects, such as PROBES (National Science Foundation) and individual Sea Grant (NOAA) projects, many of the activities to assess current and future impact of resource development and related activities upon the Arctic environment are shared by NOAA and the U.S. Department of the Interior (i.e., Minerals Management Service) through OCSEAP. OCSEAP's fiscal year 1984 budget is about \$11 million, of which NOAA provides \$4 million; Arctic technology development projects comprise about \$2 million of this program budget. The MMS establishes the information needs of the program depending on the OCS leasing schedule. NOAA manages the research program from its Juneau OCSEAP office. Some research is done in-house and by other federal agencies, but most is accomplished by university researchers and private consulting agencies. In keeping with current and anticipated terrestrial, nearshore, and offshore resource development activities in the U.S. Arctic, the scope of the OCSEAP is

⁵The official title is the "Prevention of Marine Pollution by Dumping of Waste and Other Matter."

restricted to the Beaufort, Chukchi, and Bering seas and their adjacent coastal zones. Because of OCSEAP's consolidated budget and reporting, the program appears to overwhelm other Arctic environmental efforts when, in fact, other independently funded projects, are also major elements in the overall assessment process.

The primary objective of Arctic Alaska OCS environmental studies, under OCSEAP, is to provide scientific information for management decisions that may be necessary to protect marine environments of the Gulf of Alaska and the Beaufort, Chukchi, and Bering seas from damage during oil and gas exploration and development, in accordance with the National Environmental Policy Act of 1969. The MMS-sponsored studies are intended to serve as the technical base for decisions concerning modification of leasing stipulations, operating regulations, and OCS operating orders to permit more efficient resource recovery with maximum environmental protection.

To fulfill these program objectives, OCSEAP addresses the following broad scientific objectives:

- Determine the nature and magnitude of contaminant inputs and environmental disturbances that may be assumed to accompany exploration and development on the Alaskan continental shelf;
- Determine the ways in which contaminant discharges move through the environment and how they are affected by physical, chemical, and biological processes;
- Determine and characterize the biological populations and ecological systems that are subject to impact from petroleum exploration and development; and
- Determine the social, cultural, and economic effects of OCS operations on the native and non-native populations of Alaska.

Achievement of the above objectives requires very broad approaches within comparatively narrow geographic limits. Thus, proper assessment of environmental hazards requires broad regional understanding of the geological, ice, and oceanographic hazards that might affect development. This involves determination and characterization of the biological populations, communities, and ecosystems that are at risk from acute or chronic impacts, and preparing estimates of the distribution and abundance of all biological populations in a potential resource development area based among other things, on knowledge of their feeding sites, migration, and behavior.

Government Interagency Activities for Operational and Informational Services

NOAA, Coast Guard, the Navy, and the Defense Mapping Agency together maintain a series of gauge networks for portions of the Arctic.

NOAA's National Weather Service leads a World Meteorological Organization (WMO) effort to establish an Aircraft to Satellite Data Relay (ASDAR) system to provide meteorological data across the Arctic region. NOAA also operates data gathering projects in solar-terrestrial physics, marine geology and geophysics, snow and ice and solid earth geophysics. These activities have led to large holdings of data on the Arctic, which are routinely exchanged through the World Data System. The data have important applications in defense, scientific research, environmental assessment, and resource development.

Joint Ice Center (JIC) Activities and Services The imagery data are used with passive microwave data from NIMBUS-7 by the NOAA/NAVY JIC as the basis for their routine issue of charts and other products showing ice boundaries, coverage, and age.

These products listed in order of decreasing frequency are as follows:

- Three times/week- ice analysis charts of the Bering Sea and North Slope (faxed to NOAA's Anchorage Ocean Service Unit (OSU) as input to their detailed ice forecasts).
- One time/week--ice analysis covering eastern Arctic and western Arctic (essentially the Northern Hemisphere).
- Seven-day ice edge forecast each for eastern Arctic and western Arctic.
- Two times/month- 30-day ice forecast for eastern Arctic and western Arctic.
- Seasonal forecast for Alaska published in May shows anticipated coverage, etc., for summer.
- Seasonal forecast as above for Baffin Bay and Greenland.
- Yearly atlas composed of the previous year's information products.

In addition, JIC tailors ice analyses for specific foreign and U.S. vessels as required. They provide twice weekly updates with intermediate 72- and 96-hour forecasts. Only specially tailored requests from private industry are handled by private sector ice information sources.

The analog products (charts) are presently being digitized to provide a data base for extensive statistical analyses of long-term ice parameters.

Modeling programs now underway, will produce a daily output from the National Meteorological Center (NMC) and a model of the Bering Sea produced by NOAA's Pacific Marine Engineering Laboratory (PMEL) in cooperation with the NMC and JIC.

The JIC and National Weather Service's (NWS) Anchorage offices collaborate to produce a detailed ice forecast. NWS Anchorage uses JIC microwave-data (60-kilometer resolution) -derived ice analyses when visual or IR imagery, which is transmitted directly to them from the Gilmore Creek ground station, is unavailable due to weather limitations. This is provided from Anchorage in broadcast and fax form.

JIC expects to employ SAR data from the European satellite ERS-1 and altimetry data from the Navy via GEOSAT to enhance their coverage and products.

Summary of Government Activities Supporting Arctic Ocean Engineering

The federal projects discussed in this report that are related to offshore and coastal development and to the protection of the environment will exceed \$50 million in fiscal year 1984. Recent informal estimates of all government research, including support service for both land and marine applications in the Arctic approach \$100 million. The magnitude of research applicable to Arctic offshore development in the government is imprecise, and estimates cannot be compared since such research is seldom identified as a budgetary line item for Arctic applications. Moreover, the costs for logistical support of research are usually not identified with specific projects. Even so, the civil works Arctic-related research of the Army Corps of Engineers (nearly \$16 million in fiscal year 1984) and the OCSEAP activities supported by the Department of the Interior and NOAA (at approximately \$11 million in fiscal year 1984) are the largest single research endeavors. OCSEAP research includes environmental and engineering-related projects, as discussed in this report. A summary of research and activities, by agency, is provided in Table 8.

THE FRAMEWORK FOR COORDINATION OF TECHNICAL SUPPORT AND SERVICES FOR ARCTIC OCEAN ENGINEERING

Until the Arctic Research and Policy Act of 1984 became law, there was no lead agency or effective government coordinating group for government support of Arctic research and development, including offshore-related activities. However, before this recent act, some agencies had established a leadership role, often as part of interagency agreements, to provide continuing support of specific services.

In 1965, the Navy initiated the Joint Ice Center (JIC) with NOAA to meet national goals beyond limited military objectives and, in effect, gave NOAA the "lead agency" responsibility in civil polar (in this case, Arctic) oceanographic forecasting.

Table 8 Summary of Government Activities Related to Arctic Ocean Engineering and Development

Department/Agency	Research and Development and Technical Services		Estimated Funding Range in \$M (FY84)	Indirect Services and Research
	Areas of Research	Location		
Department of Defense				
Navy	Sea ice characteristics	U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) Hanover, NH		
	Ice dynamics, acoustics, ice scattering, meteorology, geophysics, sediment distribution	Naval laboratories, universities, and oceanographic organizations (applied research)	8.0	
	Sea ice cover forecasts	Joint Ice Center Suitland, MD (with NOAA)		
Air Force				Ionospheric research, operation of Global Positioning System
U.S. Army Corps of Engineers	Geophysics, permafrost, sea ice mechanics, ice navigation	CRREL	14.-16.0	Other agencies supporting research at CRREL: Minerals Management Service, Navy, USGS, NASA, NSF, Air Force, Coast Guard
Defense Mapping Agency				Private industry (joint studies) Charting Satellite tracking
Department of Transportation				
Coast Guard	Maritime trafficability studies with MarAd			Icebreaker service, including support for scientific operations, search and rescue
	Pollution response in Arctic		0.1 (0.2 in FY85)	
	OHMSET test facility (with MMS)			
Maritime Administration (MarAd)	Trafficability studies		0.4	
Department of Commerce				
National Oceanic and Atmospheric Administration (NOAA)	Sea ice phenomena and forecasting	Joint Ice Center (with Navy)		Atmospheric and oceanographic research
	Ice accretion	NOAA Pacific Marine Environmental Laboratory	0.1	
	Arctic oceanography and biology, marine mammal studies	Univ. of Alaska		NOAA satellites
		OCSEAP studies-contractors and universities	4.0	

(Continued)

Table 8 (Continued)

Department/Agency	Research and Development and Technical Services		Estimated Funding Range in \$M (FY84)	Indirect Services and Research
	Areas of Research	Location		
Department of the Interior Minerals Management Service (MMS)	Structures and materials	Contracts with industry and AOGA, National Bureau of Standards	0.4 (.6 in FY85)	
	Ice forces	Univ. of Alaska, CRREL		
	Icing on structures	Clarkson College, CRREL		
	Oil spill and cleanup	OMSETT-oil spill in ice tests		
	Noise, effects on endangered species	Naval Ocean Systems Center		
	Environmental studies-OCSEAP	Universities, CRREL, contractors	7.0	
U.S. Geological Survey (USGS)	Beaufort/Chukchi Surveys		0.6 (offshore only)	
Department of Energy Arctic and Offshore Program	Ice characteriza- tion	Univ. of Alaska CRREL USGS	0.3	
	Seafloor soils	CRREL USGS	0.2	
	Data base, tech- nology transfer	Sandia Natl Lab DOE-Morgantown	0.4	
National Aeronautics and Space Administration				Ice cover and upper atmospheric analysis for Arctic Estimated basic research, \$1.8m FY84
National Science Foundation	Processes and Resources of the Bering Sea Shelf (PROBES)	Univ. of Alaska		
	Greenland Ice Sheet Program (GISP)			
	Arctic atmospheric/ climate research	Universities, contractors	14.0-15.0	
	Sea ice in coastal waters			
	Permafrost charac- teristics			
	Arctic marine and land ecosystems			
Approximate Total			\$50M	

NOTE: FY84 budget estimates are based on combination of published statistics and estimates of individual project cost based on interviews. Also, there may be some overlapping of agency budgets because of joint projects, such as those at CRREL.

Even earlier, the Navy gave the Coast Guard its icebreakers, thus turning over surface navigation in ice to the Coast Guard. Since this transfer, funding to support Coast Guard icebreaking operations and replacement vessels has been a controversial issue.

The broad scope of government activities directly related to engineering concerns in the development of the U.S. Arctic offshore areas, and the dispersion of these activities among various agencies that have varying objectives, make coordination by the government agencies most difficult. Various organizational approaches to focus government activities have been used in the past, including interagency committees, but the coordination committee approach generally degrades as the key administrative level personnel cease participating and as budgetary action severely reduces the government's ability to implement policy.

Despite the frequent ineffectiveness of interagency technical program coordination efforts, the committee recognized that the Arctic Research and Policy Act of 1984 provides the initial framework for interagency coordination, and it should encourage the attention and participation of upper echelon technical and administrative personnel from the agencies specifically named in the act.

A brief review of the Arctic Research and Policy Act of 1984 is provided in the following paragraphs, and the salient features that could fit into an effective framework for coordination are noted. First, the purposes of the Arctic Research and Policy Act of 1984 are as follows:

- To establish national policy, priorities, and goals and to provide a federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials, physical and biological sciences, and social and behavioral sciences;
- To establish an Arctic Research Commission to promote Arctic research and to recommend Arctic research policy;
- To designate the National Science Foundation as the lead agency responsible for implementing the Arctic research policy; and
- To establish an Interagency Arctic Research Policy Committee to develop a national Arctic research policy and a five-year plan to implement that policy.

The Arctic Research Commission, to be appointed by the President, is to cooperate with and assist the Interagency Arctic Research Policy Committee in establishing a national Arctic research program plan to implement the Arctic research policy. Moreover, the commission is to help in developing cooperation between the federal government, the state of Alaska, and local governments with respect to Arctic research. For this purpose, representation on the Commission will be

from academic or other research institutions and will be persons having expertise in various areas of Arctic-related research, including the physical, biological, health, environmental, and social sciences. In addition, one member will be a representative of the needs and interests of Arctic residents in areas directly affected by resource development, and another member will be familiar with the needs and interests of private industry engaged in Arctic resource development.

Among several significant requirements of the act, one states that the Office of Management and Budget (OMB) shall consider all agency requests for research related to the Arctic as one, integrated, coherent, and multiagency request, and that OMB will review this budget in regard to its adherence to a five-year Arctic research plan to be prepared by the Interagency Arctic Research Policy Committee. The act also states that NSF and the interagency committee would have several duties; of particular note is their responsibility to survey Arctic research conducted by federal, state, and local agencies, universities, and other public and private institutions, to help determine future research priorities, and to promote federal interagency coordination of logistical planning and data sharing. A representative of the NSF will serve as chairman of the Interagency Arctic Research Policy Committee, which is charged with implementing coordination and planning.

The act addresses the need for coordination of research activity but does not cover the equally important need for coordination of a large amount of federal support to Arctic operations, which extends beyond research. Those government services and activities, other than research, which have been identified earlier in the report, include weather and ice cover analysis and forecasting; icebreaker services; communication and navigation systems, such as the Global Positioning System (GPS); and acquisition of data essential to the government's role in planning and administering lease sale areas. The government will continue to have responsibilities for acquiring data, performing analyses and monitoring environmental conditions before and after offshore and coastal areas undergo development activities, as has been discussed earlier in this report. Effective coordination of Arctic marine and maritime operations requires agreement at the top levels of agencies involved, and this in turn indicates a need for a coordinating body made up of senior executives from concerned agencies.

The committee considered several alternatives in regard to the means of improving cooperation and coordination of activities that provide the technical information and service basis for federal support of Arctic offshore and coast development, and for federal and industry cooperation. Much research coordination is already evident in specific discipline areas and in interagency programs, as has been noted earlier in the report. A major deficiency, which became evident to the committee, is in the need to assure adequate logistical support and services, such as in icebreaker service, search and rescue, ice cover and weather forecasting. These and other services are critical to the success of research projects and to the Arctic development in general.

The agencies having Arctic technical interests will all be represented on the Interagency Arctic Research Policy Committee. In addition, the act provides sufficient motivation for high-level management participation to provide coordinated budgeting and the necessary long-range planning. Expansion of the function of the Interagency Arctic Research Policy Committee would appear to be an opportunity for improving the organizational framework for coordination of technical activities for Arctic offshore development. Such an expansion of the purview of the interagency committee would also provide a central point of contact for cooperation between government and industry.

Within the federal government the capability exists for support of industrial as well as joint efforts in Arctic ocean engineering. At the same time, it should be noted that historic services provided in the past by the federal government may be limited in the near future. These services are broad based geographically, as opposed to being precise and specific, and have historically been a federal responsibility because of their high cost and risk, as well as because they serve multiple users.

There could be concern that expansion of the Interagency Arctic Research Policy Committee's purview beyond research would undercut the research coordination effectiveness of the committee. The committee recognizes this danger, but expects that the advantages of coordination of technical services and logistical support of Arctic research and development will more than offset the added complexity and increase in committee effort.

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APPENDIX A
SUMMARY OF BACKGROUND REPORTS AND FINDINGS
IN ARCTIC OFFSHORE ENGINEERING

In conducting its study of the national capability to support Arctic Ocean engineering, the Marine Board's Committee on Assessment of Arctic Ocean Engineering Support Capability used the findings of these studies as a "point of departure" in its assessment. Summaries of the findings follow.

U.S. Arctic Oil and Gas, National Petroleum Council (NPC), 1981 This report, prepared in response to a 1980 request from the secretary of Energy, is a comprehensive assessment of U.S. Arctic oil and gas development, both on land and sea. The ocean areas discussed are the same as those considered to be "Alaskan Arctic" in this report. A key finding in the NPC study was that:

The basic technology is available to safely explore for, produce, and transport oil and gas in most of the U.S. Arctic. Industry experience in the North Slope area, Cook Inlet, Gulf of Alaska, Canadian Arctic, North Sea, and in other cold, hazardous, or deep-water areas provides the basis for the design, construction, and operation of systems in Arctic regions. Proven technology exists for onshore operations. Proven technology and sufficient information and technical expertise for advanced design work is available for industry to proceed confidently with operations in water as deep as 184 meters (650 feet) in the southern Bering Sea and to about 60 meters (200 feet) in the more severely ice-covered areas of the northern Bering, Chukchi, and Beaufort seas. These capabilities will allow development of prospective areas in all of the northern Bering Sea, most of the southern Bering Sea, and well out into the ice-covered areas of the Chukchi and Beaufort seas.

The principal technological need identified is to improve knowledge of ice conditions, ice properties, and ice forces in the Arctic Ocean off the North Coast of Alaska. The data on ice are

needed to refine the engineering design, construction, and operation of drilling platforms, seabed pipelines, and tankers, so that an adequate margin of safety can be assured, presumably at less cost.

In regard to offshore pipelines and drilling, the report noted the need for statistical data on ice gouging of the seabed, the characteristics and methods for detecting permafrost and frozen gas hydrates under the seafloor, thaw and subsidence in permafrost, effects of frost leave, and methods for drilling and setting casing through hydrates. The need for improved and more timely information on ice and weather forecasting and search and rescue support also was identified.

In regard to government services, the report made the following recommendation:

Government agencies with legislated responsibilities for conducting operations in support of exploration, production, and transportation activities in the Arctic should be organized and staffed to meet in a timely manner those responsibilities. Some of these responsibilities include search and rescue, oil spill surveillance, weather and ice forecasting, structure accreditation, vessel inspection, preparation of environmental impact statements, and surface and air navigational aids.

Research in Sea Ice Mechanics, Marine Board, National Research Council, 1981 This report was produced by the Panel on Sea Ice Mechanics and was initiated by the Marine Board. The panel recommended laboratory testing to obtain mechanical characteristics of sea ice with appropriate internal states, experimenting to determine the large-scale mechanical characteristics of natural sea ice cover of known internal state, and developing theories to provide satisfactory properties essential for engineering design.

The panel concluded that the mechanical behavior of sea ice aggregates, as they interact with structures, is not well understood and recommended that further knowledge be obtained through field observations. Laboratory studies should be conducted to better understand the formation and interaction of ice aggregates with engineering structures. Analytical studies combining field observations and laboratory experiments with the basic laws of mechanics should be conducted to develop theoretical models of the mechanical behavior of various ice types.

Much understanding of ice processes and the interactions of ice structures will be derived from small-scale model tests. The panel recommended that a systematic research program be conducted to investigate the properties of different materials for modeling ice. The feasibility of using model ice to determine the large-scale mechanical properties of ice features also should be investigated.

The panel concluded that a systematic approach to sea ice research at the national level will require an integration of government and

private planning, long-term research, contractual commitments, and the interpretation of research missions in relation to national needs. The government needs to increase its sea ice research efforts by stating a clear commitment to their pursuit, coordinating the activities of the several agencies with an interest in results, promoting the dissemination of research results, and attracting more investigators into the field. The panel recommended that one government agency be designated to lead and coordinate all federal work in sea ice mechanics technology.

Understanding the Arctic Sea Floor for Engineering Purposes, Marine Board, National Research Council, 1982 The assessment by the Committee on Arctic Seafloor Engineering of the relationship between seafloor phenomena and Arctic engineering has shown that engineering techniques and systems are available to anticipate, overcome, or control potential seafloor hazards. A substantial body of seafloor engineering technology for supporting operations in the Arctic offshore is found in universities, government agencies, engineering consulting firms, and the engineering organizations of oil companies. A large part of this base has been developed by joint industry programs, supplemented by proprietary research.

The committee recognized the special engineering challenges that the Arctic seafloor poses. Government agencies, some corporate research organizations, and university laboratories, could participate in many aspects of recommended research. Moreover, the use of results from engineering-oriented research would be responsive to the objectives and needs of both industry and government. Governmental agencies with interests in these technical issues include the U.S. Army Corps of Engineers, the U.S. Geological Survey, the Minerals Management Service, the National Oceanic and Atmospheric Administration, the National Science Foundation, the Bureau of Land Management, and the U.S. Coast Guard.

The committee emphasized that the following seafloor conditions have great influence on the design and economics of projected offshore activity that depends on seafloor-based structures:

- o Thaw subsidence develops axial and circumferential forces acting on oil production conductors and casings, and is a serious threat to well integrity. This difficulty can be dealt with if site information is available and has been correctly analyzed. For this purpose, it is essential to know the mechanical properties of saline permafrost. The subsidence problem for the pipeline transportation of oil is similar to that of oil production, but not as severe.
- o Sedimentary erosion is a concern in all aspects of offshore hydrocarbon development and recovery, and it may be an impediment to mining development and production. There are wide-ranging consequences of sedimentary erosion beyond those

specific to the site. These include the effects of artificial island and structures on coastal processes, ice-pack movement, and the migration of other islands.

- o Ice gouging is a phenomenon having a major economic impact on oil pipelines and cables crossing the frequently shallow Arctic seafloor shelf. It is necessary to quantify the risk to transport systems caused by contact with, or the indirect effects of, crushing ice keels. Trenching is an expensive engineering response in Arctic offshore areas of overconsolidated sediments or thin sedimentary cover. Mapping techniques can assist in providing more rigorous information leading to improved risk and investment analyses.
- o Soil mechanics of silts is a primary problem area that confronts engineering in Alaskan Arctic offshore development. Fundamental knowledge is needed of the shear resistance of surficial soils. Shear resistance at the seabed surface and at incremental depths under static (pseudo-static) and cyclic loading is particularly needed. Shear resistance determines a bottom-founded structure's size, which in turn is related to ice loading. Shear resistance is a major concern for seasonally constrained Arctic mining operations in locations where production time and capital costs are affected by seabed characteristics.

In addition, the committee noted Arctic geophysical and ocean phenomena that influence development; such phenomena include permafrost-related frost heave and freezeback, release of gas and subsidence caused by hydrate deterioration, thermal erosion, ice ride-up on structures and overconsolidated soils. These problems, while severe at times, are specific to particular sites, and must be analyzed accordingly. The committee has made specific recommendations to anticipate these problems better and to improve the technical response to them.

Maritime Services to Support Polar Resource Development, Maritime Transportation Research Board, National Research Council, 1981 This report, prepared by the Committee on Maritime Services to Support Polar Development, investigated maritime requirements and potential for servicing resource development in polar areas. The report's conclusions deal with several topics of interest to this study on Arctic Ocean engineering capabilities.

Many resources are available in the Arctic that will use maritime services as economic forces dictate their development. The clear immediate opportunity is for alternative transportation of oil and gas products.

Transportation technology, supporting Arctic resource development, exploration and production, can be developed when economic and institutional factors are favorable, providing appropriate engineering research and development programs are instituted to provide the necessary fundamental knowledge.

Economic and institutional constraints so far have made movement of Arctic resources by marine transport impractical. Although the problems of pipeline operation have not all been solved, the pipeline provides a baseline against which costs and risks of other transportation systems can be compared. No similar cost data are available for marine transportation systems.

Against these conclusions, the committee then recommended development of Arctic marine transportation systems on a phased development basis, the first increment being a single small- to medium-sized oil tanker with corresponding local terminal facility. Government financial sponsorship is recommended initially, with later participation by industry. The committee recommended that an Arctic transportation system be designed to provide information and experience to evaluate the advantages and disadvantages of marine transportation of Arctic resources. The recommendations went on to state that:

The Congress should direct appropriate agencies of the federal government to take long-range responsibility for Arctic weather and sea ice prediction services, collection of ice data, ice-breaker support, rescue capability, enforcement of regulations pertaining to Arctic operations, and fundamental research leading to development of marine transportation systems. To facilitate cooperation in maritime transportation research and development, a close and continuing relationship should be maintained with countries having interest in the Arctic. Development of Arctic marine systems should be coordinated, especially with Canada and the state of Alaska to resolve environmental and indigenous population problems and rights of passage, all of which have economic and institutional ramifications.

APPENDIX B
MARAD ANALYSIS OF FUTURE TANKER AND
OTHER COMMERCIAL SHIP REQUIREMENTS AND
RELATED TECHNICAL PROBLEMS

The discovery of oil in Prudhoe Bay in the late 1960s and the subsequent exploratory voyages of the icebreaking tanker MANHATTAN dramatically raised the level of interest in commercial Arctic shipping. Commencing in the early 1970s, the Maritime Administration (MarAd) has conducted a series of studies with assistance, to determine the types of vessels required, to evaluate their technical, economic and institutional feasibility, and to devise ways of making their construction and operation by U.S. companies attractive.

At the present time, about 1.5 million barrels of oil per day extracted from the Prudhoe Bay field are being shipped from Valdez, Alaska, to U.S. refineries. About 60 U.S.-flag vessels are utilized in this trade. In the next 10 years, an equal amount of oil (plus associated gas) is likely to be produced from offshore areas of the U.S. Continental Shelf in the Bering, Chukchi, and Beaufort seas.

Assessment of U.S. maritime alternatives in the Arctic made a major breakthrough when the SS MANHATTAN project was initiated by Exxon, ARCO, and BP in the 1968 to 1971 time period. That project was an experimental attempt to determine the feasibility of transporting North Slope Alaskan crude oil by the use of icebreaking tankers.

Interest in all Arctic resources was expressed in the efforts conducted by the Arctic Institute of North America from 1972 to 1973 under contract to MarAd. Results of that work predicted cargo demands for commodities from the Arctic such as oil, gas, coal, copper, fluorite, and other hard mineral resources through the year 2000.

With this background MarAd research explored alternative ship technologies for avoiding the Arctic ice in its sponsorship of an evaluation of nuclear powered submarine tankers. That work was conducted in 1974 and 1975 by an industry team consisting of Newport News Shipbuilding, Westinghouse, Bechtel, and Mobil Shipping and Transportation. This study indicated that the technology existed, the cargo could be delivered where it was needed on the East Coast, the economics were attractive, no subsidies would have been required, and a total U.S. system would be possible.

In 1976 to 1977, MarAd funded ARCTEC, Inc., to develop topics of an Arctic research plan dealing with ship powering in the Arctic. The general research topics were: hull ice resistance, maneuverability in

ice, hull structural integrity, propulsion performance, and environmental definitions. After priorities were evaluated there were seven projects selected by the U.S. Canadian Advisory Board as being of high priority. These were as follows: collect and analyze pressure ridge data; model and analyze full-scale hull data; correlate model data to MANHATTAN data; collect hull-ice impact data on POLAR Class icebreakers; conduct parametric ice resistance model tests; develop advanced electric transmission system; and conduct systematic tests of maneuverability. Some of these have been done; others await research funding.

During 1979 and 1980, the U.S. Department of the Interior investigated the technologies and economics of oil and gas resources development in the National Petroleum Reserve-Alaska (NPRA). MarAd funded J.J. McMullen to complement the work done by the Interior Department. That study addressed the icebreaking tanker transportation of crude in a variety of large tankers ranging from 60,000 to 400,000 DWT. Eastbound and westbound routes from the NPRA were considered. A similar review was made for natural gas as LNG or methanol. Results indicated that icebreaking ships were economically feasible.

From 1977 to 1979, the MANHATTAN data was made available to MarAd by Exxon, and ARCTEC was given a contract to put the data into an easy-to-use set of volumes. Copies of the MANHATTAN documents are available through MarAd for use by U.S. maritime interests.

The latest work funded by MarAd, in 1981 and 1982, was an updated evaluation of methods for transporting Alaskan natural gas to the consumer markets. That work was done by ICF, Inc.; it reviewed prior work by industry and government to develop a common-cost base, and then addressed specific transport options. The study dealt with Arctic icebreaker technology, but proposed a gas pipeline to south Alaska with LNG being transported to either U.S. or Japanese markets. These results show an economic balance which is about equal to the early Alaska Natural Gas Transportation System (ANGTS) predictions of cost, about of \$6 per million BTU.

Following the research plans developed with ARCTEC, MarAd joined with the U.S. Coast Guard, the Alaska Oil and Gas Association, and the government of Canada to conduct tests on the ability to transit Arctic ice in the winter using the U.S. Coast Guard Polar class icebreakers. This also gave a team of Arctic research scientists the opportunity to gather offshore ice data not previously available. Ice ridges were profiled, ridge frequencies were determined, ice quality was measured, and a multitude of measurements were made on ice and the icebreaker hull. Correlations were developed relating ice conditions and transit speeds.

APPENDIX C
SELECTED REFERENCES ON ACOUSTIC EFFECTS OF OCS OIL
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APPENDIX D

JOINT GOVERNMENT AND INDUSTRY ARCTIC PROGRAMS

Case I. The jointly sponsored research program at CRREL to measure the engineering properties of multiyear sea ice.

The jointly funded industry and government ice research program at the U.S. Army Corps of Engineers Cold Regions Research Engineering Laboratory (CRREL) was initiated through discussions between industry and CRREL personnel.

A number of studies had indicated a need for field measurements of ice strength characteristics of multiyear and conglomerate ice. CRREL personnel had participated in the Arctic tanker MANHATTAN transportation project, conducted considerable laboratory measurements of ice strength, and contributed to various ice engineering requirement studies.

Personnel at the Shell Research Laboratory proposed additional ice property measurements of multiyear ice. Because of a lack of available commercial laboratories with adequate test facilities, Shell inquired if CRREL could undertake a industry and government jointly funded field ice sampling and laboratory ice-strength measurement program.

After it was determined by CRREL that it was of benefit to undertake the program and that there were no comparable facilities in industry to make the measurements, Shell invited CRREL to develop a program. A proposed experimental program evolved, and a meeting was set up in Houston, Texas, for CRREL and Shell to present the proposed program to other potentially interested government agencies and oil companies.

As a result, a three-year, three-phase data gathering and measurement program was initiated, the first phase costing \$750,000. Ten sponsors were obtained with a fee of \$75,000 (equivalent services) for the first phase. The nine industry participants for the first phase included: Shell Development Company, Exxon Production Research Company, Amoco Production Company, Sohio Petroleum Company, Gulf Research and Development Company, ARCO Oil and Gas Company, Chevron Oil and Field Research Company, Texaco Inc., and the Mitsui Engineering and Shipbuilding Company Ltd. Four sponsoring government agencies included the Minerals Management Service (MMS) of the U.S.

Department of the Interior, the National Science Foundation, the U.S. Coast Guard, and the Department of Energy. Each of the government agencies sponsored differing amounts, for the total of \$75,000.

The Phase I CRREL reports issued in April 1984, are available to the public (CRREL Report #84-8, Testing Technique; and #84-9, Test Results).

Five of the industry companies did not sponsor Phase II. Those remaining are the first four listed above; the remaining participating government agency is MMS. The funding for Phase II per group, because of the decreased number, has risen to \$120,000. The Phase II report is expected to be released in early 1985. Phase III activities are in the planning stage.

All raw field data are in the public domain. Analyzed data by Shell have a three-year restriction on public release. However, the analyzed data is generally available to the sponsors. For example, data analysis performed by Shell is in use by the Alaska office of the MMS.

Case II. The MarAd Arctic trafficability studies to measure the forces of ice on icebreakers and to determine the navigability within the Arctic pack ice.

In informal conversations between ARCTEC, MarAd's Office, and the U.S. Coast Guard's Operations Office, the question of how to measure trafficability in the Arctic became a common concern. Trafficability includes the ability to navigate in the ice and the amount of time required to move from one point to another under various conditions. In particular, Arctic trafficability information is required to analyze possible future commercial icebreaker operations needed to support Arctic shipping.

As in most Arctic operations, the cost of obtaining the required data was critical to undertaking a study. It was also evident to ARCTEC personnel that there were numerous potential users of the data.

ARCTEC, Inc. developed a multiple-funded, 5-year trafficability study program. Sponsors have included MarAd, U.S. Coast Guard, inter-agency Ship Structures Committee, and Newport News Shipbuilding Company. Synergistically related studies also have been initiated.

Several oil companies have developed individual contracts with ARCTEC to participate in the field trials, contributing both funds and personnel. Through the Canadian subsidiary of ARCTEC, the Canadian government sponsorship was developed for icebreaker vibration measurements during navigation through the ice. Thus, the objectives of the field program have been increased over the years. However, some original objectives have been dropped; for example a Northwest Passage trafficability study has never been carried out.

Funding for icebreaker ship time is a critical financial concern. At present it amounts to about \$5.5 million for 60 days of ice operations. At the start of the program, the ship operations funds were provided by the Coast Guard. After the shifting of icebreaker operational funds to user agencies in fiscal year 1983, the ship operations funds came from the MarAd budget. For fiscal year 1984, however, the MarAd user funding for the Coast Guard icebreakers was

deleted by the administration from the 1984 budget. For the field program of the Arctic trafficability studies, the Coast Guard has provided the necessary ship time without reimbursement. Hence, continuation of the trafficability study is in question.

Under this program, each of the participants could send technical personnel to the field to aid in obtaining the needed data. Thus, organizations could gain valuable experience in Arctic field operations.

Parts of the program come under varying restrictions with regard to data obtained. For example, the hull-force measurements reports, undertaken with Ship Structures Committee support, will become available as soon as it is published. Trafficability studies conducted with joint support of MarAd and industry will have an embargo on data to nonparticipants of 1-3 years.

Case III. Joint industry research coordinated by member companies of the Alaska Oil and Gas Association.

The primary industry organization involved in Arctic oil and gas development is the Alaska Oil and Gas Association (AOGA). Within AOGA, Arctic research and engineering is addressed through the Lease-Sale Planning and Research Committee and the technical subcommittee (LPRC).

The LPRC functions as a forum for proposing and cataloging joint research studies. LPRC meets every 2 months on a regular basis. The meetings provide an opportunity for individuals, contractors, universities, and government agencies to propose research for joint funding. If sufficient interest is shown, meetings between potential funding companies and the project originator may be held to discuss the project and make suggestions for strengthening the proposed research. Finally, each of the interested companies negotiates and contracts with the performing organization.

Specific stipulations are made regarding restrictions on the release of data from the study. Such restrictions indicate the period of time and the cost to additional organizations for joining the shared program. Nonmembers of AOGA and government agencies may participate as long as equal funding and restrictions on data release are agreed upon.

If a project is funded by one or more companies, LPRC assigns a project number to the study. One of the participating companies is designated to write a one-page project description to be included in a compilation of projects published by AOGA. In addition, the company reports on nonproprietary progress of the study at an LPRC meeting held every second month.

At least one other type of study may be included in the AOGA project list. In some cases, an individual company may perform research, then offer the research for sale under a license agreement. Again, any individual (or organization) may purchase the information.

More than 250 research projects have been jointly undertaken by AOGA members at a total cost of \$225 million through 1983. Most of

the research falls into the following categories: environmental conditions; environmental effects on equipments, structures; sensors and instruments to acquire environmental data; sensors and instruments to acquire environmentally induced forces; structural design to withstand environmental conditions; and engineering materials, transportation, and logistics for the Arctic environment.

Many of the early studies undertaken were data survey projects. Initial offshore data of interest was largely related to weather and sea ice descriptions and seasonal characteristics. Environmental investigations moved from acquisition and analysis of historical and archived data to the acquisition of new data for specific engineering and environmental purposes. The data base has been expanded upon as new lease areas have become important and as new sensors and instrumentation and analysis techniques have become available. Thus, sea ice gouging studies conducted in the Beaufort Sea in the early 1970s have continued as sensors and techniques improved.

As to facilities to conduct investigations, in most cases the facilities and equipment used by industry are industry facilities. There are, however, several notable exceptions. These are:

- o Ice force measurements on vessels. These are cooperative studies with the USCG using icebreaker hulls.
- o Ice condition documentation. Increasing use is being made of remote sensors i.e., radar, infrared and multispectral sensors, high resolution aerial photography, and ocean floor and submarine mounted sonar. Satellite sensor data from federally provided satellites and platforms are used to determine ice conditions, breakup, and motion. Navy upward-looking sonar data have been used to provide a general characterization of the roughness of the underside of ice in deeper waters.
- o Ice strength measurements: In cooperation with the Minerals Management Service, industry has been supporting work to determine the strength of sea ice. The program uses the CRREL which has specialized cold rooms equipped with instrumentation required to make laboratory measurements of the physical and engineering properties of ice.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Previous studies by the National Research Council's Marine Board and by the National Petroleum Council have identified engineering-related research and development needed to support offshore development in U.S. Arctic waters. This report focuses these earlier reports on sea ice mechanics, seafloor engineering in the Arctic and polar engineering needs in the 1980's and also considers the support requirements for navigation, icebreaking as well as university research and education for Arctic engineering. Recommendations		

are made affecting the means of enhancing technical support of Arctic ocean engineering and operations. ,

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