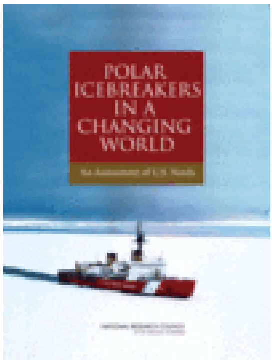

Polar Icebreakers in a Changing World: An Assessment of U.S. Needs

Committee on the Assessment of U.S. Coast Guard Polar Icebreaker Roles and Future Needs, National Research Council

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POLAR ICEBREAKERS IN A CHANGING WORLD

An Assessment of U.S. Needs

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Polar Research Board
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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by George M. Hornberger, University of Virginia, and John B. Mooney, Jr., U.S. Navy (retired). Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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APPENDIXES

Summary for Congress

The United States has enduring national and strategic interests in the Arctic and Antarctic, and the importance of these regions is growing with time. In the north, the United States has territory and citizens above the Arctic Circle, creating significant national interests. In the south, the United States maintains three year-round scientific stations to assert U.S. presence and ensure U.S. leadership among the nations that are signatories to the Antarctic Treaty. Repeated high-level policy reviews have reaffirmed the importance of this U.S. presence and leadership in the polar regions.

To achieve national purposes in both polar regions, the nation needs to be able to access various sites throughout these regions at certain times of the year, reliably and at will. Ensured access to the polar region requires polar icebreaking ships capable of operating in a variety of challenging ice conditions. Over the past several decades, the U.S. government has supported its polar interests with a fleet of four icebreakers. The current seagoing U.S. fleet of four ships includes three multimission ships operated by the U.S. Coast Guard (POLAR SEA, POLAR STAR, and HEALY) that support U.S. Coast Guard missions as well as science and one single-mission ship operated by the National Science Foundation that is dedicated solely to scientific research (PALMER). Today, two of the multimission ships, the POLAR STAR and the POLAR SEA, are at the end of their service lives. Over the last decade, some routine maintenance on these ships has been deferred due to a lack of funds and no major life extension program has been planned; as a consequence, U.S. icebreaking capability is now at risk of being unable to support national interests in the north and the south.

FUTURE NEEDS FOR ICEBREAKING CAPABILITY

In the Arctic, economic activity is expected to increase as the southern extent of the Arctic summer ice pack thins, providing opportunity for ice-capable ships to travel through these regions. Greater human activity will increase the need for the United States to assert a more active and influential presence in the Arctic to protect not only its territorial interests, but also its presence as a world power concerned with the security, economic, scientific, and international political issues of the region. Icebreakers will play a critical role in supporting U.S. interests because the sea-ice margin does not retreat uniformly or predictably, which may create difficult ice conditions in these waters. Possible U.S. ratification of the U.N. Convention on the Law of the Sea will require the United States to collect data to extend its economic zone and/or to counter territorial claims by other Arctic nations. Icebreakers will be needed to provide access to ice-covered waters to acquire this necessary data.

In the Antarctic, multiple national policy statements and Presidential Decision Directives have reaffirmed the importance of an "active and influential" U.S. presence in Antarctica and U.S. leadership in the Antarctic Treaty governance process. The U.S. presence at McMurdo and South Pole Stations cannot be ensured without reliable icebreaking support to allow resupply of fuel, food, and cargo. At some point in the near future it may be possible to store enough fuel and supplies to skip a resupply in a given year, but even then the United States will need the ability to break a channel and resupply McMurdo Station by ship in most years. Reliably controlled icebreaker capability that can be ensured over decades is therefore vital to U.S. interests in the Antarctic. For the purposes of the single mission of resupplying McMurdo Station, the icebreakers do not necessarily need to be operated by the U.S. Coast Guard, but to best meet mission assurance requirements they should be U.S. flagged, U.S. owned, and U.S. operated. Without specific design proposals, it is not possible to evaluate the cost-effectiveness of specific approaches or explore the possibility that other nations might partner to invest in a Polar class icebreaker with the United States.

Polar research has brought, and will continue to bring, tangible societal benefits. The success of polar research is intimately linked to the availability of appropriate infrastructure and logistical support to allow scientists to work in these natural laboratories whose unique settings enable research on fundamental phenomena and processes that are feasible nowhere else. Access to the polar regions, predicated on the availability of adequate icebreaking capability, is essential if the United States is to continue as a leader in polar science.

RENEWAL OF THE NATION'S POLAR ICEBREAKING FLEET

Based on the current and future needs for icebreaking capabilities, the committee concludes that the nation continues to require a polar icebreaking fleet that includes a minimum of three multimission ships and one single-mission ship. The committee finds that although the demand for icebreaking capability is predicted to increase, a fleet of three multimission and one single-mission icebreakers can meet the nation's future polar icebreaking needs through the application of the latest technology, creative crewing models, wise management of ice conditions, and more efficient use of the icebreaker fleet and other assets. The nation should immediately begin to program, design, and construct two new polar icebreakers to replace the POLAR STAR and POLAR SEA.

Building only one new polar icebreaker is insufficient for several reasons. First, a single ship cannot be in more than one location at a time. No matter how technologically advanced or efficiently operated, a single polar icebreaker can operate in the polar regions for only a portion of any year. An icebreaker requires regular maintenance and technical support from shipyards and industrial facilities, must reprovision regularly, and has to effect periodic crew change-outs. A single icebreaker, therefore, could not meet any reasonable standard of active and influential presence and reliable, at-will access throughout the polar regions.

A second consideration is the potential risk of failure in the harsh conditions of polar operations. Despite their intrinsic robustness, damage and system failure are always a risk and the U.S. fleet must have enough depth to provide backup assistance. Having only a single icebreaker would necessarily require the ship to accept a more conservative operating profile, avoiding more challenging ice conditions because reliable assistance would not be available. A second capable icebreaker, either operating elsewhere or in homeport, would provide ensured backup assistance and allow for more robust operations by the other ship.

From a strategic, longer-term perspective, two new Polar class icebreakers will far better position the nation for the increasing challenges emerging in both polar regions. A second new ship would allow the U.S. Coast Guard to reestablish an active patrol presence in U.S. waters north of Alaska to meet statutory responsibilities that will inevitably derive from increased human activity, economic development, and environmental change. It would allow response to emergencies such as search-and-rescue cases, pollution incidents, and assistance to ships threatened with grounding or damage by ice. Moreover, a second new ship will leverage the possibilities for simultaneous operations in widely disparate geographic areas (e.g., concurrent operations in the Arctic and Antarctic), provide more flexibility for conducting Antarctic logistics (as either the primary or the secondary ship for the McMurdo break-in), allow safer multiple-ship operations in the most demanding ice conditions, and increase opportunities for international expeditions. Finally, an up-front decision to build two new polar icebreakers will allow economies in the design and construction process and provide a predictable cost reduction for the second ship.

Given the length of time needed to program, budget, design, construct, and test a new ship, it is expected that the new polar icebreakers will not enter service for another 8 to 10 years. During this time the nation needs a transition strategy to ensure a minimum level of icebreaker capability. A continuing maintenance and repair program for the POLAR SEA, building on the work recently completed, is needed to keep it mission capable until at least the first new polar ship enters service. The cost to keep the POLAR SEA mission capable will be much less than a full service life extension program. The resulting capability, an upgraded POLAR SEA together with a fully capable HEALY, is less than the nation needs, but a cost-effective strategy should emphasize new construction rather than maintenance of aging ships. The committee also advises that the POLAR STAR continue to be kept in caretaker status, indefinitely moored at the U.S. Coast Guard pier. If the POLAR SEA has catastrophic problems, the POLAR STAR could be reactivated and brought back into service. The nation may need to charter supplemental ship services during the transition to new ships. This transition strategy carries risk, but due to the long lead time for new ships there are no alternatives.

CONCLUSIONS AND RECOMMENDATIONS

The committee finds that both operations and maintenance of the polar icebreaker fleet have been underfunded for many years, and the capabilities of the nation's icebreaking fleet have diminished substantially. Deferred long-term maintenance and failure to execute a plan for replacement or refurbishment of the nation's icebreaking ships have placed national interests in the polar regions at risk. The nation needs the capability to operate in both polar regions reliably and at will. Specifically, the committee recommends the following:

- The United States should continue to project an active and influential presence in the Arctic to support its interests. This requires U.S. government polar icebreaking capability to ensure year-round access throughout the region.
- The United States should continue to project an active and influential presence in the Antarctic to support its interests. The nation should reliably control sufficient

icebreaking capability to break a channel into and ensure the maritime resupply of McMurdo Station.

- The United States should maintain leadership in polar research. This requires icebreaking capability to provide access to the deep Arctic and the ice-covered waters of the Antarctic.
- National interests in the polar regions require that the United States immediately program, budget, design, and construct two new polar icebreakers to be operated by the U.S. Coast Guard.
- To provide continuity of U.S. icebreaking capabilities, the POLAR SEA should remain mission capable and the POLAR STAR should remain available for reactivation until the new polar icebreakers enter service.
- The U.S. Coast Guard should be provided sufficient operations and maintenance budget to support an increased, regular, and influential presence in the Arctic. Other agencies should reimburse incremental costs associated with directed mission tasking.
- Polar icebreakers are essential instruments of U.S. national policy in the changing polar regions. To ensure adequate national icebreaking capability into the future, a Presidential Decision Directive should be issued to clearly align agency responsibilities and budgetary authorities.

Summary

The United States has enduring national and strategic interests in the Arctic and Antarctic, and the importance of these regions is growing with time. In the north, the United States has territory and citizens above the Arctic Circle, creating significant national interests. In the south, the United States maintains three year-round scientific stations to assert U.S. presence and ensure U.S. leadership among the nations that are signatories to the Antarctic Treaty. The United States uses this leadership to ensure that the Antarctic Treaty area, comprising all land and waters below 60 degrees South latitude, is preserved for peaceful purposes and scientific research.

Antarctica is an ice-covered continent surrounded by an ocean, parts of which are seasonally ice covered. The central Arctic Ocean is perpetually ice covered, and in the winter ice extends along the northwestern Alaskan coast and south through the Bering Strait. Asserting national interests and achieving national purposes in both polar regions requires polar icebreakers, ships capable of operating in a variety of challenging ice conditions. Over the past several decades, the U.S. government has supported its polar interests with a fleet of four icebreakers. Three of these, including the world's most powerful nonnuclear icebreakers, POLAR SEA and POLAR STAR, and the modern research icebreaker HEALY, have been operated by the U.S. Coast Guard. These three ships are designed to support U.S. Coast Guard missions and to support science: They are referred to as "multimission" ships as opposed to single-mission vessels. The National Science Foundation (NSF) leases a fourth ship that has limited icebreaking capabilities and is dedicated entirely to Antarctic research—a single mission. Today, the POLAR STAR and the POLAR SEA are at the end of their designed service lives of 30 years.

As directed by Congress, the U.S. Coast Guard requested the National Research Council of the National Academies to convene the committee on the Assessment of U.S. Coast Guard Polar Icebreaker Roles and Future Needs. The committee was asked to provide a comprehensive assessment of the current and future roles of U.S. Coast Guard polar icebreakers. The committee was also asked to analyze any changes in roles and missions of polar icebreakers in the support of all national priorities, including consideration of ongoing and predicted environmental change, and to assess whether changes are needed to the existing laws governing U.S. Coast Guard polar icebreaking operations to address potential new missions and new operating regimes. Appendix A contains the committee's Statement of Task. This report documents the findings and recommendations of the committee, which are summarized below.

ICEBREAKING NEEDS IN THE ARCTIC

During winter, the entire Alaskan northern coast and a substantial portion of the Alaskan western coast are ice bound. In summer the Arctic sea-ice margin retreats northward, although not uniformly or predictably, usually creating open waters along the entire coastline for several weeks to several months. Summer sea-ice extent is expected to continue to retreat over the next several decades, creating more broken ice along the Alaskan coastline.

Economic activity is predicted to increase and move northward as a result of sea-ice retreat. Those deploying fishing fleets, cruise ships, mining, and the associated ore transit ships, as well as petroleum recovery and tanker ship transport, anticipate increased operations in the region. When current orders for ice-strengthened tankers have been filled, the worldwide fleet of these vessels will double in number. Ice retreat increases the cost-effectiveness of using the Northern Sea Route (primarily north of Russia) and the Northwest Passage (primarily north of Canada) for transporting petroleum, ore, and cargo. Both routes include U.S. Arctic waters.

The potential for increased human activity in northern latitudes will likely increase the need for the United States to assert a more active and influential presence in the Arctic not only to protect its territorial interests, but also to project its presence as a world power concerned with the security, economic, scientific, and international political issues of the region.

Possible ratification of the U.N. Convention on the Law of the Sea implies that the United States would require extensive mapping of the U.S. continental shelf off Alaska, should the United States wish to use Article 76 in the Convention to extend its continental shelf beyond the 200 nautical mile economic zone and/or to counter territorial claims by other Arctic nations.

More variable and less predictable weather and sea-ice conditions now occur in the Arctic. Both have made it more difficult for indigenous populations to predict when to initiate and terminate the culturally important, annual whale hunt, as well as when it is safe to travel over coastal ice or hunt further from shore.

Over the past decades the U.S. Coast Guard has not conducted routine patrols in ice-covered waters due to a lack of funding. The growing human presence and increased economic activity in the Arctic will be best served by reinstating patrols in U.S. coastal waters and increasing U.S. presence in international waters of the north. To assert U.S. interests in the Arctic, the nation needs to be able to access various sites throughout the region at various times of the year, reliably and at will. While the southern extent of the Arctic ice pack is thinning and becoming less extensive during the summer, there is no question that polar icebreakers will be required for many decades for egress to much of the Arctic Basin. Ice conditions in the U.S. Arctic are among the most variable and occasionally challenging through the circum-Arctic. National interests require icebreakers that can navigate the most formidable ice conditions encountered in the Arctic.

Recommendation 1: The United States should continue to project an active and influential presence in the Arctic to support its interests. This requires U.S. government polar icebreaking capability to ensure year-round access throughout the region.

ICEBREAKING NEEDS IN THE ANTARCTIC

Multiple national policy statements and Presidential Decision Directives have reaffirmed the importance of an "active and influential" U.S. presence in Antarctica in support of U.S. leadership in the Antarctic Treaty governance process and as a geopolitical statement of U.S. worldwide interests. The United States is committed to preserving Antarctica exclusively for peaceful purposes, furthering scientific knowledge, and preserving and protecting one of the most pristine environments on the globe.

The U.S. presence in Antarctica is established principally by the year-round occupation of three stations: McMurdo, Palmer, and South Pole. This presence secures the influential role of the United States in the treaty's decision-making system and maintains the political and legal balance necessary to protect the U.S. position on Antarctic sovereignty. Many view the permanent year-round presence of the United States as a major deterrent to those countries that might otherwise wish to exercise their overlapping territorial claims. Thus, scientific activity in the Antarctic is an instrument of foreign policy.

The U.S. research presence in Antarctica currently relies on shipborne resupply, with the majority of fuel and cargo for the U.S. Antarctic Program delivered to McMurdo Station by tanker and container ship. Fuel and supplies are ferried from McMurdo to the South Pole Station and remote field sites by aircraft or overland traverse. Multiple studies over the years have repeatedly confirmed that the safest and most cost-effective means of transporting the necessary quantities of fuel and cargo to McMurdo Station is by ship.

Presently two ice-strengthened ships chartered by the Military Sealift Command transport cargo and fuel and remove refuse. These ships *require* icebreakers to open a shipping channel through the shore-fast ice to McMurdo Station, which has been up to 80 miles long, and to provide close escort to and from the ice pier. During the past six years, the break-in through McMurdo Sound has become increasingly more challenging. Until 2006, large icebergs in the Ross Sea blocked wind and currents from clearing the ice from McMurdo Sound, and the blockage increased the amount of harder, thicker, multiyear ice in the sound. The last six seasons have generally required two icebreakers to break and groom the channel and escort transport ships through the channel.

For the past couple of years, because the condition of the POLAR STAR and POLAR SEA has required increased maintenance as they near the end of their service lives, the National Science Foundation contracted the services of the Russian icebreaker KRASIN. Approximately the same age as POLAR STAR, KRASIN assisted the POLAR STAR in 2005 and in early 2006 conducted the break-in alone but broke a propeller blade (which a U.S. Navy diving and salvage team could not repair) before escorting the tanker and container ship through difficult ice conditions. The POLAR STAR was dispatched from Seattle, where it was in standby status. The KRASIN was able to escort the tanker to the pier, and when refueling of the McMurdo tank farm commenced, only five days of fuel remained.[1] These events highlight the difficult ice conditions, the aging condition of the two U.S. icebreakers powerful enough to perform the McMurdo break-in, and the condition of icebreakers that can be chartered on the open market. These circumstances make future resupply missions vulnerable to failure.

While there is ongoing discussion of the possibility of

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[1] Erick Chiang, National Science Foundation, testimony to the committee.

being able to store enough fuel and supplies to skip a resupply in a given year, the fact remains that the United States will need the ability to break a channel and resupply McMurdo Station by ship in any given year. This reality requires reliably controlled icebreaker capability that can be ensured over decades. Annual charter—commercial or from another nation—provides insufficient assurance of successful resupply for the long term.

The committee concludes that for the purposes of the single mission of McMurdo resupply, the icebreakers do not necessarily have to be operated by the U.S. Coast Guard, but to best meet mission assurance requirements they should be U.S. flagged, U.S. owned, and U.S. operated. Without specific proposals it is difficult to evaluate the cost-effectiveness or the possibility that other nations might partner to invest in a Polar class icebreaker with the United States.

Ice conditions will be increasingly difficult until a considerable portion of the multiyear ice in the sound is removed by natural processes. For the foreseeable future, two polar icebreakers will be needed to support the resupply mission at an acceptable level of risk. U.S. icebreaking assets must be sized to handle the most difficult ice conditions in McMurdo Sound.

Recommendation 2: The United States should continue to project an active and influential presence in the Antarctic to support its interests. The nation should reliably control sufficient icebreaking capability to break a channel into and ensure the maritime resupply of McMurdo Station.

SUPPORT OF U.S. POLAR RESEARCH

The history of polar research is tied directly to the geopolitical circumstances following World War II and the subsequent Cold War era. In the south this was evidenced by the deployment of nearly 3,000 personnel to Antarctica in the U.S. commitment to the International Geophysical Year (IGY) in 1957-1958. While polar research was seen as important, it also provided a mechanism to project U.S. global presence and power in a manner that served U.S. interests. Construction of the Distant Early Warning (DEW) Line radars looking toward the former Soviet Union necessitated a year-round presence, creating the need for a better understanding of the Arctic environment and an improvement in our ability to work and live in the extreme cold. The establishment of research facilities in Barrow was an outgrowth of the political and military necessities of the time.

Fundamental advances resulting from polar research have directly benefited society. Polar research led to the identification of the presence and cause of the "ozone hole" and has resulted in coordinated worldwide actions to discontinue the use of chlorofluorocarbons. Understanding how the polar regions affect ocean circulation is leading to a better understanding of global climate. The study of Weddell seals, which dive to great depths and cease breathing for long periods, led to better understanding of how such mammals handle gas dissolved in blood during and after deep diving events. This has contributed to advances in understanding sudden infant death syndrome (SIDS). The study of mammals, insects, and plants that endure freezing temperatures, yet prevent the formation of ice crystals in their internal fluids, is aiding in the design of freeze-resistant crops and improved biomedical cryopreservation techniques.

The Arctic and Antarctic are natural laboratories whose extreme, relatively pristine environments and geographically unique settings enable research on fundamental phenomena and processes that are feasible nowhere else. Today, researchers seek a better understanding of how new ocean crusts form, how organisms adapt to the extremes of temperature and seasonality (light conditions), how ice sheets behave, and how the solar wind and the earth interact. Unexplored, subglacial lakes in the Antarctic that have been sealed from the atmosphere for millions of years are soon to be explored and entered. Beneath the South Pole Station a cubic kilometer of clear ice is being instrumented with 5,000 detectors to observe high-energy neutrinos that may tell us about phenomena such as supernovae. Pristine ice cores that span centuries give direct data about temperature changes and atmospheric gas concentrations in the past.

As global climate has garnered worldwide attention, the polar regions have been found to react acutely to fluctuations in climate and temperatures. The 40 percent reduction in Arctic sea-ice thickness over the past four decades is one of the most dramatic examples of recent changes. Because ice tends to reflect solar radiation and water absorbs it, melting in the polar regions can exert a strong influence on both atmospheric climate and ocean circulation. Huge reservoirs of water are held in massive ice sheets and glaciers; substantive release may create major climate and social dislocations. Thus, research in these regions plays a pivotal role in the global Earth system exerting influences of critical importance. Scientists have declared 2007-2008 the International Polar Year. Multinational collaboration and new polar research activities are planned.

The health and continued vitality of polar research are intimately linked to the availability of the appropriate infrastructure and logistical support to allow scientists to work in these harsh environments. Access to the polar regions is essential if the United States is to continue to be a leader in polar science. To operate reliably and safely in these regions necessitates a national icebreaking capability. Icebreakers enable resupply of land-based stations and field camps in the south. The availability of polar icebreakers with greater icebreaking capability would enable important new research in the Southern Ocean in locations where ice is thick. While other assets and platforms such as airplanes and spaceborne sensors are useful tools, surface ground-truth and in situ sampling will not be replaced in the near future. Because there are no land sites in the central Arctic, an icebreaker is an essential platform to support sustained scientific measurements in the Arctic Ocean. The availability of adequate icebreaking capabilities will be essential to advancing research in both polar regions.

Recommendation 3: The United States should maintain leadership in polar research. This requires icebreaking capability to provide access to the deep Arctic and the ice-covered waters of the Antarctic.

RENEWAL OF THE NATION'S POLAR ICEBREAKING FLEET

Projecting an active and influential presence in the polar regions requires that the United States be able to access polar sites at various times of the year to accomplish multiple missions, reliably and at will. Airborne, spaceborne, and submarine assets can only partially address these missions. The presence of surface ships in ice-covered waters is necessitated by geopolitics. In recent correspondence to this committee, the Department of State, Department of Defense, and Department of Homeland Security further validated that icebreaking capability is necessary to protect national interests in the polar regions. Thus, the United States requires ships that can ensure access through thick, multiyear ice in the northern and southern polar regions. Based on these broad missions, the committee believes that the core of the icebreaking fleet must be the multimission ships operated by the U.S. Coast Guard, a military organization.

The current seagoing U.S. fleet of four ships includes three multimission ships operated by the U.S. Coast Guard and one ship, the PALMER, dedicated to scientific research and appropriately operated by NSF. One of the three multimission ships, the HEALY, was commissioned in 1999, and its performance has exceeded design specifications. The HEALY's operating time is dedicated to the support of Arctic research. Although capable of performing many additional U.S. Coast Guard missions including search and rescue, sovereignty, presence and law enforcement, the HEALY cannot operate independently in the ice conditions of the central Arctic and McMurdo Sound. The HEALY was built to complement the Polar class ships.

The two polar icebreakers in today's U.S. icebreaker fleet are at the end of their 30-year designed service lives. Over the last decade, some routine maintenance has been deferred due to a lack of funds, and no major life extension program has been planned to extend their service. As a consequence, U.S. icebreaking capability is today at risk of being unable to support national interests in the north and the south.

The committee believes that the nation continues to require a fleet that includes a minimum of three multimission ships. This conclusion is consistent with the findings of an earlier study, the 1984 United States Polar Icebreaker Requirements Study conducted by the U.S. Coast Guard, Office of Management and Budget (OMB), NSF, National Oceanic and Atmospheric Administration (NOAA), Department of Defense, Maritime Administration, and Department of Transportation. It is also consistent with a 1990 Presidential Report to Congress that reiterated that polar icebreakers were instruments of national policy and presence and that three (multimission) polar icebreakers were necessary to meet the defense, security, sovereignty, economic, and scientific needs of the nation (together with a fourth, dedicated research ship, the PALMER). The committee agrees with the findings of the two previous reports. In addition, the committee notes that icebreaking needs have increased since 1990 and will continue to increase into the foreseeable future. This projected increased demand is a direct effect of a changing climate that facilites increased human presence in the Arctic.

Although the demand for icebreaking capability is predicted to increase, the committee believes that the application of the latest technology, creative crewing models, wise management of ice conditions, and more efficient use of the icebreaker fleet and other assets can be used to meet increased requirements while maintaining the number and configuration of the icebreaker fleet the same as today—two Polar class ships, HEALY and PALMER. The demand for icebreaking capability in support of research is also increasing. Increasing science requirements will likely be met by a more capable replacement for the PALMER to conduct Antarctic research, and by a planned ice-strengthened Alaskan Region Research Vessel for light ice conditions in the Arctic. The committee has concluded that the demand of the science community for dedicated research vessels with a variety of icebreaking capabilities will greatly increase in both polar regions. When used in conjunction with polar icebreakers, research ships will be able to venture into waters that they could not safely transit alone, maximizing the return on the nation's investment in science and the icebreaking fleet.

One new polar icebreaker is insufficient for several logical reasons. First, a single ship cannot be in more than one location at one time. No matter how technologically advanced or efficiently operated, a single polar icebreaker can be operational (on station) in the polar regions for only a portion of any year. An icebreaker requires regular maintenance and technical support from shipyards and industrial facilities, must reprovision regularly, and has to effect periodic crew change-outs. These functions cannot be conducted practically or economically "in the ice" and therefore require transit time to and from polar operating areas. A single icebreaker, therefore, could not meet any reasonable standard of active and influential presence and reliable, at-will access throughout the polar regions.

A second consideration supporting the need for more than a single polar icebreaker is the potential risk of failure in the harsh conditions of polar operations. Icebreakers are the only ships designed to collide regularly with hard objects and to go independently where no other surface vessels can survive. Despite their intrinsic robustness, damage and system failure are always a risk, and the U.S. fleet must have enough depth to provide backup assistance. Being forced to operate with only a single icebreaker would necessarily require the ship to accept a more conservative operating profile, avoiding more challenging ice conditions because reliable assistance would not be available. A second capable icebreaker, either operating elsewhere or in homeport, would provide ensured backup assistance and would allow for more robust operations by the other ship.

From a more strategic, longer-term perspective, two new icebreakers will far better position the nation for the increasing challenges emerging in both polar regions. Building two new icebreakers will ensure maintenance of this level of capability. A second new ship would allow the U.S. Coast Guard to reestablish an active patrol presence in U.S. waters north of Alaska to meet statutory responsibilities that will inevitably derive from increased human activity, economic development, and environmental changes. Other unplanned situations can include search-and-rescue cases, pollution incidents where initial response and U.S. Coast Guard monitoring are necessary, and assistance to ships threatened with grounding or damage by ice. The likelihood of these situations will increase as the number of ice-strengthened tankers, tourist ships, and other vessels in the polar regions grows.

Moreover, a second new ship will leverage the possibilities for simultaneous operations in widely disparate geographic areas (e.g., concurrent operations in the Arctic and Antarctic), open additional solutions for conducting Antarctic logistics, allow safer multiple-ship operations in the most demanding ice conditions and areas, and increase opportunities for international expeditions. Finally, an up-front decision to build two new polar icebreakers will allow economies in the design and construction process and provide a predictable cost reduction for the second ship.

The committee was asked to consider alternative ship ownership options. Considering the McMurdo break-in mission alone, the committee found that to best meet mission assurance requirements, only a U.S.-flagged, U.S.-owned, and U.S.-operated ship provides sufficiently reliable control. While that ship might be leased commercially through a long-term lease-build arrangement, from a total fleet perspective it may be more cost-effective if science mission users pay only incremental costs—as has been the case in the past—and if the U.S. Coast Guard provides McMurdo resupply support from the multimission icebreaker fleet. Also, the sovereign presence of the United States is not well served by a "leased ship." Lease arrangements do not ensure that the United States could assert its foreign policy will at times and places of its choosing.

The committee concludes that the research support mission and other U.S. Coast Guard missions can, in many cases, be compatibly performed with a single ship. The two existing Polar class ships and the HEALY are equipped to support research and have productively served that mission. The committee believes that it is advantageous to configure the U.S. Coast Guard ships with appropriate science facilities as well as facilities for the U.S. Coast Guard's more general missions. In the long run, constituting the nation's icebreaking fleet as a single fleet of complementary ships will yield more capability and should be more cost-effective than if each agency independently acquires icebreaking ships. This approach is in line with the long-held belief that the nation can gain the greatest economy from the sharing of assets across agencies and programs when appropriate and feasible and that those users should share in the incremental increase in cost associated with directed usage of national assets.

The committee was asked in what manner to acquire ships. The benefits of constructing a new ship were compared to overhauling and extending the life of POLAR STAR or POLAR SEA. A so-called service life extension program (SLEP) involves wholesale replacement of the propulsion plant and of auxiliary, control, and habitation support systems. While the cost of a new hull could be avoided, the retrofit of most systems would be costly and limited by the constraints of the existing hull. The committee recommends new construction for several reasons. There is effective, new technology—particularly new hull designs—that could not be retrofitted to an existing ship. The hull and ship interior structure limit retrofit design choices, thus diminishing capability. The committee estimates that a SLEP would likely cost at a minimum more than half of a new construction cost. Some SLEP programs have overrun their budgets and have cost as much as the construction of a new ship. A newly designed ship would also meet more stringent environmental standards than the current ships.

Recommendation 4: National interests in the polar regions require that the United States immediately program, budget, design, and construct two new polar icebreakers to be operated by the U.S. Coast Guard.

TRANSITION TO A NEW POLAR ICEBREAKING FLEET

It is expected that the new polar icebreakers will not enter service for another 8 to 10 years until the program, budget, design, construction, and test phases are completed. During this time the United States needs a transition strategy to ensure a minimum level of icebreaker capability. The committee recommends a continuing maintenance and repair program for the POLAR SEA, building on the work recently completed, to keep it mission capable until at least the first new polar ship enters service. The cost to keep this ship mission capable will be much lower than a service life extension program. The resulting capability, an upgraded POLAR SEA and a fully capable HEALY, is less than this committee believes the nation needs, but a cost-effective strategy should emphasize new construction rather than maintenance of aging ships. The nation may have to charter supplemental ship services during the transition to new ships. The committee also advises that the POLAR STAR continue to be kept in caretaker status, indefinitely moored at the U.S. Coast Guard pier. If the POLAR SEA has catastrophic problems, the POLAR STAR could be reactivated and brought back into service within a year or so.

This transition strategy carries risk, and that risk comes from a decade of inaction. The strategy would permit the United States to locate an icebreaker (POLAR SEA and HEALY) in each polar region as needed. The two ships could leverage each other—for example on a central Arctic mission or in McMurdo Sound. The NSF may have to supplement the POLAR SEA with a commercial or internationally chartered ship when the McMurdo break-in is particularly difficult as is expected in the coming year. This strategy is not ideal, and it carries significant risk, but due to the long lead time for new ships there are no alternatives.

Execution of this transition strategy has already commenced. The POLAR SEA completed sea and ice trials in August 2006 after undergoing repair work at a cost of approximately $30 million.

Keeping the POLAR SEA mission capable to roughly 2015 will require further investment in maintenance and system renewal. The U.S. Coast Guard should determine the best way to do this work One strategy is for the POLAR SEA to be taken out of service for a year of shipyard work around 2012, at a cost of roughly $40 million. An alternative maintenance strategy that avoids having the POLAR SEA out of service for a year is to perform the work in year-by-year increments when the ship is in port. Careful planning would be required for the U.S. Coast Guard to determine which upgrade strategy is better. (Chapter 10 of this report discusses these issues in more detail.) By 2012, NSF may be prepared to skip the McMurdo resupply for one year, or it might arrange for an alternative icebreaker to perform the break-in during a year in which the POLAR SEA is in the shipyard.

Recommendation 5: To provide continuity of U.S. icebreaking capabilities, the POLAR SEA should remain mission capable and the POLAR STAR should remain available for reactivation until the new polar icebreakers enter service.

MANAGING THE NATION'S POLAR ICEBREAKING FLEET

Both icebreaker operations and maintenance of the polar icebreaker fleet have been underfunded for many years. Deferring long-term maintenance and failing to execute a plan for replacement or refurbishment of the nation's icebreaking ships have placed national interests in the polar regions at risk. The recent transfer of budget authority for the polar icebreaking program by OMB from the U.S. Coast Guard to NSF did not address the basic problem of underfunding routine maintenance or providing funds for U.S. Coast Guard nonscience icebreaker missions. The transfer has increased management difficulties by spreading management decisions across two agencies and multiple congressional oversight committees.

The NSF now has fiscal control over direct costs associated with the polar icebreaking program, including personnel, training, operations, and maintenance. The NSF is now fiscally responsible and making decisions for missions outside its core mission and its expertise. The U.S. Coast Guard is operating a ship for which it does not have full budget and management control.

The committee believes that the total set of U.S. Coast Guard icebreaking missions transcends the mission of support to science, despite the fact that the majority of icebreaker usage at the current time is to support research. The U.S. Coast Guard should have the funds and authority to perform the full range of mission responsibilities in ice-covered waters of the Arctic. This will require resumption of regular patrols of coastal waters and an increased U.S. presence in international Arctic waters by the nation's multimission icebreaker fleet.

It is not sufficient to provide funds only to maintain the fleet; it is necessary to provide funds to operate it effectively. The committee strongly believes that management responsibility should be aligned with management accountability.

When NSF, NOAA, or another "user" agency employs a U.S. Coast Guard icebreaker to support some directed activity, the user agency should pay incremental operational costs associated with direct mission tasking. This arrangement has worked well for decades, though it would be useful for the financial arrangement to be clarified and reasserted by the administration. If the U.S. Coast Guard is funded to operate a vessel, then direct tasking reimbursement would typically include the cost of fuel for extended transit beyond patrol, and on-ship engineering and habitation costs that derive from research activities. The committee encourages the U.S. Coast Guard to invite researchers and educators on planned patrols to conduct science of opportunity. Only the former, direct tasking, should require reimbursement to the U.S. Coast Guard above congressionally appropriated operational funds.

Recommendation 6: The U.S. Coast Guard should be provided sufficient operations and maintenance budget to support an increased, regular, and influential presence in the Arctic. Other agencies should reimburse incremental costs associated with directed mission tasking.

CLARIFICATION OF NATIONAL POLICY

The U.S. need for polar icebreaking has been studied several times over the past two decades. The conclusions remain the same. As a nation with citizens in both the Arctic and the Antarctic, the United States has a clear obligation to ensure the welfare of these citizens and to protect its national interests in the polar regions. The U.S. Coast Guard polar icebreaker fleet is a national asset that is best managed to serve multiple missions.

The last declaration of presidential-level policy regarding U.S. requirements for polar icebreaking was a Presidential Report to Congress in 1990. While recognizing the continuing national need for polar icebreaker operations, that report does not adequately address current and future issues.

Immediate policy action is needed for several reasons: wholesale ship obsolescence in the fleet; lack of adequate U.S. Coast Guard capability in the Arctic; increased human presence and economic activity in the Arctic region; and threats to Native American communities due to accelerating environmental changes. Clear direction for sustaining icebreaking capabilities needs to be asserted to ensure that the United States does not find itself without adequate polar icebreaking capability in the future as it has in the past and as it does today. If the multimission ships are to be used effectively as a national asset, then the agency with the core mission to support the polar icebreaking needs of the nation—the U.S. Coast Guard—must have adequate budgetary authority and operational control of the fleet. The U.S. Coast Guard's full operational mission in the ice-covered waters of the Arctic needs to be reaffirmed.

Recommendation 7: Polar icebreakers are essential instruments of U.S. national policy in the changing polar regions. To ensure adequate national icebreaking capability into the future, a Presidential Decision Directive should be issued to clearly align agency responsibilities and budgetary authorities.

1

Introduction

The United States has important strategic interests and enduring missions in the polar regions. In the Arctic, a portion of Alaskan citizens live north of the Arctic Circle and extensive commercial exploitation of marine and terrestrial resources occurs. The United States has commercial and political relations with the other Arctic nations; both Canada and Russia are taking action to secure and extend their Arctic interests as they contemplate increased use of the Northern Sea Route and the Northwest Passage. In the Antarctic, the United States fields a substantial scientific research presence and has both obligations and leadership roles that are defined by the 1961 Antarctic Treaty. The United States has a stated national interest in shaping international policy regarding the Antarctic continent and its surrounding waters.

Over the years, statements of national policy such as Presidential Decision Directives have reaffirmed the importance of a U.S. presence and leadership in scientific discovery and stewardship in the polar regions (PDD/NSC-26, 1996; PIRS, 1984; PRS, 1990). The most recent of these, the 1996 Presidential Decision Directive, states that "the achievement of United States interests . . . rests upon the year round presence in Antarctica maintained by the United States Antarctic Program (USAP), the program of scientific research and associated logistics funded and managed by the National Science Foundation."

With respect to the Arctic, the most recent National Security Council (NSC) review of U.S. Arctic policy, undertaken in 1994, lists "national security and defense" as a principal interest in the Arctic, noting that "fundamentally, we must ensure that the Arctic Ocean is treated like other oceans for purposes of sovereignty and jurisdictional claims and that these activities are in accord with the principles of the 1982 U.N. Law of the Sea Convention" (NSC-NSDD-90, 1994).

U.S. government presence in the polar regions is necessary to support economic interests, environmental protection, support of scientific research, logistics and supply activities, search and rescue, diplomatic missions related to U.S. strategic interests, national defense readiness, homeland security readiness, maritime domain awareness, sovereignty, and maritime mobility interests, as well as resource exploration and exploitation. Such presence requires reliable access to polar sites during virtually any season of the year. The means the nation needs a strategy for a dependable capability to work in the ice-covered waters.

In the Antarctic, icebreaking and escort are an essential element of the resupply of McMurdo and South Pole Stations. In support of this mission (Operation Deep Freeze), icebreakers perform three activities: They break a channel in the Ross Ice Shelf to McMurdo Station (sometimes as long as 80 miles, Box 1.1); they groom the channel to keep it sufficiently wide for fuel and resupply vessels to enter and exit; and they escort the tanker and the cargo ships that, although ice strengthened, could easily be beset in the ice typically encountered.

In the Arctic, icebreaking capability is required to reach regions north of the Bering Strait at certain times, to access the North Slope of Alaska by sea under most conditions, and to venture into the central Arctic Ocean, including the North Pole. Environmental changes occurring in the polar regions, particularly in the Arctic, are unprecedented in modern observations. Satellite images show that the Arctic sea-ice cover has declined substantially in thickness and extent over the past three decades, (Comiso, 2002; Rothrock et al., 2003; ACIA, 2005). The rate of decline for the 2002-2005 time period is approximately 8 percent per decade. During the last four years (2001-2005), Arctic summer sea-ice extent was approximately 20 percent less than the average from 1978 through 2000. This decline in sea ice amounts to approximately 1.3 million square kilometers (500,000 square miles), an area equivalent to roughly twice the size of Texas (ACIA, 2005). During September 2005, the extent of the Arctic summer sea-ice cover reached a record minimum. Concurrent ecosystem changes are apparent and are also giving rise to increased scientific study of the polar regions.

BOX 1-1
The Annual McMurdo Break-In

For the past two Antarctic summer seasons (2004-2005 and 2005-2006), unusually heavy ice conditions necessitated use of two heavy icebreakers for the McMurdo break-in. During both operations, the POLAR SEA was in dry dock and was not mission capable. NSF was forced to contract for the services of the Russian icebreaker KRASIN, operated by the Far East Shipping Company (FESCO). During Operation Deep Freeze 2004-2005, the POLAR STAR was assisted by the KRASIN; during the 2005-2006 break-in, the KRASIN was hired to break the channel to McMurdo Station and the POLAR STAR was on “standby” in port in Seattle to assist the KRASIN if needed. During the 2005-2006 mission, the KRASIN lost a propeller blade, and the POLAR STAR was sent to help with the resupply. The POLAR STAR arrived in McMurdo Sound after a rapid, 23-day transit; however, NSF decided it was not necessary to utilize the POLAR STAR to assist in the resupply because the KRASIN was able to escort the tanker and cargo ship to the pier. At the conclusion of the break-in, the POLAR STAR returned to Seattle and was put in “caretaker” status with the crew reduced from approximately 135 to 34.

The POLAR STAR will remain in this state indefinitely until a budget decision can be made to either repair it or possibly decommission it. Meanwhile, POLAR SEA has received the minimum repairs required to make it mission capable to support Operation Deep Freeze 2006-2007. Hiring the KRASIN to assist with the McMurdo break-in is not an option in the near future because this ship has been chartered for the next several years by private companies to work in the Arctic. Although NSF is currently investigating options to provide a secondary icebreaker to assist the POLAR SEA for Operation Deep Freeze 2006-2007, in the near future the U.S. polar icebreaker fleet will consist of only two ships in active duty, the HEALY and the POLAR SEA. Due to the aging core systems, a regular and fully funded repair and maintenance schedule would keep the Polar class ships mission capable for only several more years, although this may provide a bridge to a long-term solution.

The decrease in summer Arctic sea-ice extent implies heretofore unanticipated increases in commerce, military operations, and transit in the Arctic via the Northwest Passage (north of Canada) and the Northern Sea Route (north of Russia). These activities can be expected to increase demand for access and support operations required by treaties, laws, and U.S. policies. For example, Articles 211 and 234 of the United Nations Convention on the Law of the Sea (UNCLOS) clearly state the national rules to prevent pollution from vessels and outline special rules for vessels operating in ice-covered water, respectively. These rules will have to be enforced in the Arctic. Further, it is reasonable to expect that the support of U.S. interests in the polar regions under these changing environmental conditions, especially with potential increases in strategic and commercial endeavors in the Arctic, will affect future demands for icebreaker services (see “The U.S. Arctic Presence” in Chapter 2, and “Arctic Environmental Change and Potential Challenges” in Chapter 3 for a discussion of the evidence for and indicators of these potential trends.).

Since 1965, the U.S. Coast Guard has been the sole federal agency responsible for providing national polar icebreaking capabilities. Its missions include law enforcement, marine pollution response, search and rescue, providing a U.S. presence, defense operations, and other unique missions, including diplomatic treaty activities, support for the Department of Defense, and scientific research. Although U.S. Coast Guard icebreakers do not perform all of these missions with great frequency in the polar regions, whenever and wherever a U.S. Coast Guard ship is operating, it is *available* to perform one or more of these other missions as the situation requires.

Budget base transfers in the 1970s and 1980s placed annual funding resources in the budgets of agencies with programs benefiting from icebreaker support in that era, including the Department of Defense, National Science Foundation, and Maritime Administration. Memoranda of Agreement (MOAs) implemented these budget transfers to the U.S. Coast Guard by providing for incremental reimbursement of deployment-related expenses (primarily fuel and other consumables) back to the U.S. Coast Guard. Although the U.S. Coast Guard retained a budget base for icebreaker crews, maintenance, training, and other support to ensure that ships were ready for operations, it did not have budget authority to specifically deploy icebreakers in support of U.S. Coast Guard mission responsibilities. Changes in programs and levels of user agency funding resulted in the decommissioning of older icebreakers in the late 1980s, and some changes were made in the reimbursement formula, but the general concept of agencies “buying” operational icebreaker days continued until 2005.

In preparing the President’s budget for fiscal year

2006, the Office of Management and Budget (OMB) transferred budget authority for the polar icebreakers from the U.S. Coast Guard to the National Science Foundation (NSF), while the U.S. Coast Guard was to retain custody of the polar icebreakers and continue to operate and maintain this fleet. Congress enacted this one-time transfer of $48 million from the U.S. Coast Guard to NSF, which was intended to offset all direct costs associated with the polar icebreaking program, including personnel, training, operation, and maintenance. These funds constitute the U.S. Coast Guard's entire noncapital budget for polar icebreakers. This amount, however, was essentially less than two-thirds of the $65 million to $75 million (Science, 2005) that the U.S. Coast Guard estimated it would cost to maintain the ships. Congress finalized the transfer of funds in Conference Report H.R. 109-272 between the House and Senate Appropriations Subcommittees that are responsible for NSF.

According to briefings received from OMB budget examiners (October 7, 2005), this action was based on the fact that the vast majority of icebreaker ship time has been employed for scientific research. The availability and readiness of the polar icebreakers to address other national needs such as law enforcement, marine pollution response, search and rescue, providing a U.S. presence, and defense operations was not cited as a factor in the decision to transfer the ships to NSF.

With this transfer, NSF assumed control of the polar icebreaker program, and an MOA between the U.S. Coast Guard and NSF regarding polar icebreaker support and reimbursement was established in August 2005. The purpose of this MOA is to "implement the [then proposed] budget base transfer for use of the U.S. Coast Guard icebreakers for scientific and operational support for all planned U.S. Coast Guard operations for FY 2006 and beyond."

Under the 2005 MOA, NSF agrees to consider all national priorities and maintenance requirements when allocating the limited budget. In addition, NSF will identify icebreaker mission needs for the succeeding fiscal year to the U.S. Coast Guard. The responsibilities of the U.S. Coast Guard under this agreement are scheduled on an annual basis by NSF. The U.S. Coast Guard has agreed to provide support staff and services necessary to operate and maintain the polar icebreaker fleet and to inform NSF of secondary polar icebreaker missions as they occur. These missions include the traditional U.S. Coast Guard missions of the polar icebreakers (search and rescue, enforcement of laws and treaties) that were conducted as needed and funded from the base funding. Under this agreement, the U.S. Coast Guard will continue to perform these missions (as needed), and NSF will continue to fund these missions from the program base that was transferred to NSF in FY 2006. In addition, if a situation arises that requires long-term polar icebreaker involvement (major marine pollution or humanitarian relief efforts), then funding and scheduling impacts will be coordinated between the U.S. Coast Guard and NSF.

THE U.S. ICEBREAKER FLEET

Today, the U.S. polar icebreaker fleet ostensibly consists of three ships. The HEALY is the most technologically advanced polar icebreaker, designed to meet the needs of polar research as well as conduct U.S. Coast Guard missions. Although the HEALY was sent to McMurdo Sound in early 2003 to assist the POLAR SEA with break-in operations, HEALY's lower maximum power and lack of maneuverability during ship escort operations limit her utililty for Antarctic logistics. Moreover, using HEALY in Antarctica draws it away from its Arctic missions.

The most powerful icebreakers in the fleet are the two Polar class icebreakers—the POLAR STAR and the POLAR SEA. When these ships were built in the 1970s, they were of state-of-the-art design, power, strength, and weight and incorporated many innovative features. The Polar class icebreakers were designed with 30-year service lives, to support the McMurdo break-in and a variety of science and logistics missions in the Arctic. They were built with basic science facilities, which were substantially upgraded in the late 1980s, and although neither ship has been equipped as a full-service research vessel, POLAR STAR and POLAR SEA supported a broad spectrum of polar research until HEALY became operational**.** The POLAR STAR and POLAR SEA have operated in both polar regions for 29 and 28 years, respectively, and are near the ends of their design service lives. Necessary maintenance has been deferred on both polar icebreakers due to the lack of funding for the polar icebreaker program. From 2000 to 2004, the total gap in funding for the maintenance of the icebreaker fleet was roughly $16 million. The U.S. Coast Guard used funds from the general cutter maintenance during and prior to FY 2003 to cover the maintenance expenses. In FY 2004 additional funding to cover the maintenance of the fleet was provided from the U.S. Coast Guard overall maintenance account (funds not designated just for cutters). In FY 2005, additional funding was provided by NSF and from the U.S. Coast Guard overall operating expense account, and in FY 2006, all additional funding was provided by NSF. Both ships are becoming inefficient to operate because they now require substantial and increasing maintenance efforts to keep vital ship systems operational, and their technological systems are becoming increasingly obsolete. This situation has created major mission readiness issues.

PURPOSE OF THIS REPORT

The immediate problem for the U.S. polar icebreakers is that given the current mode of operation, their activity is underfunded. Moving budget authority for the icebreaking program to NSF did not address the base funding problem and substantially increased the difficulty of program management. Currently, the polar icebreakers are multipurpose ships, supporting multiple government responsibilities and associated agencies. Although the vast majority of their deployment time in recent years has been in support of science for several agencies, these ships still support other necessary U.S. Coast Guard missions (e.g., national and homeland security, maritime safety, search and rescue), traditional missions that can be expected to increase as human presence in the Arctic increases due to environmental changes and emerging economic opportunities. Having now been given budget authority over the icebreaking program, NSF is today fiscally responsible for missions well outside its core mission and expertise. Without budget authority, the U.S. Coast Guard has been put in a situation in which it has the role of operating ships for which it does not have full management control. Issues such as how to fund or choose among crew training alternatives for nonscience missions are not fully under its control. This situation is further complicated by the fact that the government agencies whose missions these ships support are overseen by multiple congressional committees. This arrangement of decentralized stakeholders and distributed oversight complicates authorization and appropriations for the maintenance, operation, and recapitalization of the ships that are expected to deliver the nation's required icebreaking capabilities. In essence, management responsibility is not clearly aligned with management accountability.

Although there are many stakeholders and potential users directly and/or indirectly reliant on icebreaking capabilities in the Arctic and Antarctic, the path or mechanism to rebuild the capabilities necessary to serve U.S. interests is unclear. Thus, we face a challenge today: the aging condition of the U.S. Coast Guard's POLAR SEA and POLAR STAR means that significant U.S. government investment would be needed to continue their service and/or replace them.

In late 2004, Congress passed P.L. 108-334, instructing the U.S. Coast Guard to ask the National Academies for advice on this issue. In response, the National Academies created the committee on the Assessment of U.S. Coast Guard Polar Icebreaker Roles and Future Needs. The principal task of the committee is to provide a comprehensive assessment of the current and future roles of U.S. Coast Guard polar icebreakers in supporting U.S. operations in the Antarctic and the Arctic (see Appendix A, Statement of Task). The committee's goal is to look at past, current, and anticipated future needs for U.S. icebreaking capabilities; explore different scenarios of operation, from continuation of current operations to innovative alternative approaches; and also consider how the nation's need for icebreaking capabilities will change in the Arctic in the context of ongoing and future environmental change.

The committee's preliminary report was released in December 2005. In that report (see Executive Summary in Appendix B), the committee described present and expected future uses of polar icebreakers with respect to relevant U.S. Coast Guard missions in the Antarctic and the Arctic, including national defense, homeland security, support of economic activity, law enforcement, search and rescue, environmental protection, and support and conduct of science, as part of an overall demand for icebreaking services. That report also addressed potential changes in the roles and missions of U.S. Coast Guard polar icebreakers in support of future marine operations in the Arctic that may develop due to environmental change. The committee addressed what it believed were the most time-dependent issues for decisions makers, focusing in particular on the urgent, short-term need for reliable icebreaking support.

This second report is the committee's final, in-depth analysis with recommendations for future actions to address the challenge presented by U.S. strategic interests in the polar regions and these aging ships. Specifically, the committee describes the expected future needs for polar icebreakers in terms of the current and future missions of the U.S. polar icebreaker fleet, the approximate number and types of polar icebreakers needed in the future, where and when these ships will be expected to operate, and what capabilities will be needed to accomplish all missions in the polar regions.

This report presents and analyzes a small number of feasible scenarios for continuing polar icebreaker operations in the polar regions, including service life extension of existing U.S. Coast Guard icebreakers, replacement of existing U.S. Coast Guard icebreakers, and alternate methods of meeting identified needs (e.g., resupply of McMurdo Station, availability of platforms for marine research), including use of ice-strengthened vessels, foreign vessels, and other options that do not use U.S. Coast Guard services, and provides an analysis of these options. In addition the current authorities and policies that govern U.S. Coast Guard polar icebreaking operations are reviewed in terms of potential missions and new operating regimes that may arise.

The committee appreciates the presentations and supplementary materials provided by the U.S. Coast Guard, NSF, Arctic Research Commission, Department of State, National Oceanic and Atmospheric Administration, Office of Management and Budget, and others in the marine transport and science communities. The committee's findings and recommendations are based on its analysis of the materials and briefings received and the committee's expert judgment. Committee members have expertise in icebreaker command and operations, ship design and operations, national defense, naval architecture, marine transport-shipping industry, polar ship technologies, science management, oceanography, glaciology, sea-ice dynamics, paleoclimatology, and Antarctic policy.

Together, the committee's two reports are intended to inform the decision-making process. The committee provides information needed by Congress, OMB, the U.S. Coast Guard, NSF, and other relevant agencies (e.g., the U.S. Department of State, Department of Defense, National Oceanic and Atmospheric Administration), all of whom have responsibilities related to the U.S. presence in polar regions. The United States has important foreign policy as well as research interests in both polar regions and that asserting those interests requires a reliable icebreaking capability under the control of the U.S. government. Today, the U.S. icebreaking capability resides with the U.S. Coast Guard and is based on the three icebreaking ships, the two most capable of which are at the end of their service lives. This report provides a comprehensive assessment of the current and future roles of U.S. polar icebreakers in supporting U.S. strategic missions and interests in the polar regions.

2

U.S. Strategic Interests and Missions in the Polar Regions

Scientific exploration of Antarctica began in earnest in the early 1950s when the 67 member nations of the International Council of Scientific Unions (ICSU) endorsed a proposal to conduct an International Geophysical Year (IGY) in 1957-1958 and intensive, scientific exploration of Antarctica began on an international level.[1] The ICSU nations agreed that the IGY would focus especially on research in Antarctica and outer space. Twelve of the ICSU member countries (Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the United Kingdom, the United States, and the Soviet Union) met in July 1955 to commence planning the Antarctic science program. Up to this point, only a few permanent stations had been established in Antarctica. The first recorded ongoing settlement dates back to 1903 when the Scottish National expedition established a building on Laurie Island. The station was handed over to Argentina the following year and was later named Orcadas. It is the longest continuously operating station in Antarctica. During International Geophysical Year activities in 1957, more than 40 stations were established in Antarctica for the IGY at many points around the continent, including two on the Antarctic plateau: one at the South Pole by the United States and the other at the Pole of Inaccessibility (farthest points from the coasts) by the Soviet Union.

During the International Geophysical Year 1957-1958, the United States committed to a significant program of exploration and study of the Antarctic and has maintained an active presence in Antarctica ever since. The United States was instrumental in the development of the Antarctic Treaty of 1959, which was signed in Washington, D.C., on December 1, 1959, and entered into force on June 23, 1961. The Antarctic Treaty System includes a series of agreements that regulate relations among states in Antarctica. The original 12 signatories consisted of the seven countries with claims over parts of Antarctica—Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom—and five other countries with Antarctic activities, namely Belgium, Japan, South Africa, the Soviet Union, and the United States.

Today the Antarctic Treaty System[2] is embedded in a system of conventions, measures, and annexes that reflect changes in the world over nearly the last five decades. Evolution of the geopolitical framework that brought the original 12 founding nations together has resulted in correlative changes in U.S. influence and interests in Antarctica. The original 12 member nations have now grown to 45 countries that accede to the Antarctic Treaty (Table 2.1). These 45 countries represent two-thirds of the world's population.

The Antarctic Treaty requires that governing countries

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[1] Much of the exploration of the Antarctic islands and coastal waters that occurred during the early nineteenth century was a by-product of commercial sealing and whaling activities. Occasionally discoveries in the peninsula region were accidental when vessels were blown off course through adverse weather conditions. As seal colonies were progressively depleted, commercial operators extended their exploration and mapped substantial areas of the Antarctic coast in their search for wildlife resources. In addition, a number of countries mounted national expeditions of exploration during the nineteenth and early twentieth centuries. The fact that early ship-based exploration achieved so much in charting the hazardous and unknown regions of Antarctica is testament to the courage and seamanship of the early mariners. It is indeed remarkable that much of this work was undertaken using timber-hulled, sailing ships, which lacked the structural strength, power, and sophisticated navigation aids available today.

[2] The Antarctic Treaty System has grown from the original treaty and now consists of the following three agreements in addition to the treaty itself: (1) the Convention for the Conservation of Antarctic Seals (CCAS), signed in London on June 1, 1972; (2) the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), signed in Canberra on May 20, 1980; and (3) the Protocol on Environmental Protection to the Antarctic Treaty, signed in Madrid on October 4, 1991. In addition, there are some 300 measures adopted by the Antarctic Treaty Consultative Meeting (ATCM), which has met annually since 1994.

TABLE 2.1 List of Signatories to the Antarctic Treaty

No.	State	Date	Status	Date Acceding State Became Consultative Party
1	United Kingdom	May 31, 1960	OS/CP	
2	South Africa	June 21, 1960	OS/CP	
3	Belgium	July 26, 1960	OS/CP	
4	Japan	August 4, 1960	OS/CP	
5	United States of America	August 18, 1960	OS/CP	
6	Norway	August 24, 1960	OS/CP	
7	France	September 16, 1960	OS/CP	
8	New Zealand	November 1, 1960	OS/CP	
9	Russia[a]	November 2, 1960	OS/CP	
10	Poland	June 8, 1961	AS/CP	July 29, 1977
11	Argentina	June 23, 1961	OS/CP	
12	Australia	June 23, 1961	OS/CP	
13	Chile	June 23, 1961	OS/CP	
14	Czech Republic[b]	June 14, 1962	AS	
15	Slovak Republic[b]	June 14, 1962	AS	
16	Denmark	May 20, 1965	AS	
17	Netherlands	March 30, 1967	AS/CP	November 19, 1990
18	Romania	September 15, 1971	AS	
19	German Democratic Republic[c]	November 19, 1974	AS/CP	October 5, 1987
20	Brazil	May 16, 1975	AS/CP	September 12, 1983
21	Bulgaria	September 11, 1978	AS/CP	May 25, 1998
	Germany, Federal Republic of	February 5, 1979	AS/CP	March 3, 1981
22	Uruguay	January 11, 1980	AS/CP	October 7, 1985
23	Papua New Guinea[d]	March 16, 1981	AS	
24	Italy	March 18, 1981	AS/CP	October 5, 1987
25	Peru	April 10, 1981	AS/CP	October 9, 1989
26	Spain	March 31, 1982	AS/CP	September 21, 1988
27	China, People's Republic of	June 8, 1983	AS/CP	October 7, 1985
28	India	August 19, 1983	AS/CP	September 12, 1983
29	Hungary	January 27, 1984	AS	
30	Sweden	April 24, 1984	AS/CP	September 21, 1988
31	Finland	May 15, 1984	AS/CP	October 9, 1989
32	Cuba	August 16, 1984	AS	
33	Korea, Republic of	November 28, 1986	AS/CP	October 9, 1989
34	Greece	January 8, 1987	AS	
35	Korea, Democratic People's Republic of	January 21, 1987	AS	
36	Austria	August 25, 1987	AS	
37	Ecuador	September 15, 1987	AS/CP	November 19, 1990
38	Canada	May 4, 1988	AS	
39	Colombia	January 31, 1989	AS	
40	Switzerland	November 15, 1990	AS	
41	Guatemala	July 31, 1991	AS	
42	Ukraine	October 28, 1992	AS/CP	May 27, 2004
43	Turkey	January 25, 1996	AS	
44	Venezuela	May 24, 1999	AS	
45	Estonia	May 17, 2001	AS	

NOTE: OS = original signatory; CP = consultative party; AS = acceding state; dates represent the dates of ratification of the treaty by the original signatories or the dates of accession or succession by other states.

[a] Known as the Soviet Union until December 1990.
[b] Succeeded to the Treaty as part of Czechoslovakia which separated into two republics on January 1, 1993.
[c] Became united with Federal Republic of Germany on October 3, 1990 (now known as Germany).
[d] Acceded to the Treaty after independence from Australia.

SOURCE: Antarctic Treaty Secretariat web site (http://www.ats.aq) conduct an active scientific program in the region. In the United States, the State Department is the U.S. representative in the Antarctic Treaty process, and management of the United States Antarctic Program (USAP) was assigned to the National Science Foundation by Presidential Memorandum 6646 (1982). National policy directives have consistently reiterated the national importance of maintaining a visible presence and an active U.S. Antarctic Program in the region. U.S. interests were most recently articulated in a Presidential Decision Directive (NSC, 1994), which states four U.S. interests in Antarctica:

1. Protecting the relatively unspoiled environment of Antarctica and its associated ecosystems;
2. Preserving and pursuing unique opportunities for scientific research to understand Antarctica and global physical and environmental systems;
3. Maintaining Antarctica as an area of international cooperation reserved exclusively for peaceful purposes; and
4. Ensuring the conservation and sustainable management of the living resources in the oceans surrounding Antarctica.

In 1996, the Committee on Fundamental Science of the President's National Science and Technology Council (NSTC) reviewed U.S. activities in the polar regions. That committee confirmed that "the National Science Foundation has implemented U.S. Policy in an effective manner" and that "the USAP research program is of very high quality" (NSTC, 1996). In 1997, an in-depth review of the U.S. Antarctic Program again confirmed the importance of a continued strong science program in the Antarctic and made recommendations for improvement (NSF, 1997). In a recent briefing to this Committee, the Department of State once again stated that it is essential for the United States to maintain an active and influential presence in Antarctica, including but not limited to year-round operation of the South Pole Station and other permanent stations. The long-term cooperative management of Antarctica achieved under the Antarctic Treaty is a significant accomplishment and the central role of science cannot be overstated.

Under the treaty, the United States and other signatories are guaranteed freedom of scientific research and provided inspection rights to ensure compliance. Specifically, the Antarctic Treaty ensures "in the interests of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord." To this end it prohibits military activity, except in support of science; prohibits nuclear explosions and the disposal of nuclear waste; promotes scientific research and the exchange of data; and holds all territorial claims in abeyance for 50 years. The treaty applies to the area south of 60 degrees South Latitude, including all ice shelves and islands. As for the sovereignty issue, the status quo of 1959 with regard to claims or their recognition is maintained, although the claims of many nations remain unresolved and overlapping (Figure 2.1). "No acts or activities taking place while the present Treaty is in force shall constitute a basis for assenting, supporting or denying a claim to territorial sovereignty in Antarctica or create any rights of sovereignty in Antarctica" (Antarctic Treaty, 1959).

With the increased interest in Antarctica, human presence has increased over the years as more nations have joined the Antarctic Treaty system, and many more scientific stations have been established. It is important to note, however, that the maximum number of U.S. personnel present in Antarctica actually peaked during Operation Deep Freeze at the height of the Cold War. Since that time, the increased level and complexity of human activities in Antarctica have been due to the ever-increasing presence of other nations' personnel and the establishment of additional scientific bases in Antarctica. In addition, as technology and scientific advances shrink the globe, interest in the natural resources of Antarctica has increased. Although no mineral or resource exploitation (other than fisheries and tourism) has taken place in Antarctica, as perceived distances to market decrease and commodity prices increase, the pressure to exploit this once-remote continent are expected to increase.

The United States has strong interest in preserving and protecting one of the most pristine environments on the globe, ensuring that the Antarctic continent is reserved exclusively for peaceful purposes, and pursuing unique opportunities to gain new scientific knowledge. In support of these interests, the United States does not claim territory in Antarctica (although it does maintain the basis for a claim) and it does not recognize the (overlapping) territorial claims made by seven other countries (Figure 2.1). Although, the U.S. Antarctic Program remains by far the largest in the world,[3] the operation of the treaty by unanimous consent and the one country-one vote approach has meant in recent years that U.S. influence has diminished and its leadership is challenged on a regular basis. However, as the lead proponent of the original treaty, the United States has established an influential presence in Antarctica and as such has served a critical role in maintaining the integrity of the Antarctic Treaty and fostering an atmosphere of cooperation and partnership.

The influential U.S. presence in Antarctica is principally a result of the operations of the U.S. Antarctic Program and its three year-round research stations: McMurdo Station, Palmer Station, and South Pole Station. This presence protects the U.S. stance on Antarctic sovereignty, secures the United States an influential role in the treaty's decision-making system, and helps maintain the political and legal balance necessary for success of the treaty. Many view the permanent year-round presence of the United States as a major

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[3] As measured by the dollar amount invested in science and support, by the number of people on the continent, or by the number and complexity of stations.

FIGURE 2.1 Antarctic territorial claims.

deterrent to those countries that might otherwise wish to exercise their territorial claims. The South Pole Station is of particular importance to sovereignty issues because the South Pole is at the apex of the areas claimed by the seven countries that assert territorial claims. The year-round presence of U.S. scientists at South Pole Station preserves U.S. interests and influence.

The U.S. national presence in the Antarctic is possible at present because of the logistical support of U.S. military forces that are charged to resupply the permanent science stations. Both Navy and U.S. Coast Guard icebreakers supported Antarctic operations until the U.S. Coast Guard assumed all polar icebreaker responsibilities in 1965. The U.S. Navy continued to provide airlift support to Operation Deep

Freeze (the long-lived science mission) until the mid-1990s, when this task was transferred to the Air National Guard. The principal role of the U.S. Coast Guard has been to provide logistics support to the U.S. Antarctic Program by breaking a channel into McMurdo Sound to allow resupply of McMurdo Station by tanker and cargo ships. Supplies from McMurdo are transferred to the South Pole Station by air, recently supplemented on a developmental basis by ground traverse. Icebreakers are a lifeline to and critical for the maintenance of USAP operations at the shore of McMurdo Sound and at the South Pole.

Until recently, the two Polar class icebreakers (sometimes together and sometimes separately depending on ice conditions) were used to break open a channel for resupply.[4] However, more challenging ice conditions and the deteriorating status of the Polar class ships now adds uncertainty and risk of failure to the operation. The National Science Foundation (NSF) is concerned that the lack of reliable icebreaking support may make it increasingly difficult to maintain the permanent stations and associated science programs. Investigations of alternate logistics plans by NSF (discussed in Chapter 8) have reaffirmed that icebreaker support is necessary to the Antarctic resupply chain for now and in the foreseeable future. According to a representative of the Department of State assigned to Antarctic issues, if resupply of South Pole Station is not successful and the station were abandoned, this would jeopardize, and probably reduce, the influence of the United States in Antarctic governance. There would be significant consequences because abandonment of that key site would create a vacuum in leadership and likely result in a scramble for control. Abandoning it would be detrimental to the U.S. position as well as to the stability of the treaty system. To preserve the U.S. presence in Antarctica and hence its influential role in the Antarctic Treaty, it is paramount to maintain the three permanent research stations and their associated active research programs throughout the Antarctic continent. Icebreaker operations are critical to the continued existence of these stations and their associated outlying field sites.

THE U.S. ARCTIC PRESENCE

The United States is one of eight nations that have territory and citizens in the Arctic. Thus, the nation has obligations to the population of Alaska as well as a range of international responsibilities, treaty obligations, and policy interests in the region. New opportunities for Arctic cooperation arose in the late 1980s (shortly before the dissolution of the former Soviet Union) and "environmental cooperation was identified as a first step in promoting comprehensive security in the region" (*www.arctic-council.org*). The eight Arctic nations (Canada, Denmark [including Greenland and the Faeroe Islands], Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States) adopted an Arctic Environmental Protection Strategy in 1991, and in 1996 the Arctic Council was formed. The United States is a founding signatory and member state of the Arctic Council, a regional intergovernmental forum whose purpose is to address all aspects of sustainable development—environmental, social, and economic—addressing issues and challenges shared by the Arctic nations.

The most recent National Security Council policy review of U.S. Arctic policy, undertaken in 1994, lists "national security and defense" as among the key principal interests in the Arctic. Typically, U.S. national security and foreign policy concerns in the Arctic involve sovereignty and jurisdictional issues within the Arctic Ocean. Since the Arctic Ocean is treated like other oceans for purposes of sovereignty and jurisdictional claims, issues typically focus on freedom of access to ice-covered boundary areas as well as international straits and waterways in the Arctic, such as the Bering Strait and the Northwest Passage.

In addition, obligations under international agreements, such as the United States-Denmark bilateral agreement regarding airbases in Greenland and the multilateral agreement concerning the North Atlantic Ice Patrol, must be fulfilled. At present, resupply of the U.S. Thule Air Force Base in Greenland is achieved through an agreement between the Canadian and U.S. Coast Guards. The Canadian Coast Guard is responsible for resupplying the base in exchange for icebreaking services provided by the U.S. Coast Guard in the western Arctic. Reciprocal support for Canadian icebreaking requirements is routinely offered. In practice, this has consisted mostly of joint science program support, and operational support, such as resupply of the Surface Heat Budget of the Arctic Ocean (SHEBA) project in 1998.

Of special importance in the near term is the approaching enforcement of the 1982 U.N. Convention on the Law of the Sea. Since the seventeenth century, the oceans have been subject to a "freedom of the seas" doctrine, a principle limiting national rights and jurisdiction over the oceans to a narrow belt of sea surrounding a nation's coastline. The remainder of the seas was proclaimed free to all and belonging to none, but by the mid-twentieth century there was growing concern over the toll on coastal fish stock caused by long-distance fishing fleets, pollution from transport ships, and other demands. In 1945 the United States extended its jurisdiction to include all natural resources on the continental shelf; other nations soon followed suit. As pressure on ocean resources increased, amplified by advances in technology, discussions began in 1973 that culminated in the 1982 adop-

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[4] Research needs at Palmer Station on the Antarctic Peninsula require nearly year-round access. However, this area has more benign ice conditions and does not require heavy icebreaking for resupply. Access is accomplished by the LAURENCE M. GOULD and the NATHANIEL B. PALMER, leased by NSF's prime contractor, currently Raytheon Polar Services, from Edison Chouest Offshore. These ships are designed primarily as oceanographic research vessels but with enough icebreaking capability for the Antarctic Peninsula region.

BOX 2.1
United Nations Convention on the Law of the Sea

Article 76 of UNCLOS outlines the specific geologic and morphological criteria to be followed in delimiting the continental shelf. It is based largely on either of two formulas (Mayer, 2003; Gardner et al., 2006): a distance formula that allows an extension of the shelf to 60 nmi beyond the foot of the continental slope (defined as the point of maximum change in gradient at its base) (Figure 2.2), or a sedimentary rock thickness formula that allows extension of the shelf to where the thickness of sediments (or sedimentary rock) is 1 percent of the distance back to the foot of the slope (Figure 2.2). Following either of these criteria, the outer limit (cutoff lines) of the continental shelf cannot extend more than 350 nmi from the coast, or cannot exceed 100 nmi from the 2,500-meter isobath, whichever is more beneficial for the coastal state. In the U.S. Arctic, the continental shelf may extend as far as 600 nmi from the baseline. Key to implementing any of these criteria are a clear bathymetric delineation of the 2500-meter isobath and the foot of the continental slope and accurate geophysical data to determine seabed sediment thicknesses. Submission by any country of its continental shelf limits will be based on a combination of high-resolution, state-of-the-art bathymetric and geophysical data.

However, scientific knowledge of seafloor geology involves more than just bathymetry and sediment thickness. Article 76, paragraphs 3 and 6, makes a distinction between oceanic ridges, submarine ridges, and submarine elevations that are natural components of the continental margin, such as plateaus, rises, caps, banks, and spurs. The interpretation of these definitions impacts how one defines shelf delimitation. The treaty states that the continental margin consists of the submerged prolongation of the landmass of the coastal state. Yet, the distinction between those parts of the ocean that are a natural prolongation of the landmass and those that are part of the deep ocean floor lies in the geologic and tectonic context of the rocks. The wording implies that the continental shelf may extend to 200 nmi on oceanic ridges, to 350 nmi on submarine ridges, and to either 350 nmi or 100 nmi beyond the 2,500-meter isobath on submarine elevations. According to one interpretation (*http://www.unclosnz.org.nz/ridges.html*), if the feature is morphologically continuous with the continental margin regardless of its origin, and is not an oceanic ridge, then it is either a submarine ridge or a submarine elevation that is a natural component of the margin, depending on the degree of geological and tectonic continuity between the landmass and the ridge. What is important to grasp is that seabed claims require sound geological data.

Any submission for an extended continental shelf by the United States in the Arctic would likely be based on the sediment thickness formula. This requires precise data on the location of the foot of the continental slope (based on bathymetry) and would be limited by the position of the 2,500-meter isobath plus 100 nmi. The U.S. claim will require both accurate bathymetry and accurate sediment thickness data.

tion by the United Nations of a constitution for the seas, the U.N. Convention on the Law of the Sea (UNCLOS).

UNCLOS was crafted to manage and protect the natural resources of the world's oceans and outline unifying provisions concerning rights of maritime navigation, transit regimes, continental shelf jurisdiction, exclusive economic zones (EEZs), and seabed mining. Exactly 149 countries have ratified the convention, including almost every industrialized nation except the United States.[5] When first proposed in 1982, President Ronald Reagan had objections to the convention's provisions on seabed mining. This part of the convention was rectified in the 1994 Agreement on Part XI. President Clinton signed the treaty and sent it to Congress where it still awaits accession. It is clear that accession to the treaty by Congress has been supported by more than one administration with the concurrence of the Senate Foreign Relations Committee, the U.S. Commission on Ocean Policy, the Pew Commission, the U.S. Navy, and others. Because the United States is the world's largest maritime power with the longest coastline and largest continental shelves in the world, the country is poised to benefit the most from ratification. This far-reaching framework is consistent with our national security, economic, and environmental interests in the oceans while promoting international approaches to dispute settlements and means of managing open sea resources.

UNCLOS allows a territorial sea for all coastal nations extending 12 nautical miles (nmi) from the shore (baseline),

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[5] A list of all countries that have ratified UNCLOS, dates of ratification, and so forth is available on the Web at *http://www.un.org/depts/los/reference_files/chronological_lists_of_ratifications.htm#Agreement%20relating%20to%20the%20implementation%20of%20Part%20XI%20of%20the%20Convention.*

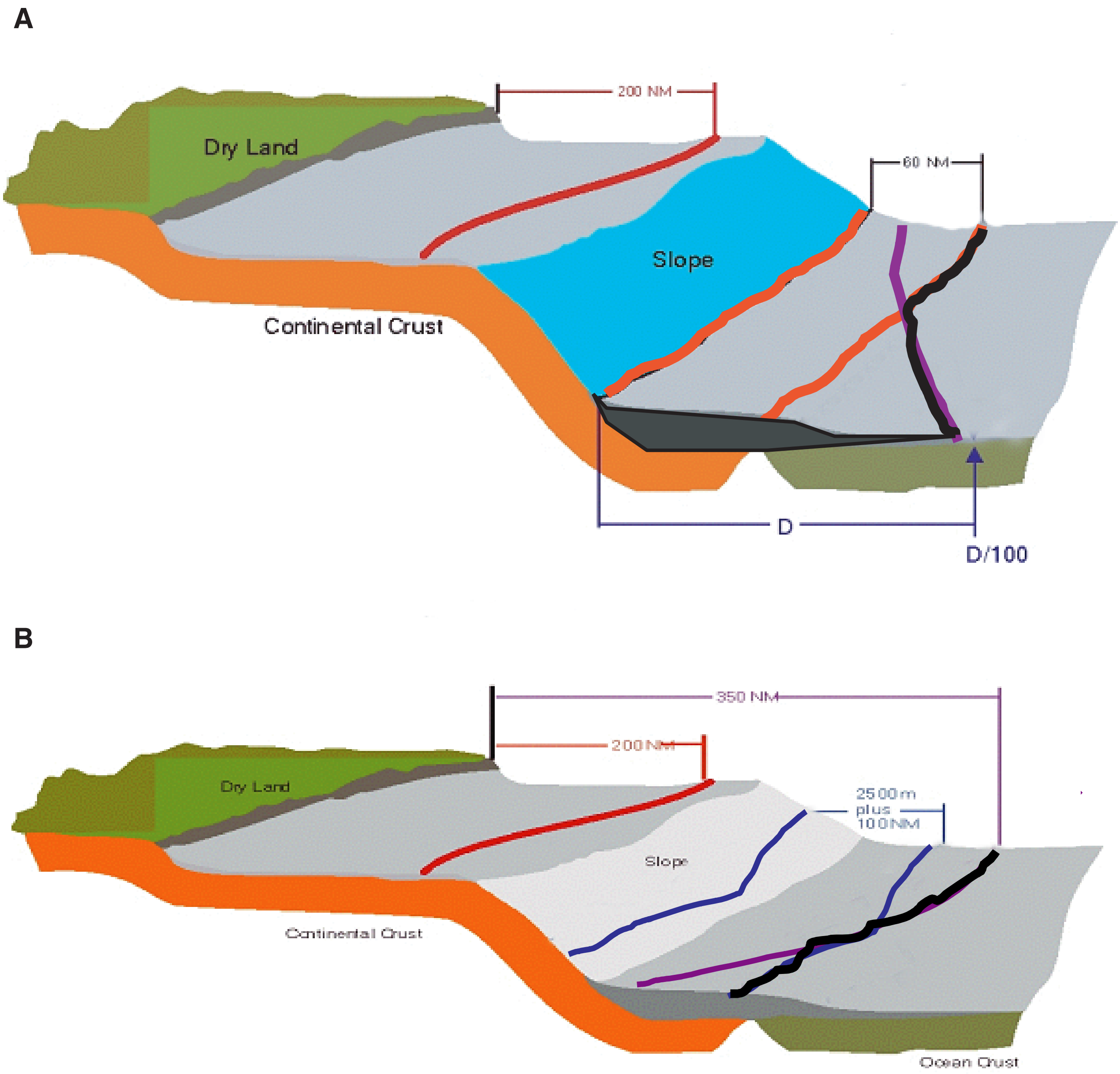

FIGURE 2.2 Specific geologic and morphological criteria to be followed in delimiting the continental shelf for UNCLOS claims. SOURCE: L. Mayer, University of New Hampshire.

within which countries can exercise their sovereignty (1 nautical mile =1.852 km, or 1.150779 statute mile) (Figure 2.1). Beyond this limit, the convention recognizes a contiguous zone to a distance of 24 nmi, in which a country can exert limited controls necessary to prevent and punish infringements of immigration, customs, fiscal, and sanitary laws that occur in its territory or its territorial sea. The treaty also provides coastal countries with the sovereign right to explore and exploit resources (e.g., fisheries, oil, gas, gas hydrates) from their EEZ to a distance of 200 nmi from the coast. Moreover, it allows coastal states the sovereign right to explore and exploit the natural resources of the continental shelf both within and beyond 200 nmi based on a fixed set of geologic criteria (see Box 2.1 and Figure 2.2).

U.S. accession to UNCLOS will set in motion a 10-year deadline for the United States to make a submission on the limits of its continental shelf beyond 200 nmi to the Commission on the Limits of the Continental Shelf (CLCS). Article 76 of UNCLOS outlines the specific geologic and morphological criteria to be followed in delimiting the continental shelf. To do this, or even to substantiate a claim independent of the UNCLOS process, the United States must conduct extensive bathymetric and geologic studies.

The submission of claims to the CLCS was expected to take place within 10 years of any nation acceding to the treaty (under Article 4 of annex II to the Convention). Among the Arctic nations, Finland signed on in June 1996; Norway and Sweden in November 1996; Iceland in February 1997; Russia in March 1997; Canada in March 2003; and Denmark in November 2004. The United States is the last Arctic nation still to sign the UNCLOS treaty. Because of the complexity and technical challenges faced by some developing nations and island states seeking shelf extensions and, significantly, because the Science and Technological Guidelines for delimiting shelf extensions were not adopted until May 1999, it was agreed by parties to the convention in June 2001 that all countries ratifying UNCLOS before 1999 have until May 2009 to submit their claims (SPLOS/73, 2001). Russia made its initial submission on December 20, 2001, but was told to resubmit with additional geologic evidence. All other Arctic countries have active science programs involving icebreaker support in data gathering across their respective Arctic shelf borderlands.

Some countries that have made submissions spent more than 10 years collecting and analyzing the required data, which suggests that the United States should begin as quickly as possible to move forward with a coordinated research plan for continental shelf delimitation. In the Arctic, this will require icebreaker support.

U.S. scientists have already begun the task of gathering the bathymetric data needed for submitting our claim to the continental shelf beyond 200 nmi. Since 2002, the University of New Hampshire's Center for Coastal and Ocean Mapping-Joint Hydrographic Center has been tasked by Congress, through a grant from the National Oceanic and Atmospheric Administration, to conduct seafloor bathymetric mapping using high-resolution multibeam echo sounding technology. Selected portions of the continental shelf have already been mapped, including parts of the Arctic margin off northern Alaska and the Bering Sea (Gardner et al., 2006). However, a great deal of the Arctic Basin adjacent to the Alaskan Chukchi and Beaufort shelves remains to be explored, especially addressing the question of sediment or sedimentary rock thicknesses and tectonic relationships to the adjacent shelf. The U.S. claim will require both accurate bathymetry and sediment thickness data (L. Mayer, personal communication, 2006). Although some seismic surveys conducted by U.S. scientists in 2005 and 2006 on the HEALY[6] could eventually contribute to the database for future U.S. claims, the United States, as present, does not have an immediate research strategy or focused proposal competition for determining sediment thickness or for the geologic and tectonic continuity of submerged portions of the continental shelf (i.e., the Chukchi Cap). What will be needed are high-density surveys of multichannel seismic data, gravity data, and sonobuoy velocity calibrations executed in a fashion adapted to Arctic conditions. The collection of these data will, by necessity, require the support of the U.S. polar icebreakers to ensure that data of sufficient quality and quantity are collected to make a legitimate claim of sovereign rights over a larger part of the Arctic Basin beyond the present 200 nmi EEZ limit.[7]

Asserting a national presence in the Arctic requires access to the region, and icebreaker support is the preferred way of ingress into ice-covered boundary areas. Although U.S. Navy submarines and Air Force aerial assets are present in the Arctic region, the U.S. Coast Guard is the principal government agency that is capable of year-round operations in Arctic surface waters. The U.S. Coast Guard, through use of the HEALY and the Polar class vessels, is the main—and visible—federal presence in the waters of this region. Although devoted primarily to oceanographic research, the HEALY is available for other missions ranging from national defense, to law enforcement, search and rescue, and support of U.S. commerce (shipping, tourism, fishing, and resource exploration).

Changing Arctic environmental conditions reinforced by robust climate model predictions for widespread ice-free summer conditions in the coming decades (Holland and Bitz, 2003; Meier et al., 2005; Arzel et al., 2006; Zhang and Walsh, 2006) should provide new impetus to the Senate debate over U.S. accession to UNCLOS. A more accessible Arctic in the near future has profound implications for changing the polar mission of the U.S. Coast Guard given the expectation for increased surveillance of commercial ship traffic transiting either the Northern Sea Route (across northern Russia) or the Northwest Passage (Canada) via the Bering Strait around Alaska. Growing demands for oil, gas, minerals, and fisheries will drive many of the developed Arctic countries to look to the polar regions for accessible untapped resources. Estimates by the U.S. Geological Survey and other international sources indicated that up to 25 percent of the world's undiscovered petroleum reserves are in the Arctic. Of great importance will be planned and unplanned tasking that requires use of polar icebreakers to exert a national presence within the U.S. EEZ and across an expanded continental shelf region year-round.

WELFARE OF ALASKAN CITIZENS

Society, technology, and the environment are closely linked today. Because of atmospheric circulation patterns, large-scale environmental changes may result in regional impacts that differ from those on the global scale. Large-

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[6] For details, see *http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0327626 and http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0449898.*

[7] Submissions and deliberations of CLCS are not entirely public information, but a summary of the public data on submissions and deliberations is available on the UNCLOS Web site (*http://www.un.org/Depts/los/reference_files/new_developments_and_recent_adds.htm*; see also *http://www.un.org/Depts/los/clcs_new/commission_documents.htm*).

scale environmental changes in the polar regions within the past few decades are more pronounced than changes in the mid-latitudes or tropics (ACIA, 2005). A warming environment in Alaska will cause permafrost melting and deterioration of infrastructure that supports utilities, such as water, electricity, and sewage, as well as pipeline stability. These changes affect human daily life and economic and strategic activities, including communications technologies; ground, air, and sea transportation; and failure of roadways and foundations under freeze-thaw conditions.

These human-environment linkages directly involve the people who live in northern regions in many ways, but also involve people all around the world. For example, at this global level, changing environmental conditions—including the frequency and duration of severe weather events such as storms, precipitation, or drought—can have a range of impacts on human daily activity in temperate as well as polar regions. The Arctic Oscillation-North Atlantic Oscillation, the El Niño-Southern Oscillation, and the Antarctic Oscillation are all multiyear, low-frequency patterns of atmospheric and oceanic circulation that have effects ranging from major flooding in some regions to droughts and fires in others (NRC, 2002).

The United States also has an interest in protecting the welfare of the citizens of Alaska. This has direct implications for their collective and individual safety as well as for the environment in which they live.

Environmental changes in the Artic will likely have profound effects on the citizens of Alaska. These changing conditions affect systems used every day, from the impact of snow on the mobility of vehicles and freeze-thaw destruction of roadways to the icing of aircraft wings, and these pose engineering challenges. Permafrost has received much attention recently because surface temperatures are rising in most permafrost areas of the Earth, bringing some permafrost to the edge of widespread thawing and degradation. Thawing permafrost due to warming is resulting in the loss of soil strength, and this has already caused the failure of roadways, runways, and pipelines and is causing the foundations of some structures to collapse (ACIA, 2005).

Modern technologies also can be affected by changes in the environment. The solar processes that produce disturbances in the Earth's space environment (space weather) affect high-frequency communications, including cell phones, global positioning systems, and power systems. Changes in ocean circulation and temperature patterns have an impact on acoustic propagation pathways for subsea communications. Changes in the pattern and severity of winters on land affect many modern technologies, from snow and ice impacts on ground travel to ice formation on aircraft wings (NRC, 2006).

Environmental changes in the Arctic will likely have profound effects on Alaska Natives and indigenous peoples throughout the circum-Arctic regions who have lifestyles closely tied to the marine environment (ACIA, 2005; see also Alaska Native Science Commission, *http://www.nativescience.org/issues/climatechange.htm*). Projected seawater temperature increases will likely have detrimental impacts on cold-water-adapted fish, wildlife, and habitats, causing temperature stress to fauna and habitat deterioration. Thus, indigenous peoples in the circumpolar regions will be some of the first impacted by environmental change in the north (ACIA, 2005). The potential for destabilizing change and its impacts on local Arctic communities is already in progress, from increased storm surges with longer fetch and an extended open-water season as a result of ice retreat and enhanced erosion (e.g., at Shishmaref, Alaska) to variable sea-ice conditions during the spring and fall marine hunt period that increases uncertainty and personal risk for local hunters in the marine environment (ACIA, 2005).

Changes in the Arctic sea-ice extent and ecosystems may affect Alaska Native communities through potentially negative impacts on the marine food supply as a result of changing trophic dynamics (marine mammals, fish, and seabirds), impacts on subsistence hunting, and concerns for personal safety to maintain a lifestyle in a changing, uncertain environment (variable ice conditions, weather). The firsthand impacts of environmental change are being felt by Arctic subsistence communities, such as those who practice reindeer husbandry in Finland and Russia, hunt caribou in northern Canada and Alaska, and hunt whales on the Alaskan North Slope (Krupnik and Jolly, 2002; Putkonen and Roe, 2003). Local Native hunters are seeing more variable seasonal ice conditions that are making it more difficult to predict weather conditions for hunting, such as when to initiate and terminate the hunt (Huntington, 2000; Krupnik and Jolly, 2002).

Earlier seasonal ice retreat has opened up the coastal waters, increasing the distance that the waves may travel unobstructed (which facilitates increased amplitudes), thus jeopardizing the safety of small-boat deployments. In particular, the rapid retreat of spring ice has forced boats working near the ice to move further offshore during hunts, resulting in greater risks to personal safety. Possible changes in current patterns with changing ice and weather patterns impact both operational aspects of the hunt and the location of different marine mammal species.

Coastal erosion caused by unusual and irregular storm patterns, permafrost thaw, and rising sea level has threatened coastal communities in the Arctic. U.S. government agencies have taken emergency actions to cope with the increased beach erosion and relocation of some communities in northern Alaska due to sea-level rise (NRC, 2004). Northern communities in permafrost regions will face significant engineering and infrastructure challenges if the permafrost thaws further.

Beyond these physical impacts of the changing environment on people, there is strong concern about how rapid social and economic changes will continue to affect indigenous cultures in the northern high latitudes. Some of these impacts are undoubtedly positive: satellite communications now link even the most remote northern communities to the rest of the world, allowing, for example, doctors to render care using telemedical technologies and northern hunters to travel with increased safety using global positioning systems as navigation aids (NRC, 2004). In addition to many benefits of advances in technology and communications, rapid cultural change has also been accompanied by some health and social problems in some northern communities, as it has in lower latitudes (NRC, 2004). A significant need for Natives of the Arctic is timely, effective healthcare delivery methods, particularly for diagnostic and acute care, plus regular dental care. More research is needed to better understand how new technologies can help northern indigenous peoples preserve their own cultural heritage, rather than allowing the same technologies to simply play a homogenizing role.

Safety is a key issue for Native Alaskans especially during the spring and fall hunting period. The availability of U.S. government assets (e.g., polar icebreakers) in the region, particularly helicopter support, would be an important aspect for local communities. Of course, an increased U.S. Coast Guard presence in the region would have to be coordinated with local interests and concerns. Recently, much progress has been achieved in the planning and execution of U.S. Coast Guard HEALY cruises in northern Alaska waters. Mechanisms for accommodating overlapping and conflicting interests have been developed, while at the same time increasing outreach to Native coastal communities and enhancing local awareness of U.S. Coast Guard services.

The key concerns identified by residents of the North Slope of Alaska (in the written record, *www.north-slope.org*, as well through personal communication with the North Slope Borough Mayor Edward Itta) are to provide baseline data on the current state of and changes in the marine physical and biological environment. In reference to U.S. Coast Guard icebreaker operations, Mayor Itta stressed the importance of collection of scientific information, including during dual-use cruises as part of a regular presence in the summer months. Another major concern for coastal communities, which are heavily dependent on marine mammal subsistence harvests, is the recent increase in offshore oil and gas exploration and production activities. The components of the U.S. Coast Guard mission that address prevention and response to environmental disasters and public safety are viewed as particularly important, with the appropriate presence of icebreakers seen as an important component of the special relationship between the U.S. government and Alaska Natives (Edward Itta, personal communication, 2006). The Canadian Coast Guard's summer patrol missions, which include regular visits to coastal communities and monitoring of activities throughout the Canadian Arctic, represent a more developed model of how to address such concerns.

3

Arctic Environmental Change and Potential Challenges

OVERVIEW OF ARCTIC ENVIRONMENTAL CHANGE

The Arctic seas have experienced major shifts in water mass properties, circulation, sea-ice coverage, and ecosystems over the past few decades. Some of the first indications of widespread, systematic change in the Arctic were the observations of successive pulses of warm, salty water from the Atlantic Ocean deep within the Arctic Ocean (Carmack et al., 1995; Morison et al., 1998; Steele and Boyd, 1998). Another indication of change is that recent satellite images have shown that summer ice extent has been reduced significantly. From 1979 through 2000, Arctic sea-ice extent has been shrinking by about 2.2 percent per decade, driven mostly by reductions during the ice melt season (Comiso, 2003). The rate of decline of summer minimum ice extent amounted to almost 8 percent per decade from 1979 to 2005 (NSIDC, 2006). At the same time, submarine sonar data collected in the central and western Arctic indicate that the Arctic ice pack thinned by approximately 40 percent from the 1950s to the 1990s (Rothrock et al., 2003).

The past several years have been nothing short of remarkable. Since 2000, four out of the five Arctic ice seasons have exhibited consecutive record summer ice minima (Stroeve et al., 2005). From the available record it appears that perennial ice extent is as low as it has been in the past few centuries. Moreover, most recent indications are that winter ice extent is now also starting to retreat at a faster rate, possibly as a result of the oceanic warming associated with a thinner, less extensive ice cover. These observations of a shrinking, thinning Arctic sea-ice cover are consistent with climate model predictions of enhanced high-latitude warming, which in turn is driven in significant part by ice-albedo feedback[1] (Holland and Bitz, 2003). It has been argued that the Arctic climate system has reached a "tipping point" and is now on a trajectory to a different, stable state, characterized by a greatly reduced or absent summer ice cover (Lindsay and Zhang, 2005; Overpeck et al., 2005) and—by inference—significantly thinner, less extensive winter ice.

These changes in the physical ocean and sea-ice environment affect ecosystem structure and function as well as other key ecological processes, such as the exchange of gas between the ocean and atmosphere and the transfer of material from land to the sea, and these changes ultimately affect the living resources on which local human populations depend. In fact, these types of changes in the Arctic marine ecosystem are currently under way; dramatic shifts in the structure of the Bering Sea ecosystem have occurred (Brodeur et al., 1999; Hunt et al., 2002; Grebmeier and Dunton, 2000; Overland and Stabeno, 2004; Grebmeier et al., 2006). The ranges of species such as salmon, seabirds, and gray whales have extended north- and eastward into the Beaufort Sea (Moore et al., 2003). Changes in the timing of the northward migration of animals, such as walrus, associated with the timing of the retreat in the annual ice cover, are impacting the hunting success of local human communities. Despite numerous observations that ecosystem change is ongoing, the extent and magnitude of these changes, the range of natural variability of many characteristics, and the interactions between the biological, physical, and chemical components that shape ecosystem change are still poorly understood.

High latitude ecosystems are sensitive to climate, and recent studies indicate that the northern Bering and Chukchi Seas are shifting toward an earlier spring transition between ice-covered and ice-free conditions (Grebmeier et al., 2006). The detection of biological changes in the Bering Strait region coincides with recent observations of larger-scale Arctic environmental changes in water temperature, hydrography, and sea-ice regimes (Overland and Stabeno, 2004).

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[1] Ice-albedo feedback is a positive feedback loop whereby melting sea ice exposes more seawater (of lower albedo, or less reflective), which in turn absorbs heat and causes more sea ice to melt.

Thus, ecosystem change on the shallow shelves of the northern Bering and Chukchi Seas is likely to be directly connected to systems further to the north.

POTENTIAL ENVIRONMENTAL CHALLENGES

The Arctic Climate Impact Assessment (ACIA, 2005), a major multinational compilation of information, concluded that reduced sea-ice extent will pose new challenges for the Arctic environment because increased human presence in the Arctic Ocean is highly likely. When historically closed passages become open to navigation, increased marine transport and improved access to resources are expected. It is further expected that questions regarding sovereignty over shipping routes and seabed resources, as well as issues of security and safety, will arise (ACIA, 2005). Potential conflicts among competing users of Arctic waterways and coastal seas, for example, in the Northern Sea Route and Northwest Passage are likely. Commercial fishing and sealing, hunting of marine wildlife by indigenous people, tourism, and shipping all compete for use of the narrow straits of these waterways, which are also the preferred routes for marine mammal migration.

Global crude oil prices are currently at historic highs and projected to continue at present levels (Garfield, 2005.). This has led to increased exploration and development budgets for the oil industry and to the development of oil fields in more challenging environments. The Arctic is one of the major areas in which increased oil exploration and development are occurring. Price increases for basic commodities are not limited to crude oil, which is spurring increasing investments in gas exploration and development as well as other commodities.

Ships operating in the Arctic environment are exposed to a number of unique risks. Poor weather conditions and the relative lack of reliable charts, underdeveloped communication systems, and insufficient navigational aids pose challenges for mariners. The remoteness of Arctic areas makes rescue or cleanup operations difficult and costly. Cold temperatures may reduce the effectiveness of numerous components of the ship, ranging from deck machinery to emergency equipment. When ice is present, it can impose additional loads on the hull, propulsion system, and appendages.

Safe navigation in any area depends on accurate knowledge of hydrographic data. Unfortunately, these data, as well as standard aids to navigation (e.g., channel marking buoys) are lacking along much of the Arctic shipping lanes. For example, the Russian Ministry of Transport's Federal State Unitary Hydrographic Department, responsible for mapping the hydrographic details of the Northern Sea Route, reports that the mapping along the Northern Sea Route is "far from finished" (Garfield, 2005). Similarly, the hydrographic charts for the Northwest Passage are incomplete. The Canadian Hydrographic Service reports that although Canadian charts in the Arctic are generally adequate for navigation in most traffic corridors, there are significant unsurveyed areas within the limits of many charts and many charts exist that do not meet modern Canadian Hydrographic Service standards.

In addition, unique Arctic conditions require supplementary operational guidelines to account for the operating environment. Recognizing the need for recommendatory provisions applicable to ships operating in Arctic ice-covered waters, additional to the mandatory and recommendatory provisions contained in existing instruments, several organizations[2] have developed guidelines for ships operating in Arctic ice-covered waters. It should be noted, however, that these guidelines are simply recommendatory and that the wordings are commonly interpreted as providing recommendations rather than mandatory direction. On the other hand, Part XII, section 8, Article 234 of the United Nations Convention on the Law of the Sea (UNCLOS), specifically allows coastal nations to adopt and enforce rules for vessels operating in ice-infested waters in their exclusive economic zone (EEZ) or territorial sea in order to prevent and protect against marine pollution and similar environmental accidents.

Concerns about the increasing commercial activities in the Arctic region led the Arctic Council to issue a declaration in 2002,[3] which stated that the existing and emerging activities in the Arctic warrant a more coordinated and integrated strategic approach to address the challenges of the Arctic coastal and marine environment. The declaration further stated that the Arctic Council agreed to develop a strategic plan for the protection of the Arctic marine environment under the leadership of its Protection of the Arctic Marine Environment (PAME) working group. The Arctic marine strategic plan established the following four goals: (1) reduce and prevent pollution in the Arctic marine environment; (2) conserve Arctic marine biodiversity and ecosystem functions; (3) promote the health and prosperity of all Arctic inhabitants; and (4) advance sustainable Arctic marine resource use.

With increased marine access in Arctic coastal areas—shipping, offshore development, fishing, and other uses—and the apparent lack of strict operational guidelines and aids to navigation, national and regional governments will be called upon to revise and to develop new national and

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[2] The International Maritime Organization adopted the *Guidelines for Ships Operating in Arctic Ice-covered Waters*. BIMCO (Baltic and International Maritime Council) published the *BIMCO Ice Handbook*—a quick reference manual that includes a "Captain's Checklist" that "should be readily available to anyone involved in chartering before they direct a vessel into waters where ice may be present at the time of call." The Artic Council's working group on the Protection of the Arctic Marine Environment (PAME) published *Guidelines for Transfer of Refined Oil and Oil Products in Arctic Waters (TROOP)* (PAME, 2004).

[3] Declaration was issued by the Ministers at the Third Arctic Council Meeting in Finland, October 2002.

international regulations focusing on marine safety and environmental protection (ACIA, 2005). Nations will also be required to provide increased services such as icebreaking assistance, improved ice charting and forecasting, enhanced emergency response in dangerous situations, and greatly improved cleanup capabilities. The sea ice, while thinning and decreasing in extent, is likely to become more mobile and dynamic in many coastal regions where fast ice and relatively stable conditions previously existed. Competing marine uses in newly open or partially ice-covered areas will call for increased enforcement presence and regulatory oversight (ACIA, 2005).

Potential for Increased Commercial Vessel Operations in the Arctic

Commercial vessel operations in the Arctic consist primarily of (1) natural resource exploration, development, and production; (2) fishing; (3) tourism; and (4) commercial vessel transits. Commercial vessels are used to support exploration or transport developed natural resources (e.g., oil, gas, minerals, ores) from Arctic sources to non-Arctic destinations. Commercial fishing operations currently are restricted to certain areas of the Bering Sea and, to a lesser extent, to certain areas of the Chukchi Sea. Ships in these regions harvest specific fish stocks and, in U.S. territorial waters, are strictly regulated by the Alaska Board of Fisheries, whose main role is to conserve and develop the fishery resources of the state. Tourism is typically in the form of ocean cruises that occur in the summer months between July and September when the ice pack is at a minimum extent. Destinations throughout the Arctic including the Canadian Arctic, Greenland, Spitsbergen, Alaska, the Russian Far East, and even the North Pole are visited by large icebreakers, luxury cruise ships, and small (~50 passenger) converted research ships. Commercial vessel transits typically encompass cargo vessels transiting either the Northern Sea Route (above Russia) or the Northwest Passage (above Canada) or the delivery of supplies to Arctic destinations along either of those routes. In 2004, $4.5 billion dollars worth of orders were placed for the construction of ice class tankers. Additionally, the ice class tanker fleet will grow by 18 million deadweight tons (dwt) by 2008; 262 ice class ships are presently in service and another 234 are on order (ABS, 2005).

Natural Resource Exploration in the U.S. Arctic

The Arctic has long been viewed as a likely source of natural resources such as oil, gas, minerals, ores, and other commodities.[4] Indeed, U.S. West Coast Refineries are fueled primarily by Arctic oil produced on Alaska's North Slope. In 2005, approximately 335 million barrels of oil was produced on Alaska's North Slope (State of Alaska Department of Resources). There is further expectation that additional large volumes of recoverable oil are to be found in the Arctic National Wildlife Reserve, although environmental concerns and political pressures have blocked development to date. Alaska's North Slope has large proven natural gas reserves that have not been developed in commercial quantities as of yet. The principal producers (ExxonMobil, BP, and ConocoPhillips) are planning to build a pipeline for moving Alaska North Slope gas directly to the U.S. Midwest.

Sustained high oil prices have invigorated industry interest in oil and gas exploration in the Alaskan Beaufort and Chukchi Seas. Exploitable natural resources in the U.S. Arctic are found throughout the region, but the majority of active leases and current exploratory drilling occur within the Beaufort Sea. There are currently 181 active outer continental shelf (OCS) leases in the Beaufort Sea (Figure 3.1). Thirty-one exploratory wells have been drilled in this area, and there is production from a joint federal-state unit, with federal production of more than 15 million barrels of oil since 2001. Ten OCS lease sales have been held in the Beaufort Sea since 1979, and an additional sale is scheduled in the current five-year program for 2007. The proposed sales include consideration of 1,877 whole or partial lease blocks in the Beaufort Sea Planning Area, covering about 9.8 million acres (3.95 million hectares).[5]

There have been two sales in the Chukchi Sea, the most recent in 1991. There have been five exploratory wells drilled with no commercial discoveries. While there are no existing leases at this time, this area is included in the current program as a special interest sale during 2007 to 2012. No interest was expressed in the first two calls for information in 2003 and 2004. Industry interest was expressed in a large portion of the area in response to the call in early 2005, but there was not adequate time remaining in the current program to complete the necessary pre-lease steps and environmental documentation. The sale was deferred for consideration in the 2007- 2012 program, which was released in draft form. The new five-year oil and gas leasing plan proposes four additional annual lease sales in the Beaufort and Chukchi Seas between 2007 and 2012 (MMS, 2006).

It is not possible to accurately predict the level of oil and gas activity that will occur in the U.S. Arctic over the

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[4] The Antarctic Treaty prohibits these commercial operations in Antarctica.

[5] Minerals Management Service Five-Year Leasing Program: The five-year program is the basis for leasing. It identifies the areas to be offered for leasing during a five-year period and establishes the schedule for individual lease sales. No area will be offered for sale that is not included in the five-year program. During the course of developing the five-year program, all affected states and applicable federal agencies will be consulted; comments from interested parties and the general public will be solicited. From 2002 to 2007, for the Beaufort Sea OCS Planning Area, Sale 186 was scheduled for September 2003; Sale 195 for 2005; and Sale 202 for 2007.

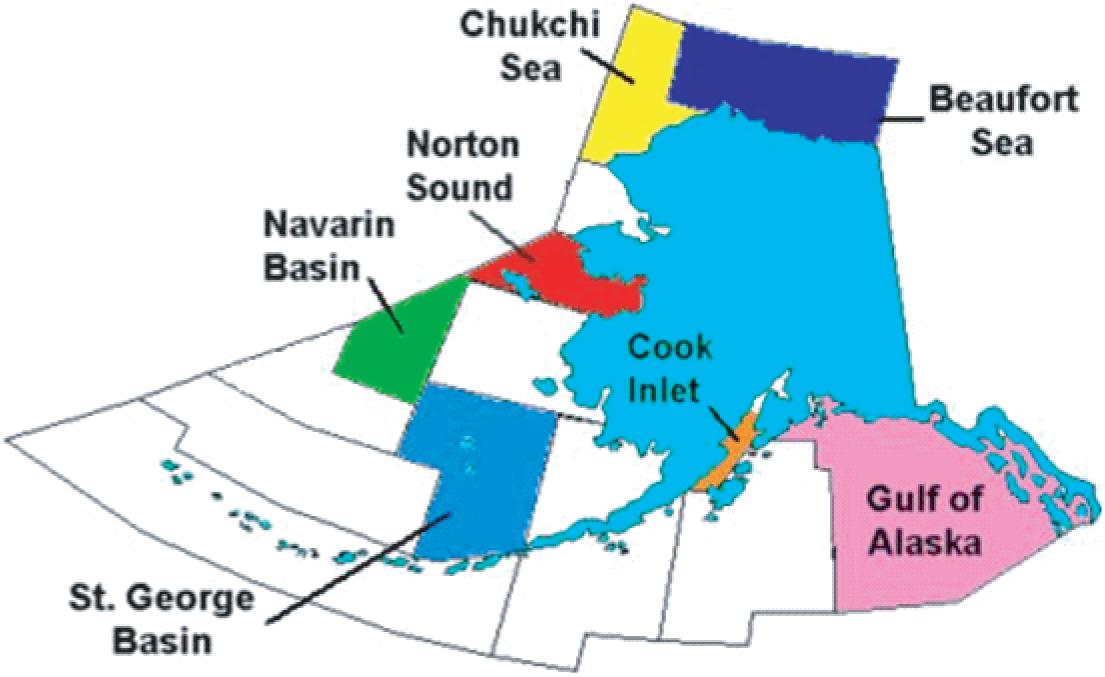

FIGURE 3.1 OCS leases in the Arctic. SOURCE: *http://www.mms.gov/*.

next decade because oil prices, exploration, and development activity onshore and State of Alaska offshore areas adjacent to the OCS and in the Canadian Beaufort Sea influence the rate and level of activity. However, the U.S. Minerals Management Service (MMS) anticipates that between one and three exploratory wells will be drilled annually over the next five years (Elmer Danenberger, personal communication). To support resource exploration efforts, the MMS anticipates multiple geophysical (seismic) surveys to occur in the Beaufort and Chukchi Seas over the next several years during the open-water seasons. Up to four seismic vessels could be operating in any one year. In addition, MMS expects that up to two ice-reinforced floating drilling units will be operating simultaneously in the Beaufort and/or Chukchi Sea during open-water conditions. Drilling operations could extend into the early fall freeze-up conditions. Each drilling operation would be supported by an icebreaker to provide ice management during drilling and to assist in demobilization to "over-wintering" harbors at the end of the drilling season. Additionally, up to two ice class vessels and ice-reinforced barges could be staged in the Beaufort Sea during drilling to support oil spill response operations.

Exploratory drilling from bottom-founded drilling structures during the winter solid ice season is also anticipated. Bottom-founded drilling structures, such as the Steel Sided Drilling Caisson, would be mobilized to location during the open-water season using tugs, left on location throughout the winter, and removed the following open water season. Bottom-founded structures would be used only in the Beaufort Sea; water depths are restrictive in the Chukchi Sea.

Natural Resource Development and Production in the U.S. Arctic

Over the next five years, at least two new development projects will most likely begin in the Beaufort Sea (Elmer Danenberger, personal communication). The Liberty Development Project, proposed by British Petroleum Exploration Alaska (BPXA), Inc., will develop the Liberty reservoir, which is located about 6 miles offshore in the central Beaufort Sea. BPXA is proposing to develop this reservoir from onshore using extended-reach drilling technology, and no offshore facilities are proposed. Following exploration activity in the 2007 or 2008 drilling seasons, MMS anticipates at least one other commercial discovery in the Beaufort Sea. The time line from discovery to design, permit, construction, and installation of a new production facility is between three and four years. The MMS anticipates that new development will involve a purpose-built, bottom-founded concrete and steel structure fabricated offsite and installed during the open-water season. The new product will most likely be brought onshore by subsea pipeline. Unlike the plans for the Beaufort Sea, no new start development is projected in the Chukchi Sea over the next five years; the first lease sale is scheduled for 2007 and initial exploration would not likely occur until 2008.

Additional development activity beyond 2012 is difficult to project, however an offshore production facility and pipeline in the Beaufort Sea may provide synergy for additional development opportunities through subsea completion technologies and tie-backs to an existing facility (Elmer Danenberger, personal communication). Additional exploration may lead to additional commercial discoveries that can support independent production facilities; however, the MMS does not anticipate oil tankers or offshore loading facilities in either the Beaufort or the Chukchi Seas. It should be noted, however, that industry has independently been evaluating the potential for using offshore loading and tankers in the Chukchi Sea. While the oil and gas industry would not seek or expect assistance from the U.S. icebreaker fleet in support of exploration or development activities, there may be increased need for shared information, ice surveillance, reconnaissance, and emergency response (Elmer Danenberger, personal communication) as well as environmental monitoring.

Russian Arctic Natural Resource Exploration, Development, and Production

Russian Arctic oil is expected to move from offshore production platforms in ice-strengthened shuttle tankers (with icebreaking capability) to Murmansk (the most northerly ice-free port in the world). At Murmansk the crude oil will be transshipped into ice-strengthened tankers for export to U.S. and European refineries. The Murmansk transshipment facility is expected to have a throughput capacity of 1 million barrels per day. The Murmansk facility is expected to handle crude oil delivered via pipeline as well as by shuttle tankers from offshore platforms. Russia's largest ice-affected oil export port is Primorsk in the Gulf of Finland (Baltic Sea). Primorsk is fed by Transneft's Baltic Pipeline System, which opened in 2001 and carries crude from onshore western Siberian oil fields as well as the Timan-Pechora fields (Garfield, 2005). Additionally, Russia's Prirazlomnoye field in Pechora Bay (Barents Sea) has reported reserves of more than 200 million tons.

The tankers required to move Arctic oil through ice-affected waters are specially designed and built to meet those special requirements (to move safely through ice). Ice class tankers range from ice-strengthened tankers up to and including super ice class tankers such as the state-of-the-art double-acting icebreaking tankers being built to serve Russia's offshore Arctic oil fields. There are currently 210 ice class tankers on order with a capacity of 16 million deadweight tons (Garfield, 2005).

Russia has begun development of its Shtokman gas field in the Barents Sea, which is expected to come online in 2010. The current plan calls for building ice-capable ships for transporting the natural gas in liquefied form to U.S. and European markets. Additional gas fields in the Yamal-Kara Sea region will likely follow the same pattern. Russia is producing large volumes of oil from its Arctic oil fields in the Baltic, Barents, and Kara Seas as well as onshore oil fields in Siberia.

Asian Energy Demand

The average demand for oil in China and India is expected to grow by approximately 4 percent per year until 2020, increasing Asia's foreign oil dependence from 69 percent (1997) to 87 percent in 2020 (Ögütçü, 2003). In addition, China's need for natural gas will out strip its own resources and will force new energy agreements, most likely with Russia in the near future (Ögütçü, 2003). In anticipation of the increased demand for oil and potential economic and environmental changes, China has begun building strategic relationships to secure the sea lanes from the Middle East to the South China Sea to ensure unimpeded delivery of oil (Ögütçü, 2003). Instability in the Middle East, coupled with increased demand in Asia, may make Arctic oil reserves more economically attractive, spurring further oil exploration, development, and production.

Chinese demand for these resources may fundamentally alter shipping patterns if the Arctic sea ice recedes and the Arctic routes become routinely navigable (Hanna, 2006). With potential access to the Northern Sea Route and the Northwest Passage at certain times of the year, the Chinese may pursue these northern routes. In support of national interests, the United States currently patrols the Straits of Malacca and Hormuz and is prepared to defend these important shipping lanes, but if transit routes develop in the Arctic, the United States must be prepared to patrol and defend these routes equally (Hanna, 2006).

Minerals and Ores

The largest zinc mine in the world, the Red Dog Mine, is located in northwest Alaska above the Bering Strait about 50 miles inland from the Chukchi Sea in the DeLong Mountains. The mine's remote location is 200 miles north of the Arctic Circle. The Red Dog Mine produces approximately 1.2 million tons per year of lead and zinc ore concentrates. It began production in 1989, and the first ore was moved in 1990. The Red Dog Mine's output is trucked to a specially developed port on the Chukchi Sea for shipment to markets. Because of the shallow draft at the Chukchi Sea port, the dry bulk ships used for the long-haul ocean movement must anchor offshore in deeper waters. The mined ore is moved offshore to those vessels using two specially designed self-unloading barges operated by Foss Maritime. Because of ice conditions, the shipping season is restricted to about 90 to 100 days per year. If current trends in decreasing Arctic sea ice and the retreating ice margin continue, commercial endeavors such as these will extend the time during which they operate each year, resulting in a potential increase in demands for icebreaker services given the variability that occurs in the formation and melting of Arctic sea ice from year to year.

Effects of Environmental Change on Marine Resources

The Arctic marine environment is biologically important. The cold waters, ice, and ice edges of the Arctic seas are enormously productive, and seasonal phytoplankton and algae blooms support the entire Arctic food web (Markham et al., 1993). Although a few degrees increase in seawater temperature may not seem critical, the consequences would affect the Arctic marine ecosystem in many ways. For example, because many Arctic species are dependent on and adapted to floating sea ice and ice edges, changes in ice extent and timing will affect the ice-associated community, including fish species such as polar cod. In addition to commercial species in the Bering and Barents Seas, there are expected impacts on other parts of the marine ecosystem, such as Arctic and migratory whale species that feed along the ice edge. Populations of Arctic marine birds would also be affected (Alexander, 1992). Animals that depend on the ice as a platform, such as ringed seals, walruses, and polar bears, would lose habitat and possibly prey species (Alexander, 1992).

Recent research shows that some changes are already under way in the northern Bering Sea ecosystem (Grebmeier et al., 2006). The northern Bering Sea provides critical habitat for large populations of sea ducks, gray whales, bearded seals, and walruses, all of which depend on small bottom-dwelling creatures for sustenance. These bottom-dwellers, in turn, are accustomed to colder water temperatures and long periods of extensive sea-ice cover. Research data from long-term observations of physical properties and biological communities have been used to conclude that previously documented physical changes—including rising air and seawater temperatures and decreasing seasonal ice cover—in the Arctic in recent years are profoundly affecting Arctic life. Data showed, for instance, that a change from Arctic to sub-Arctic conditions is under way, causing a shift that favors fish and other animals that until now have stayed in more southern, warmer seawater. Fishing operations are following these species as they migrate into the more dangerous northern waters, with implications for the U.S. Coast Guard's capabilities to perform search and rescue as needed.

Effects of Environmental Change on Tourism

The spectacular scenery found in the Arctic—including mountains, glaciers, fjords, and tundra, combined with distinctive wildlife, including rare marine mammals, massive herds of caribou, and millions of migratory and resident birds—and unique native cultures give the region significant tourism potential. Among the eight Arctic nations, tourism is most well developed in Alaska. In 2001, the state hosted 254,000 visitors during the autumn and winter and 1,202,800 visitors during the summer; 510,000 of those arrived by cruise ship (Pagnan, 2003). Cruise tourism experienced annual growth of about 11.6 percent a year between 1991 and 2003, although growth has since tapered off. In summer 2001, tourists spend $1.2 billion and the industry accounted for about 20,000 direct jobs (Pagnan, 2003). Greenland, as another example, hosted about 3,000-5,000 mountain climbers a year in the 1970s, and by 2002 it was attracting 32,000 visitors doing a range of activities such as dog sledding, enjoying the Midnight Sun, experiencing the culture, and participating in extreme events such as ice golf, snow festivals, and the Polar Circle marathon. The industry has grown to be a significant component of the economy (approximately 19,000,000 Danish kroner annually in 2003). Although the tourist season is short and transportation costs are high, tourism is looked to as a growth opportunity and one of few sectors of the economy offering new jobs. Cruise tourism is a growing portion of the total, with coastal tours particularly popular (Pagnan, 2003).

Throughout the Arctic, ship-based tourism has become an especially important part of the market. Cruises now go to various Arctic regions, including the Canadian Arctic, Greenland, Svalbard, the Russian Far East, and Alaska. The peak season now for exploring the Arctic Ocean runs from July to September, when the pack ice recedes, but this season is likely to expand as the extent and thickness of summer ice change.

Arctic tourism is, in general, a marginal enterprise that is vulnerable to shifts in demand. The high costs of transportation and infrastructure present ongoing challenges. The possible impacts of environmental changes are important. On the positive side, reduced ice could increase tourist access, as well as contribute to a longer tourist season. On the negative side, any disruption of the natural setting or wildlife on which the industry depends could have serious and far-reaching effects on the industry (Pagnan, 2003). Anecdotal information from tourism professionals about the impacts of the changing polar regions on tourism includes the following:

- The severe epidemic of the Spruce Bark Beetle on Alaska's Kenai Peninsula, caused by warming conditions, has created some 60,000 acres of dead trees in a prime tourist area, harming the visual experience and causing a risk of forest fire.
- Glaciers have been melting at unprecedented rates in the last decade, reducing one of the primary sights that tourists expect to see.
- Some migratory birds have been arriving earlier and staying later, expanding opportunities for operators bringing visitors specifically for the migrations.
- Ice along the coasts is melting earlier and freezing later, extending the cruise ship season.

Commercial Vessel Transits

Although most oil in the Arctic region moves overland through pipelines, tanker trafficking of this commodity is certainly feasible and can provide transport from offshore production platforms. In 1969, the 108,000 dwt oil tanker SS MANHATTAN transited the Northwest Passage in an experiment run by Exxon to understand the viability of using an ice-strengthened oil tanker for moving Alaskan North Slope oil to mainland East Coast U.S. refineries. This major research project demonstrated the feasibility of moving oil through the Arctic region in tankers. However, the difficult ice conditions and the lack of year-round access resulted in an industry decision to build the trans-Alaska pipeline as the more proven and lower-risk alternative.

Commercial vessel transits fall into two types: vessels delivering cargo to Arctic destinations and vessels using the Arctic sea routes as "shortcuts" for delivering cargoes between Asia, Europe, and/or North America. Through-transits of the Arctic, using either the Northwest Passage (above Canada) or the Northern Sea Route (above Russia), are being discussed primarily as options for moving containerized cargo. Containerized cargo to or from Asia's more northern Pacific ports (e.g., Japan, Korea, Shanghai) to northern Europe (e.g., Rotterdam, Copenhagen, Hamburg) could use the Northern Sea Route instead of the much longer route through the Malacca Strait and Suez Canal. Similarly, containerized cargo to or from these same northern Pacific Asian ports could move to the U.S. East Coast by transiting the Bering Strait and continuing through the Northwest Passage to Halifax, Boston, New York, and other eastern seaboard ports (Table 3.1).

For shipments from Asia to North Europe, Hong Kong represents the southernmost Asian port where using the Malacca Strait-Suez Canal route is equidistant to the Northern Sea Route (NSR). The distance from Murmansk to the Bering Strait using the NSR is 3,454 nmi (voyage of oil tanker UIKKU in 1997) (see Niini, 2000).

Russia opened the Northern Sea Route to foreign navigation on July 1, 1991. The first non-Russian vessel transit was by the French Antarctic supply ship ASTROLABE in August 1991. The ASTROLABE sailed from Murmansk to Provideniya, south of the Bering Strait, in 12 days at an average speed of 11 knots (Garfield and Corbett, 2005). Despite the distance savings the NSR has seen relatively little commercial traffic. For example, during 2004 there were no commercial through-transits of the NSR, which may be due to the high risks associated with the unpredictable environment and the complete lack of fuel or resupply stations along the route. Despite the shorter transit distance, the Arctic routes present significant reliability problems compared to Suez Canal or Panama Canal transit, and the economics would not support a switch to Arctic routes for transit voyages under present environmental conditions (Richard Voelker, U.S. Department of Transportation's Maritime Administration, personal communication, October 7, 2005).

TABLE 3.1 Northern Sea Route Comparative Distances

Port	Port	Via NSR (miles)	Via Canal (miles)	Percentage difference
Murmansk	Yokohama	5,770	12,840	55%
Rotterdam	Yokohama	7,350	11,250	35%
Murmansk	Vancouver	5,400	7,350	27%
Rotterdam	Vancouver	6,920	8,920	22%

SOURCE: Frank, 2000.

Although there were no through-transits, significant vessel traffic occurs along the Northern Sea Route between Arctic ports (Figure 3.2). Approximately 52 vessels made on the order of 165 voyages into the Northern Sea Route carrying 1.75 million tons of cargo (AMSA, 2005).

However, it is the consensus of the committee that it would be short-sighted to assume that Arctic transit routes will continue to be devoid of commercial shipping. Continued improvement of sea-ice conditions will make Arctic routing more attractive, especially in the summer. In addition, secondary factors may provide incentives in this direction. Escalating fuel prices will improve the economies of shorter Arctic routes. Political instability in the Middle East and in Southern Asia, including the risk of piracy and terrorism, could also improve the Arctic as an option. Finally, increased Arctic experience with oil and gas development may transfer to general cargo movement as ice-strengthened tankers become more common. In short, there remains considerable potential for increased traffic in the Arctic.

It is not yet certain what changes in Arctic sea-ice extent will have on the U.S. need for icebreakers. Winter Arctic sea ice extends southward through the Bering Strait and into the northern Bering Sea, so that the entire Alaskan northern coast and a substantial portion of the Alaskan western coast are ice-covered in winter. In summer months, the Arctic sea-ice margin retreats northward, which creates open waters around the entire Alaskan coastline for several weeks to several months. Model projections of Arctic sea-ice extent over the next several decades show that the early spring and late summer (shoulder seasons) sea-ice cover is likely to be reduced. Northward retreat of the ice margin in early spring will create more broken ice along the Alaskan coastline as the sea ice begins to melt. These conditions will remain late into the summer until the ice margin begins to advance toward the south in response to cooling seasonal temperatures. These models also show greater spatial and temporal variability in sea-ice extent and thickness throughout the Arctic, which may influence the capability needed to break ice of differing thicknesses in certain regions of the Arctic. Ice conditions may require occasional heavy icebreaking capabilities.

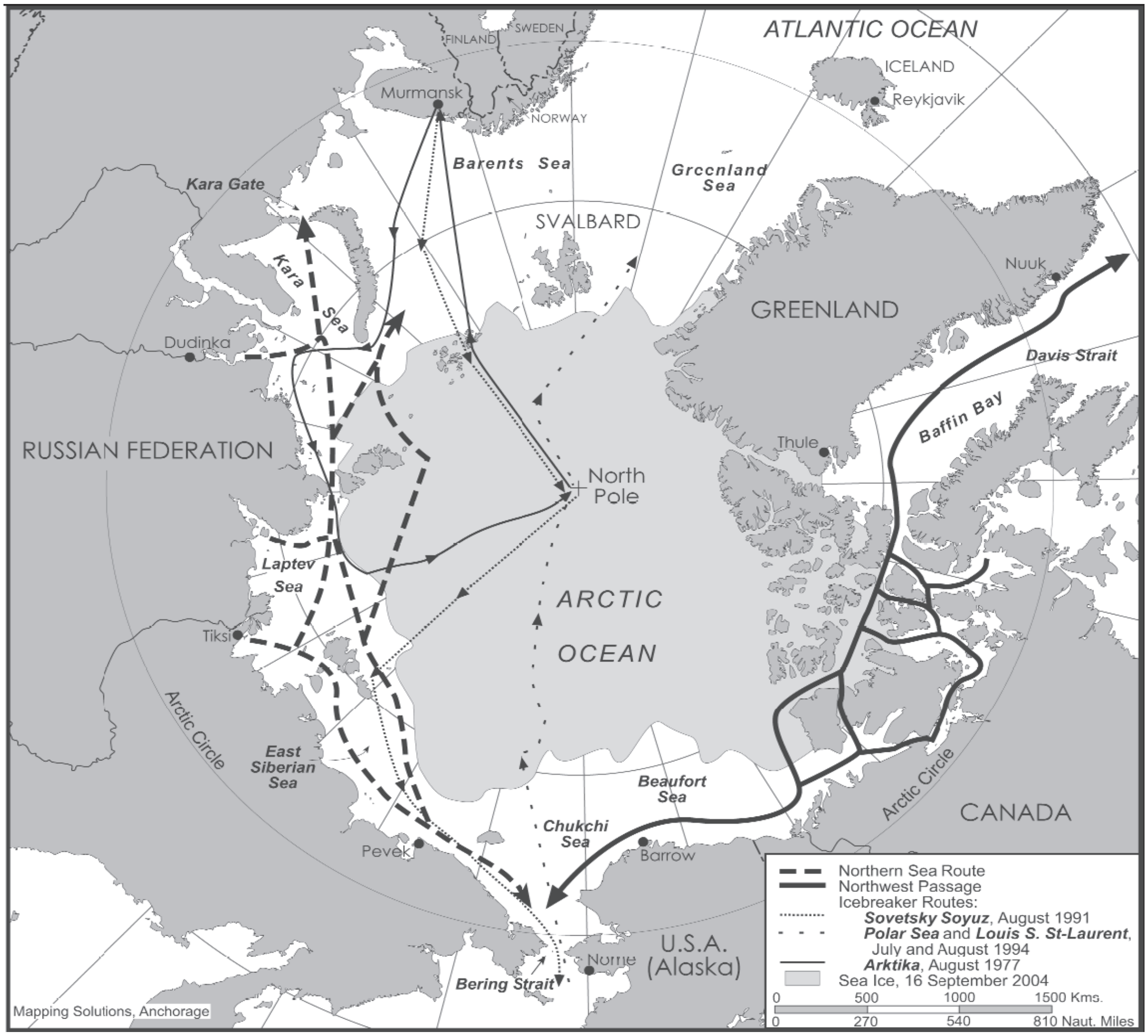

FIGURE 3.2 Arctic Ocean Marine Routes. Source: USARC, 2004.

The dramatic ice margin retreat over recent years has affected human activities in the Arctic. The change has caused hardships and challenges for some and provided opportunities for others. Some economic activities appear to be moving northward as Arctic fishing fleets have begun to follow the fish stocks that migrate northward as the ice edge retreats. This may lead these fleets to areas further from safe harbors. For indigenous populations in the Arctic, including the Inupiaq and Yupik Eskimo of Alaska and the Inuit in the Canadian Arctic, sea-ice retreat disrupts and significantly restricts their subsistence hunting and food-sharing lifestyles as many key species become less accessible due to northward migrations or, in the worst-case scenario, become extinct (ACIA, 2005). The number of search-and-rescue (SAR) events occurring when the HEALY is in the Arctic for science missions are well documented, yet there has been loss of life due to lack of rescue platforms available for Native populations that rely on the coastal marine environment for food and maintaining a traditional way of life.

A workshop on marine transportation in the Arctic (Arctic Marine Transport Workshop, 2004) suggested that it is plausible to expect increased marine tourism as cruise ships venture further north following the retreat of the ice edge. There has also been an increase in oil and gas tanker traffic, particularly in the Siberian Arctic and sub-Arctic. It is also likely that resource exploration, recovery, and shipping activities will expand into previously inaccessible areas. Several companies have begun to develop the extensive oil and gas fields near Sakhalin (Mikko Niini, personal communication, 2005) and the Chukchi and Beaufort Seas. These companies have begun to charter the majority of existing icebreakers for the foreseeable future, which could create a scarcity of these types of ships on the world market. In addition, many orders for double-acting tankers—ships that can both break ice and transport cargo—have been placed and demand is expected to grow (Mikko Niini, personal communication, 2005).

Any increase in marine activity in the Arctic will almost assuredly create greater risks of environmental impact and the potential for human activities that push the limits of safety near the ice edge, especially in the shoulder seasons. These activities will increase the necessity to respond to accidents and create a greater need for law enforcement in ice margin areas, which will increase the need for ice-capable ships (ice-strengthened ships and icebreakers) in the Arctic. This increase in human activity in more northerly latitudes will most likely increase the demand on the United States to have a greater presence in and around the ice margin to perform its many safety, security, and law enforcement missions. U.S. government-controlled access and oversight will be needed with increased vessel traffic, particularly to maintain U.S. interests around the State of Alaska and in U.S. territorial waters.

4

Polar Science's Key Role in Earth System Science

The history of scientific activity in the polar regions is intimately tied to the geopolitical circumstances following World War II and the subsequent Cold War era. In the south, this was dramatically evidenced by the U.S. commitment to the International Geophysical Year (IGY). While polar science, in and of itself, was considered important, it was also an act of U.S. foreign policy to project U.S. global presence and power to serve U.S. interests. As an illustration, the deployment of nearly 3,000 personnel to the McMurdo Sound area in 1957 and 1958 remains the largest presence of U.S. personnel in Antarctica to date. In the north, the advent of the Distant Early Warning (DEW) Line necessitated a year-round presence and created the need for a better understanding of the Arctic environment. The establishment of research facilities in Barrow was an outgrowth of political and military activity of the time. This marriage of science and politics benefited both communities and established a relationship between polar scientists and the military that remains intact today.

With the end of the Cold War and the collapse of the USSR, the political and military rationales for a strong U.S. presence in the polar regions have changed. At the same time, polar science, on its own merits, has assumed a central role in Earth system science. The investments in polar science are extraordinary and reflect the added value placed on a U.S. presence in the polar regions over the years. This is exemplified by the recent agreement to rebuild South Pole Station at a cost of more than $140 million dollars.

The presence of a U.S. territory, Alaska, and U.S. citizens in the Arctic brings significant new emphasis on and importance to science in the north. Historical and projected economic development in the Arctic and the specter of environmental change have added to both its inherent value and the need for polar science, notably in monitoring the effects of climate and providing a predictive capacity for potential future effects. To this end, polar science has grown and matured to a point where it is an important and essential focus of the U.S. research enterprise.

Because science and engineering research in the polar regions is critical to U.S. national interests, its relevance and impact continue to increase. The Arctic and Antarctic provide natural laboratories where extreme environments and geographically unique settings enable research on fundamental phenomena and processes not feasible or possible elsewhere (NSF, 2005). Significant advances in many scientific disciplines and engineering applications have resulted from polar research and many of these discoveries have provided critical knowledge of direct benefit to society (Box 4.1). As global climate has garnered worldwide attention, the polar regions have been found to react acutely to fluctuations in climate and temperature. Since ice tends to reflect solar radiation and water absorbs it, melting in the polar regions can exert a strong influence on both atmospheric climate and ocean circulation. Huge reservoirs of water are held in massive ice sheets and glaciers; substantial release may create major climate and social dislocations. Thus, research in these regions plays a pivotal role in the global Earth system exerting influences of critical importance. The 40 percent reduction in Arctic sea-ice thickness over the past four decades and the collapse of ice shelves in West Antarctica are some of the most dramatic examples of recent changes that have captured the public's imagination. In many ways, these events have come to represent societal concerns about human influence on Earth's climate. From a scientific standpoint, evidence continues to accumulate that not only are the polar regions an important focus of research as unique systems, but they also play a pivotal role in global Earth systems.

The execution of polar science faces special challenges due to the harsh environment encountered in conducting experiments, making observations, and collecting samples. A primary characteristic of the polar regions—the presence of ice—while fundamental to the global importance of these regions, presents major logistical challenges. Many locations are difficult to access, and reliable infrastructure must be maintained to safeguard scientists operating safely in these

BOX 4.1
Major Discoveries and Findings from Polar Science

- The presence and cause of the "ozone hole"
- The molecular and genetic mechanisms of living systems for coping with freezing conditions
- The Southern Ocean's role in driving the deep ocean "conveyor belt"
- Characterization of climate and effects in both the Arctic and the Antarctic
- Biological isolation as a fundamental force in the evolution of life
- A record of past climate changes in ice cores and sedimentary sequences
- Unique views of our universe and clues to its formation
- Organic pollutant transport to polar food webs and persistence
- The slowest spreading center and thinnest oceanic crust on Earth
- Subglacial environments and hydrological systems beneath ice sheets
- Paleo outbursts of subglacial waters as a geomorphologic agent of change
- Meteorological observations critical to weather prediction

areas. To this end, a network of stations, field camps, laboratory facilities, ships, airplanes, observing networks, and other support infrastructure has been developed over the years in both the Arctic and the Antarctic.

Essential to these operations is access through and operation ice-covered oceans and coastal seas. The support of polar research requires ships of various icebreaking capabilities, including those that are the subject of this report. This chapter highlights some of the major research themes being pursued in polar science, demonstrating the value provided by this work to the nation. A glimpse of where this science will go in the future is also provided. The scientific value justifies the significant investment needed for polar research to continue and indeed flourish over the next several decades. Simply put, access to the polar regions is fundamentally important if the United States is to continue to be a leader in polar science. Icebreakers are a key part of the necessary infrastructure: They are needed to conduct science in Arctic waters and to open a channel to allow resupply of McMurdo Station (and, in turn, South Pole Station and inland sites) in Antarctica.

ARCTIC SCIENCE

The Arctic Ocean is surrounded by land, with much of the terrain and adjacent shorelines difficult to reach because of ice and challenging weather conditions. Routes to coastal areas are from the south; there are few roads, rail lines, or airports, and there are few or no infrastructure or support facilities along the coast. The conduct of science on land and in coastal areas tends to be based at a few sparsely distributed, remote outposts. In many cases, ships are the most reliable means of access. To date, research that uses icebreakers has focused either on ocean or coastal processes, although icebreakers may be employed to bring sophisticated science assets to remote Arctic terrestrial localities. For example, the Swedish icebreaker ODEN was used to deliver scientific equipment and personnel to remote terrestrial sites in the Arctic during the Swedish "Beringia 2005" expedition. The Coast Guard icebreaker HEALY routinely supports biological, sea ice, marine geological and geophysical, oceanographic, and atmospheric studies.

Life in the Arctic

Arctic biological research addresses basic questions about the role of the Arctic in the global carbon cycle, arctic biodiversity, and adaptations of living systems to cold environments. A multiyear study of biological production and transport of carbon from the Bering and Chukchi Sea shelves to the ocean basin north of Alaska has been conducted from icebreakers. Shelf-basin transport is relatively poorly understood and is hypothesized to play a significant role in the global carbon system. Arctic Basin biodiversity is being studied as part of the Exploration of the Seas and the Census of Marine Life programs. Other programs are studying the ability of polar organisms to avoid freezing and to withstand the formation of ice in their body fluids.

Animals in the Arctic do not freeze to death when their core body temperature falls as low as 2°C but return to a metabolically active state when the body's heat-generating mechanisms are activated. Many polar insects and plants attain even lower cell temperatures, yet their cells remain ice-free because of antifreeze compounds in their biological fluids (NRC, 2004). Some polar animals and plants experience ice formation in extracellular fluids and yet appear to be undamaged. The knowledge gained from studies of the mechanisms that regulate freezing of extracellular water and protect against damage from ice formation will continue to advance our knowledge of cryotechnologies and biomedicine. An already important application is improvement in methods for low-temperature storage of biological materials, ranging from isolated cells to intact organisms (NRC, 2004). Understanding mechanisms of freezing resistance has broad technological applications in agricultural science (e.g., design of freeze-resistant crops) and biomedicine (e.g., development of improved cryopreservation techniques) (NRC, 2004).

Geology and Geophysics

Exploration of the Gakkel Ridge is shedding light on how new ocean crust is formed and tectonic plates are spreading apart in the central Arctic Basin. The studies being conducted at the Gakkel Ridge can be accomplished only with the use of an icebreaker. Data gathered in HEALY's 2001 cruise already have confirmed that Gakkel Ridge is the slowest spreading mid-ocean ridge on Earth. The oceanic crust at this location is also the thinnest yet observed. Cleary, the tectonic history of the Arctic Basin is key to understanding past ocean circulation and climate, and very little information is available. Exploration of the Arctic ocean floor will clarify the geological history of the polar regions and allow reconstruction of Arctic tectonics, notably providing information on how it has influenced ocean circulation (NRC, 2004). A return to the Gakkel Ridge area will address this knowledge gap.

The international Law of the Sea Treaty enables countries to lay claim to ocean bottom and subbottom areas for economic activities, but requires that these claims be based on seafloor configuration and seaward extensions of terrestrial land features. This is determined through the examination of ocean bottom topography, generally using multibeam sonar profiling. The Arctic Basin is one of the most poorly understood basins for seafloor topography. Icebreaker cruises in the north routinely collect multibeam sonar data, and specific expeditions have been conducted to establish bottom topography in areas critical to potential claims under the Law of the Sea. Given that other countries are making aggressive claims in the Arctic Ocean, these data are important to substantiate U.S. claims. To collect the data needed, a ship with multibeam sonar equipment able to break ice at a reasonable speed is critical. Also, the use of towed seismic arrays for sub-seafloor imaging will be increasingly important in the future and have a role in Law of the Sea territorial claims.

Our ability to describe the variability, change, and extremes of the polar region environment is limited by a lack of observations in both space and time. Records of past environmental conditions, retrieved from paleoarchives such as ice cores or sediments, provide clues to nature's response to forcing, but these too are incomplete, especially in terms of spatial coverage (NRC, 2004). For example, the Arctic Basin appears to play a critical role in the global carbon balance; however the mechanism by which this carbon is transported from the Arctic continental shelf to the deep basin is poorly understood. Significant changes appear to be occurring in the balance between waters of Pacific and Atlantic origin, and this may threaten key features of the thermohaline profile (heat and salt balance) that are thought to prevent much of the surface ice from melting.

The tectonic history of ocean gateways, which allow passage of warm or cold currents between oceans, is useful for understanding climate in both Arctic and Antarctic regions. For example, Fram Strait, between Svalbard and Greenland, is the only deep-water gateway between the Arctic Basin and the global oceans, and the date of its formation is unknown (NRC, 2004). Similarly, constraints on the opening history of Australia-Antarctica and South America-Antarctica gateways will allow better understanding of the onset of the Antarctic Circumpolar Current and its effects on climate and biological evolution (NRC, 2004).

Atmospheric Science

Atmospheric processes in the Arctic, such as the formation and persistence of clouds, the transport and disposition of solar radiation, and large-scale patterns of variability in the atmospheric pressure fields, play a central role in global climate. A more detailed understanding and representation of these processes in global climate models is essential to improving predictions of future climate (ACIA, 2005). Such advances in understanding require intensive observations of the Arctic atmosphere over the oceans, which depend strongly on icebreaker support, for the deployment of drifting ice camps, transects with icebreakers across the Arctic Ocean, and deployment of measurement systems (e.g., Perovich et al., 2003).

Oceanography

The Arctic Basin remains to be sampled properly from the standpoint of understanding its physics and chemistry. There is a need to increase physical exploration of the Arctic Ocean Basin. To date studies have focused on the quantifying deep circum-Arctic circulation. Biological studies of shelf basins and examination of the flux of material out of the Arctic through the Canadian Archipelago have to be done. This work is conducted by submarines or supported by aircraft, both of which have severe limitations on payload, thus limiting the kinds of data that can be obtained. An icebreaker provides the ideal platform necessary for this work because of its laboratories and capacity to carry large, multidisciplinary science teams.

Sea Ice

Research on the physics, chemistry, and biology of oceanic sea ice is dependent on the availability of icebreakers, submarines, and/or sea-ice camps. Access from submarines for the civilian research community is no longer available, and sea-ice camps are infrequently deployed. Icebreakers are the most effective platform for these studies. Because sea ice provides the interface between atmosphere and water, it is one of the most important components of the system. While some work can be done near shore on coastal ice or using specialized aircraft for excursions into the ocean environment, the wide geographic coverage made possible by icebreakers is an important factor.

Human Disturbances of the Environment

The discovery of "Arctic haze" in the 1970s and early 1980s (Barrie, 1992) demonstrated that the Arctic no longer is a pristine environment isolated from human activity, if it ever was. The Arctic is connected to global sources of natural and anthropogenic chemicals via winds, ice movement, and marine currents (NRC, 2004). The study of this phenomenon led to the discovery of ozone depletion in the troposphere and in the Arctic marine boundary layer at polar sunrise (Oltmans, 1981; Bottenheim et al., 1986). In the mid-1980s the depletion of Antarctic ozone was measured. It was established that industrially produced chlorofluorocarbons were the dominant cause of the ozone hole. Discovery of the relationship between chlorofluorocarbons and ozone loss sparked international policy makers to adopt the Montreal Protocol to phase out these chemicals. By the end of the 1990s, global production of these compounds had decreased by more than 90 percent.

ANTARCTIC SCIENCE

In contrast to the Arctic, Antarctica is a continent surrounded by oceans. The continent has been mostly entombed in a thick ice cover for millennia, creating a unique setting for research. Research in the Antarctic and the Southern Ocean addresses a wide array of topics across many disciplines**.** Antarctic research requires access throughout the Southern Ocean as well as the continent, both of which depend on capable and reliable icebreakers and ice-strengthened ships. Ongoing research falls into five major areas: biology and medicine, geology and geophysics, ocean and climate systems, aeronomy and astrophysics, and glaciology. The following discussion provides examples of research in Antarctica, but the list is not exhaustive.

Biology and Medicine

Antarctic biological research focuses on three broad themes: (1) adaptation of organisms to the extremes of temperature and seasonality; (2) the characteristics, structure, and functions of marine and terrestrial ecosystems; and (3) responses of organisms and ecosystems to global change. Research over the last few decades has shown that there is significant biodiversity in both the marine and the terrestrial environments. Much of this diversity arises from unique functional adaptations that allow organisms to survive and thrive in Antarctica. The current scientific frontier in the discipline is the application of modern methods of molecular biology to gain an understanding of the genetic basis for these important adaptations. Study of genes associated with cold tolerance and freeze avoidance in fish provides insights into the evolution and adaptation of organisms in extreme environments. This research has already resulted in the discovery of new compounds and molecules useful to society and most certainly will continue to do so.

The Southern Ocean marine environment is one of the most biologically productive regions in the world. This ecosystem has fewer trophic pathways than do tropical marine systems, making it easier to study both its components and its entirety. It also is characterized by extensive seasonal variations in light and the extent of sea ice that exert different pressures on seemingly similar organisms. For instance, some penguin species thrive in regions of widespread and persistent sea ice, yet others need more open-water conditions. As a result, changes in sea ice in the Antarctic Peninsula that may be associated with global change cause shifts in breeding areas and, thereby, reproductive success for some penguin species. Thus, research on the native marine mammals of the Antarctic Peninsula is an important contribution to understanding the physiological and genetic functions of these mammals and the potential effects of changing climate on this unique ecosystem. Weddell seals that live in the Antarctic dive to great depths in search of food and consequently sustain long periods without breathing. Research on these seals has provided fundamental knowledge of how mammals, including humans, handle gas dissolved in blood during and after deep diving events and has even contributed to advances in understanding sudden infant death syndrome (SIDS).

The Antarctic terrestrial environment supports a sparse but hardy biota. Work at the Dry Valleys Long Term Ecological Research (LTER) site, a "cold desert" member of the LTER network, is elucidating how seemingly depauperate systems respond to both short-term events and longer-term global change. Researchers at the recently established Microbial Observatory in the McMurdo Dry Valleys employ molecular, genetic, and genomic methods to understand the fundamental basis for microbial adaptation to the harsh conditions. The results of these studies contribute significantly to our understanding of the role microorganisms play in global systems ecology.

Geology and Geophysics

Antarctic research in this area includes paleontology, which reveals the history of life as it evolved in Antarctica—including the presence of dinosaurs and large marine reptiles—and studies of the Earth's deep interior through seismic observations that are not possible anywhere else in the world. Research is also aimed at the recovery and interpretation of sediment records from continental margin regions. Sediments provide information about changing conditions in the oceans over geological time. These sediment records complement ice core records, forming a powerful approach to studying the changing Earth. ANDRILL is an international collaboration of the United States, Italy, Germany, and New Zealand to recover and study sediment cores that span important intervals of time as the Earth transitioned from a greenhouse world to an icehouse world. These records will reveal the history of ice sheet development on the continent and go beyond the proxy records of general ice mass that have been inferred from deep ocean sediments. Another area of research is the remote study of the subglacial lithosphere via remote sensing—often using airborne sensors. These studies have revealed important characteristics of the subice materials such as the presence of sediments versus hard rock, geological structures, and potential areas of high heat flow that are key to fully modeling ice sheet dynamics.

The land beneath the ice sheets of Antarctica remains poorly understood and largely unexplored, yet knowledge of the geological and hydrological characteristics of these subglacial regions is vital for understanding ice sheet development. The nature of the underlying bedrock is a crucial boundary condition that defines the stability of the ice sheet to climatic changes (NRC, 2004). Major regions of Antarctica that are crucial to deciphering the intertwined geodynamic-limatic history puzzle remain to be explored for the first time. For example, the Gamburtsev Mountains in East Antarctica cover an immense region the size of Texas, yet detailed topography and peak elevation of the mountains remain matters of conjecture. Climate models suggest that the high elevation of these mountains was crucial in localizing the first Cenozoic ice sheets that formed 34 million years ago. This onset of glaciation affected the entire Earth, as global climate changed from the hothouse world of the early Cenozoic to the more recent world in which whole continents are covered in ice.

Recent discoveries show that beneath several miles of Antarctic ice, there are subglacial lakes that range in size from Lake Vostok, a body the size of Lake Ontario, to small marshy accumulations of a few kilometers' dimension. More than 145 lakes have been identified (Siegert et al., 2005), suggesting that the subglacial environments may be interconnected hydrological systems (Wingham et al., 2006). The extent and degree of interconnection among the lakes are unknown. These recently discovered subglacial environments formed in response to the complex interplay of tectonics and topography with climate and ice sheet flow over millions of years. The temperatures and pressures of subglacial lakes are similar to the environment of the deep oceans. However, subglacial environments are unique planetary-scale mesocosms found nowhere else on Earth. Sealed from the atmosphere for many millions of years, subglacial environments are the closest Earth-bound analogues to the icy domains of Mars and Europa (Siegert et al., 2001). These environments will be a target of intense study over the next decade or more. The potential for being able to study microorganisms of prehistoric origin is extraordinary, allowing a lens to be focused on the early history of life on this planet.

Ocean and Climate Systems

Antarctic research in this area includes both oceanography and lower-atmospheric studies. Oceanographers study the formation and distribution of cold-water masses that affect global circulation in the oceans. Processes of production and flow of Antarctic bottom water are tied to the annual formation of sea ice and circumpolar circulation. Southern Ocean circumpolar currents, the largest of the ocean's currents, combine with air mass and heat exchange in the atmosphere to affect climate on regional and global scales. In addition, atmospheric and oceanic research is trying to better understand ice sheet behavior. Researchers are determining the effect of ocean circulation (including melting) on ice shelves. This component of ice sheet behavior may determine when ice shelves form and when coalescing icebergs are thick enough floating glaciers to buttress ice streams. Without ice shelves, inland ice moves faster and thinning of the ice sheet occurs. Loss of ice is balanced by new snow on the ice sheet.

At the heart of climate, its variability and change derives from meteorology and atmospheric sciences, significant aspects of which can be studied effectively from icebreakers. Changes in polar regions are tightly coupled to global earth systems, with changes in one strongly impacting the other. Evidence of abrupt climate changes was found in the analysis of ice cores from the Greenland Ice Sheet Project (GISP 2). Pronounced changes in climate were found to occur (see, e.g., NRC, 2002) on a time scale of a few years and to extend for centuries. Antarctic Vostok ice cores provide a spectacular record of changes in temperature and atmospheric gas concentration over the last four glacial-interglacial cycles—400,000 years. The International Trans-Antarctic Scientific Expedition (ITASE) is collecting detailed records at a large number of sites in Antarctica. These records span the last several hundred years and offer information about changes in climate during the transition from low to high anthropogenic greenhouse gas production. Research is also under way to understand how precipitation has changed over time and how recent precipitation patterns relate to global phenomena such as El Niño and La Niña events.

The Climate Monitoring and Diagnostics Laboratory at South Pole Station is one of four National Oceanic and Atmospheric Administration (NOAA) atmospheric baseline observatories that monitor atmospheric gases, aerosol particles, solar radiation, the Earth's atmospheric system controlling climate forcing, ozone depletion, and baseline air. These observations produce long-term records used to improve global and regional environmental information and services. Large unmanned helium balloons are launched routinely from sites throughout Antarctica. These balloons provide the National Aeronautics and Space Administration (NASA) with an inexpensive means to place payloads into a space environment. The unique capabilities of this program are crucial for the development of new technologies and payloads for NASA's space flight missions. Many important scientific observations in fields such as hard x-ray/gamma-ray and infrared astronomy, cosmic rays, and atmospheric studies have been made from balloons.

McMurdo Station is one of the ground stations for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). Polar-orbiting satellites observe Earth from space and collect and disseminate data on Earth's weather, atmosphere, oceans, land, and near-space environment. Ground stations provide connectivity for the system of satellites to enable monitoring of the entire planet and provide data for long-range weather and climate forecasts, which increases the timeliness and accuracy of severe weather event forecasts. Operational environmental data from polar-orbiting satellites are important to the achievement of U.S. economic, national security, scientific, and foreign policy goals. For NPOESS to collect and disseminate data for the entire planet, all ground stations must be operational. McMurdo Station is the southernmost ground station and provides critical data to NPOESS. Without support from the McMurdo ground station, data transfer may be interrupted and hinder long-range weather and climate forecasts.

While many significant scientific discoveries have come from exploration and scientific investigations of the polar regions, many of the large-scale environmental changes witnessed in the polar regions within the past few decades involve poorly understood linked regional and global processes. In many areas the changes and their causes are only partly perceived because the polar regions are not completely "mapped," and exploration of such elements as the seafloor, the ice sheet bed, the crustal domain, and the biota is still needed to understand fully the nature and cause of past changes (NRC, 2004).

Glaciology

Antarctic research in glaciology focuses on studies of climate variation through ice cores and studies of the ice sheet to understand how they work and how this might change in the future. Earth's climate has changed dramatically over geological time. More recent changes can be studied by extracting both direct and proxy records from snow and ice cores. These records are used to understand how the Antarctic has responded to, and how it has been a forcing factor in, climate over the last 500,000 years. Over the next several years, a deep ice core will be drilled in central West Antarctica (the WAISCORES Project) to produce records of climate and atmospheric gases over the last 120,000 years, not only to understand change in Antarctica but also for comparison with a similar record from central Greenland, thus gaining understanding of interhemispheric variations.

Substantial research is also being done to understand the dynamics of the ice sheets—how they change and how fast they can change. Achieving reliable prognostic models for ice sheet behavior is important because of the large effect that changes in the ice sheet have on global sea level. Recent work in this field was conducted in collaboration with the British Antarctic Survey. A joint aerogeophysical survey of the Thwaites-Pine Island Glacier drainage was conducted to gather important boundary conditions, such as ice thickness, sub-ice bed elevation, and nature of the bed, for ice sheet models. Research is aimed at understanding the effects of ocean tides on ice shelves and ice streams far into the interior of the ice sheets.

Aeronomy and Astrophysics

Antarctic research in this area covers a spectrum of activities including solar-terrestrial interactions and the Earth's magnetosphere, as well as astronomy and astrophysics. The observations made at stations and remote sites are essential to understanding solar processes. Much remains to be learned about the Sun and the interactions of its highly variable photon, plasma, and particle emissions, which are the key "upper" boundary conditions to processes at work in the polar regions. A better understanding of the Sun and solar variability is necessary to understand how natural variations affect polar phenomena and human existence (NRC, 2004).

Magnetic field lines stretching out from the polar regions interact with the flowing and variable solar wind, transferring electromagnetic and charged particle energy to the upper atmosphere of the polar caps. The portions of such energies that may be responsible for such important polar phenomena as, for example, noctilucent clouds are completely unknown today (NRC, 2004). Variabilities in the emission of solar photons over all wavelengths—the so-called solar constant—affect the polar regions and global climate in ways that are only beginning to be studied through models and simulations. Global cloud cover data, including in the polar regions, which are important for models and which can be affected by solar emissions and their variability, are almost absent from databases of the polar environment. Except for the past 10 years or so, actual solar variability data needed for models have been taken largely by proxy from studies of polar and glacial ice sheets, ocean sediments, and other terrestrial sources (NRC, 2004). The polar regions are uniquely suited to studies of interaction of the solar wind and the Earth because particles and energy from these interactions travel along Earth's magnetic field to Earth's surface in the polar regions, where they can be measured. South Pole Station, being located high on the interior ice plateau, is the best site in the world for certain kinds of astronomy because of the low sky temperature, ultralow moisture content, and long periods suitable for observations. These conditions facilitate discoveries that are not possible elsewhere in the world.

Information about the early history of our solar system is enhanced through the collection of Antarctic meteorites made available to scientists around the United States and the world. Although rare, several samples of the Moon and Mars have been discovered and have provided important information about how these celestial bodies formed.

Radio astronomy has proven very successful, particularly with regard to studying the cosmic microwave background radiation, left over from the Big Bang, which offers important clues to the origin of the universe. In addition, the clear ice found deep beneath South Pole Station has proven to be an excellent site for a new kind of observatory, one designed to study high-energy neutrinos that provide information about phenomena such as supernovae in the universe. Neutrinos are abundant in the universe but interact with other matter very infrequently. Consequently, a very large detector is needed. Under construction at South Pole Station is the first and largest high-energy neutrino observatory in the world. When completed, it will consist of a cubic kilometer of ice that has been instrumented with nearly 5,000 detectors to find these elusive particles and determine their source in the universe.

THE INTERNATIONAL POLAR YEAR 2007-2008

Another consideration in thinking about the future use of icebreakers is the upcoming International Polar Year (IPY) 2007-2008 and its legacies. IPY will be an intense, coordinated field campaign of polar observations, research, and analysis that will be multidisciplinary in scope and international in participation. More than 35 nations are committed to participate. IPY 2007-2008 will provide a framework to undertake projects that normally could not be achieved by any single nation. It permits thinking beyond traditional borders—whether national borders or disciplinary constraints—toward a new level of integrated, cooperative science. Its coordinated international approach maximizes both impact and cost-effectiveness, and the international collaborations started today will build relationships and understanding that will bring long-term benefits. Within this context, IPY will seek to galvanize new and innovative observations and research while at the same time building on and enhancing existing relevant initiatives. IPY will serve as a mechanism to attract and develop a new generation of scientists and engineers with the versatility to tackle complex global issues. In addition, IPY is clearly an opportunity to organize an exciting range of education and outreach activities designed to excite and engage the public, with a presence in classrooms around the world and in the media in varied and innovative formats.

The IPY will use today's powerful research tools to better understand the key roles of the polar regions in global processes. Automatic observatories, satellite-based remote sensing, autonomous vehicles, the Internet and other modern communications tools, and genomics are just a few of the innovative approaches to help us study previously inaccessible realms. IPY 2007-2008 will be fundamentally broader than past international scientific years because it will explicitly incorporate multidisciplinary and interdisciplinary studies, including biological, ecological, and social science elements. Continued exploration and scientific study of the polar regions will lead to answers to important scientific questions and provide unexpected discoveries. New logistical capabilities and recently developed technologies will further augment the major breakthroughs in scientific understanding of the extreme environments that have been accomplished to date (NRC, 2006). Because large portions of the Arctic and Antarctic are accessible only by ship, realization of this potential for new insights and advances in polar research will depend heavily on ships capable of operating in ice-covered regions, either as research platforms or as key components of the logistics chain supporting on-continent research in the Arctic and the Antarctic (NSF, 2005).

FINAL THOUGHTS

This chapter has highlighted some of the most exciting polar research being conducted today. Polar research is contributing to a wide range of disciplines, providing fundamental information about Earth's systems and how they operate. The continued vitality of polar research is intimately linked to the availability of the appropriate infrastructure and logistical support to allow scientists to work in these challenging environments. Conducting research in the polar regions is as complex and challenging as space science. Like research in outer space, U.S. leadership in international polar science is being challenged as countries increasingly exercise their national prerogatives at the poles. As polar science advances, more and more difficult scientific questions are being asked that will require sustained and continuous observations and measurements in these regions. In the north, access to the central Arctic Basin will provide an understanding of the evolution of northern climates. Prediction of future change can be based only on a full understanding of the Arctic and Antarctic systems. In the south, year-round scientific access will be vital, with current research limited by the ability of researchers and teams to access on a regular basis all of the ice-covered seas of Antarctica and the Arctic. While assets and platforms such as airplanes and spaceborne sensors are important technological tools for future investigations, surface ground-truth and in situ sampling cannot and will not be replaced in the foreseeable future. The availability of adequate icebreaking capabilities is fundamental and essential to research in the polar regions of our planet, from which we gain an understanding of human life on Earth, both historically and climatically. The committee noted the successful relationship between U.S. Coast Guard HEALY operations and the U.S. Arctic marine science community, fostered in part by the UNOLS (University-National Oceanographic Laboratory System) Arctic Icebreaker Coordinating Committee (AICC) and supports the continuation of this successful relationship.

5

U.S. Coast Guard Roles and Missions

The U.S. Coast Guard is a military, multimission, maritime service within the Department of Homeland Security (DHS) and one of the nation's five armed services. The core roles of the U.S. Coast Guard are to protect the public, the environment, and U.S. economic and security interests in any maritime region in which those interests may be at risk, including international waters and America's coasts, ports, and inland waterways. Both the Arctic and the Antarctic regions fall within the scope of U.S. Coast Guard responsibilities.

From its inception as the Revenue Marine in 1790, the service has possessed a military character. Alexander Hamilton, later to become the first Secretary of the Treasury, conceived the need for a capable maritime presence as early as 1787 when he noted, "A few armed vessels, judiciously stationed at the entrances of our ports, might at a small expense be made useful sentinels of the laws" (Hamilton, 1787). For almost seven years, the Revenue Cutters represented the only naval force of the United States. Revenue and U.S. Coast Guard cutters have been employed as naval assets in every maritime conflict since the quasi-war with France in 1798-1800.

From the outset, the service's maritime expertise and military discipline suited it well for acquiring additional tasking. Law enforcement duties expanded beyond a narrow focus on customs laws to include prevention of slave importation, and winter cruising by cutters to assist vessels in distress began in the 1830s. United States involvement in polar operations dates from the purchase of Alaska in 1867, when Revenue Cutters accepted possession of the territory and began exploration of the Bering Sea and Arctic Ocean coastlines. By the 1870s, cutters made annual patrols to the Alaskan Arctic to enforce sealing and whaling laws, prevent the illegal introduction of alcohol and other contraband, provide medical and other assistance to Native communities, assist ships affected by ice, and support scientific inquiry. These multidisciplinary patrols fit well within the service's increasingly diverse duties and organizational culture of independent operations. The Lifesaving Service and Revenue Cutter Service were merged in 1915 to form the U.S. Coast Guard. Patrol activities in ice-affected waters of the Arctic represented the only regular government presence for many years and were conducted regularly until the late 1940s.

During World War II, the U.S. Coast Guard polar operations expanded to secure Greenland against German incursions. The U.S. Coast Guard oversaw the design of deep-draft polar icebreakers and shared the operation of these seven ships with the Navy in the postwar era. U.S. Coast Guard and U.S. Navy icebreakers were kept busy throughout the subsequent Cold War years with massive operations to build and resupply Defense Early Warning (DEW Line) sites in the Arctic, establish Thule Air Base in northwestern Greenland, conduct submarine warfare-related research in the Arctic Ocean and peripheral seas, and support large-scale exploration of Antarctica.

After World War II, the Lighthouse Service and Steamboat Inspection Service were assimilated into the U.S. Coast Guard. Polar operations continued throughout the Cold War and into the 1970s. U.S. Coast Guard icebreakers assisted summer tug-and-barge sealifts to Prudhoe Bay in the 1970s as the Alaska Pipeline was built and supported several years of testing in Maritime Administration studies of commercial icebreaking ship design. Even before the end of the Cold War, icebreakers were increasingly in demand for nondefense research in the Arctic.

Throughout its history, the U.S. Coast Guard's mission has expanded in response to the changing needs of the nation. Today, the U.S. Coast Guard provides unique benefits to the nation because of its distinctive blend of military, humanitarian, and civilian law enforcement capabilities. To serve the public, the U.S. Coast Guard has organized its responsibilities into five fundamental roles: (1) maritime safety, (2) national defense, (3) maritime security, (4) maritime mobility, and (5) protection of natural resources, and a unique mission in ice operations in which icebreakers play a key role.

These roles may again be altered in response to the pronounced, large-scale environmental changes that are occurring in the Arctic. It is highly likely that commercial endeavors will develop in this region; these developments will lead to increased commercial traffic, resource exploitation, and associated international interface, which will directly affect U.S. Coast Guard statutory responsibilities and pose significant challenges to the Coast Guard's future ability to execute these responsibilities in the ice-affected waters of the Arctic.

MARITIME SAFETY

In the role of maritime safety, the U.S. Coast Guard seeks to eliminate deaths, injuries, and property damage associated with maritime transportation, fishing, recreational boating, and other maritime activities. Safety missions can be described in terms of prevention, response, and investigation. Prevention activities include developing commercial and recreational vessel standards, licensing commercial mariners, operating the International Ice Patrol to protect ships transiting North Atlantic shipping lanes, and educating the public. The U.S. Coast Guard represents the nation in the International Maritime Organization (IMO), which promulgates measures to improve shipping safety, pollution prevention, maritime security, and mariner training and certification standards worldwide. The U.S. Coast Guard develops and ensures compliance with domestic shipping and navigation regulations by inspecting U.S. flag vessels, mobile offshore drilling units, and marine facilities; examining foreign flag vessels based on the potential safety and pollution risks they pose; reviewing plans for vessel construction, repair, and alteration; and documenting and admeasuring U.S. flag vessels.

As National Recreational Boating Safety Coordinator, the U.S. Coast Guard works to minimize loss of life, injury, property damage, and environmental harm associated with water recreation, through education programs, regulation of boat design and construction, approval of boating safety equipment, and courtesy marine examinations of boats for compliance with federal and state requirements. The all-volunteer U.S. Coast Guard Auxiliary plays a central role in boating programs.

Despite extensive prevention programs, response to maritime incidents is still necessary. As the lead agency for maritime search and rescue (SAR), the U.S. Coast Guard maintains a coastal network of boat stations, aircraft, communications systems, and a command-and-control network to respond to those in peril at sea. Any U.S. Coast Guard unit can respond to SAR requirements, and the Coast Guard also coordinates other federal, state, local, and private assets, including the world wide Automated Mutual-assistance Vessel Rescue (AMVER) program. Finally, the U.S. Coast Guard investigates accidents to determine if laws have been broken and whether changes should be made to improve prevention programs.

In the Arctic Ocean and Bering Sea, the U.S. Coast Guard's search-and-rescue efforts involving coastal communities and fishing vessels have not been uncommon. Decreasing and more unpredictable ice concentrations may increase the risk to Native peoples pursuing traditional hunting and fishing in boats or on sea ice. These small communities might logically demand increased government SAR services as a quid pro quo for the impacts of development on their lifestyles. Fishing vessels working in or near the ice edge have also experienced dramatic losses, of both crew and vessels, and have required occasional urgent SAR assistance. Although the well-endowed North Slope Borough operates its own SAR helicopter, maritime SAR over the more extensive area falls clearly in the U.S. Coast Guard's portfolio. For both communities and vessels, a mobile, helicopter-equipped ship would seem to offer more economical SAR services than fixed stations with low seasonal workload.

As ship traffic increases in U.S. Arctic waters, the U.S. Coast Guard's maritime safety and security roles will be significantly affected as enhanced maritime domain awareness (MDA) is increasingly desirable. Longstanding U.S. positions on freedom of navigation would argue against direct regulation of vessels transiting along the North Slope and through the Bering Strait. However, the ability to monitor all vessels in these waters would be beneficial for both safety and security purposes. Increased presence by government icebreakers or other surface vessels would contribute to better awareness, but a more comprehensive monitoring capability may be needed. As an example, in 2004 the Malaysian freighter SELENDANG AYU went aground and spilled oil near Unimak Pass. The impacts were exacerbated by lack of knowledge of the ship's presence, which prevented dispatch of assistance until it was too late to avoid the vessel's total loss, crewmember deaths, fouling of pristine coastline, and expensive cleanup action. As a result of this incident, the U.S. Coast Guard is installing automatic identification system (AIS) equipment to monitor shipping in this highlytrafficked area of the Aleutians. Similar AIS capability may be helpful in the vicinity of the Bering Strait and along the Arctic coastline.

NATIONAL DEFENSE

As one of the five U.S. armed services, the U.S. Coast Guard helps to defend the nation and supports the National Security Strategy. The U.S. Coast Guard has served alongside the Navy in all wars and most armed conflicts since 1798, and has maintained weapon systems, training programs, and operating procedures that facilitate readiness and interoperability with the Navy and the other services. Many U.S. Coast Guard capabilities have military applications as well as domestic civilian purposes. Current agreements with the Department of Defense assign the U.S. Coast Guard five specific defense missions in support of U.S. combatant commanders: (1) creating a visible presence and thereby maritime interception operations; (2) military environmental response operations; (3) port operations, security and defense; (4) peacetime military engagement; and (5) coastal sea control operations. During Operation Iraqi Freedom, the United States employed U.S. Coast Guard capabilities, which currently remain a key component of maritime security in the Persian Gulf. As part of its national defense role, the U.S. Coast Guard operates the nation's only multimission polar icebreakers, projecting U.S. presence and protecting national interests in the Arctic region.

With the breakup of the Soviet Union and the end of the Cold War, there are no direct military threats in the Arctic basin. However, with the most recent missile testing, although seen as a failure, it may be possible for missiles launched from North Korea to reach parts of Alaska. In response, the United States has positioned significant missile tracking assets in the Aleutian Islands. Although at present, the U.S. Coast Guard is not actively patrolling these waters for national defense, this may change if the political climate in this region changes. It also appears that geopolitical competition in the Arctic is under way and increasing. Indicators include Canadian initiatives toward a more overt Arctic presence, aggressive Russian and Danish claims to the Arctic, and Danish-Canadian sovereignty disagreements over Han Island. This competition will likely develop further if exploitation of oil and gas reserves proves economical. U.S. national interests can only benefit from an active and capable presence in this competitive environment. Icebreaking capability would strengthen U.S. defense posture in the Arctic by (1) creating a visible presence and thereby providing a clear statement of national interest in the region; (2) establishing an ability to monitor and react to events as necessary; and (3) preserving a basic capability for direct military action if ever required. The U.S. Coast Guard's military status would offer advantages for protecting U.S. interests anywhere along the spectrum from peacetime operations to conflict.

MARITIME SECURITY

The U.S. Coast Guard's principal objective under its role of maritime security is to protect America's maritime borders and sovereignty. As the nation's primary maritime law enforcement service, the Coast Guard enforces or assists in enforcing federal laws, treaties, and other international agreements on the high seas and in waters under U.S. jurisdiction. U.S. Coast Guard units have authority to board any vessel subject to U.S. jurisdiction to make inspections, searches, inquiries, and arrests. With a capable fleet of cutters, aircraft, and trained personnel, the U.S. Coast Guard can leverage the responsibilities of other agencies. As part of its maritime security role, the Coast Guard operates the nation's only multimission polar icebreakers, projecting U.S. presence and protecting national interests in the Arctic and Antarctic regions.

Two of the most visible recent security roles have involved the interdiction of illegal drugs and illegal migrants. The National Drug Control Strategy designates the U.S. Coast Guard lead agency for maritime drug interdiction, involving forward deployment of cutters and aircraft throughout the Caribbean Sea and the west coast of Central America. Illegal migrant interdiction, which in a majority of cases begins as a search-and-rescue operation, has been characterized by the movement of hundreds of thousands of people from Cuba, Haiti, the Dominican Republic, and China.

Passage of the Magnuson-Stevens Fishery Conservation and Management Act in 1976 extended the U.S. exclusive economic zone (EEZ) offshore to 200 nautical miles (nmi). The U.S. Coast Guard provides the principal U.S. capability for patrolling and enforcing fisheries laws in the EEZ. A variety of international fisheries agreements have further expanded U.S. jurisdiction to high seas beyond the EEZ, such as the prohibition of high-seas drift net fishing in the North Pacific Ocean and continuing effort focused on the maritime boundary line in the Bering Sea.

Since 9/11, the U.S. Coast Guard's long-standing role in port security has received tremendous emphasis and resources. The U.S. Coast Guard was responsible for reviewing, approving, and enforcing security plans for port facilities and for vessels using U.S. ports as security measures were increased after 9/11. In addition, the U.S. Coast Guard has added new resources to protect critical port infrastructure, including defense assets, and respond to potential security threats in U.S. ports and waterways.

The post-9/11 emphasis on security has highlighted the vital need for maritime domain awareness. The concept of MDA encompasses real-time or near-real-time information on every aspect of maritime areas surrounding the nation: ships and their intended activities, cargoes, marine events and operations, environmental conditions, and so forth. Reporting requirements, such as 96-hour prenotification by vessels bound for U.S. ports, fulfill some MDA requirements, as do existing vessel traffic services in many port areas. U.S. legislation and international agreements now require most commercial cargo and passenger vessels to have AIS transponders, which broadcast information about the vessel's identity and position to other vessels and centers on shore.

An increasingly accurate MDA picture not only will enhance maritime security but will aid other U.S. Coast Guard missions as well. The ability of the U.S. Coast Guard to monitor AIS signals is being expanded through the use of AIS receivers in satellites, on U.S. Coast Guard ships and aircraft, and on offshore installations. While AIS is nominally a short-range system, MDA will also be enhanced by the integration of AIS with an IMO Long Range Identification and Tracking (LRIT) requirement currently under development. The LRIT system will use satellite-based communications already required on board most commercial vessels. These satellite systems however, are not reliable above 76 degrees North latitude, and a provision in the international agreement has been made to use iridium technology in areas where the satellites are unreliable.

Although the need for routine interdiction of drugs or aliens in the Arctic seems unlikely at this point, the need for law enforcement may increase. There are indications that the northern Bering Sea is rapidly changing from an Arctic to a sub-Arctic body of water. These changes favor increases in commercially valuable fishery stocks and their possible movement northward into the Arctic Ocean. While open-water monitoring and enforcement of commercial fishing could be accomplished by thin-hulled cutters that now perform these tasks in the Bering Sea, there may be significantly increased risk of "shoulder" season ice blockages in the Bering Strait and along the coastline. Mitigating this risk would require available icebreaking capability for effective U.S. Coast Guard enforcement.

MARITIME MOBILITY

Within the role of maritime mobility, the U.S. Coast Guard facilitates maritime commerce and eliminates interruptions and impediments to the efficient and economical movement of goods and people, while maximizing recreational access to and enjoyment of the water. The U.S. marine transportation system is a critical component of the nation's economy, and the U.S. Coast Guard has primary responsibility for managing waterways and ports. U.S. Coast Guard cutters, boats, and personnel maintain the aids to navigation system, marking navigable areas and obstructions with buoys, fixed structures, and a variety of audible, visual, and electronic signals. Notices to Mariners provide up-to-date navigation information on system exceptions, special events, et cetera. The U.S. Coast Guard operates vessel traffic services (VTS) using AIS technology, tailored to the needs of particular port areas, to monitor and direct waterborne traffic. VTSs promote the efficient movement of vessels, seek to prevent collisions and groundings, and enhance the security of critical port areas. Small icebreakers and ice-strengthened cutters in the Great Lakes and the northeastern United States assist vessels and facilitate their movement in port areas and along the St. Lawrence Seaway system. Oversight of bridge design standards and drawbridge openings ensures that waterway transportation needs are accommodated. Polar icebreaking to facilitate maritime commerce, scientific exploration, and national security activities is included in the goal of maritime mobility.

The role of vessel assistance, which was formally instituted by a 1936 Executive Order (Appendix C) and what the U.S. Coast Guard has termed "domestic" icebreaking, has historically been confined to the Great Lakes and northeastern United States. Similar routine icebreaking services have never developed in Alaska due to the rarity and limited seasonal nature of commercial shipping in ice-affected area, other than occasional events such as the Prudhoe Bay sealifts mentioned above. New commercial ventures, exemplified by the Red Dog Mine north of the Bering Strait, and planned offshore North Slope oil and gas development, may result in pressure for a capable icebreaker presence in the spring and fall "shoulder" seasons. From a business perspective, the presence of an icebreaker operating in the general area could serve to mitigate the risks of unpredictable ice and weather conditions and improve the economics of projects subject to seasonal shipping limits. This would be a natural extension of the rationale for U.S. Coast Guard domestic icebreaking.

PROTECTION OF NATURAL RESOURCES

The U.S. Coast Guard seeks to protect the nation's natural resources by eliminating environmental damage and the degradation of natural resources associated with maritime transportation, fishing, and recreational boating. Closely tied to the U.S. Coast Guard's safety prevention efforts, avoidance of accidents is a key component of protecting the U.S. marine environment. The U.S. Coast Guard enforces regulations and laws protecting sensitive marine habitats, marine mammals, and endangered marine species, as well as laws preventing discharge of oil and other hazardous materials. A wide range of activities addresses environmental objectives in offshore lightering zone regulation, domestic fisheries enforcement, and foreign vessel inspection. U.S. Coast Guard units are often the first on scene when a pollution incident is reported, and the Coast Guard is typically the lead agency for a pollution response effort. Under the National Contingency Plan, U.S. Coast Guard captains of the port are the designated federal on-scene coordinators (FOSCs) for oil and hazardous substance incidents in all coastal and some inland areas. The FOSC is responsible for forging a coordinated and effective response effort with a complex group of government and commercial entities, often in dangerous and emotion-laden situations.

Protecting the Arctic marine environment begins with ensuring the safety of vessels operating in these challenging conditions, including the availability of icebreaking assistance and comprehensive monitoring of vessel movements. Prevention might also include a regulatory regime, limiting vessels to geographic areas and seasonal periods appropriate to their ice capabilities. The Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR) would serve as an obvious example. Increases in traffic, especially from Russian or Canadian waters, may create U.S. interest in establishing regulations; enforcement and deterrence would necessitate an on-scene presence capable of operating in ice. The U.S. Coast Guard would clearly have regulatory responsibility for this type of waterways management. Responding to a major oil spill in the Arctic is challenging, as cleanup activities for an onshore spill near Prudhoe Bay in early 2006 attest. Oil cleanup offshore would be even more difficult due to the dearth of infrastructure and the possibility of ice. Where depth of water permits access, an icebreaker could offer command-and-control capabilities, communications, berthing, helicopters, boats, cargo space, heavyweight handling gear, tankage, and support services to smaller craft, all of which would be of great benefit to cleanup operations. Direct oil recovery could also be included as an icebreaker capability: POLAR SEA successfully tested a boom-mounted skimming system known as the Vessel of Opportunity Skimming System (VOSS) (as well as other capabilities) while participating in an oil spill exercise off Sakhalin Island in 1998. The U.S. Coast Guard's new fleet of coastal buoy tenders is equipped with VOSS, and thought should be given to the need for new polar icebreakers to be equipped with the latest technology for oil spill response.

ICE OPERATIONS

The principal objective of the U.S. Coast Guard's polar ice operations role is to support U.S. interests in the polar regions by providing the icebreaker operating time and capabilities required by the U.S. Coast Guard and user agencies in polar regions. This objective is selected as the U.S. Coast Guard's long-term first priority because Coast Guard icebreakers are the only national icebreaking resources that can reliably accomplish national objectives in the polar regions. Although, the U.S. Coast Guard has included polar icebreaking as part of its national defense role, polar operations have in fact spanned all of the mission areas to some degree. The U.S. Coast Guard polar icebreakers have been tasked at various times to support the national objectives in the polar regions by (1) providing platforms for scientific research in the Arctic and Antarctic; (2) performing logistical and supply activities in the Arctic and Antarctic; (3) providing support for resource exploration, shipping demonstration projects, and research, development, and testing projects in the Arctic; (4) performing military missions in the Arctic; (5) supporting diplomatic missions related to U.S. strategic interests; and (6) coordinating an international exchange of information on ice operations.

Even before the effects of environmental changes were widely recognized, the Arctic was a target for scientific inquiry as one of the least explored areas of the planet. It seems clear that the rapid environmental changes now under way will continue to require active scientific observation and study. While science support is not exclusively a U.S. Coast Guard mission, oceanographic research is directed by statute and has been part of the service's Arctic operations since John Muir sailed with the Revenue Cutter CORWIN in 1884. Science support remains a compatible mission for U.S. Coast Guard-operated icebreakers. U.S. icebreaker presence in the Arctic, for any or all of the potential missions discussed above, would synergistically enhance the ability to conduct scientific sampling and observation. In yet another area of competition, robust marine research capabilities in the Arctic will also bolster the international standing of U.S. scientists and research programs, as well as preserve the benefits of applied research.

The U.S. Coast Guard's science support role, primarily through logistics in McMurdo Sound, is addressed in U.S. Coast Guard statutory authorities. The presence of U.S. Coast Guard icebreakers in the Antarctic every year brings a variety of additional national capabilities to the region, not the least of which is a visible maritime presence.

The need for future U.S. Coast Guard presence in Antarctica could unfold in three possible ways. First, increased geopolitical competition in Antarctica—perhaps manifested by more aggressive activities by other nations or even outright abrogation of the Antarctic Treaty—might call for a more forceful and visible U.S. presence. U.S. Coast Guard units would be obvious candidates for such a presence in Antarctic coastal areas. A second need might result from extensions of the Antarctic Treaty system, or other international agreements, aimed at managing Antarctic activities such as fishing or other resource exploitation. Again, U.S. Coast Guard capabilities would offer an on-scene solution. Finally, Antarctic tourism is growing rapidly and involves thousands of American tourists sailing on foreign-flag vessels in an area with no sovereign regime of safety, security, or environmental regulation and enforcement. These are all areas of U.S. Coast Guard responsibility and expertise, and changes in the dynamics of Antarctic tourism could require U.S. federal action to protect American citizens. The likelihood of any of the foregoing possibilities is difficult to assess, but all could be accommodated by continued U.S. Coast Guard icebreaking support in the Antarctic.

6

U.S. Polar Icebreaker Fleet

ICEBREAKING SHIPS—AN HISTORICAL PERSPECTIVE

The Early Years

Icebreaking ships are a relatively new evolution in the history of ship design and construction. Conventional ships in or near ice-covered waters from the earliest years of recorded history had to do their best to avoid the ice. If they failed, they risked being trapped in ice with the potential loss of the ship and crew due to the extreme pressures and strength of the ice.

As early as 1819, Lt. William E. Parry of Great Britain tried to sail his 375-ton bark, HECLA, through the Northwest Passage. He was forced to winter on Melville Island before turning back in 1820 due to his inability to penetrate the ice. HECLA was not designed for operation in ice, and this was true of many of the other early polar explorers' ships. Although the desire to explore the Antarctic and Arctic may have initiated the development of ships designed to operate in and around ice-covered waters, this desire was closely coupled with the commercial aspirations of whalers and seal hunters. Initially, these purpose-built ships were intended only to survive in the harsh environments, not to routinely break ice. As such, they were considered ice-strengthened ships.

By the latter part of the nineteenth century, ships were being built for the purpose of breaking ice. British shipyards constructed several powerful icebreaking ships for the Imperial Russian government. Around the same time Canada ordered several smaller icebreakers to perform escort service in the St. Lawrence River and Gulf.

The U.S. Navy and the Revenue Cutter Service each had interests in ice-filled waters, but neither had specialized ships for operation in the ice until the late 1800s. The Revenue Cutter Service used conventional cutters to perform patrols in the Arctic on a regular basis since 1880 when CORWIN made her first patrols there. The Revenue Cutter Service acquired its first ice-strengthened ship in 1884 when the U.S. Congress authorized the purchase of BEAR, a 10-year-old sealing vessel built in Scotland. BEAR was purchased to perform a rescue mission of a U.S. Army expedition stranded on northern Ellesmere Island. The rescue mission was a success and showed BEAR's characteristic to be ideally suited to Arctic Ocean cruising around Alaska. BEAR was originally built as an ice-going sealing ship with closely spaced 24-inch oak frames, heavy internal beams and stanchions, a reinforced bow, and Australian iron-bark sheathing covering the oak hull planking from keel to waterline.

While some cities in the United States had employed ships to work in harbor ice as early as 1837 when CITY ICE BOAT NO. 1 was built in Philadelphia for use on the Delaware River, the first large U.S. ship built to work in ice was not designed and built until 1927. Drawing on the experience of 47 officers with Arctic experience, the U.S. Coast Guard contracted with Newport News Shipbuilding and Drydock Company to build the 216-foot steel-hulled NORTHLAND. Displacing 1,785 tons with welded and riveted construction, an industry periodical stated that "for its size, [it was] the strongest and heaviest steel hull which has ever been projected."

Although the NORTHLAND patrolled the Alaskan Arctic for 11 years, she was a disappointment. Her slowness and poor handling characteristics prevented her effective use in the waters of the "lower 48." This, coupled with the end of commercial whaling in the Arctic, caused Coast Guard Headquarters to question the need for continued operation of a large specialized cutter for only six months each year. "Even a former NORTHLAND commanding officer believed that a regular cruising cutter could perform all of the routine Arctic cruise functions, except for assisting vessels in ice." Unstrengthened cutters cruised to Point Barrow in 1939, 1940, and 1941.

President Franklin Roosevelt issued an Executive Order on December 21, 1936, directing the U.S. Coast Guard to assist in keeping channels and harbors open to navigation by means of icebreaking operations. Recognizing that the nations of northern Europe whose waters were often ice-covered had made major advances in icebreaking ship development in the early twentieth century, the U.S. Coast Guard directed Lt. Edward H. Thiele to make a survey of northern European icebreakers. He obtained valuable information, especially from the Swedes and the Finns. It was ironic that Thiele found that one of the most advanced Swedish icebreakers, the 258-foot YMER built in 1932, had been designed using the bow form of the Great Lakes car ferry ST. MARIE. Subsequently, Thiele was part of a team that designed a class of successful 110-foot icebreaking tugs for harbor and channel work—the first completed in 1939.

In 1941, another large icebreaking vessel was authorized and commissioned in 1942 as the STORIS. She was an enlarged 230-foot version of a class of 180-foot buoy tenders. Although STORIS was designed to serve as a light icebreaker in Greenland waters, she gained special recognition in 1957 when she, with two 180-foot tenders, became the first U.S. ship to travel the Northwest Passage from west to east.

World War II

All of the foregoing designs led to the development of the first true U.S. icebreakers, the Wind class. Once again the President of the United States was instrumental in this decision.

Rear Admiral Edward H. Thiele remembered that in 1941 he had obtained orders to the AMERICAN SAILOR as executive officer, believing that too much Washington duty might affect his career adversely. While the ship was fitted out in Baltimore, he was recalled to Coast Guard Headquarters by Engineer-in-Chief Harvey Johnson, who took him to the commandant's office. There Commandant Waesche handed him a note that the President had written to Treasury Secretary Morganthau stating, "I want the world's greatest icebreakers." Thiele speculated that these ships were to support the construction of an airfield at the head of Greenland's Sondre Stromfjord and to aid in the shipment of lend-lease supplies to Archangel, the Russian White Sea port.

Thiele, tasked to lead the design effort, was exploring various alternatives. At the same time, Secretary Morganthau recommended to the Secretary of State that the United States negotiate the purchase of one or more Russian icebreakers. The Russians offered the KRASIN built in 1917 in Great Britain. While Thiele felt KRASIN was "ancient history at best," the deal fell through only due to the pressing need of Russia to keep the seaway to Archangel open. Thiele's design was far different from anything ever built in the United States.

The Wind class would have half again the beam (63 feet, 6 inches), two-thirds more draft (25 feet, 9 inches), and almost four times the displacement of STORIS. Five and a half times more horsepower required two shafts, one of the most radical differences from the previous succession of single-shaft icebreaking ships, that also offered obvious advantages of redundancy in case of shaft or propeller damage far from repair facilities. The large beam let the ship cut a wide track in ice for escorted ships to follow and, as importantly, decreased the risk of ice damage to the propellers set as far inboard as possible. Similarly, the deep draft enabled the use of large propellers for strength and power, and put their blade tips deep enough to lessen contact with floating ice.

A diesel-electric propulsion plant was chosen. Proven in several previous applications, it offered economy in fuel consumption and generated relatively high horsepower for the space required. The machinery components could be arranged flexibly within the ship. The six diesel engines and generators provided redundancy and flexibility for operations that would include long periods of icebreaking at full power and lengthy, open-water transits at low power levels. Diesel-electric propulsion would also deliver maximum thrust when the ship was stopped, a frequent occurrence when operating in difficult ice conditions. Additionally, the operating environment required that machinery remain unaffected by the shocks that result from propellers striking ice, which a diesel-electric plant addresses by electrical, rather than mechanical, linkages between components.

An icebreaker's hull form is crucial to its effectiveness. The Wind class design incorporated a sloped forefoot that met the ice at a 30-degree angle. By that time, this had become a distinguishing feature of icebreaking ships. This bow configuration, with its surface sloping down and aft below the waterline, is key to how an icebreaker works. As the ship forces itself against a horizontal ice surface, the bow rides up on the ice until the vessel's weight breaks the ice in a downward motion and displaces the broken pieces to each side. In the Wind class design, this action distributed the icebreaking forces efficiently over the entire forebody. The stern was similarly shaped to permit backing into ice when backing and ramming.

To absorb the repeated impacts of ice and withstand its potential crushing pressures, the hull had enormous strength. Flare in the hull helped reduce frictional effects when moving through ice and in ice under heavy pressure would cause the ship to be lifted rather than crushed. The 1 $^1/_4$-inch hull plating of high-tensile steel increased to a thickness of 1 $^5/_8$ inches along the ice belt. However, the real strength lay in the entire structure of deck beams, structural bulkheads, and frames spaced 16 inches apart. Double bottoms and wing tanks surrounded the engineering spaces with a layer of protection in the event the hull plating was punctured.

The Swedish icebreaker YMER served as a general prototype for the Wind class design. The YMER influence can be seen most readily in the inclusion of heeling tanks and a bow propeller. The three pairs of heeling tanks were connected by 24-inch ducts and 60-horsepower (9hp) reversible pumps that could transfer 13,600 gallons of water per minute to induce a heel of about 5 degrees to each side of the vertical in 90-second cycles. This capability offered a means of breaking the frictional "lock" of ice and snow on the ship's sides. Peak tanks at the bow and stern permitted the ship's fore-and-aft trim to be varied as much as 5 feet so that the bow could attack the ice at a better angle under different conditions of loading. The reversible bow propeller protruding forward from the forefoot near the keel could apply up to 3,300 horsepower to assist in breaking ice. However, it proved easily damaged and of little practical use in polar ice conditions and was soon removed from all Wind class vessels.

Based on this initial design, the U.S. Coast Guard hired Gibbs and Cox, one of the largest naval architectural companies in the United States, to perform the detailed design. Finally, on November 15, 1941, a contract was awarded to Western Pipe and Steel Company to construct four ships at its newly created shipyard near Los Angeles. This company had the experience and technology to work with heavy high-tensile steel plating. Thus, the NORTHWIND, EASTWIND, SOUTHWIND, and WESTWIND were born.

Subsequently, it was decided to transfer the NORTHWIND to the Soviet Union to help ensure her continuation in the war. She was renamed SEVERNI VETER in 1943 and sailed off to the Russian Arctic. A replacement was ordered, and EASTWIND, SOUTHWIND, and WESTWIND were delivered in June, July, and September of 1944. In 1945, WESTWIND and SOUTHWIND were turned over to the Soviets and two more replacements were ordered. By war's end, EASTWIND and the "new" NORTHWIND were serving the U.S. Coast Guard, while the last two replacement icebreakers were delivered to the U.S. Navy as the BURTON ISLAND and EDISTO, beginning the Navy's entry into icebreaker operations.

Postwar Fleet

The United States secured the return of the icebreakers loaned to the Soviet Union; and they joined the U.S. fleet as the ATKA and STATEN ISLAND (flying the Navy ensign) and the WESTWIND (returning to the Coast Guard). In addition, Gibbs and Cox designed a larger version of the Wind class known as the GLACIER. When commissioned by the Navy in 1955, at 310 feet long, 74 feet abeam, and displacing 8,449 tons with 10 diesel engines producing 21,000 horsepower on two shafts, she was the largest icebreaker among the eight heavy icebreakers then operated by the United States.

While the two services exhibited an extraordinary level of cooperation over the years, it became apparent that the Navy could not justify continuing operation of icebreakers when it needed combatant ships to replace its aging World War II fleet. Consequently, a Memorandum of Agreement was signed between the Department of the Treasury and the Department of the Navy providing for "The permanent transfer to the Coast Guard, at the earliest practicable date, but not later than 1 November 1966, of jurisdiction, control over, and responsibility for operating and manning the five U.S. Navy icebreakers in high latitudes to fulfill U.S. Navy mission requirements." Thus, after a 20-year presence in operating icebreakers, the Navy relinquished its role to the Coast Guard.

Even with a fleet of eight icebreakers, the workload for the ships was large. Supporting logistics, escort, and patrol in both the Antarctic and the Arctic was a challenge because of the virtual explosion of these activities in the years immediately following the war. However, by the mid-1960s these activities were beginning to abate and budgetary constraints led to the retirement of the first Wind class ship in 1969, the EASTWIND.

As early as 1963, the Coast Guard began discussing the need for new icebreakers. A design team was formed by 1965 and commenced a lengthy period of review, research, and design. In 1969, based on the anticipated acquisition of new highly capable icebreakers, U.S. Coast Guard planners projected a need for a fleet of only five polar icebreaking ships to meet requirements. The fleet was to consist of four new icebreakers and GLACIER.

The final design of what was to become the Polar class, was a ship design that substantially exceeded the capability of previous U.S. icebreakers. At 399 feet and 13,190 ton displacement (more than twice the displacement of the Wind Class), the ships had space for two helicopters and an unprecedented suite of scientific facilities. The hull design was well researched, and special alloy steel that possessed a 50 percent increase in yield strength over mild steel was used in hull plating, ice frames, and weather decks. The first new ship contract was awarded to Lockheed Shipbuilding and Construction Company in Seattle in 1971. Two years later a contract was awarded for a second ship. These were to become the POLAR STAR and the POLAR SEA, respectively.

Recognizing that the new ships could not be completed for some time, a program was created to rehabilitate and modernize two Wind-class ships to bridge the gap. NORTHWIND and WESTWIND were selected to undergo vessel rehabilitation and modernization (VRAM) at the Coast Guard Yard in Curtis Bay, Maryland. This work was completed and the two ships returned to service in 1974-1975, six months before the POLAR STAR was delivered to begin its shakedown process. During 1974, SOUTHWIND, EDISTO, and STATEN ISLAND were decommissioned. POLAR SEA was delivered in 1978. When BURTON ISLAND was decommissioned in 1978, the Coast Guard had a fleet of five icebreaking ships.

ASSESSMENT OF NATIONAL ICEBREAKER REQUIREMENTS

While the U.S. Coast Guard continued to prepare a series of icebreaking ship designs, the costs associated with proposed new ships was growing. This caused the proposals to be reanalyzed and reconsidered, and ultimately, in 1980, the Office of Management and Budget (OMB) rejected the proposed budget request for a new icebreaker. Study followed study until 1983 when the Coast Guard organized a Polar Icebreaker Requirements Study (PIRS), which was unique in that it involved other federal agencies for the first time. The other agencies included the Department of Defense, National Science Foundation, and Maritime Administration, all of which were utilizing the services of the existing fleet. In the same year, OMB directed that all icebreaker costs be fully reimbursable, and a complex scheme of fixed costs to be reimbursed to the Coast Guard was developed along with actual expenses incurred in polar regions. Ultimately the National Oceanic and Atmospheric Administration (NOAA), Department of Transportation, and OMB joined the PIRS study group. The final 400-page report stated that there were "no satisfactory alternatives to take the place of polar icebreaking services." A summary of the PIRS findings follows.

In studying icebreaker funding, PIRS reviewed the full reimbursement system in detail. While recognizing the theoretical advantages of incorporating full icebreaker costs in the budgets of user agency programs, the PIRS report also reflected the general discontent with reimbursement. The report cited the following disadvantages:

- Increased difficulty in managing an icebreaker fleet, when unexpected perturbations in agency budgets can eliminate large amounts of funding with little notice,
- Inefficient utilization due to the rigid allocation of icebreaker days,
- Difficulty in providing support for other than the designated users, and
- Potential for reduction in the icebreaker fleet due to distorted reimbursement incentives.

The impact of reimbursement was felt even before completion of the PIRS report. The $5.3 million transferred to the Maritime Administration (MARAD) bloated the small agency's research and development budget substantially. When the 1984 budget reduced MARAD's R&D appropriation to its traditional level, MARAD redirected its icebreaker funding to its other traditional programs. The Coast Guard was left without funding for one of the five ships.

PIRS also assessed funding acquisition costs under shared arrangements with other agencies and with industry without discovering any attractive alternatives. After making estimates of operating and capital costs, PIRS concluded that an icebreaker fleet is essential to the national interest and should be operated by the U.S. Coast Guard. The report's significant recommendations include the following:

- The Coast Guard should maintain a fleet of four icebreakers to meet the projected requirements. In a minority opinion the Coast Guard argued that a fifth icebreaker should remain "in reserve" due to the age of the ships and a possible increase in requirements.
- Design of a new icebreaker should start immediately, emphasizing research as well as escort and logistics capabilities, and should reflect the needs of both primary and secondary users. Icebreaking capability should be between that of the Wind and Polar classes.
- Capital cost of replacement icebreakers should be funded by the Coast Guard.
- Reimbursement should be reexamined and a joint recommendation for change pursued through the budget process.
- Scientific capabilities of the Polar class icebreakers should be improved.

Based on the PIRS, the U.S. Coast Guard began consulting with other agencies concerning requirements for a future icebreaker design. At the same time, three of the existing ships were experiencing increased wear and tear and the Coast Guard had funds to operate only four, not five, ships. Consequently, WESTWIND was placed in layup with a small caretaker crew. By 1986, Coast Guard engineers were expressing concerns about the structural integrity of the GLACIER. Because 21 to 28 percent of her hull plating had been lost to corrosion, much of her hull framing and some 20 percent of structural decks and bulkheads were deemed inadequate. Emergency repairs permitted her to sail on the 1986-1987 Antarctic mission, but she was operationally restricted to "limited ice transit." The cost of a full refurbishment, coupled with her manpower-intensive configuration and high operating costs, led the commandant to decommission her in 1987. This left the nation with four icebreakers.

Bringing WESTWIND back into service proved more challenging than expected, and NORTHWIND too began to falter. Engine problems forced her to miss resupply operations in Greenland in 1987, and with the lack of a backup, the commandant was forced to request Canadian assistance. This led to the decommissioning of WESTWIND in 1988 and NORTHWIND in 1989, leaving the United States with only two heavy icebreakers.

THE PRESENT FLEET OF U.S. ICEBREAKERS

Even as the old fleet was in rapid decline, but not yet lost, there was a strong sense that new icebreakers were needed. The PIRS report was one of the indicators, and the Coast Guard Authorization Act of 1984 stated:

> It is the sense of the Congress that the United States has important security, economic, and environmental interests in developing and maintaining a fleet of icebreaking vessels capable of operating effectively and independently in the heavy ice regions of the Arctic and the Antarctic. The Secretary of the Department in which the Coast Guard is operating shall prepare design and construction plans for the purchase of at least two polar icebreaking vessels to be opera-

TABLE 6.1 Current U.S. Coast Guard Polar Icebreakers

Characteristic	POLAR STAR and POLAR SEA	HEALY
Length (feet)	399	420
Displacement (long tons)	13,334	16,165
Cruise speed (knots)	12	12
Endurance (days, nautical miles)	205, 23,000	205, 23,000
Power (SHP)	60,000	30,000
Crew size	134	67
Scientists	20	50
Icebreaking capability	6 feet at 3 knots	4.5 feet at 3 knots

NOTE: SHP = shaft horsepower.

> tional by the conclusion of fiscal year 1990. . . . In preparing such plans, the Secretary shall consult with other interested federal agencies for the purpose of ensuring that all appropriate military, scientific, economic and environmental interests are taken into account.

The design proceeded expeditiously, but delays occurred when a company with Arctic experience proposed to lease an icebreaker to the government. Consequently, OMB denied replacement icebreaker funding in the 1988 budget. An A-104 lease-buy analysis was completed in 1989 and showed that the net present value of a lease would be 10 to 15 percent more expensive than buying the ship. This finding cleared the way for Congress to appropriate funds to procure one ship. Funding was provided in the Defense budget thereby further slowing actual procurement. HEALY, delivered in 1999, was designed with modern science facilities to meet the increasing demand for Arctic research and has proven highly capable in that role. The characteristics of the current fleet are listed in Table 6.1.

THE CURRENT WORLD FLEET OF POLAR ICEBREAKERS

The U.S. Coast Guard generally has used the thickness of ice broken continuously at 3 knots as a simple measure of icebreaking capability. Therefore, icebreaking ships for Coast Guard or military owners are not required to be built to meet classification society requirements. However, requirements for the structural integrity of ice-capable ships are specified in the rules of the various classification societies, for example, the Russian Maritime Register of Shipping, Lloyd's Register, Det Norske Veritas, American Bureau of Shipping, and Germanischer Lloyd, and national regulatory authorities (Canadian, Finnish-Swedish, and Russian). These requirements are divided broadly into Baltic Rules for ice-strengthened vessels and Arctic Class Rules for icebreaking ships.

Most classification societies have similar requirements for ice-strengthened vessels or ice type ships, which are divided into classes depending on their design ice thickness of up to 1.2 meters. Local structure design ice pressures depend principally on the ice class and hull area.

In contrast, classification society requirements for icebreaking ships have historically varied somewhat in terms of definitions of hull areas, which are strengthened, and design load intensity relative to design ice and operating conditions.

An approximate correspondence between different classification societies' ice classes is shown in Table 6.2. How-

TABLE 6.2 Approximate Equivalencies Between Classes

Classification Society/ National Administration	Approximate Class Equivalents								
	Most ice capable →								Less ice capable
Canadian Arctic Shipping Pollution Prevention Regulations		CAC 1	CAC 2	CAC 3	CAC 4	Type A	Type B	Type C	Type D
Russian Maritime Register of Shipping	LL1	LL2	LL3	LL4	ULA	UL	L1	L2	L3
Det Norske Veritas	P30	P20	P10 I15	I10	I05	1A*	1A	1B	1C
Lloyd's Register of Shipping	LR 3	LR 2	LR 2 LR 1.5	LR 1.5	LR 1	1A	1B	1B	1C
Finnish-Swedish Maritime Administrations						1AS 1A	1B	1B 1C	1C
Germanischer Lloyd						E4	E3	E2	E1
Bureau Veritas						1AS	1A	1B	1C
American Bureau of Shipping						1AA	1A	1B	1C

TABLE 6.3 Approximate Equivalencies Between Classes per ABS (from most ice capable to less ice capable)

Baltic	ABS	Russian Vessel	Russian Icebreaker	Canadian	Proposed IACS
	A5		LL1	CAC1	PC1
	A4		LL2	CAC2	PC2
	A3	LU9	LL3	CAC3	PC3
	A2	LU7/8	LL3-LL4	CAC4	PC4-PC5
IAS	A1	LU6/LU5	LL4	Type A	PC6
IA	A0	LU4		Type B	PC7
IB	B0	LU3		Type C	
IC	C0	LU2		Type D	
	D0	LU1		Type E	

ever, because the rules are different, any attempt to draw equivalencies is somewhat subjective, and this can place serious restrictions on ships that could conceivably operate in regions governed by different national regulations. For example, the American Bureau of Shipping (ABS) has constructed a recent comparison among selected classification societies shown in Table 6.3 that defines new categories and variations in correspondences. It is also important to note that the International Association of Classification Societies (IACS) has been working on a standard range of ice classifications shown as PC 1 through PC 7. It is anticipated that these will be adopted in the near future and should be helpful in describing the capabilities of ships classified by those societies that belong to IACS.

While there are differences, the essential approach taken in the more recently revised rules is to specify maximum design loads based on ship-ice interaction models that have been calibrated with full-scale measurements. The design loads depend on displacement and power and are applied to different structural elements according to a pressure-area relationship. Scantlings are determined using elastoplastic criteria that permit stresses in excess of yield so that some permanent hull deformation is acceptable. Compared to traditional ship structural design methods, this leads to a combination of thinner plate, bigger frames, and larger frame spacing.

As noted earlier, the U.S. Coast Guard has generally used the thickness of ice that can be broken continuously at 3 knots as a measure of icebreaker performance; but it was too difficult to extract this information for all icebreakers in the world fleet, and this simple, loosely defined rule-of-thumb cannot be matched consistently to the various ice classification schemes. In seeking a general definition of a polar icebreaker, one authority has developed a listing that includes the following parameters:

- Having sailed in significant sea ice in either the Arctic or the Antarctic,
- Ice strengthening sufficient for polar ice, and most significantly,
- Installed power of at least 10,000 horsepower

Historically, ships with lower power levels have successfully operated in polar regions, but as demonstrated by the evolution of U.S. Coast Guard designs in the last 40 years, mass and velocity are the key factors in breaking heavy ice. Propelling heavy ships and/or developing higher speeds requires considerable power. Thus, while information has been obtained and could be provided on as many as 60 icebreaking ships, many of these are not believed truly suited for polar icebreaking.

Table 6.4, which draws heavily on data provided by L.W. Brigham (personal communication, October 2000), provides a listing of the current inventory of polar icebreakers organized by country of ownership. Baltic icebreakers have also been included, although it is often a matter of opinion rather than fact which ships have some polar capability. This presentation was chosen to highlight both the fleet size and the key data for various nations having interest in the polar regions.

The world fleet of icebreakers with greater than 10,000 horsepower is 50. Russia has the largest fleet. Finland, Canada, and Sweden each operate six to seven icebreakers. The Unites States has four ships, and six other countries have one to three ships. Only Russia has used nuclear propulsion plants (seven ships). Only Russia and the United States operate ships with propulsion greater than 30,000 horsepower. Most icebreakers operate primarily in the Baltic Sea area. Russia is notable for its emphasis on icebreaker tourism.

ICEBREAKER TECHNOLOGY

In continuous running mode, icebreakers break ice by weight. As an icebreaker is propelled forward, it moves up onto the ice, and the weight of the hull breaks the ice. The traditional icebreaker bow is in the form of a spoon that fa-

TABLE 6.4 Current Polar and Baltic Icebreakers in the World Fleet, February 2006

Ship Name	Country of Ownership	Year Entered Service	Propulsion Plant	Operations
ARKTIKA	Russia	1975	N:75,000	NSR
ROSSIYA	Russia	1985	N:75,000	NSR
SOVETSKIY SOYUZ	Russia	1990	N:75,000	NSR; Arctic tourism
YAMAL	Russia	1993	N:75,000	NSR; Arctic tourism
50 LET POBEDY	Russia	2006 (est.)	N:75,000	Not yet operational
TAYMYR	Russia	1989	N:47,600	NSR
VAYGACH	Russia	1990	N:47,600	NSR
KRASIN	Russia	1976	DE:36,000	NSR; Antarctic
VLADIMIR IGNATYUK	Russia	1977	D:23,200	Arctic escort
KAPITIN SOROKIN	Russia	1977	DE:22,000	NSR; Baltic escort
KAPITIN NIKOLAYEV	Russia	1978	DE:22,000	NSR
KAPITIN DRANITSYN	Russia	1980	DE:22,000	NSR; Arctic and Antarctic tourism
KAPITIN KHLEBNIKOV	Russia	1981	DE:22,000	NSR; Arctic and Antarctic tourism Tourism
AKADEMIK FEDOROV	Russia	1987	DE:18,000	Arctic and Antarctic research and logistics
FESCO SAKHALIN	Russia	2005	DE:17,500	Standby or supply vessel, Sakhalin Island
SMIT SAKHALIN	Netherlands–Russia charter	1983	D:14,500	Beaufort Sea; Sea of Okhotsk; Sakhalin Island
SMIT SEBU	Netherlands–Russia charter	1983	D:14,500	Beaufort Sea; Sea of Okhotsk; Sakhalin Island
MUDYUG	Russia	1982	D:10,000	NSR coastal
MAGADAN	Russia	1982	D:10,000	NSR Pacific coastal
DIKSON	Russia	1983	D:10,000	NSR coastal
URHO	Finland	1975	DE:21,400	Baltic escort
SISU	Finland	1976	DE:21,400	Baltic escort
OTSO	Finland	1986	DE: 20,400	Baltic escort
KONTIO	Finland	1987	DE: 20,400	Baltic escort
FENNICA	Finland	1993	DE:20,000	Arctic offshore/ Baltic escort
NORDICA	Finland	1994	DE:20,000	Arctic offshore/ Baltic escort
BOTNIKA	Finland	1998	DE:13,000	Arctic offshore/ Baltic escort
LOUIS ST. LAURENT	Canada	1969, 1993[a]	DE:30,000	Arctic research and escort
TERRY FOX	Canada	1983	D:23,200	Arctic escort and logistics
HENRY LARSEN	Canada	1988	DE:16,000	Arctic escort and logistics
AMUNDSEN	Canada	1982, 2002[b]	DE:15,000	Research
PIERRE RADISSON	Canada	1978	DE:13,400	Arctic escort and logistics
DES GROSSELIERS	Canada	1983	DE:13,400	Arctic research and escort
ODEN	Sweden	1989	D:23,200	Arctic research/Baltic escort
ATLE	Sweden	1974	DE:22,000	Baltic escort
YMER	Sweden	1977	DE:22,000	Baltic escort
FREJ	Sweden	1975	DE:22,000	Baltic escort
TOR VIKING	Sweden	2000-2001	DE:18,000	Baltic escort
BALDERR VIKING	Sweden	2000-2001	DE:18,000	Baltic escort
VIDAR VIKING	Sweden	2000-2001	DE:18,000	Baltic escort/Arctic research
POLAR STAR	US	1976	GT:60,000 DE:18,000	Arctic and Antarctic research and logistics
POLAR SEA	US	1977	GT:60,000 DE:18,000	Arctic and Antarctic research and logistics
HEALY	US	2000	DE:30,000	Arctic research and response
NATHANIEL B. PALMER	US	1992	D:12,700	Antarctic research and logistics
SHIRASE	Japan	1982	DE:30,000	Antarctic research and logistics
POLARSTERN	Germany	1982	D:17,200	Arctic and Antarctic research and logistics
KIGORIAK	Netherlands	1979	DE:16,600	Offshore support
ALMIRANTE IRIZAR	Argentina	1978	DE:16,000	Antarctic research and logistics
SVALBARD	Norway	2002	DE:13,500	Patrol
AURORA AUSTRALIS	Australia	1990	D:12,000	Antarctic research and logistics

NOTE: D = Geared Diesel; DE = Diesel-Electric; GT= Gas Turbine; N= Nuclear; NSR = North Sea Route. Ships of at least 10,000 propulsion horsepower are listed.

[a] LOUIS ST. LAURENT in service in 1969 was rebuilt and recommissioned in 1993.

[b] AMUNDSEN in service in 1982 as SIR JOHN FRANKLIN was converted and returned to service in 2002.

cilitates this action. The ability of an icebreaker to break ice is, therefore, a function of the ship's weight (displacement) and propulsive power for forcing it onto the ice. Successful year-round navigation in any area depends on the ability of icebreakers to escort tankers through anticipated ice regimes consistently, with minimum delays and with no additional risk to ships or crew caused by ice conditions (Johansson, 2004). Developments in icebreaker technology in the last quarter-century have been inspired in large measure by the oil industry. Proven technological advances during this period have made it possible to construct reliable icebreakers capable of assisting year-round tanker transportation within the limits of safety and pollution prevention regulation. Ships presently in service demonstrate that this can be accomplished by icebreakers of much less power than many others still operating with older technology (Johansson, 2004). Level ice is broken by using the force of the ship to bend the ice to its breaking point, rather than by crushing it. Early experience and theoretical calculations showed that blunt bow forms with small stem angles could break level ice more efficiently than wedge-shaped bows with larger stem angles (Johansson, 2004). However, problems occur at sea when icebreakers encounter ridges formed by the movement of highly mobile sea ice. The first seagoing icebreaker, MURTAJA, built in Sweden in 1890, had a blunt spoon-shaped bow form that was designed for breaking level ice efficiently. However, the bow pushed ice ahead of the ship, hindering performance at ridges. Seagoing icebreakers were designed with comparatively inefficient wedge-shaped bows, while those built for level ice in lakes and rivers had blunt bows (Johansson, 2004).

In 1979, the KIGORIAK was the first seagoing icebreaker since MURTAJA to have a blunt spoon-shaped bow. The KIGORIAK had three major design features. The first was a water wash system that pumps large volumes of seawater onto the ice in front of the ship, which is designed to reduce the friction between the bow and the ice to permit the bow to ride up onto the ice. This ship also employed a stream of water along both sides in an attempt to reduce friction against the hull. The second design feature consisted of reamers fitted to the hull of the ship at the widest part of the hull. The reamers were designed to reduce the friction along the mid-body of the ship. Operating in an asymmetrical fashion, they were designed to break ice by bending it downwards as the ship moves forward and by bending it upwards when the ship moves backward. The reamers create a channel of about 1-meter width on each side of the ship, greatly reducing friction between the ice and the hull and allowing greater maneuverability in ice. The third was the installation of a nozzle surrounding the ship's propeller, which has the effect of increasing thrust and protecting the propeller from larger ice pieces (Johansson, 2004).

In 1982 when the ROBERT LEMEUR was built, low-friction Inerta paint was applied to its hull in an attempt to reduce hull corrosion. (Inerta paint has been used on U.S. Coast Guard polar and domestic icebreaking vessels since the 1970s.) Conventional paint is removed by the ice, and unprotected portions of the hull corrode. The corrosion results in an uneven surface that causes more friction between hull and ice. These improvements in the ROBERT LEMEUR led to a further 20 percent reduction in the power necessary to accomplish the same tasks performed by the KIGORIAK (Johansson, 2004).

In 1989, the Swedish icebreaker ODEN, was delivered. The ODEN was built on the ROBERT LEMEUR concept and had 24,000 horsepower. In addition to using the spoon-shaped bow form, Inerta paint, and a hull wash system, the ODEN was fitted with larger reamers than its predecessor and a fast-heeling system. The system pumps water very quickly within the vessel from one side to the other (as much as 800 tonnes in 25 seconds), rocking the ship in heavy ice so that the reamers break the ice at the sides of the ship. In full-scale operation the ODEN has moved at a continuous speed of about 3 knots in 2-meter-thick ice. On several occasions she has reached the North Pole during research expeditions (Johansson, 2004).

Two Finnish icebreakers, FENNICA and NORDICA, built in the early 1990s, were built with symmetrical reamers, designed to break the ice by bending it downwards when moving forwards and backwards. The icebreakers were also fitted with two stern propellers that are able to turn 360 degrees around an almost vertical axis. The initial purpose of the rotating propellers was to improve maneuverability in both ice and open water to make dynamic positioning possible in concert with three transverse thrusters in the bow (Johansson, 2004).

In 2005 the U.S. Coast Guard accepted delivery and commissioned its newest icebreaker, the MACKINAW (WLBB 30). This icebreaker replaced the 290-foot icebreaker of the same name (WAGB 83), built in 1944 to provide icebreaking services on the Great Lakes. The new MACKINAW is considered a multimission vessel because it was designed both to provide heavy icebreaking services and to maintain floating aids-to-navigation on the Great Lakes. The new MACKINAW incorporates several state-of-the-art icebreaking features including the following:

- Twin azimuth pod propulsion with the ability to rotate 360 degrees, integrated with a bow thruster for maximum maneuverability in ice and in open water;
- Integrated electric propulsion system using diesel-powered generators with electric motors in the azimuth pods;
- Computer-based monitoring and control providing extensive automation of ship maintenance and operation;
- An integrated bridge system providing the flexibility to operate the ship with only one watchstander; and
- A podded propulsion system, which is the first ever used on a U.S. Coast Guard vessel and was incorporated in the design after ice tank testing of podded and conventionally shafted models in Helsinki.

Icebreaker technology has changed over the past several decades in four primary areas (Mikko Niini, personal communication):

1. Hull design
2. Auxiliary icebreaking capability
3. Propulsion plant design
4. Dual-role (double-acting) vessel designs

Hull Design

An icebreaker's performance is heavily dependent on its hull design. Current icebreaker designs were developed with heavy reliance on historical designs with incremental improvements being driven by model tank testing (ice capable). A primary consideration is control of the flow of broken ice around and under the hull. Protecting the rudder(s) and propellers(s) or propulsion units is of paramount importance in icebreaker hull design. Advances are usually achieved through trial and error in ice tank testing and are validated in full-scale tests.

Several new icebreaker concepts have been proposed but not yet put into practice. For example, the oblique icebreaker is an asymmetrical hull design that is meant to enable one small icebreaker to perform the escort service that usually requires two. The specific oblique icebreaker design tested is for a small escort vessel with a 20.5-meter beam overall that is capable of opening a channel in ice more than 40 meters wide in a single pass. Model tank tests showed the design to be viable.

Auxiliary Icebreaking Capability

Auxiliary icebreaking capabilities include water wash systems where large volumes of water are pumped over the bow to reduce ice-hull friction, and fast heeling systems for rocking an icebreaker in tight ice conditions.

In addition, bubbler systems have also been utilized effectively. A bubbler system blows compressed air out under the hull that will exert upward buoyant force on the ice causing it to lift and break. The compressed air also serves as a friction reducer to improve hull performance.

Propulsion Plant Design

Icebreaker propulsion plants have changed dramatically since the first sail-powered icebreakers. Steam and later diesel engines drove power through reduction gears to fixed pitch propellers. Those systems were prone to mechanical damage as the propeller struck ice chunks broken at the bow. Later, controllable pitch propellers were tried.

The current systems use electric drives that decouple the propellers from the prime mover to reduce ice impact damage. (Consider that some of the ice chunks moving under and along the icebreaker's hull are the size of a school bus). The electric drive systems use propellers connected directly to an electric motor. The electricity to drive the motors is produced by onboard generators. Those generators can be driven by diesel engines, gas turbines, or steam turbines (with either nuclear or conventional fossil fuel boilers). The electric drive systems also give greater flexibility for engine room design and eliminate the need for shafts and reduction gears.

To further protect the exposed propellers, nozzles or ducts were installed around the propellers. These had the added benefit of increasing thrust by improved water flow. The current state of the art in icebreaker electric drive with power units is considered to be azimuth pod drives (as installed on the latest U.S. Coast Guard icebreaker MACKINAW); however, some consider them to still be in the developmental stage and unreliable. An azimuth pod drive is an enclosed unit that hangs below the hull and contains the electric drive motor attached directly to a propeller. The azimuth pod is capable of being rotated 360 degrees, enabling full thrust to be applied in any direction very quickly. Azimuth drives have been used extensively on cruise ships and other commercial vessels including ice-strengthened ships.

It is anticipated that the next generation of icebreakers will likely be equipped with azimuth drives. The biggest challenge is building larger azimuth drive units to power icebreakers capable of working in multiyear ice. The goal is to build single-unit azimuth drives capable of 25 megawatts (~33,000 horsepower). Current azimuth drives are available up to 20 megawatts (~26,000 horsepower). Additional work is being done on improving the efficiency of the electric drive systems such as those using AC–AC drives.

Dual-Role (Double-Acting) Vessel Design

Possibly the most innovative concept to emerge in recent years in icebreaker technology has been the introduction of double-acting hull designs. A vessel with a double-acting hull has standard seakeeping characteristics when moving forward. The vessel is reversed with an icebreaking stern shaped for breaking ice. This concept has been used on a range of vessels including offshore supply vessels (e.g., FESCO SAKHALIN, delivered 2005), general purpose or container ships (e.g., NORILSKIY NICKEL, delivered 2006), and AFRA-max tankers (MT TEMPERA and MT MASTERA, delivered 2003). Azimuth pod drives have been installed on double-acting ships.

It is possible that the next-generation polar research vessel will incorporate a double-acting hull design (to improve seakeeping while in transit to the polar region) with twin azimuth pods, diesel-electric power plants (efficiency and emission considerations), redundant machinery (safety and reliability), and extensive use of stainless steel (hull and propellers). It is not yet clear, however, if the double-acting hull design is completely applicable for a polar icebreaker, which must occasionally work in the heaviest navigable ice, where frequent back-and-ram operations are required.

Icebreakers Under Construction

There are currently six icebreakers under construction in the world's shipyards:

- Construction of a large Russian icebreaker of the existing ARKTIKA class has been under way for more than 10 years, with commissioning expected in October 2006. The nuclear icebreaker is 522 feet long with a 100-foot beam. It is reported at 25,000 deadweight (deadweight is a measure of cargo capacity, whereas displacement is usually reported for icebreakers), making it the largest nuclear icebreaker in the world. This icebreaker was originally named URALS but now appears to be named 50 LET POBEDY.

- Two offshore icebreakers are being built at Aker Yards for the Sakhalin 2 project (offshore oil development in the Russian Far East).
- One terminal icebreaker at Aker Yards is planned for the Sakhalin 1 project (offshore oil development in the Russian Far East).
- Two Baltic Sea escort icebreakers (diesel powered) are under construction at Baltic Shipyard, Russia, for Rosmorport of Russia.

Five of the six icebreakers under construction are being built for specific commercial operations. The sixth, the Russian nuclear icebreaker, is being built for general Arctic operations support.

Shipbuilding for Arctic operations is focused primarily on building ice-strengthened commercial ships such as oil tankers, offshore supply vessels, bulk carriers, and container ships. Ice-strengthened liquefied natural gas tankers are also being planned.

U.S. POLAR ICEBREAKER OPERATIONS IN THE LAST TWENTY YEARS

The mission deployment of U.S. polar icebreakers has evolved in the last half-century. During World War II, the Arctic became for the first time a national security concern, and this perspective of the Arctic, as a zone of defense, extended seamlessly into the Cold War period. The operational focus for icebreakers was concentrated in these years almost exclusively on defense-related logistics. Postwar Antarctic operations took on a similar military character, where even after the International Geophysical Year (1955-1956) the massive logistics of the U.S. science program continued to be conducted as military operations. The beginnings of mission change were indicated by the Navy's decision to leave the icebreaker business in the 1960s, which signaled the end of polar logistics as a naval mission of importance. By the 1980s, science activities overshadowed the remaining defense logistics mission in Greenland, where the abandonment of bases left only Thule with a requirement for sealift. The need for better polar science capabilities was a key theme of the 1984 Polar Icebreaker Requirements Study.

Increasing interest in polar research brought new users, from the Department of Defense science establishment and from civilian agencies such as the National Oceanic and Atmospheric Administration, U.S. Geological Survey (USGS), Maritime Administration, and academic associates of their programs. In 1970 the National Science Foundation assumed overall management of the U.S. Antarctic Program. The U.S. Coast Guard icebreaker fleet began to be operated with other agencies requesting specific cruises and funding the fuel and variable costs on a reimbursable basis.

Throughout the 1980s and 1990s, POLAR STAR and POLAR SEA alternated deployments to Antarctica each year to conduct the McMurdo break-in, Palmer Station resupply, and other logistics and science tasking. On two occasions a second Polar class ship went south either in standby status (1988) or to perform Antarctic Treaty inspections (1995). Until decommissioning in 1987 (after her twenty-ninth Antarctic deployment), GLACIER also spent several months of the Antarctic summer each year conducting science support in the vicinity of the Weddell Sea and Antarctic Peninsula. The POLAR SEA and POLAR STAR performed the heavy icebreaking associated with the break-in, while GLACIER generally operated in open water, the marginal ice zone, and sea ice where demanding icebreaking was rarely required.

In the western Arctic—the Bering, Chukchi, and Beaufort Seas—either POLAR STAR or POLAR SEA usually deployed during the summer and fall months each year. The work was almost entirely research related in a variety of disciplines, for USGS, NOAA, and both classified and unclassified work for the Office of Naval Research. Both POLAR STAR and POLAR SEA conducted a series of trafficability studies, under MARAD sponsorship, to measure shipboard stresses and icebreaking performance in various ice conditions. These cruises occurred in the Chukchi and Bering Seas in both summer and winter conditions. In 1984, POLAR SEA was nipped between two moving ice sheets north of Prudhoe Bay for five days and faced the prospect of wintering over. Fortunately, a combination of transferring weight aft and using full power, the heeling system, and an ice anchor implanted off the stern freed the ship. The trafficability research program sought to provide design knowledge for icebreaking commercial ships, especially for crude oil transport, and was completed by the late 1980s.

The annual resupply of Thule Air Base necessitated the presence of an icebreaker in the eastern Arctic every summer, although ice conditions were variable and actual vessel ice escort was needed infrequently. This mission requirement—"Operation Pacer Goose"—was satisfied easily by the East Coast-based NORTHWIND or WESTWIND, often in conjunction with research work for the International Ice Patrol, until 1988. From 1989 until 1993, either the POLAR STAR or the POLAR SEA was deployed from Seattle for Pacer Goose. Although research projects were usually integrated into these lengthy deployments, icebreaker standby for Thule was provided more efficiently by an agreement with the Canadian Coast Guard in 1993.

In 1985, POLAR SEA made a rare transit of the Northwest Passage in order to facilitate her return from Thule. The only U.S. vessels to have previously made the passage were three ice-strengthened Coast Guard cutters in 1957 and NORTHWIND in company with the tanker MANHATTAN demonstration project in 1969. POLAR SEA's transit aroused considerable Canadian concern over sovereignty issues and the status of the waterway. The need for routine use of the Northwest Passage by U.S. icebreakers resulted in a practical agreement with Canada. In 1988, heavy pack ice moved down to Point Barrow and blocked POLAR STAR's western exit from the Beaufort Sea, requiring an escape to the east via the Northwest Passage and return to Seattle via the Panama Canal. Subsequent transits of the Northwest Passage were made by POLAR STAR in 1989 and HEALY in 2000 and 2003.

By 1990, the U.S. polar icebreaker fleet consisted only of POLAR STAR and POLAR SEA. Nevertheless, the early 1990s were a period of especially active operations. The POLAR STAR and POLAR SEA operated in the eastern Arctic annually for six consecutive years, while still continuing to meet McMurdo Sound tasking and occasional western Arctic cruises as well. During these years the POLAR STAR and POLAR SEA also underwent major system upgrades to their science equipment and laboratories. Arctic science expeditions became larger and more international. The ambitious International Arctic Ocean Expedition sought to reach the North Pole from the Norwegian Sea in 1991, but U.S. participation had to be aborted when POLAR STAR suffered damage to a propeller shaft. However, the challenging Northeast Water Polynya projects (NEWP I and II) were completed successfully in northern Baffin Bay in 1992 and 1993. POLAR SEA crossed the Arctic Ocean via the North Pole in company with LOUIS ST. LAURENT in 1994, historic "firsts" for both the United States and Canada.

The latter half of the 1990s were leaner operational years. Antarctic operations continued routinely, although in 1998 POLAR STAR towed the resupply tanker 1,500 nautical miles from the Ross Sea to New Zealand after the much larger vessel lost propulsion. However, few Arctic deployments were funded by other agencies. The Coast Guard initiated and funded several science-of-opportunity cruises to the Chukchi Sea, some deep into the Arctic pack, in order to maintain proficiency and meet increasing science needs. POLAR SEA began one of these cruises by participating in a multinational oil spill exercise near Sakhalin Island and ended it with a diversion to change out the crew and science party of the Canadian icebreaker DES GROSEILLIERS, which had drifted unexpectedly beyond air resupply range during a 13-month in-ice drift project.

The icebreaker fleet gained new capacity and capability, especially with regard to research in the Arctic, with HEALY's delivery in 2000. After completing ship performance and science testing and arriving in Seattle via the Northwest Passage, HEALY conducted a challenging geologic exploration of the Nansen-Gakkel Ridge northeast of Greenland for her first research cruise in 2001. Since that time, the new icebreaker has conducted annual Arctic deployments between April and November. HEALY deployed to the western Arctic in 2002 and 2004, worked in both western and eastern areas in 2003 and 2005, and had spring and summer projects scheduled for the Bering and Chukchi Seas in 2006.

The Antarctic resupply mission has become increasingly challenging since 2000. With ice dynamics in McMurdo Sound disrupted by massive tabular icebergs calved from the Ross Ice Shelf, the annual break-in has faced multiyear ice and fast ice extents up to three times the normal situation. Both POLAR STAR and POLAR SEA were deployed in 2002 and 2004, and HEALY was dispatched at short notice to assist in 2003, between Arctic summer missions. The small U.S. fleet could not sustain the pace of two-ship operations at McMurdo; HEALY could make the long deployments south only by curtailing planned Arctic science missions significantly, and both POLAR STAR and POLAR SEA faced serious age-related mechanical problems requiring extended time in a shipyard. Accordingly, the Russian icebreaker KRASIN was chartered to assist POLAR STAR in 2005. In 2006, KRASIN attempted the break-in alone but broke a propeller blade before escorting the tanker and container ship through difficult ice conditions. U.S. Navy divers were unable to replace the propeller blade. POLAR STAR was dispatched from standby in Seattle and made a direct transit to McMurdo Sound. Fortunately, the supply ships successfully delivered their cargoes by the time POLAR STAR arrived, leaving her only some grooming work for next year's airfield.

POLAR SEA completed extensive repair and maintenance work in June 2006 and deployed to the Arctic in July and August. POLAR SEA is scheduled to conduct the break-in early in 2007. To save money, POLAR STAR has been laid up with a small caretaker crew. KRASIN will be unavailable in 2007, and prospects for an assisting or backup icebreaker are unknown.

7

Icebreaking Environments and Challenges to the U.S. Fleet

OPERATING ENVIRONMENTS

Distribution and Characteristics of Sea Ice and Icebergs in the Polar Regions

Sea ice is a defining characteristic of the polar oceans and throughout the course of the year occupies between 15 million and 25 million square kilometers or up to 7 percent of the world's ocean surface. Polar sea ice undergoes tremendous seasonal changes every year. During the winter, the extent of the Arctic ice pack grows to the size of the United States; in the summer, more than half of the ice disappears. On the other side of the globe, ice covers nearly 98 percent of the Antarctic continent and averages 1 mile thick. Depending on the season, the sea ice may cover roughly 2 million square kilometers in the Antarctic summer (February) and increase to 20 million square kilometers during the austral winter (September). The total Antarctic ice volume is so large that it accounts for 90 percent of the world's ice and 70 percent of its fresh water.

Antarctic Sea-Ice Characteristics

In the Southern Ocean, the vast sea-ice apron that rings the Antarctic continent attains its maximum width of around 2,000 km in the Ross and Weddell Sea sectors of the Southern Ocean (Figure 7.1). In austral summer, most of the remaining sea ice is found in the western Weddell and Amundsen Seas, with some multiyear ice also found in the Ross Sea (Comiso, 2003). First-year Antarctic drift ice typically does not grow to more than 0.5 to 1 meter thickness (Haas, 2003) because substantial heat from the ocean is transferred to the base of the sea ice (heat flux), which keeps this ice relatively thin. Substantially thicker ice may develop due to deformation processes such as rafting and ridging and multiyear ice growth. Another key aspect of sea ice in the Southern Ocean is snow accumulation, which can build up to mean depths of well above 0.5 meter in some areas (Massom et al., 2001). Sea ice is free to drift (driven by winds) in a large-scale pattern around the Antarctic continent because there are no bays or basins to restrict its movement. In general, the sea ice in the Weddell and Ross (slightly lesser extent) Seas typically exhibits a clockwise motion.

Although the Southern Ocean ice cover changes dramatically from season to season, change in ice extent between years is small, typically on the order of 2 percent of the mean maximum ice extent. The northernmost position of the ice edge in September is controlled largely by the location of the polar front separating cold Antarctic surface water from warmer sub-Antarctic water masses. The position of the front, and hence to some degree the maximum ice extent, is determined primarily by the surface wind field and the submarine topography. Large-scale coupled atmospheric circulation patterns such as the El Niño-Southern Oscillation are also impacting regional ice distribution. Scrutiny of the past three decades of satellite-derived records of global sea-ice distribution so far yields conflicting results as to whether the Antarctic sea-ice extent has marginally decreased or increased during this time period, depending on the methodology employed in extracting ice information from the satellite instrument record (Cavalieri et al., 2003; Comiso, 2003). The geological record (Gersonde et al., 2005) indicates that sea-ice conditions in the Antarctic appear to have followed a fairly consistent, stable pattern during interglacial periods. Nevertheless, there is some indication that regional warming in the Antarctic Peninsula region has led to significant reductions in perennial ice extent during the austral summer in the Bellingshausen, Amundsen, and Weddell Seas (Comiso, 2003).

Arctic

In the northern hemisphere, maximum ice extent reaches up to 16 million square kilometers in March, when the entire

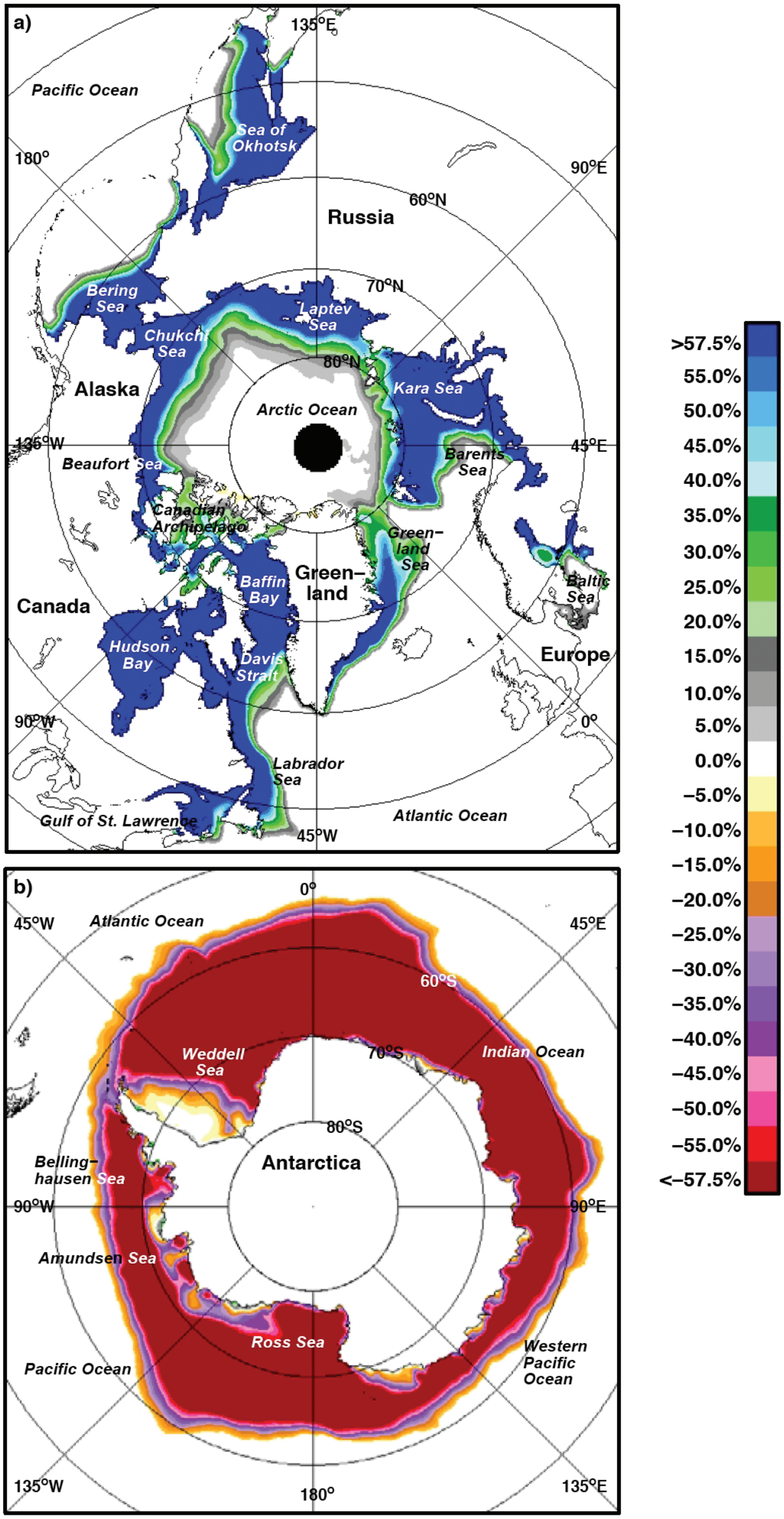

FIGURE 7.1 Map of mean differences in ice concentration from the seasonal minima corresponding to (a) the September climatology in the Arctic and (b) the February climatology in the Antarctic. SOURCE: Comiso (2003).

Arctic Ocean and its marginal seas as well as parts of the sub-Arctic seas are covered by ice. In summer, up to 6 million square kilometers of perennial ice remains in the interior Arctic (Comiso, 2003; Figure 7.1). Such multiyear ice can grow to between 3 and 5 meters in thickness while it resides in the Arctic, with deformed ice building up to more than 30 meter thickness in the form of pressure ridges (Wadhams, 1998). Sea-ice circulation in the Arctic is dominated by the clockwise Beaufort Gyre extending over much of the western and west-central Arctic (with mean ice age on the order of three to five years), and the Transpolar Drift, transporting ice from the Siberian shelves across the Pole into the Greenland Sea (with mean age of less than three years).

Interannual variability in ice extent in the Arctic is more pronounced than in the Southern Ocean, with anomalies in some years approaching 10 percent of the mean maximum extent. While maximum ice extent at the end of winter (March) has remained fairly stable since the establishment of a consistent satellite record of ice conditions (1978), summer ice extent (i.e., the perennial ice area, corresponding roughly to the extent of multiyear ice) has been reduced significantly. Thus, from 1979 through 2000, Arctic sea-ice extent has been shrinking by about 2.2 percent per decade, driven mostly by reductions during the ice melt season (Comiso, 2003). The rate of decline of summer minimum ice extent amounted to almost 8 percent per decade from 1979 to 2005 (NSIDC, 2006). At the same time, submarine sonar data collected in the central and western Arctic indicate that the Arctic ice pack thinned by approximately 40 percent from the 1950s to the 1990s. This thinning is attributed mostly to changes in atmospheric circulation and radiative forcing (Francis et al., 2005; Rothrock and Zhang, 2005). Interpretation of ice variability is hampered to some extent by incomplete instrumental records, in particular for ice thickness, and a comparatively short satellite-derived ice extent record. This renders separation of inherent decadal- and centennial-scale variability from any trends due to anthropogenic warming, which is predicted to be greatest in the Arctic (Holland and Bitz, 2003; ACIA, 2005), difficult. These challenges notwithstanding, the past several years have been nothing short of remarkable: Since 2000, four out of the five Arctic ice seasons have exhibited consecutive record summer ice minima (Stroeve et al., 2005). From the available record it appears that perennial ice extent is as low as it has been in the past few centuries. Moreover, most recent indications are that winter ice extent is now also starting to retreat at a faster rate, possibly as a result of the oceanic warming associated with a thinner, less extensive ice cover (Meier et al., 2005). These observations of a shrinking, thinning Arctic sea-ice cover are in line with climate model predictions of enhanced high-latitude warming (ACIA, 2005), which in turn is driven in significant part by ice-albedo feedback (Holland and Bitz, 2003). It has been argued that the Arctic climate system has reached a "tipping point" and is now on a trajectory to a different, stable state, characterized by a greatly reduced or absent summer ice cover (Lindsay and Zhang, 2005; Overpeck et al., 2005) and—by inference—significantly thinner, less extensive winter ice.

Floe-Scale Sea-Ice Characteristics Relevant to Icebreaking

From the perspective of sea-ice trafficability, the ice cover of the polar seas is far from homogeneous, and an assessment of the hazards posed by sea ice to navigation, coastal infrastructure, or other human activities requires a more detailed examination of ice characteristics at the scale of individual ice floes (kilometers to tens of meters). Of particular importance are the distribution of openings in the ice (leads or polynyas), the thickness and extent of level ice, and the morphology and thickness of pressure ridges or hummocks formed as a result of ice deformation (see Figure 7.2 for explanation of terms and schematic representation of ice evolution).

The thickness of level ice, growing through accretion at the base of the ice sheet (or also, as is often the case in the Antarctic, through flooding of submerged ice at the top) depends on the amount of heat that can be extracted from the ocean water and transferred to the cold atmosphere. In the marginal seas of the Arctic Ocean, where the insulating effects of a snow cover are typically low and where the amount of heat transferred from the ocean to the base of the ice has historically been small, as much as 1.5 to 2 meters of level ice can grow within a single season. Repeated cycles of summer melt and winter accretion can increase this value to at most 3-4 meters in ice that is between a few years and a decade old. In recent years, due to reduced residence time of ice in the Arctic Ocean, diminished winter growth and increased summer melt, maximum thicknesses of level multiyear ice are typically less than 3 meters throughout much of the Arctic (Perovich et al., 2003; Haas, 2004). In the Antarctic, high ocean-to-ice heat fluxes and the insulating effects of the snow cover (typically not compensated for by snow-ice formation) result in level ice thicknesses that are mostly well below 1 meter and in many areas around 0.5 meter (Wadhams et al., 1987; Worby et al., 1998). An important exception is the narrow, stationary landfast ice belt that is attached to the coastline or the floating ice shelves.

With the exception of landfast ice that is firmly attached to a coast, sea ice is in near-constant motion, with velocities typically on the order of 5 to 10 km per day. On shorter (i.e., operationally relevant) time scales of days to weeks, this motion is mostly a result of wind forcing and—to a lesser extent—transfer of momentum from the ocean through currents, with tidal currents of particular importance. The response of the ice cover to such forcing depends in part on its variable thickness and roughness. Furthermore, wind or ocean forcing itself may be divergent or convergent on scales of tens to hundreds of kilometers. Hence, openings develop

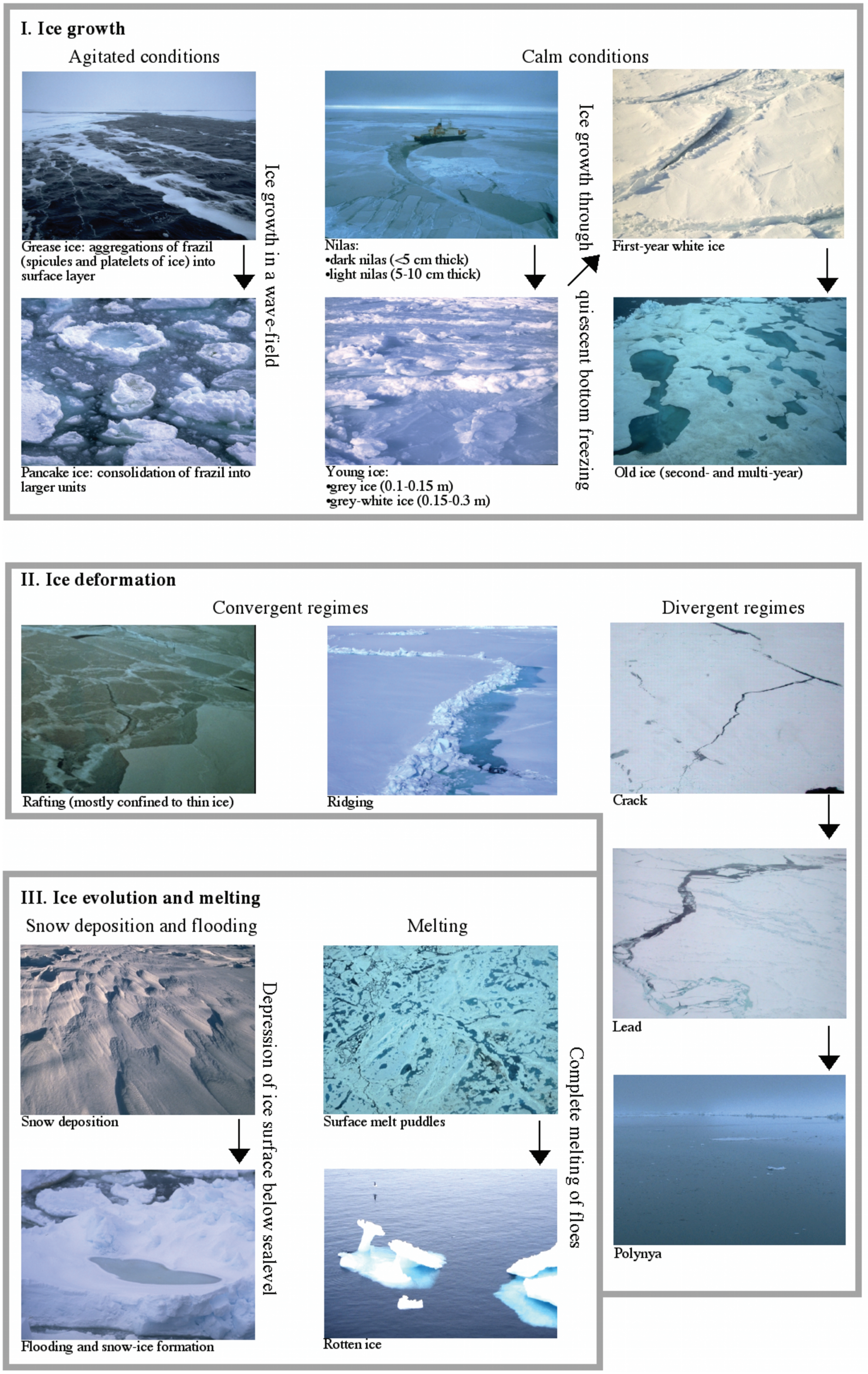

FIGURE 7.2 Examples of different ice formation and evolution processes, and associated nomenclature. SOURCE: H. Eicken, University of Alaska.

at regular spatial and temporal intervals in areas of divergent ice motion (Figure 7.2), and deformation features such as rafting or ridging (Figure 7.2) appear in areas of convergent ice motion or along coasts with onshore ice drift. The geography and stronger wind regime of the Southern Ocean compared to the enclosed Arctic "Mediterranean" seas typically results in more openings and fewer deformation features in the Antarctic compared to the Arctic, with the exception of some of the sub-Arctic seas, such as the Bering Sea. The shallow Arctic shelves and complex coastal morphology, in particular those areas comprising the Northern Sea Route along the Siberian coastline and the Northwest Passage through the Canadian Archipelago, foster substantial interaction between drifting and stationary ice or coastlines, resulting in strongly deformed ice bodies. Russian ice navigators have coined the term "ice massifs" for such highly deformed areas—often tens of thousands of square kilometers in extent—that contain little to no open water and exhibit ridges that are more than 20 meters thick and capable of grounding on the seafloor. Often such highly deformed areas lack undeformed, level ice altogether, which can make navigation through these regions challenging or impossible even for the most powerful icebreakers (see also "Icebreaker Technology" in Chapter 6).

Icebreaker design depends on where you want to go, when you want to go, and what you want to do when you get there. The answers to these questions may well produce operational scenarios in very different ice conditions in the Arctic and the Antarctic, but the differences in Arctic and Antarctic ice do not directly explain or drive icebreaker design.

Small-Scale Properties of Sea Ice Relevant to Icebreaking

As explained in detail in the discussion of icebreaker technology in Chapter 6, modern icebreaker design aims to achieve the following, to some extent conflicting, goals: (1) increase the local bending moment resulting in failure of the ice sheet flexing under the vessel's weight when in continuous icebreaking mode; (2) effectively fragment or displace broken ice to the sides of the channel while minimizing the amount of ice submerged to the depth of the vessel's keel; (3) reduce friction exerted on the vessel's hull by the ice sliding past the ship; and (4) increase the fragmentation and displacement efficiency when in ramming mode. In addition to the distribution of open water and ridges and the thickness of the ice cover discussed in the previous section, two additional, small-scale properties of the ice cover are of prime importance in this context.

First and foremost of these is the strength (typically referred to as the yield stress under which an ice sheet fails, i.e., loses mechanical integrity) of the ice cover and, to a lesser extent, a variable referred to as fracture toughness, which often scales with ice strength, that determines the resistance offered to the breaking action of an icebreaker. Ice strength depends greatly on the porosity or volume fraction of brine- and gas-filled void space of the sea ice. Sea ice retains a portion of the salt contained within seawater in the form of brine inclusions, which can occupy more than 10 percent by volume of warm first-year sea ice. In conjunction with the temperature, the amount of salt present within a volume of ice determines the bulk porosity and hence ice strength. All other factors being equal, Arctic multiyear ice has substantially lower salinity (approaching 0 in the uppermost decimeters) than first-year ice because low-salinity meltwater generated at the surface of the ice (see melt pools evident in Figure 7.2) flushes out saline brine during summer melt. As a result, the strength of Arctic multiyear ice is considerably higher than that of first-year ice. In the Antarctic, the multiyear drift ice found in the Weddell and Ross Seas typically does not exhibit reduced salinity due to the lack of surface melt (Eicken, 2003). Hence, at the decimeter scale, Antarctic multiyear ice is not substantially stronger, though still somewhat thicker, than first-year ice. As explained in more detail below, however, the situation is somewhat different in McMurdo Sound.

The second factor that needs to be considered is friction exerted on a vessel's hull during passage through the ice. Here, it is mostly the presence and, to a lesser extent, the thickness of a snow cover that determines the magnitude of surface friction. Bare ice, as commonly found in the Arctic during summer months, but also in some locations such as McMurdo Sound, where little snow accumulation and strong winds prevent buildup of a substantial snow cover, has significantly lower friction coefficients.

Icebreakers and Breaking Ice

As a general rule, icebreakers usually do not seek to break ice per se. Whether the task at hand is escorting a less capable vessel, proceeding to a science station, or simply transiting, the icebreaker crew is almost always searching for the fastest and most economic route. This usually means avoiding ice to the degree possible, finding leads and areas of lesser ice concentration. The best route is rarely the most direct.

However, vast areas of consolidated sea ice, water depth, or other navigational obstacles may limit or preclude ice avoidance techniques. This is especially true in certain areas of the Northwest Passage and skirting the multiyear pack in the vicinity of Point Barrow, Alaska, where the shore lead may be too shallow. It is also true in establishing a fixed channel through the fast ice in southern McMurdo Sound to resupply the major U.S. Antarctic base there. In these cases the only options are to break the ice or wait for better conditions.

In areas of large sea-ice fields the process of icebreaking essentially consists of making a passage by breaking the solid ice under the weight of the icebreaker and pushing away the broken ice fragments. If there are areas of open water nearby, ice can usually be pushed into these unoccupied spaces. In high concentrations, usually represented in tenths of surface ice coverage or in a sheet of level fast ice, the ship must force broken pieces of ice under or onto the adjacent ice cover, or under the ship itself, in order to proceed. Ice may be broken into pieces of such small size that the broken track is filled with a slurry of brash ice. Obviously, thinner ice can be broken more easily than thicker ice, and much thicker ice can be broken in lower concentrations than in higher ones (MacDonald, 1969).

The icebreaking problem must be considered in terms of both ice properties and ship design. Ice resists the ship progress. Resistance depends on flexural strength, friction, buoyancy, and wind- or current-induced lateral pressure from the surrounding ice fields (Booz Allen Hamilton, 2005). The strength of ice depends on the thickness and salinity, which are a function of its age as well as temperature. The frictional resistance of ice is most significantly affected by the presence, amount, and condition of snow cover and the condition of the hull surface. Several inches of snow will notably slow the progress of an icebreaker, increasing friction between the surface and the ship's hull and absorbing energy from the ship's momentum. Thicker ice exerts more upward buoyant pressure that an icebreaker must overcome, and the amount of lateral pressure in an ice field hinders the displacement of broken ice as described above and also increases the frictional force by increasing the normal force on the hull.

The ability to break ice efficiently and effectively depends directly on the icebreaker's hull form characteristics, propulsion power, and type and arrangement of propellers. The bows of icebreaking ships are generally inclined aft toward and below the waterline, as an inclined wedge, so that as the ship moves forward, ice is broken from above and forced downward and to the sides. If the ice is sufficiently thick, the sloped bow will slide on the ice until the weight of the ship exceeds the ice's flexural strength and breaking occurs. Ice may be broken continuously, or if the ship is stopped, continued progress would require backing down several ship lengths and ramming at high power levels.

Icebreaker hull forms have evolved continually since the nineteenth century. Early wooden ships featured, in addition to thick planking and strong framing, rounded hulls intended to counteract the crushing forces of ice under pressure. With the relatively higher power levels available in modern ships (e.g., 10,000 shaft horsepower (SHP) in the World War II-era Wind class ships versus 60,000 SHP in the Polar class), the hull form has become increasingly important for its efficiency in displacing ice to the sides, under the ship, and away from the propellers.

In addition to the sloped bow and rounded hull form, older icebreaker design characteristics have generally favored a relatively wide beam (to provide a broad track for ships to follow), a curving rather than a parallel middle body (to facilitate maneuverability in ice), a single rudder on the centerline (for maximum protection), poor sea-keeping qualities in open water (a regrettable result of the rounded hull and lack of bilge keels or other appendages to dampen roll), and higher propulsion power than conventional ships (MacDonald, 1969).

Although there has never been a single, standard icebreaker design, recent years have seen much greater diversity in designs. This variation is due to advances in engineering knowledge (especially enhanced by accurate model testing), as well as vessel specialization beyond the predominant escort role of the mid-twentieth century. Today, icebreakers tend to be bigger (reflecting increased mission demands), have greater power (enabled by propulsion advances), and feature more flat hull surfaces (producing effective performance with cheaper construction costs). There appears to be a trend toward azimuthing thrusters in icebreaking vessels, which can provide full power in all directions, over conventional shafts and propellers. Design innovation continues, exemplified by a radical conceptual design for an asymmetric, "dual-acting" icebreaker that would present different aspects of the hull in the direction of motion for icebreaking and open-water navigation.[1]

Linking the ice environment and the icebreaker is a third factor: skill in operating the ship. At a fundamental level, icebreaking is unnatural for mariners because it requires purposefully hitting objects with a ship. Active navigation of a ship in ice involves continual decision making: searching for obstacles and paths of least resistance in the ice field, assessing environmental conditions, changing headings, adjusting power levels, and so forth. Knowledge of the ship's capabilities is essential. Much has been written about icebreaking technique, but following "rules of thumb" from an older text are still valid today and gives a good sense of the judgment required in icebreaking (MacDonald, 1969):

- Steer courses that will take advantage of ice weaknesses—The shortest way in the ice is almost always the longest way around.
- Do not hit ice at high speed.
- Never hit a large piece of ice if you can proceed around it; if you must hit it, strike it head on.
- Protect propellers and rudder at all times.
- Refrain from using all engine power just because power is available. There is danger in the philosophy that difficulties can be overcome by weight and power alone.
- Do not hesitate to apply full power when necessary.
- Keep moving. If progress is unsatisfactory, either change your tactics, seek better ice conditions, or lie-to to await a change for the better.

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[1] Mikko Ninni, presentation to the committee, 3 November 2005.

POTENTIAL CHALLENGES TO THE U.S. FLEET

Production, Distribution, and Drift of Icebergs in the Ross Sea, Antarctica, and Their Potential Impact on Sea-Ice Conditions

In spring 2000, several of the largest icebergs ever witnessed calved from the Ross and Ronne-Filchner ice shelves. These icebergs were named B15, A43, and A44 by the U.S. National Ice Center, and together they represent approximately 5,000 km^3, or about 2.5 times the annual accumulation of ice on the entire Antarctic ice sheet. Despite the fact that the titanic size of these icebergs garnered a great deal of public attention, their creation was not glaciologically unusual or unexpected. The initial width of these icebergs, approximately 40 km, represents about 50 years of the forward flow of the ice shelves—floating glacial ice that is hundreds of meters thick—from which these icebergs calved; thus, their sudden appearance after 50 years of slow northward advance of the ice shelves represents the normal maintenance of Antarctica's glacial ice coverage. In a steady state the various ice shelves, including the Ross Ice Shelf, must undergo calving of these behemoth icebergs about once every 50 years, simply because the Antarctic ice sheet is either in steady state, or very close to steady state. Aside from a small piece of the Ross Ice Shelf's front located near 180 degrees longitude, the entire front of the ice shelf has calved back since B15 was released; this means that the next calving, all other effects being equal, is not expected until 2050 or so.

Following the release of B15 from the eastern half of the Ross Ice Shelf's calving margin, the iceberg broke into several small pieces. Unlike the sibling pieces, B15A failed to take a course of drift that would eject it from the Ross Sea in a matter of a few months. Instead, B15A crashed into the ice front near Ross Island, spawning a smaller iceberg, C16, which quickly ran aground in Lewis Bay and finally settled itself into a "holding pattern" just north of Cape Crozier on the eastern end of Ross Island. B15A remained adrift in this holding pattern for the next four years (until November 2004, when it began to move away) constantly gyrating on the ocean's diurnal tide.

The reason for B15A's apparent attraction to the area just north of Ross Island is still a subject of research and debate. It is possible, for example, that the prevailing southerly winds in the region of McMurdo are blocked by the high topography of the island's tall volcanic cones (Mt. Erebus and Mt. Terror), and this contributes to the protection of icebergs from the effects of fierce winds. Other factors contributing to the iceberg's failure to flush from the area may include the inverse barometer effect (there is a persistent atmospheric low in the lee of Mt. Erebus and Mt. Terror), and general localized convergence of the ocean currents generated on the western side of the Ross Sea Polynya discussed below.

By April 2006, both C16 and B15A had left the area of Ross Island; the conditions that triggered this move are unclear. B15J continues to hover near Ross Island; however, this smaller, round-shaped iceberg tends to have less of an impact on sea-ice conditions because of its size and inability to move into shallower waters west of its current position (e.g., to run aground on the pinning point that held C16 for so long in a position that could "blockade" sea ice west of Cape Bird).

Ice Conditions in the Ross Sea and McMurdo Sound, Antarctica

With annual resupply of the U.S. Antarctic Program's major bases, McMurdo and South Pole, currently dependent on ship access into McMurdo Sound, ice conditions in this region are a major factor in recommending a sound strategy in the context of this report. Large-scale ice conditions in the Ross Sea are characterized by the Ross Sea Gyre that transports water and ice in a clockwise fashion through the southwestern Ross Sea off McMurdo Sound. The prevailing strong, offshore winds coming down the Ross Ice Shelf result in the development of the Ross Sea Polynya, a vast expanse of open water and thin ice maintained by wind-driven advection of ice to the north (Figure 7.1). This results in a sea-ice thickness gradient such that the thinnest ice in the Ross Sea is found in the very north along the marginal ice zone and the very south where young thin ice emerges from the polynya region (Jeffries et al., 2001). As a consequence of this distribution of thin ice, the ice cover in the Ross Sea typically recedes from both the northern and the southern edges during summer. In most years, however, some ice survives summer melt. This ice is typically confined to the eastern Ross Sea (see Figure 7.1) and occupies less than one-tenth of the total ice-covered area.

The seasonal ice retreat typically does not start until mid-November, with the summer minimum ice extent in the Ross Sea reached during mid-February. Thus, much of the icebreaking associated with resupply efforts (which, of course, are constrained by more than ice conditions, see Chapter 10) takes place one to three months before the climatological seasonal ice minimum in the Ross Sea sector. (This seasonal sea ice is relatively thin and does not pose an undue icebreaking burden.)

In the 1980s and 1990s, the Ross Sea sector of the Antarctic experienced an increase in maximum ice extent of about 9 percent per decade. At the same time, the ice cover of the neighboring Amundsen and Bellingshausen Seas declined by 10 percent per decade, suggesting that at least part of this increase is explained by advection of ice from the west. Despite the increases in ice extent, a freshening of the Ross Sea also points toward reduced ice production and hence overall thinner ice (Jacobs et al., 2002).

McMurdo Sound itself is characterized by a complex ice regime that depends strongly on the interplay of calving

BOX 7.1
McMurdo Ice Management

In the Antarctic, polar icebreakers are tasked with opening a shipping channel for the resupply of the U.S. Antarctic Program's McMurdo Station. The difficulty of this task, particularly in challenging ice years, and the use of icebreakers primarily as ice management tools call for an integrated ice management and resupply strategy, ensuring the success of the mission while minimizing the effort expended in high-cost, high-risk icebreaking activities. Key components of such an approach include the following.

- Minimum Ross Sea ice extent is attained in mid-February (see discussion of McMurdo ice conditions in this chapter), with ocean swell-mediated break-up of the McMurdo Sound ice cover typically occurring after this date. Hence, the most expedient and cost-effective resupply mission would be much later than current operations, which typically begin in early December. The PALMER, a light icebreaker, has repeatedly traversed the entire Ross Sea in mid-winter, requiring less icebreaking capability due to diminished ice thickness early in the season than navigation in thick Ross Sea ice at the end of austral spring. Advanced remote-sensing and ice reconnaissance tools, such as the new generation of high-resolution, weather-independent microwave radiometers, need to figure prominently in such efforts.
- The current channel leads in a direct path to the station. However, anecdotal evidence suggests that this may not lead through the thinnest ice, with substantial thickness variations (factor two or more) observed across the sound. Routing of the most efficient icebreaker channel requires collection and analysis of relevant data (ice thickness, snow cover, prevailing wind direction, etc.) across the sound. By avoiding thick ice, this channel may deviate from the shortest route (e.g., in the southern sound, multiyear ice thickness may be substantially lower west of the current icebreaker channel where ice shelf meltwater runoff helps keep ice thickness down; see dark area in Figure 7.3). Under-ice currents and snow accumulation also have to be quantified as important variables controlling ice thickness and potential icebreaker progress.
- The challenge of breaking in to McMurdo Station derives from the fact that level ice thicknesses here are the highest anywhere in the Antarctic, with multiyear ice frequently present near the station. It needs to be evaluated whether even a lighter icebreaker would be capable of maintaining a stretch of thin ice up to McMurdo Station through mid-winter ice management activities once thicker ice has been completely removed. An icebreaking campaign to remove ice in winter, possibly by a less capable vessel stationed in the southern hemisphere, may help keep ice thickness along a navigation channel down to 1 meter at season's end. Because of thinner mid-winter ice, this approach would also be less demanding on the vessel.
- At McMurdo, effective removal of broken ice from the channel is particularly important and consistently presents a challenge. Here, changes in icebreaker design or the harnessing of natural processes such as currents or winds (e.g., through artificial roughening of the ice or optimized channel routing) may help clear the channel more effectively than is currently the case.

In conjunction with changes in the resupply schedule, integrated ice management may result in significant savings and streamlining of operations in the long run. Examples of such a comprehensive approach based on optimization and coordination of all components of a mission include trafficability studies in Alaska's coastal seas (using the Polar class vessels) or the European Union's Arctic Demonstration and Exploratory Voyage, focusing on the implementation of a near year-round transportation system in Siberian waters.

of icebergs from and ocean circulation underneath the neighboring Ross Ice Shelf as well as the local surface climate (Box 7.1). Typically, a seasonal, landfast ice cover develops in the sound, extending out to about 20 to 60 km from McMurdo Station at the end of the ice growth season (Brunt et al., 2006; Figure 7.3). As a result of low air temperatures, lack of substantial snow cover and the contribution of underwater ice forming from water emerging from underneath the Ross Ice Shelf and accumulating or growing at the base of the ice sheet, the sea-ice cover in McMurdo Sound is in general the thickest level ice in the Antarctic, growing to more than 2 meters thick during a regular ice season. In a typical ice year, ice retreat in the Ross Sea, heating of McMurdo surface waters, and the action of swell penetrating from the open Ross Sea foster the break-up and removal of much if not all of the landfast ice by February (Crocker, 1988). However, on occasion (roughly once every decade) the landfast ice would not break or clear out far into the sound for one or two seasons.

The most notable effect of the icebergs was the creation of a natural "breakwater" that extended from Cape Bird, the normal place where McMurdo Sound opens to the Ross Sea, to Franklin Island, approximately 100 km to the north. This breakwater, acting in concert with the transverse breakwater presented by the Drygalski Ice Tongue to the north, created a mediterranean encompassing McMurdo Sound and a 200 km stretch of the Victoria Land Coast that reduced sea-ice mobility and favored the appearance of large areas of multiyear fast ice (Brunt et al., 2006). While causes remain tentative, it appears that the obstruction presented by the icebergs reduced penetration of swell and warm summer water into the sound to the extent that much of the ice in the interior sound could not clear out by the end of the summer melt

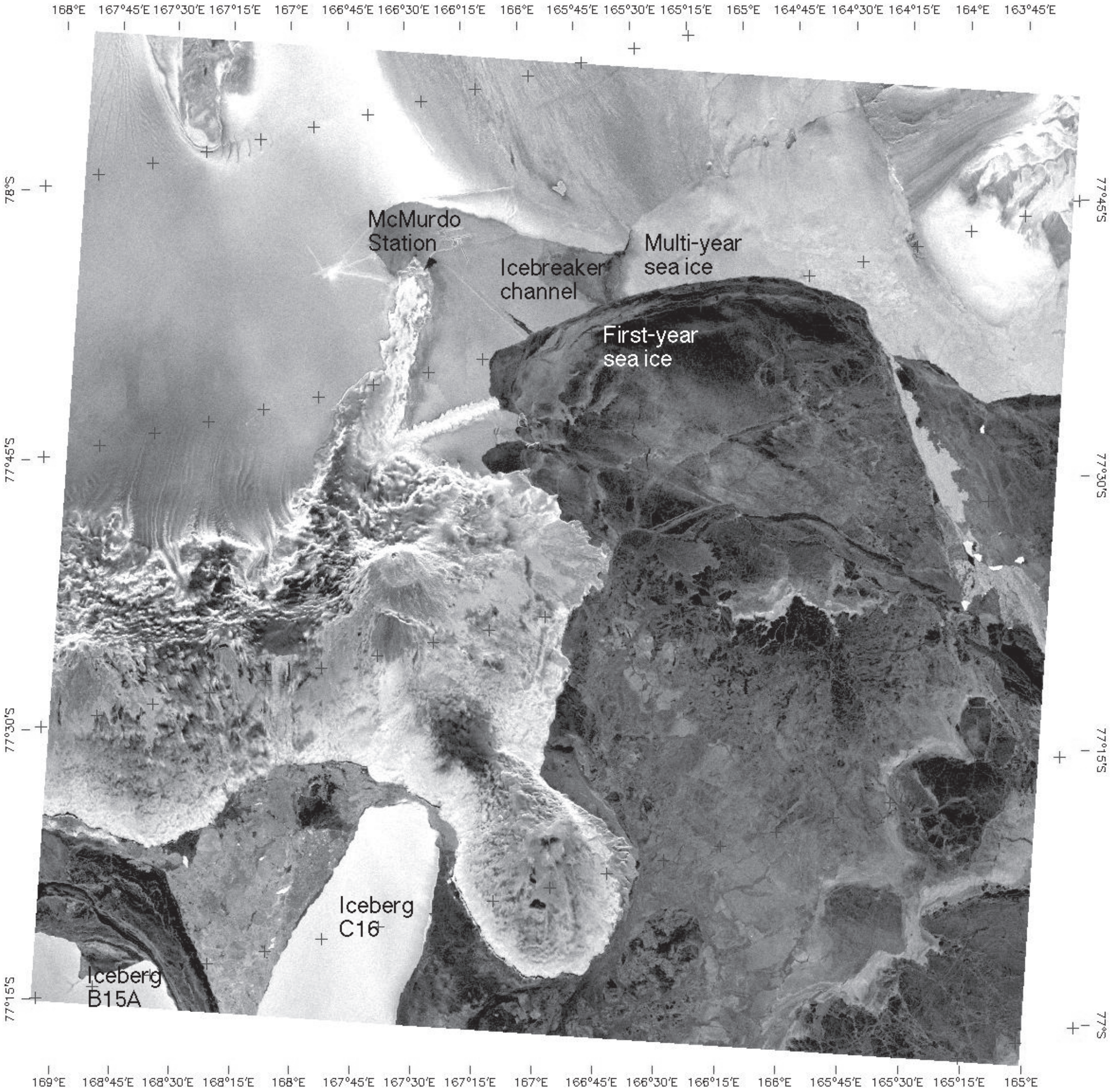

FIGURE 7.3 Radarsat synthetic aperture radar (SAR) scene of McMurdo Sound region, showing ice conditions in austral winter of 2002. The satellite scene (north is down) shows the extent of the multiyear landfast ice cover in the southern stretches of the sound (light gray) as well as first-year ice further north (dark) that has since also remained partially in place. The icebreaker channel to McMurdo Station is also evident. In the lower part of the image, icebergs C16 and B15A appear. SOURCE: Canadian Space Agency.

season. This led to the accumulation of ice between 4 and 6 meter thickness in large areas south of Cape Evans.

At the same time, a combination of factors resulted in surface melting of the ice cover, likely increasing the strength of this ice due to the associated desalination of the underlying ice layers. The only relatively thin ice found in the inner sound (south of Cape Evans to Cape Armitage) is now confined to the icebreaker channel maintained over the past summer seasons (discernible in the synthetic aperture radar image shown in Figure 7.3). Because of the thickness of the surrounding level ice, it may become increasingly difficult to manage (i.e., displace) the mix of ice fragments and new ice forming each year as this channel is rebroken by icebreakers. As of summer 2006, the iceberg blockade had substantially reduced: B15A left the Ross Sea in October 2005; C16 is currently approaching Coleman Island; and B15J has historically remained east of Lewis Bay, close to Cape Crozier, where it has not had a substantial impact on sea ice. Also, collisions with B15A and C16 in 2005 and 2006, respectively, have shortened the Drygalski Ice Tongue by approximately 20 km. Nevertheless, there is a possibility that the level ice in McMurdo Sound that was fostered by the icebergs over the past several years has now reached such substantial thickness that only a major "centennial" storm is capable of breaking it up and clearing it from the sound. In summary, with several independent factors required to act upon the ice cover for decay and removal, it is at this point quite difficult to predict when the ice situation will improve again from the perspective of resupply operations. If the ice does not clear out on its own, then heavy ice conditions (level ice thicker than 4 meters and high concentrations of very thick ice fragments in a partially cleared channel) in subsequent years, starting with the 2006-2007 resupply season, may present a substantial challenge and could potentially thwart efforts to maintain an open channel to McMurdo pier.

At the same time, however, the factors that led to the development of the difficult sea-ice situation have now abated (with the departure of B15A and C16), and this means that once the sea ice does clear from McMurdo Sound, renewal of difficult sea-ice conditions would be unlikely until another period of unlucky iceberg circumstances (which may not develop again for 50 years, depending on the frequency of calving of the Ross Ice Shelf).

Ice Conditions in the Western Arctic

Ice-covered U.S. waters in the Arctic and sub-Arctic include the Bering Sea as well as parts of the Chukchi and Beaufort Seas, the latter typically referred to as the western Arctic (Figure 7.1). While the Bering Sea has not experienced substantial reductions in winter maximum ice extent (Comiso, 2003), the onset of spring ice retreat has occurred progressively earlier since the late 1970s (Stabeno and Overland, 2001). The Chukchi and Beaufort Seas have seen some of the most substantial changes in ice conditions anywhere in the Arctic. Thus, the greatest reduction in summer ice extent has been observed in the northern Chukchi Sea (Comiso, 2002; Overpeck et al., 2005). At the same time, changes in ice circulation, diminished ice growth, and enhanced summer melt have greatly reduced the amount of thick, multiyear ice in the region (Tucker et al., 2001; Perovich et al., 2003). Whereas the ice edge remained within <50 km of the coastline in waters off northern Alaska during most years in the 1970s and 1980s, it now typically retreats by more than 200 km to the north by the end of summer. However, due to the rapid response of a loose ice cover to shifting winds, and possibly aided by increases in summer storm intensity, the ice conditions overall have also become less predictable, with significant impacts on both wildlife and human activities. Thus, Native hunters and coastal residents report significant impacts on their traditional lifestyle by the changing ice regime (Huntington, 2000; Krupnik and Jolly, 2002). Among other factors, the amount of local rescue operations (in northern Alaska typically supported by the North Slope Borough's Search and Rescue Operations Center) due to hazardous ice or open water conditions has increased substantially in the past decade or two (George et al., 2004).

Regardless of the recent changes, the western Arctic remains one of the areas with the most diverse, complex ice conditions in the northern hemisphere. This is due to the fact that the clockwise Beaufort Gyre is still advecting thick multiyear ice into coastal regions (and even through the Bering Strait in the winter of 2005-2006) while the coastal wind regime still fosters growth and export of ice in coastal polynyas and leads in the Chukchi Sea. Interactions between drifting ice and the coastline result in some of the largest ridges produced anywhere in the coastal Arctic. The changes observed so far in the ice regime have not resulted in the complete loss of any of these ice types, but rather have increased spatial and temporal variability, arguably rendering prediction and hazard mitigation more difficult. This situation is exemplified by difficulties encountered by a number of vessels in the Chukchi and Beaufort Seas during the 2006 summer. Thus, a Russian icebreaker carrying tourists into the Chukchi Sea encountered thick multiyear ice that impeded the ship progress and significantly altered cruise plans. More important, offshore oil and gas exploration activities that are resurgent as a result of past and planned federal lease sales in the Chukchi and Beaufort Seas were significantly affected, with a larger number of vessels confined to coastal stretches of the Beaufort Sea for most of the summer.

8

Analysis of Alternatives for USAP Resupply

CURRENT LOGISTICS SUPPORT IN ANTARCTICA

The key logistics element of the present United States Antarctic Program (USAP) resupply system is the annual shipborne resupply of fuel and cargo to McMurdo Station during late January and early February. During this single logistic event, nearly all fuel and cargo needed by USAP stations is transported to McMurdo Station. Throughout the austral summer season, supplies and materials are distributed from McMurdo Station, usually by air, to local science camps, South Pole Station, and remote field camps. Small amounts of materials continue to be delivered to McMurdo by air from Christchurch, New Zealand, and by direct sea deliveries to Palmer Station (amounting to approximately 5 percent and 1 percent of total USAP annual fuel and cargo, respectively, in the case of Palmer Station) during the research season.

The amount of fuel and cargo delivered annually to McMurdo Station is so large (e.g., in 2004-2005, 8,400,000 gallons of fuel [58,600,000 pounds] and 14,200,000 pounds of cargo) that the only cost-effective methodology with acceptable risk has been to utilize a fuel tanker and a cargo ship. Presently these are non-icebreaking, but ice-strengthened, ships operated by the Military Sealift Command (MSC). These require support from large icebreakers—two working together in some years—to open a shipping channel through the ice to McMurdo Station, which is then used by the resupply ships. Ice conditions on the final 20 km of the sea approach are nearly always heavy and have been increasingly very heavy in the past six years. The sea approach to McMurdo Station has also in recent years involved a much longer ice transit than the norm experienced by USAP in earlier decades (recently up to 135+ km). These factors, plus the aging condition of the only two U.S. icebreakers designed to be powerful enough for the McMurdo icebreaking mission, have made future annual break-ins unduly vulnerable to failure. It is therefore important to understand alternatives for the USAP resupply.

Recognizing this situation, the National Science Foundation (NSF) Office of Polar Programs (OPP) initiated an internal study in 2004 of several USAP resupply alternatives. The OPP director subsequently asked the external OPP Advisory Committee (OAC) to form a resupply subcommittee to oversee and guide this analysis of alternatives and to develop its own recommendations concerning resupply options, both to ensure continuity of operations and national policy of the USAP and to help ensure that the most cost-effective and reliable approaches are implemented. The following discussion is a synthesis of the NSF subcommittee's report.[1]

ALTERNATIVES FOR ANTARCTIC RESUPPLY

A review of the current USAP logistics plan highlighted that a single point of potential failure within the resupply system exists because of dependence on the annual, shipborne delivery of fuel and cargo to the hub at McMurdo Station. Simply stated, under the system prevailing through 2005, if the ships miss one delivery of fuel and/or cargo to McMurdo Station, the logistics chain is broken. This dependence places the whole USAP at risk due to the role of McMurdo Station as the sole redistribution point for USAP fuel and cargo and the lack of on-continent reserves. Therefore, it is prudent to amend this single point of potential failure and also provide means to continue science support at and from McMurdo and South Pole Stations in the event of a temporary disruption in delivery. In fact, recent iceberg calving and drift in McMurdo Sound created difficult icebreaking conditions that could easily have made the present mode of resupply inoperable, even for 100 percent fit icebreakers.

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[1] For details see the full report at *http://www.nsf.gov/od/opp/opp_advisory/final_report/oac_resupply_report_081205.pdf*

This highlighted that a backup, alternative, or redundant supply system is necessary for the USAP. The appropriate choices can both result in efficiencies in the present system and enable new major science by virtue of the developed logistics plus net USAP energy savings that can then be applied to science.

First, it is widely recognized that although the approach is not new, the most cost-effective manner to transport the large amount of fuel and cargo required for the USAP, with acceptable risk, is through shipborne delivery to the principal point of use and redistribution (i.e., McMurdo Station). The tonnage that USAP requires to be delivered to McMurdo Station makes annual air delivery of the total both impractical on several grounds and unrealistically expensive. Hence, it can be assumed that barring an as-yet-unprecedented crisis, fuel and at least a major share of cargo will be delivered there by sea. Also, there is no alternative deep-water harbor within hundreds of miles. Thus, if a ship with fuel or cargo destined for McMurdo Station cannot reach the pier, the USAP must contend with unloading the fuel or cargo onto shelf (glacial) ice or onto sea ice. Consequently, the preferred mode for shipborne logistics support remains to provide tankers and cargo ships, escorted to the pier by an icebreaker capable of opening the supply channel through the ice.

This mode of resupply, however, contains the single point of potential failure in the present system. If alternatives could be developed to accommodate an occasional year in which very heavy ice conditions preclude fuel delivery, the vulnerability of the resupply system would be lessened. It should be noted, however, that the heaviest ice years near McMurdo Station have recently occurred consecutively, not randomly. The presence of large icebergs kept sea ice in the McMurdo region, allowing it to grow very thick and hard in places beginning in 2000. Yet there remains the possibility that in any year the icebreaker(s) used to support the McMurdo break-in could be unavailable (e.g., damaged), the entry to the channel to McMurdo Station could be blocked by an iceberg, or other circumstances could prevent a complete seaborne resupply.

If one annual fuel delivery is missed, or deliberately skipped, the fuel storage capacity at McMurdo Station must be sufficient to supply the USAP for at least a second year; thus, a scheme to supply more fuel than at present is required to create the reserve. This is not yet possible, but there are feasible fuel management scenarios that may provide a fuel reserve. For example, an NSF internal study indicates that if total fuel storage at McMurdo Station is increased from the present 9.5 million gallons to 16 million gallons (neither unreasonable nor unduly expensive), and a tanker is used with 20 percent greater capacity than the one used at present, and if fuel reserves were employed on a one-time basis, the USAP could endure one missed annual delivery of fuel only three years after completion of the larger tank farm.

Another step in reducing the risk to the USAP from the dependence on annual delivery to McMurdo Station is through investing in resources to produce a paradigm shift in the South Pole Station supply chain logistics and methodology, with a goal to significantly reduce, if not eliminate, the single point of potential failure related to operating all South Pole Station logistics through McMurdo Station. At present, NSF is investigating the construction of a hard surface processed snow runway at South Pole Station capable of receiving heavy-lift wheeled aircraft—for example, directly from New Zealand or South America. This option appears to be relatively inexpensive and may take only a few years to construct. It also appears feasible to develop a safe, efficient ground-based traverse capability between various key points (e.g., McMurdo Station, South Pole Station, and an ice shelf or sea-ice edge) for support of both science and logistics missions of the USAP. The NSF reported that the proof-of-concept ground traverse between McMurdo Station and South Pole Station has now been completed.

These logistical changes would also allow existing resources to be used to support new expeditionary science and other program priorities. For example, a large number of valuable LC-130 aircraft flight hours—currently expended on fuel, cargo, and personnel transport flights between McMurdo and South Pole Stations—could be used to access parts of Antarctica that are now difficult or impossible for USAP to support by air from McMurdo Station.

In addition, other options may help reduce the portion of fuel and cargo required to be delivered directly to McMurdo Station. If the icebreaker(s) used to break in to McMurdo did not require refueling from the fuel delivered to McMurdo, the same fuel tanker used today could supply sufficient extra fuel to rapidly build a reserve, as long as the fuel storage capacity at McMurdo is increased. The present Polar class icebreakers require refueling in the Antarctic to maintain icebreaking capability because they do not have sufficient seawater ballast capacity to keep the hull at the depth needed to break heavy ice unless they are nearly fully fueled. NSF reports that it is examining the feasibility of these and similar measures, related to the systems under its purview.

Logically, it may appear that the present dependence on Polar class icebreakers would be eliminated by moving all USAP logistics to a base that did not require breaking heavy ice. An Antarctic coastal base must, however, offer more than simply a location accessible by sea. Major additional considerations include depth of the harbor, weather at key times of the year, suitability of local terrain for locating buildings and storage facilities, support for aircraft, relation to USAP science support and other missions, and so forth. While it is true that McMurdo Station and Scott Base (New Zealand station) are the only present-day Antarctic stations that require Polar class icebreakers for austral summer access, it should be recognized that these are the only Antarctic bases in the Ross Sea sector and also that their location is well chosen. For example, their location within the southwestern Ross Sea is particularly important because this area typically experiences wind-driven clearing of the sea ice, which greatly aids navigation and access. These conditions make McMurdo Station the southernmost station with marine access, and no other Antarctic coastal station offers 1,000 km air access to the South Pole.[2]

At least three independent government studies have examined the issue of alternate locations to carry out the functions now based at the USAP McMurdo Station.[3] Collectively, these studies stressed that McMurdo Station (1) is the most valuable high-latitude location for operations and science; (2) is suitable for airlift capability, which enables exploration of the continent for scientific study; and (3) should be maintained at its location with permanent facilities. The NSF subcommittee study also concluded that NSF should investigate ways to reduce and restructure the size and impact of its McMurdo area operations. For example, that study noted that it may be possible to (1) move some support services to New Zealand, (2) use support groups whose operational mode requires minimum on-continent personnel and limited during-season rotations, (3) limit on-continent days per science team member to those required for the immediate mission, and (4) provide economic incentives to contractors for saving energy and reducing impact on-continent.

In summary, 50 years of U.S. Antarctic experience, in addition to recent rethinking, have not yet provided the USAP with a compelling alternative to a major base at McMurdo Sound. Some alternative base locations may provide improved support for certain aircraft or reduction in required icebreaking, but not both. These do not address other vital U.S. criteria, such as support for South Pole Station or specific science activities.

One remaining aspect must be addressed: What are the alternatives in the McMurdo region for landing seaborne materials? Because no alternative harbor exists, the only potentially viable choices are landing fuel and cargo onto a glacial ice edge or onto sea ice in the vicinity of McMurdo Station and traversing them to McMurdo Station.

Antarctic ice shelves occur where glacial ice rides out over the ocean. Some ice shelf areas are relatively stable, though break-off of icebergs can and do occur. NSF internal studies show that ice shelves in the McMurdo Station region rise tens of meters above sea level, well above the reach of any ship's crane. Thus, to unload cargo onto a suitably stable, but high, ice shelf, a notch must first be cut into the ice shelf down to at least the height reachable by the ship's crane. Those experienced with this procedure, however, indicate that it is not fully satisfactory. Furthermore, it is not yet clear if any area of the Ross Ice Shelf within acceptable ground traverse range of McMurdo Station has the characteristics required to support a stable ice ramp. It might be possible, however, to locate a region of the ice shelf suitable to pump fuel up onto the shelf into a holding facility, with subsequent traverse to McMurdo Station. The NSF reports that it may further investigate this possibility, which might provide some partial, emergency backup fuel delivery capability. If an ice shelf ramp were to be constructed on the Ross Ice Shelf to support alternative remote resupply of McMurdo Station, entry-point storage and traverse infrastructure sufficient to handle the materials delivered onto the ice shelf must be developed, and appropriate personnel hired and trained.

Another technique used to deliver fuel and cargo to some nations' Antarctic stations is to discharge the materials directly onto sea ice and transport them to a base via traverse. Operators must contend with the inherent instability of sea ice and the quickly manifested effects of transient winds, but under some circumstances it can be done successfully. The USAP has on at least one recent occasion (2003) found it necessary to lay several miles of hose from the closest location its resupply tanker could reach relative to the McMurdo tank farm. The complete fuel operation took a total of 17 days (6 days setting up, 4.5 days pumping, and 6 days breaking down) and was successful. However, considering the large amount of cargo and fuel required annually, plus the many risks and uncertainties, the OAC rejected reliance on this method except as a contingency backup because the methodology carries risk presently judged unacceptable for routine use with the large amount of material landed annually for the USAP.

Hence, despite the potential logistics alternatives, shipborne delivery of fuel and cargo to McMurdo Station will continue to play a key role in current and future USAP logistics. Although steps may be employed to reduce the strict requirement for annual resupply by sea, for the foreseeable future the United States will still need to see that a sea-ice channel is broken and that cargo and fuel ships are escorted through that channel to the vicinity of McMurdo Station where supplies can be offloaded. This will require the assistance of an icebreaker capable of breaking the sea ice in the southern Ross Sea (i.e., a Polar class icebreaker).

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[2] The Argentinean Belgrano II station, in the Weddell Sea sector, is located 120 miles inland, on a tiny rock outcropping, in an area where storm winds exceed 200 km per hour. Hence, although it is only about 1,000 km from the South Pole by air, a wide variety of factors render that general location unsuitable as a major Antarctic logistics center.

[3] The Ad Hoc Working Group on the U.S. Antarctic Program, Committee on Fundamental Science; National Science and Technology Council; and the United States Antarctic Program External Panel.

9

Analysis of U.S. Current and Future Polar Icebreaking Needs

The current and anticipated needs for U.S. polar icebreakers have been discussed throughout this report. This chapter analyzes those needs and assesses how the current U.S. Coast Guard polar icebreaker fleet meets these needs today and will meet them in the future. If the current polar icebreaking capabilities are not sufficient to meet the nation's needs then options for acquiring new polar icebreaking capability must be explored. The committee's approach to this analysis is as follows:

1. Identify polar icebreaking needs.
2. Perform a "gap" analysis to determine which needs are being met and which needs are not being met in the short and long terms.
3. Identify potential options for meeting the needs that the gap analysis shows are not being met now or will not be met in the future.

NEEDS ANALYSIS

Earlier chapters discuss various needs in some depth. The summary list includes the following:

- Assured access independent of ice conditions
- McMurdo resupply
- Central Arctic Ocean science
- Onboard scientific research
- Continental shelf mapping—United Nations Convention on the Law of the Sea (UNCLOS)
- Sovereignty and presence
- Escort and assistance
- Search and rescue
- Maritime law enforcement
- Environmental protection and oil spill response
- National defense and homeland security
- Facilitation of commerce
- Treaty monitoring
- Marine casualty response

Not all needs apply, or apply in the same manner, to the Arctic and the Antarctic. In analyzing how well needs are met, the two regions are discussed separately.

Before discussing how well these needs are met in the two regions, the status of the U.S. icebreaker fleet, discussed elsewhere in more detail, is reviewed here. The fleet consists of four ships. The two Polar class ships are at the end of their operational design service lives. In the last few years, age- and wear-related problems have become apparent. The vessels are now inefficient to operate because multiple vital ship systems require substantial and increasing maintenance, and their technological systems are becoming increasingly obsolete. The POLAR STAR is in caretaker status, moored indefinitely at a U.S. Coast Guard pier in Seattle and sustained by a crew of 35.

The POLAR SEA is completing sea trials after undergoing a modest upgrade during 2006. She appears to be mission capable for the next three to five years. (Plans are being made for the POLAR SEA to participate in the 2007 McMurdo break-in.) Consequently, the HEALY will be the only mission capable icebreaker for the coming decade and more. The ice-strengthened ship PALMER is expected to be mission capable for some years; however the National Science Foundation (NSF) is considering a PALMER replacement vessel.

Table 9.1 assesses the capability of the only ships that are available to meet icebreaking needs in the Arctic region, the HEALY and the POLAR SEA. Note that the POLAR SEA is, at present, only capable for the short term (three to five years), and the POLAR STAR at this point is in caretaker status. At first glance, Table 9.1 might be interpreted to imply that there is substantial robust icebreaking capability for the Arctic. That is misleading. The HEALY is not capable of operating independently in heavy ice conditions

TABLE 9.1 Assessment of U.S. Polar Icebreaker Fleet to Meet Icebreaking Needs in the Arctic

Arctic Need	HEALY	POLAR SEA (short-term)
Assured access independent of ice conditions	Limited icebreaking	Limited remaining service life and reliability
Deep Arctic science	Limited icebreaking	Limited science facilities
Onboard scientific research	Adequate	Limited science facilities
Continental shelf mapping—UNCLOS	Adequate	Inadequate
Sovereignty and presence	Adequate	Adequate
Escort and assistance (e.g., Thule, Northwest Passage)	Limited	Adequate
Treaty enforcement	Capable[a]	Capable[a]
Search and rescue	Adequate	Adequate
Maritime law enforcement (e.g., fisheries)	Capable[a]	Capable[a]
Environmental protection	Capable[a]	Capable[a]
National defense and homeland security	Capable[a]	Capable[a]
Facilitation of commerce	Capable[a]	Capable[a]

[a] The ship is capable of supporting these missions, but may require specialized crew training and/or personnel augmentation, provided that assured access is available.

typical of the central Arctic because of her limited icebreaking capabilities. Although nominally available for Arctic operations, POLAR SEA will likely be committed to the McMurdo break-in for much of her available operational time, to save costs and to ration her current capability. There is scant capability to meet the need for assured access independent of ice conditions and for support of central Arctic Basin science. Canadian icebreakers cut the channel into Thule. With current assets the United States has little icebreaker capability to "repay" Canada in kind.

Although the HEALY has at least a limited capability to address the full range of needs, the ship is fully committed to the increasing demands for science and is often deployed far from U.S. Arctic waters. If the POLAR SEA is dedicated to the McMurdo break-in and HEALY is dedicated to science support, other Arctic needs such as sovereignty and presence, escort and assistance, and search and rescue will be supported only by HEALY and in areas where the ship is directed by research agencies.

A single icebreaker may be able to address individual mission needs sequentially, but cannot fulfill all these needs simultaneously. One ship cannot be in two places at the same time.

The U.S. Antarctic needs are listed in Table 9.2; they overlap but differ from those in the Arctic. Reliable, long-term icebreaker support to perform the McMurdo break-in is the most challenging Antarctic need. The POLAR SEA can address most Antarctic needs adequately in the short term, although until ice conditions improve in McMurdo Sound, it is risky to depend on one ship, even a Polar class ship. A chartered foreign icebreaker, KRASIN, has been employed as the assisting (2005) and as the primary (2006) icebreaker for the McMurdo break-in. Presumably, it was the most attractive of the ships available for charter. This ship was commissioned about the same time as the U.S. polar ships. The committee had no access to its maintenance records, but noted that the broken propeller blade was not fixed by the Navy dive team that was sent to repair it. This demonstrates that a charter guarantees neither lower costs nor more operational assurance than use of U.S. vessels. In any case, the

TABLE 9.2 Assessment of U.S. Polar Icebreaker Fleet to Meet Icebreaking Needs in the Antarctic

Antarctic Need	POLAR SEA (short term)	Foreign Charter	PALMER
Assured access independent of ice conditions	Limited remaining service life and reliability	Not appropriate	Limited icebreaking
McMurdo resupply	Limited remaining service life and reliability	KRASIN	Not capable
Onboard scientific research	Limited facilities	None	Adequate
Sovereignty and presence	Adequate	Not appropriate	Limited
Treaty monitoring	Adequate	Not appropriate	Capable[a]
Environmental protection	Capable[a]	Not appropriate	Limited

[a] The ship is capable of supporting these missions, but may require specialized crew training and/or personnel augmentation, provided that assured access is available.

KRASIN is reportedly unavailable in 2007 and beyond. The prospect of chartering reliable icebreakers on a short-term basis is poor, due to obsolescence of some of the Soviet-era Russian fleet, their use to take tourists to the North Pole, and increasing worldwide demand for ice-capable vessels to support Arctic oil and gas exploration and development. In this environment, annual foreign charters cannot reasonably be expected to provide assured access or environmental protection and do not provide the U.S. presence. The committee is unaware of any Polar class vessel that is owned by a private U.S. organization.

The ice-strengthened ship PALMER possesses some capability to meet U.S. Antarctic needs other than the McMurdo break-in. However, as in the Arctic, the demand for research platform time is increasing and PALMER is already fully committed to a science program. The committee concludes this analysis by observing that all current fleet and charter options are short term in nature; there is no long-term capability in the current U.S. fleet to address Antarctic needs.

GAP ANALYSIS

The committee concludes that the most serious gaps—that is, the most serious needs that are unmet in the short and long terms—are the following:

- Ability to reliably perform the McMurdo break-in (reliable control);
- U.S. Coast Guard missions in the Arctic; and
- Assured access to ice-covered seas independent of ice conditions.

While all needs are important, some are more so when national security and/or geopolitical concerns are considered. In the Antarctic, given our long-standing and important commitment to the area, the McMurdo break-in is the essential gap to be addressed. HEALY cannot perform the McMurdo break-in because this ship cannot operate independently in ice conditions that have been encountered in McMurdo Sound for the past several years. In addition, diverting the HEALY to perform the McMurdo break-in significantly impacts Arctic science missions. The United States must have the reliably controlled ships to deal with the most difficult ice conditions; in some years, this requires two ships.

In the Arctic, the need to accomplish traditional U.S. Coast Guard missions (and thereby project U.S. sovereignty and presence) constitutes a critical, unfilled gap. The U.S. Coast Guard has abandoned using polar icebreakers for regular patrols along the Alaskan coastline. Although a budget for icebreaker crews, training, and other support for ship operations exists, there is no funding to deploy the icebreakers for patrol missions. The U.S. Coast Guard polar icebreakers remain at the pier unless other agencies “purchase” operational icebreaker days. The committee believes that these patrols are important to our domestic and national interests and should be resumed.

The third gap is the unmet need for assured access to ice-covered seas independent of ice conditions in both polar regions. The HEALY is not as powerful as a Polar class ship and cannot ensure timely access to some Arctic areas during the shoulder seasons and to the deep Arctic. One ship is insufficient to fulfill the full range of missions across the two polar regions.

These gaps are complementary in the sense that the one or more ships addressing a particular need may simultaneously be serving another (a ship deployed to perform a science mission may be near enough to divert to provide timely response to an oil spill). Each ship can act as a backup for the others in some situations at some times. In addition, all U.S. government-owned ships assert U.S. presence wherever they are.

10

Options for Acquiring New Polar Icebreaking Services

The previous chapter has identified U.S. polar icebreaking needs and gaps—that is, unmet needs in the short and long terms given the current, operational U.S. polar icebreaker fleet. In this chapter, the committee analyzes options for addressing these gaps (i.e., for meeting the nation's current and future polar icebreaking needs). The acquisition of new polar icebreaker services—acceptably crewed and operated ships—could be accomplished through a number of acquisition options or a combination of these options. Ultimately, the choice of an acquisition strategy is dependent on the expected employment of the new polar icebreaking capability. There is a range of possible employment goals: at one end of the spectrum is purely Arctic and Antarctic scientific research support; the other end of the spectrum is having a true "national asset" capable of accomplishing the full range of U.S. Coast Guard mission requirements and protecting U.S. national interests.

As identified in the previous chapter, the main gaps are the following:

- Ability to reliably perform the McMurdo break-in (reliable control);
- U.S. Coast Guard missions in the Arctic; and
- Assured access to ice-covered seas independent of ice conditions.

OPTIONS FOR MEETING GAPS IN U.S. POLAR ICEBREAKING CAPABILITIES

The committee evaluated a multiplicity of approaches to meeting the gaps in U.S. polar icebreaking capabilities. To structure its considerations, the committee considered three key dimensions: (1) ownership, (2) crewing, and (3) vessel procurement. Four options in each dimension, are

TABLE 10.1 Options for Addressing Gaps in U.S. Polar Icebreaking Capabilities

Dimension	Options			
Ownership	Commercial charter	Commercial long-term lease	Foreign government	U.S. government owned
Crewing	U.S. Coast Guard	Military Sealift Command operated	Commercially operated—U.S. flagged and crewed	Commercially operated—foreign flagged and crewed
Vessel procurement	SLEP[a] of an existing Polar class icebreaker	Enhanced short-term (4 to 8 years) maintenance for a Polar class icebreaker for near-term service (e.g., POLAR SEA)	Purchase and rebuild an existing icebreaker	New construction of polar icebreaker

[a] Service life extension program

summarized in Table 10.1. Combining one option from each dimension describes the acquisition and the operation of one ship. "Ownership" was found to be the dominant dimension, partly because it determines much about funding vehicles, crewing, and operation of the ships. First, the crewing and the procurement options are discussed. Later, ownership options are evaluated (related to a single ship) against each of the four identified gaps. Then (multiship) fleet constitution is considered.

Crewing options are heavily driven by the vessel's ownership. For example, a foreign government-owned icebreaker crew would be selected and trained by the foreign government. A commercial operator would flag the ship and hire the crew. Commercial lease terms can require the ship to be U.S. flagged and the crew to be from the United States. Government-owned vessels can be crewed by either the U.S. Coast Guard or civilian mariners hired by the U.S. Military Sealift Command (MSC), and through different crewing schedules and modernized technologies, crew sizes may be reduced, thereby reducing costs. Alternative crew sizing options are discussed in detail later in this chapter. Briefly, a civilian crew may number much less than a U.S. Coast Guard crew; however, market conditions indicate that for each U.S. Coast Guard crewmember, the commercial operator (or MSC) would need to hire two mariners. Committee estimates show that total crewing costs are not appreciably different—no more than 10-15 percent in lifetime operational costs.

The scientific community has long and successful experience with civilian crews (i.e., on the PALMER and GOULD), including the advantages attendant on long-term retention of officers and crew with experience. The success of the U.S. Coast Guard Arctic marine science support with the HEALY demonstrates that this option—where crewmembers rotate more frequently—can be satisfactory as well.

In considering vessel procurement, ownership decisions admit or preclude some procurement options. The desired duration of vessel service life is another important influence. One option is a service life extension program (SLEP). As discussed in detail in Chapter 6, the life of the hull and basic structure of a ship is extended by replacing the mechanical, electrical, propulsion, waste, and other systems and likely rebuilding the spaces and, of course, reoutfitting them. The lifetime of the refitted (SLEP) ship will likely be less than that of a new ship. Incorporation of new technologies may be limited, and no new hull design is possible. The U.S. government could "SLEP" either the POLAR SEA or the POLAR STAR. A commercial company could buy an existing hull and do the same. There do not appear to be any Polar class icebreaker hulls on the market. It is also possible that a U.S. Polar class ship could be transferred to commercial ownership and then undergo a service life extension. Mariners on the committee advise, however, that a ship with life extension may be mission capable only about half as long as a newly constructed ship.

New construction—whether by the U.S. government or by a commercial company—is an option that would allow the incorporation of new technology. Chapter 6 discusses the many new, attractive, and high-performance technologies available, including the double-acting hull design.

The option of "enhanced short-term maintenance" is being exercised. In 2006, the POLAR SEA was in dry dock and interim maintenance was performed so that the ship would be mission capable for the short term (i.e., three to five years. It is the POLAR SEA that will do the 2007 McMurdo break-in, likely with assistance. This maintenance of the POLAR SEA is crucial to having polar icebreaker capability for the next several years while the nation takes action for the long term, should it choose to do so.

In the following material, the committee considers the ownership dimension with respect to each of the three identified gaps.

Assured Access to Ice-Covered Seas Independent of Ice Conditions

A basic tenet of national security, homeland security, and projection of U.S. power worldwide is assured access to all regions of the globe. In the polar regions this is manifested in a need to be able to place U.S. assets in all ice-covered waters. It is the judgment of the committee that this need can be only fulfilled partially by airborne, spaceborne, and submarine assets and that a physical surface presence is necessitated by geopolitics. The nation needs to maintain a national capability to break heavy multiyear ice in the polar regions.

The highest-priority need in the south is to support annual resupply of McMurdo Station, the hub and lifeline of U.S. operations in Antarctica. A corollary benefit could be the provision of scientific access to the ice-covered waters of Antarctica and the Southern Ocean if the ship is outfitted to support scientific research, but this is not a primary driver in justifying such capabilities. The committee reiterates that the solution could be a U.S. government ship or a long-term leased vessel, but the solution must be long term.

In the north, the need for access is multifaceted and spans many national interests including defense, economic development, scientific research, and environmental protection. The committee concluded that national interests in the north were inadequately met by the current icebreaker fleet and that the growing national interests in the north would increase the need for such capabilities in the foreseeable future. The committee also concluded that current U.S. Coast Guard activities were insufficient to achieve its missions in the Arctic and that this was due to insufficient funding for operations, rather than a lack of urgency. The U.S. Coast Guard has ceased regular patrols in the Arctic. The committee believes that changes in the Arctic necessitate reinstatement of these patrols. The current status of icebreaking assets, however, compromises the national ability to be responsive to these needs.

In addition to the basic requirement for access, in the next decade there may be a need to collect geophysical surveys and core data to support U.S. sovereignty and territorial claims in the Arctic Ocean under the United Nations Convention on the Law of the Sea (UNCLOS) and to refute the claims of other nations. In some cases, this may require ship access to the central Arctic Ocean. This need could be met by a U.S. commercially operated ship, and possibly by a foreign-owned ship, with appropriate contracts and monitoring in place, or by a U.S. government ship with suitable instrumentation. Many groundbreaking research issues in the north will require regular access to the central Arctic Ocean and the underlying sedimentary records of past climate and geological evolution.

For the purpose of science support alone, all four ownership options are acceptable. U.S. government ownership and operation provides the highest surety of U.S. access to Arctic waters. Commercial long-term lease of a U.S. icebreaker can also provide a degree of surety of access. However, the committee believes that commercial U.S. flag presence is significantly less than that provided by a government-owned ship.

The overarching need for assured access in support of U.S. national interests implies that the best form of official U.S. presence in the Arctic is uniformed military service, the U.S. Coast Guard. By this logic, U.S. government-owned and operated icebreaker capabilities are essential for supporting northern sovereignty and presence. Access to many parts of the Arctic requires significant polar icebreaking capabilities. To “ensure” access, a single vessel is inadequate since there would be no redundancy in capability and this raises the specter that a single ship in distress would have no U.S.-controlled alternatives for assistance. Also, there may be multiple, simultaneous demands for icebreaker presence in the Arctic.

Assets Necessary to Fulfill U.S. Coast Guard Missions in the Arctic

Options to address U.S. Coast Guard mission areas are limited. The ship must be government owned and operated to address sovereignty issues along with the full range of U.S. Coast Guard missions that would include law enforcement and national security interdiction operations. The most flexible option, as in other areas of national maritime interest, is that crews be trained and provided by the U.S. Coast Guard. A fully mission-capable trained Coast Guard crew is the preferred option to provide the most flexibility and to facilitate operations in remote areas. In theory, civilian mariner crews could be provided by the U.S. Military Sealift Command, with a U.S. Coast Guard detachment aboard in addition to the crew to address specific U.S. Coast Guard mission area requirements, although this operating model has never been implemented for multiple-mission operations. Vessel procurement could include a range of options: new construction, SLEP of an existing government-owned icebreaker, or SLEP of another existing polar icebreaker. As noted elsewhere in this report, new construction is most desirable from the perspective of both reliability and incorporating the newest and best available technology.

Assets to Reliably Perform the McMurdo Break-In (Reliable Control)

National presence is asserted mainly by the presence of U.S. citizens year-round in the three permanent stations. Today, U.S. presence in two of those stations relies substantially on an assured ability to break in to McMurdo Station on an annual basis. An icebreaker for the McMurdo resupply can be obtained commercially in several ways. The most likely commercial vehicles are (1) outright ownership (e.g., construct a new ship or purchase an existing ship outright); (2) long-term charters (e.g., leasing, possibly lease-build); (3) short-term charters (one month to several years); or (4) performance service contract (e.g., contract specifies the result of the charter with performance guarantees—break a path into McMurdo Station and escort the cargo vessels to the terminal). Charters can be bareboat (i.e., the charterer provides crew and all operating expenses), term charter (i.e., owner provides crewed ship for a specified period of time, and charterer pays for fuel and port costs directly), or spot charter (i.e., owner provides crewed vessel and fuel, and charterer pays an all-in fee for a specific defined service).

For the past couple of seasons the National Science Foundation (NSF) has used the commercial charter vehicle. The NSF chartered the Russian icebreaker KRASIN from the privately owned Far Eastern Shipping Company. However, when difficulties arose, NSF had military assets to call on—first the Navy diving and salvage team that sought to make emergency propeller blade repairs to the KRASIN, and then the U.S. Coast Guard cutter POLAR STAR, which by arrangement was standing by. At 36,000 horsepower the KRASIN is more powerful than the HEALY (30,000 horsepower), but significantly less powerful than the POLAR SEA and POLAR STAR (60,000 horsepower).

The Far Eastern Shipping Company (FESCO) has advised NSF that the KRASIN is not available for the 2007 resupply because she is on charter to an oil company for offshore Arctic oil development. Discussions with shipbrokers indicate that there are virtually no commercial icebreakers available for charter. The oil companies have been actively looking for icebreakers to support offshore Arctic oil projects. Other Russian icebreakers are used for North Pole tourist cruises and domestic icebreaking services.

Besides the U.S. icebreakers, only the Russians have icebreakers of greater than 30,000 horsepower. Large Russian nuclear icebreakers (75,000 horsepower) are actively used in the Arctic for navigation and commercial purposes. The Russian icebreakers are reported to have cooling system limitations that preclude them from crossing through the warm tropic waters to reach the Antarctic. It is also problematic to introduce nuclear ships into pristine Antarctic waters.

In the case of a long-term commercial lease or charter, a private operator would build and own the icebreaker that is chartered long term to NSF for use in the McMurdo resupply. There are regulatory issues relating to long-term charters to a government agency (e.g., the 1984 Tax Act and other lease financing issues). Service contracts have been used to bypass the lease financing issues. For example, NSF has procured the use of the PALMER and the GOULD, privately owned ships, through a service contract with Raytheon, which charters the PALMER from her owner, Edison Chouest Offshore.

U.S. Antarctic marine research is at present supported primarily by the two United States Antarctic Program (USAP) Antarctic research vessels PALMER and GOULD, with some research carried out from UNOLS research vessels, international programs on foreign research vessels, and a small amount of ship-of-opportunity research carried out on U.S. Coast Guard icebreakers when used to support the break-in. However, there is a demand for both increased scientific capabilities (beyond those of the PALMER) and increased icebreaking capacity to support the scientific community. The need for increased icebreaking capability would likely be provided by the conceptual PALMER Replacement Vessel (PRV) with "polar" icebreaking capability; hence the PRV falls under the scope of the committee's discussions.

There is a desire in the scientific community to conduct research in Antarctic waters that the PALMER cannot reach, due to icebreaking limitations of that ship. The current Polar class ships are not designed or equipped to conduct this research due to hull configurations that do not permit the mounting of some types of sensor systems. There has been community discussion of new construction of a PRV. It would have increased icebreaking capability, compared to the existing PALMER. If it was sufficiently capable, then the PRV could assist a heavier Polar class vessel in the break-in to McMurdo in years where heavy ice was in the sound.

The committee believes that a commercial long-term lease approach would most likely involve the construction of a new icebreaker, and unless there were other assured clients, the NSF would be billed at rates that would pay for construction, for the cost of capital, and for operations over the term of the lease. Long-term lease is a viable approach; however, the need for reliable control eliminates short-term charter as an option.

Another ownership option is to lease the icebreaker ship, or icebreaking service, from a foreign government on a long-term basis. A variant is to create a long-term partnership where part or all payment could be in trade (i.e., use of assets commanded by NSF). NSF is considering the use of the ODEN in the next McMurdo resupply operations. Operated by the Swedish Maritime Administration, the ODEN has a displacement of 11,000 to 13,000 tons and 24,500 horsepower. However, the McMurdo resupply must be done during late January-early February, which is the time of year that the Swedish- and Finnish-owned icebreakers are most needed in their home waters.

Japan, Germany, Netherlands, and Argentina each own single icebreakers that are used for polar research, offshore support, and/or Antarctic logistics. These vessels are all actively employed in their own national polar missions. It is not clear that any of these icebreakers are available for use in the McMurdo break-in, nor are they powerful enough to perform the break-in alone. It is possible that a new icebreaker could be constructed for a consortium of nations that could be used for the McMurdo resupply. For example, the European Union has been working on a plan to build an icebreaker, AURORA BOREALIS, for use by its member nations. It is also conceivable that the United States could enter into joint ownership with another government (e.g., Australia or any of numerous other countries). However, no other nations require a Polar class ship for their resupply, although they may wish to perform research in heavy ice conditions.

The last ownership option is a U.S. government-owned icebreaker. At present, the U.S. government owns and operates, through the U.S. Coast Guard, the current fleet of two operational polar icebreakers, the POLAR SEA and the HEALY. Building new polar icebreakers would address not just the McMurdo break-in mission, but all others.

Multimission Ships

The committee's analysis considered needs, gaps, and options individually, but this is not sufficient. The United States has had a multimission fleet of icebreakers in the past and has gained greatly by fulfilling multiple missions on the same cruise, by deploying icebreaking ships in concert, by placing ships in complementary locations in certain situations, and by trading icebreaking services with other nations. The nation has also benefited from redundancy and backup in having a fleet of multiple ships. In a few years, the only remaining operational ship will be the HEALY. In national security situations and in dire safety situations, the nation needs to be able to call on residual capability.

When considering the acquisition of new icebreaking services or capabilities, the issue must be dealt with at a national level—at the level of a fleet, not one ship at a time. If the nation pays for military icebreakers and separately and independently for civilian agency-procured services, then the overall cost will likely be greater than if there is a coordinated approach. If icebreakers are owned and operated independently by different agencies, redundancy and backup options are likely foreclosed or at least reduced.

Potential Operational Profiles for Multimission Ships

Table 10.2 provides a general overview of how a renewed polar icebreaker fleet might be employed operationally in support of U.S. interests in both polar regions. Clearly,

TABLE 10.2 Nominal Operational Profiles for a Renewed Polar Icebreaker Fleet

Icebreaker	Anticipated Tasking
HEALY	*All seasons*: Research support in the western Arctic (Bering, Chukchi, and Beaufort Seas); eastern Arctic (Baffin Bay, Greenland Sea, and contiguous waters); central Arctic Basin (multiship operations);participation in international expeditions and cruises; maintenance in homeport scheduled between missions
New Icebreaker No. 1	*March-June and September-December (shoulder seasons)*: Patrol presence in Bering, Chukchi, and Beaufort Seas for search and rescue, law enforcement, environmental protection and response, vessel assistance, science of opportunity, and maritime safety and security *Other months*: Arctic logistics, science, or other missions as needed; maintenance in homeport
New Icebreaker No. 2	*November-April*: McMurdo break-in as primary or secondary icebreaker; Antarctic Treaty inspections and enforcement, logistics, and science support (e.g., dual ship operations with PALMER) *May-October:* Arctic logistics, science, or other missions as needed; maintenance in homeport
PALMER and PRV	*All seasons*: Research support in waters surrounding Antarctica; maintenance scheduled between missions

it is impossible to forecast precisely how trends in the Arctic and Antarctic would require icebreaker support. However, the table shows how restoration of U.S. icebreaking capability might provide a flexible, active, and influential presence in both polar regions. The committee anticipates that the HEALY would be dedicated to research support in the Arctic and would undergo maintenance in its homeport between missions. Similarly, the PALMER or PRV would be dedicated to supporting scientific research in the Southern Ocean. The first new polar icebreaker could operate in the Arctic during the "shoulder seasons" between March and June and September and December. This ship could provide a patrol presence in the Bering, Chukchi, and Beaufort Seas, as well as support search and rescue, law enforcement, environmental protection and response, vessel assistance, science of opportunity, and maritime safety and security. In the other months, this ship could be used to support Arctic logistics, science, or other missions and undergo maintenance in its homeport as needed. The second new polar icebreaker could be tasked to support operations in the Antarctic from November to April. This ship may be used from November to April as the primary or secondary icebreaker in the McMurdo break-in, to support Antarctic Treaty inspections, and to provide logistics and science support alone or with the PALMER. From May to October the second icebreaker can be used to support Arctic logistics, science, or other missions as needed or can undergo maintenance in its homeport.

SHIP RENEWAL AND TRANSITION SCHEDULE

Today, the United States has inadequate icebreaking capability. In this section the committee discusses reconstituting a fleet. The committee assumes that two new polar ships will be built by the U.S. Coast Guard and delivered in 2014 and 2015. This is an ambitious schedule, but as a nation we are so late in recognizing the age and condition of the polar icebreaker fleet that we must act with speed and determination. The committee acknowledges that this transition may have to be sustained for a longer time and assumes that the HEALY will need a mid-life upgrade in about 12 years. It also assumes that NSF will extend the life of the existing PALMER or replace it. This would be an increase in icebreaking capability (for McMurdo resupply) only if the PRV were a Polar class icebreaker.

A key element of this schedule is to maintain one U.S. Coast Guard polar ship, the POLAR SEA, as the interim capability, with the POLAR STAR in layup (at the pier in Seattle) as an emergency backup if the POLAR SEA cannot be maintained as operational. The committee recognizes that it would take almost a year to bring the POLAR STAR back to operational status, even on an emergency upgrade schedule. U.S. icebreaking capability will not become adequate until the first new polar ship comes into service. This is a situation that the United States has created by previous inaction. The committee advises that it will be more effective to make arrangements with other nations or commercial firms to augment the shortfall in capability in the short term, rather than bring both existing Polar class ships to operational status. Emphasis should be to build new ships, rather than upgrade existing ships for short-term service.

There are two strategies available to keep the POLAR SEA operational through 2014 and in layup status to 2019 as an emergency backup to the new polar vessels and possibly the HEALY mid-life upgrade. Both strategies rely on the fact that POLAR SEA received significant maintenance and upgrade work at a cost of $30 million in 2006.

In one strategy, the POLAR SEA would be upgraded a second time in 2012 at a cost of approximately $40 million. POLAR SEA upgrades would include the following:

- Maintenance and repair upgrades to the engine and propulsion systems

- Upgrades to the black and gray water systems
- Replacement of the cranes
- Replacement or upgrades of boilers and evaporators
- Replacement of the navigation and electronic systems
- Upgrades to controllable pitch propeller systems and hydraulic control
- Science laboratory upgrades (test laboratories, controlled environment laboratories, staging bays)
- Habitation spaces and systems for crew and scientists

If the POLAR SEA is out of service for a full year before the first newly constructed ship is available, the U.S. Coast Guard and the NSF would have to provide some alternative plan for McMurdo break-in. Note that only the HEALY would be available for tasking in the Arctic during the POLAR SEA upgrade and before delivery of the first new polar U.S. Coast Guard ship.

The second strategy would place the POLAR SEA in an enhanced maintenance program, with annual upgrades designed to allow the ship to operate every year and not be taken out of service for an entire year (approximately 2012) for its second major upgrade. The U.S. Coast Guard would have to determine if this second strategy could be made to work. In particular, is there an annual maintenance program that incrementally makes the needed improvements to the ship's operating systems without placing the ship in dry dock for an extended period? This option involves additional risks to vessel service and necessitates careful development of an enhanced maintenance and repair program. The POLAR SEA must be in service for operations throughout the construction of the two new polar vessels, the last of which is to be completed and commissioned in 2016. At that point, the POLAR SEA will be placed in emergency backup status, to be available in the event of a decision to execute a mid-life upgrade of the HEALY in 2018 and 2019. The POLAR SEA can then be decommissioned in 2020.

The POLAR STAR needs to be available as a backup throughout the construction of the two new polar vessels. The two new polar vessels could begin construction in 2010 and 2011 and be in service in 2014 and 2015. The POLAR STAR can only be decommissioned when both new polar vessels are in service—that is after 2015. If the POLAR SEA must be taken out of service, the POLAR STAR may have to be activated to augment the HEALY. The schedule is shown graphically in Figure 10.1.

OPTIONS FOR POLAR ICEBREAKER CREWING

Operation and Crewing of Current World Icebreakers

Polar icebreakers currently in service throughout the world reflect a variety of design criteria, ownership structures, and operating and crewing models. Although a more common factor in the mid-twentieth century, few modern icebreakers have been designed to military standards. Of ships currently in service, only the Canadian LOUIS ST. LAURENT and the POLAR STAR and POLAR SEA in the U.S. fleet, all designed in the 1960s, could be considered to meet military standards to some extent, and none of these were designed as combatant warships. Although the HEALY can accommodate some limited military capabilities such as communications, the ship was basically designed to commercial standards.

Most polar icebreaker fleets today are owned by governments and operated directly by government agencies. Examples include the Canadian icebreaker fleet, the German research icebreaker POLARSTERN, and the Japanese icebreaker SHIRASE. Those large icebreakers, ostensibly operated by commercial entities, are in most cases part of state-owned companies (e.g., Murmansk Shipping and FESCO in Russia) or are operated by private enterprises on exclusive long-term charter to government agencies (e.g., PALMER for the U.S. National Science Foundation). Renewed interest in oil and gas exploration in Arctic and sub-Arctic areas has resulted in a number of truly commercial icebreaking ships, such as the Dutch KIGORIA and chartered icebreakers supporting Sea of Okhotsk oil development.

Table 10.3 provides information concerning the ownership, operating model, and crewing of polar icebreaking vessels currently in service around the world.

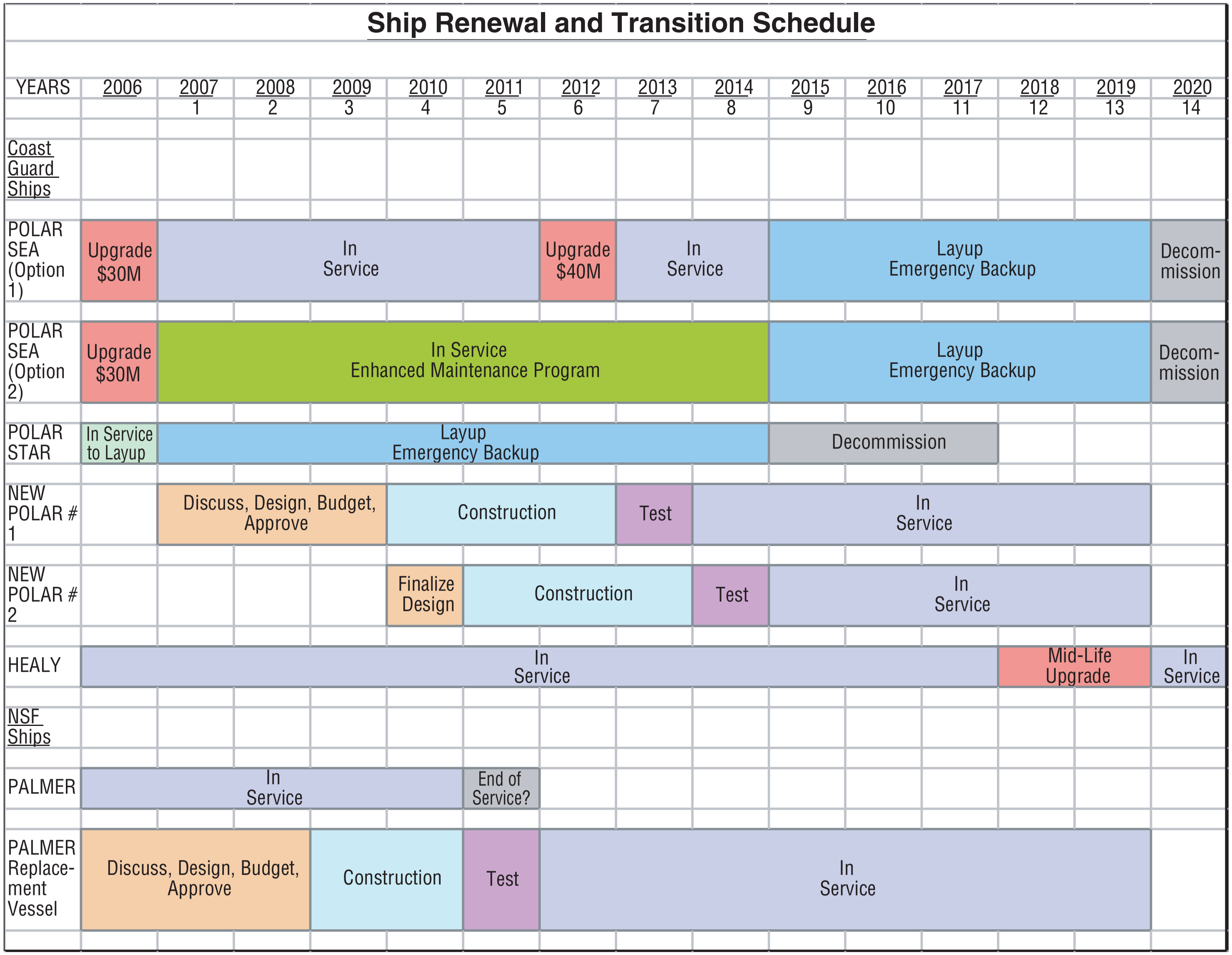
Past and Current Crewing Models

As indicated in Table 10.3, icebreaker crewing models include civilian mariners employed in accordance with commercial standards, government service civilian employees, and military personnel. Logically, these crewing choices for the wide range of icebreakers around the world are based on the following:

- Icebreaker missions and employment: extent, complexity, and area of operations; and
- Specific ship characteristics: size, complexity, age, and level of technology used in shipboard systems.

A survey of icebreakers around the world indicates that ships employed in commercial activities (e.g., Netherlands vessels) or purely for research (AURORA AUSTRALIS, PALMER) tend to be crewed in accordance with commercial standards. Icebreakers with more extensive multimission roles, particularly those representing national interests in the polar regions, have crews comprising government employees or military personnel (Canada, United States, Argentina).

Most polar icebreakers operate almost exclusively in only one of the polar regions: AURORA AUSTRALIS, ALMIRANTE IRIZAR, SHIRASE, and PALMER are almost exclusively Antarctic ships (although PALMER has



Ship Renewal and Transition Schedule

YEARS	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Coast Guard Ships															
POLAR SEA (Option 1)	Upgrade $30M	In Service					Upgrade $40M	In Service		Layup Emergency Backup					Decom-mission
POLAR SEA (Option 2)	Upgrade $30M	In Service Enhanced Maintenance Program								Layup Emergency Backup					Decom-mission
POLAR STAR	In Service to Layup	Layup Emergency Backup								Decommission					
NEW POLAR # 1		Discuss, Design, Budget, Approve			Construction			Test	In Service						
NEW POLAR # 2					Finalize Design	Construction			Test	In Service					
HEALY	In Service												Mid-Life Upgrade		In Service
NSF Ships															
PALMER	In Service					End of Service?									
PALMER Replace-ment Vessel	Discuss, Design, Budget, Approve			Construction		Test	In Service								

FIGURE 10.1 Ship renewal and transition schedule. SOURCE: J. Brigham-Grette, University of Massachusetts

TABLE 10.3 International Polar Icebreaker Ownership, Operation, and Crewing

Country Icebreaker(s)	Ownership Structure	Operating Entity	Crew	Usage
Canada	Government	Canadian Coast Guard	Civilian government employees	Logistics, escort, research, national presence
Australia—AURORA AUSTRALIS	Private—P&O Polar; part-year charter to government	Private—P&O Polar; partial-year charter to government	Civilian P&O employees	Logistics, research
Japan—SHIRASE	Government	Japanese Maritime Self Defense Force (MSDF)	Military—MSDF (Navy)	Research, logistics
Russia	Government	Private—FESCO, Murmansk Shipping Co.	Civilian—FESCO, Murmansk Shipping Co.	Logistics, escort, tourism
Sweden—ODEN	Government	Swedish Maritime Administration	Civilian government employees	Escort, research
Finland	Government	Finnish Maritime Administration	Civilian government employees	Escort, oil and gas service
Norway—SVALBARD	Government	Norwegian Navy/Coast Guard	Military—Navy	Patrol, national presence
Argentina—ALMIRANTE IRIZAR	Government	Argentine Navy	Military—Navy	Logistics, research, national presence
Germany—POLARSTERN	Government	Government—Alfred Wegener Institute	Civilian	Research, logistics
Netherlands—SMIT SAKHALIN, SMIT SEBU	Private	Private—Smit Internationale NV	Civilian—commercial	Oil service
U.S.—PALMER	Private—Edison Chouest Offshore (ECO)	Private—ECO; exclusive charter to U.S. Antarctic Program	Civilian—ECO employees	Research
U.S.—POLAR STAR, POLAR SEA, HEALY	Government	U. S. Coast Guard	Military—USCG	Logistics, escort, research, national presence

conducted one Arctic cruise). The Canadian, Russian, and Finnish fleets, and ODEN and SVALBARD, operate only in the Arctic, the exception being two Russian nonnuclear icebreakers that conduct Antarctic tourist cruises and KRASIN's logistics and escort deployments to McMurdo Sound in 2005 and 2006. The only icebreakers with regular operations in both polar regions are the U.S. polar fleet and POLARSTERN.

The other major basis for crewing—individual ship characteristics—also varies widely. In the United States, the modern icebreaker era began with World War II. Three generations of polar icebreaking ships have been developed in this country, beginning with the Wind class and GLACIER (1940s to 1954), the Polar class (early 1970s) and HEALY (2000). Each generation has been characterized by increases in ship size and complexity, increasingly sophisticated labor-saving technology, and steadily decreasing crew sizes. Less obviously, the operational effectiveness of individual ships has grown, permitting a substantial reduction in fleet size. U.S. polar icebreakers in service decreased from eight in the late 1960s to five once the polar class ships were fully operational.

The Wind class icebreakers and GLACIER featured crews of about 180 and 200, respectively, for postwar operations. Excluding training billets and marine science personnel, the far more capable Polar class vessels each have crews

TABLE 10.4 Comparison of Current Polar Icebreaker Crewing

Personnel	*Polars—* USCG	*HEALY—* USCG	*Polars—* MSC Crew[a]	*N. B. PALMER*[b]	*CCGS ST. LAURENT*
Deck—officers	8	5	5	4	4[c]
Deck—enlisted or unlicensed	39[d]	15[d]	13	7	9[e]
Engineering—officers	5	3	9	4	5[f]
Engineering—enlisted/unlicensed	49[d]	27[d]	15	4	10
Communications, information technology	6	2	1		
Supply and administration	10	7[g]	1		3[h]
Food service[i]	9	6	12	2	5[j]
Medical	1	2	1		1[k]
Ice pilots			2		1[k]
Totals	127	67	59	21[m]	38-44[n]
Marine science support	5	4	6-12[c]		
Aviation personnel[o]	5-14[p]	5-8[p]	TBD	?	2[q]
Science berths (no science suppt)	24	51	TBD	27-33[c]	35-40
Year in service	1976-77	2000	1976-77	1992	1969
Mission scope	Multiple	Multiple	Logistics	Science	Multiple
Shaft horsepower	60,000	30,000	60,000	12,700	30,000
Displacement	13,500	17,500	13,500		
Icebreaking	6+ ft	4.5+ ft	6+ ft	3 ft	
Helicopters	2 hangared	2 hangared	2 hangared	1 on deck	2 hangared

[a] As briefed to USCG, February 2006; numbers reflect full operating staffing (FOS).

[b] Information provided by NSF, January 2006.

[c] 33 total science party berths are available, split between scientists and science support personnel appropriate to the particular cruise.

[d] Under U.S. Coast Guard staffing procedures, senior enlisted personnel perform civilian licensed officer deck and engineering functions, such as watchkeeping.

[e] A Third Officer may be added based on program requirements bringing the complement to 5.

[f] A Carpenter and/or Seaman may be added based on program requirements bringing the complement to 10 or 11.

[g] Includes shoreside supply personnel.

[h] A Third Engineer may be added based on program requirements bringing the complement to 6.

[i] Additional galley staff (assistant cooks and stewards) may be required based on the number of scientific staff carried.

[j] Includes one logistics officer and two storekeepers

[k] An Assistant Cook and/or additional Steward may be added based on program requirements bringing the complement to 6 or 7.

[l] Medical Officer carried for Arctic Operations only.

[m] Information from NSF indicates Palmer "typically sails with 21-25 people" in the operating crew.

[n] Environment Canada Ice Observer carried to monitor, report and provide advice on ice conditions (not considered an ice pilot).

[o] One helicopter pilot and one helicopter engineer carried during operational periods.

[p] Reflects civilian aircraft at lower range; U.S. Coast Guard aircraft staffing at higher range.

[q] Complement may increase, as detailed above, based on program requirements.

of 127. HEALY, the most technologically sophisticated U.S. research vessel and a U.S. Coast Guard ship, is currently operated with a crew of 67 (again, excluding training billets and marine science techs). This trend in icebreaker crewing is also reflected by other U.S. Coast Guard ship acquisitions: the new high-endurance patrol cutter, larger and more capable with a crew of 108, will replace older vessels with crews of 167; and the new large Great Lakes icebreaker will service heavy aids to navigation in addition to winter icebreaking, with a crew of 54 versus 75 for her predecessor.

The trend in U.S. Coast Guard crewing clearly leans toward leveraging available technology, both to reduce crew sizes and to increase operational effectiveness. Recent practice in other maritime sectors—commercial and nonmilitary government vessels—mirrors this trend. Table 10.4 provides a crewing comparison of U.S. and Canadian polar icebreakers, including the preliminary results of an MSC feasibility study of civilian crewing for the Polar class icebreakers.[1]

The large crews on the Polar class ships result primarily from a complex, 1960s-era gas turbine and diesel electric engineering plant that requires a large number of man-hours under way for routine maintenance, repair, and monitoring. Although the engineering control and monitoring system was

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[1] As briefed to the U.S. Coast Guard by Military Sealift Command, February 2006.

updated with additional sensors and control features in the mid-1990s, the plant still requires significant human manipulation. The reliability of machinery and systems has decreased with age, more than offsetting any labor-saving benefits of the new control system. Navigation and ship control is also based largely on traditional manual methods; modern integrated bridge technology would require a major retrofit. The same issues apply to deck and aviation equipment and evolutions. The crews of the Polar class ships also reflect on-the-job training of entry-level personnel—a method that fits well with the need for ample amounts of relatively unskilled maintenance, navigation, deck, and emergency systems man-hours. Also, of course, larger crews increase the need for food service, cleaning, and administrative man-hours—all of which are suboptimized by obsolete storage and space configuration and manual support systems.

The HEALY design addressed and improved all of the Polar class issues discussed above. Most notable is a far simpler engineering plan: 5 diesel engines and 2 propulsion motors in lieu of 10 diesels, 3 gas turbines, 3 large reduction gears, and 3 motors aboard each Polar class ship. The engineering control and monitoring system reflects a generational leap in sensor and information technology. The maintenance philosophy was largely shifted from labor-intensive preventive procedures to condition-based monitoring, trend analysis, and real-time technical troubleshooting from ashore. Smoke, fire, and flooding sensors are numerous, centrally monitored, and backed by CO_2 flooding and water sprinklers. An integrated bridge system permits safe navigation by two watchstanders, and major deck and aviation evolutions can be conducted with far fewer people. Improvements in storeroom and food-service spaces also save man-hours.

It should be noted that crewing of the POLAR SEA, POLAR STAR, and HEALY reflects training and readiness to prosecute the full range of U.S. Coast Guard missions. The Military Sealift Command study primarily addresses the McMurdo break-in.

Canadian icebreaker development began shortly after the World War II with the construction of LABRADOR, a Navy-manned icebreaker based loosely on the U.S. Wind class design. By 1965, all icebreaker operations were assumed by the Canadian Coast Guard, which uses civilian government employees to operate its vessels. Canadian icebreakers assist with shipping in the Great Lakes, St. Lawrence River, and Gulf of St. Lawrence in winter, and operate in the Canadian Arctic during the summer and fall to support research and facilitate the resupply of remote communities and bases. Although Canada has not armed its icebreakers, recent security concerns have elicited discussion that new armed icebreakers may be considered and that Canadian icebreakers might carry weapons and naval detachments (Auld, 2006). The largest Canadian icebreaker, LOUIS ST. LAURENT, entered service in 1969 but was lengthened, reengined, and substantially refurbished in 1993.

Crewing Alternatives for a New Icebreaker

Because crew composition and size flow naturally from the mission and characteristics of a particular ship design, it is difficult to develop crewing alternatives without detailed information about a new icebreaker. Evolving crewing standards and technology complicate the issue. However, a review of rough order-of-magnitude projections, based on conceptual characteristics of a prospective new icebreaker, can help illuminate the policy choices. Accordingly, civilian and Coast Guard crew projections for future new construction, or complete refurbishment of a Polar class hull, were developed.

This "nominal" new icebreaker would be able to operate independently in either or both polar regions; be capable of conducting the McMurdo resupply alone in all but the most adverse conditions; and be capable of operating in the high Arctic in summer and in lesser Arctic ice conditions in other seasons. The following assumptions were used as a basis for developing potential crewing models:

- An operating profile of approximately 300 days per year, which includes days under way and working port calls;
- Import maintenance, sustainment, and preparation activities of about 65 days per year, requiring full crew availability for maintenance, supervision of contract work, gear on-load and off-load, and other cruise preparations;
- Current proven technology installed: engineering monitoring and control systems, integrated bridge system, centrally monitored smoke, fire, and flooding alarms, et cetera;
- An integrated electric power plant for propulsion and hotel services; shaft horsepower between HEALY and POLAR STAR and POLAR SEA (30,000-60,000).
- Design to incorporate labor-saving features extensively;
- Sailing crew able to operate up to four months continuously and provide support to science parties, passengers, and other mission-related personnel numbering up to 60 people;
- Ship capable of round-the-clock operations for most missions—maximum 12-hour workday while under way;
- No major weapon systems installed, but capable of carrying small arms and machine guns; and
- Crewmembers would be U.S. citizens.

Based on these assumptions, Table 10.5 provides a breakdown of prospective Coast Guard and civilian crewing models.

The Coast Guard crew is based on the personnel allowance for HEALY, projected to a new design that would incorporate features and "lessons learned" to provide additional crewing efficiencies. The detailed crewing proposal was reviewed for feasibility and critiqued by the commanding officer and other experienced officers currently serving on the HEALY, but has not been officially reviewed or approved by the U.S. Coast Guard.

TABLE 10.5 New Icebreaker Crewing Alternatives

	U.S. Coast Guard		Civilian
	Sail-away Crew[a]	Total Crew	Sail-away Crew[b]
Deck—officers	4-5	7	5
Deck—enlisted and unlicensed	7-8[b]	10	9
Engineering—officers	2	3	6
Engineering—enlisted and unlicensed	16-17[b]	25	6
Communications, information technology	2-3	4	1
Supply and administration	2	3	
Food service	4	6	3
Medical	1-2	2	1
Ice pilots			
Totals	~40	60	31
Mission-related berths, passengers	60		60
Total Berths	100		91

[a] Crewmembers required for sailing; remainder of crew rotates aboard.
[b] Standard underway manning.

The civilian crewing model is based on current commercial crewing standards, including the Delta Mariner class (highly automated with diesel Z-drive propulsion), PALMER (ice-capable Antarctic research vessel), and the MSC study for crewing the Polar class ships. The specific crew levels represent the consensus judgment of committee members with extensive experience in seagoing ships, maritime industry management, and polar icebreaking operations.

The proposed U.S. Coast Guard crew would be an independent command of 60 military members. On a rotating basis, 40 crewmembers would constitute the sailing crew while the remainder would be in homeport on leave, undergoing training, planning future deployments, and scheduling maintenance. This shoreside contingent would perform many administrative functions (e.g., parts ordering, inventory control, personnel actions, maintenance planning) that would relieve the sailing crew of significant nonoperational workload. It would provide augmented manpower for efficient in-port turnarounds. An extensive amount of crew training would be conducted during shore rotation periods, reducing the need to train under way. The concept would require five- to seven-year tour lengths for most personnel, but the ability to rotate people would ensure a balance of underway and in-port time that falls within current U.S. Coast Guard standards.

While under way, the U.S. Coast Guard crew would be capable of operating the ship and its installed winches, cranes, and boats, and supporting helicopters if carried onboard. U.S. Coast Guard marine science technicians would not be part of the permanent crew, but research could be supported with adequate science support personnel (similar to procedures used in UNOLS research vessels and PALMER). The crew would exercise the full range of U.S. Coast Guard legal authorities and respond in all U.S. Coast Guard mission areas; however, augmentation would be needed for intensive activities such as managing a major oil spill cleanup.

The civilian crew model could employ either government employees, as used by the Military Sealift Command for some naval auxiliaries and the National Oceanic and Atmospheric Administration for unlicensed shipboard personnel. Alternatively, contract mariners could be used. Government employee status would presumably afford more personnel selectivity, stability, and control over training, although these same objectives might be achieved by a long-term contract with an operating company. Clearly, however, polar icebreaking would require higher-level mariner skills, similar in concept to those needed for liquefied natural gas vessels, chemical tankers, and cable layers, and would require attention to personnel development and retention.

As with U.S. Coast Guard crewing, civilian mariners would be capable of operating the ship and its installed equipment, supporting helicopters, and conducting research with adequate support personnel. The civilian crew would lack the legal, regulatory, and use-of-force authorities of a U.S. Coast Guard-crewed vessel. With training, the icebreaker could perform basic search-and-rescue functions and assist other vessels beset or hindered by ice conditions, but it would lack the authority to order vessel movements or enforce safety and security zones. U.S. and foreign vessels could be monitored but not boarded to ascertain legitimacy or detained. Especially in Arctic operations, the civilian-crewed icebreaker would provide a significant level of capability but would constitute a less robust sovereign presence.

A possible enhancement to the civilian model would be the use of an onboard U.S. Coast Guard contingent to provide legal authorities and expertise. This alternative would be similar to U.S. Coast Guard law enforcement detachments

(LEDETs) assigned to naval vessels for drug interdiction operations in the Caribbean and eastern Pacific Ocean. The use of LEDETs has been successful, but the concept is based on prosecuting a single highly focused mission, centrally coordinated with many other assets and intelligence sources. This focus allows the LEDETs to be trained intensively in single-mission skills, and these skills are complemented by the military expertise available in the naval unit. The LEDET model may be problematic to transfer to the role of an icebreaker operating independently in the Arctic, where the needed responses would likely arise unpredictably from a wide range of missions. It would be difficult to maintain a reasonably sized team of U.S. Coast Guard personnel, possessing the weapons qualifications and skills to conduct boardings, regulatory knowledge to make safety and security decisions, expertise in search-and-rescue planning and execution, and so forth.

TABLE 10.6 New Icebreaker Crew Cost Comparison

	U.S. Coast Guard Crew[a]	Commercial Crew[b]
Number of crew billets	60	31
Cost per day[c]	$13,311	$14,314
Annual crew cost	$4,859,000	$5,225,000

[a] Calculated using 2006 standard personnel costs (includes pay, allowances, transfer, medical, and personnel training costs), which are calculated annually for budget and management purposes.

[b] Calculated using a representative 2006 industry standard personnel cost schedule.

[c] Assumes crew present or available for duty 300 days per year under way and 65 days per year for in-port preparations and maintenance.

Cost Comparison of Crewing Alternatives

Crew cost information is presented in Table 10.6. Total annual costs were calculated by multiplying the annual pay, allowance, medical, training and personnel support costs for each U.S. Coast Guard pay grade by the numbers in the prospective crew, and daily wage and benefit costs for each commercial grade level by the numbers in the commercial crew. Although the ship is assumed to operate 300 days per year, both U.S. Coast Guard and commercial crewmembers were assumed to be needed during in-port periods for deployment planning and preparations, maintenance and maintenance contract supervision, and training.

The numbers are inexact, of course, due to differing compensation systems, but they represent a rough comparison of the crew costs associated with differing crewing models. As Table 10.6 indicates, personnel costs for the U.S. Coast Guard and commercial models examined in this analysis are of the same magnitude.

11

Findings and Recommendations

The findings and recommendations of the committee are based on the analysis of written materials it received, testimony from a variety of sources, and its members' judgment. The committee hopes that its assessment of the nation's need for polar icebreaking capabilities and the role of the U.S. Coast Guard in polar icebreaking operations will contribute to the nation's taking needed actions.

ICEBREAKING NEEDS IN THE ARCTIC

The United States has territory and citizens that permanently reside above the Arctic Circle, creating significant national political, security, scientific, and economic interests in the north. An active and influential presence by the U.S. government in this region is necessary to protect and support these interests. Airborne, spaceborne, and submarine assets can only partially address these missions. Asserting a national presence in the Arctic requires assured access to the region, and icebreaker support is the preferred way to access ice-covered boundary areas. Since 1867 when it was called the Revenue Cutter Service and enforced laws and dispensed justice along the northern Alaskan coastline, the U.S. Coast Guard has provided the visible U.S. presence in this region.

The U.S. Coast Guard has the overarching missions of maritime safety, maritime security, national defense, and protection of natural resources in this region where icebreaking capabilities are sometimes required. The Coast Guard, through use of the HEALY and previously the Polar class vessels (last used in 2002 for Arctic operations), is the main federal presence in the ice-covered waters of this region. Although primarily devoted to oceanographic research, the HEALY is available for other missions ranging from national defense, law enforcement, search and rescue, to support of U.S. commerce (shipping, tourism, fishing, and resource exploration). If this ship is tasked to the Antarctic, as it was in 2002-2003, the federal presence in Arctic waters is reduced significantly.

During winter, the entire Alaskan northern coast and a substantial portion of the Alaskan western coast are ice covered. In summer the Arctic sea-ice margin retreats northward, although not uniformly or predictably, usually creating open waters along the entire coastline for several weeks to several months. Summer sea-ice extent is expected to continue to retreat over the next several decades, creating more broken ice along the Alaskan coastline. This may increase the need to break ice of differing thicknesses, requiring an icebreaker that can navigate the thickest ice encountered.

Economic activity appears to be increasing and moving northward as a result of sea ice. These economic activities involve fishing fleets, cruise ships, and increased interests in more northerly natural resource exploitation, specifically mineral mining and petroleum recovery. In addition, the projected increase in Asian energy demand may increase the use of the Northern Sea Route (primarily north of Russia) and the Northwest Passage (primarily north of Canada). Increased Arctic activity implies a greater human presence, which requires increased monitoring of the region.

Environmental change in the Arctic is already causing destabilizing changes for Alaska Natives and indigenous peoples whose lifestyles are heavily reliant on the marine environment of the Arctic region. These people are seeing increased storm surges, an extended open-water season (due to the ice retreat), and enhanced erosion (e.g., at Shishmaref, Alaska) that affects marine life near run-off. The wider variation in sea-ice conditions during the spring and fall marine hunt period maked it difficult to predict weather conditions, making it more risky to determine when to initiate and terminate the hunt, as well as when it is safe to deploy small boats or to hunt further from shore.

Possible U.S. ratification of the U.N. Convention on the Law of the Sea (UNCLOS) and conducting data collection surveys required by Article 76 would require extensive mapping of the U.S. continental shelf off the coast of Alaska, if the United States wishes to use the treaty to extend its economic zones and/or to counter territorial claims by other Arctic nations. Acquisition of the bathymetric, seismic, and coring data necessary to substantiate a U.S. claim requires access to ice-covered waters and specialized scientific equipment, which at present can be provided only by the HEALY.

The potential increase in human activity in northern latitudes will likely increase the demand on the United States to assert a greater, active, and influential presence in the Arctic to not only protect its interests, but also to project its presence as a world power concerned with security, economic, scientific, and international political issues. Routine U.S. Coast Guard patrols in ice-covered waters would contribute to the nation's presence in the region. To assert U.S. interests in the Arctic, the nation needs to be able to access various sites throughout the region at various times of the year reliably, and at will. While the southern extent of the Arctic ice pack is thinning and becoming less extensive during the summer, there is no question that polar icebreakers will be required for many decades for ingress to much of the Arctic Basin. Ice conditions in the U.S. Arctic are among the most variable and occasionally challenging through the circum-Arctic. National interests require icebreakers that can navigate the most formidable ice conditions encountered in the Arctic.

Recommendation 1: The United States should continue to project an active and influential presence in the Arctic to support its interests. This requires U.S. government polar icebreaking capability to ensure year-round access throughout the region.

ICEBREAKING NEEDS IN THE ANTARCTIC

During the International Geophysical Year of 1957-1958, the United States committed to significant exploration and scientific study of Antarctica. Since that time, the United States has maintained an active presence in Antarctica to develop and protect its strategic interests related to foreign policy and security, environmental protection, and scientific research. The United States has strong interest in ensuring that the Antarctic continent is preserved exclusively for peaceful purposes, furthering scientific knowledge, and preserving and protecting one of the most pristine environments on the globe. In support of these interests, the United States does not claim territory in Antarctica (although it does maintain the basis for a claim), and it does not recognize the (overlapping) territorial claims made by seven other countries.

Multiple national policy statements and Presidential Decision Directives have reaffirmed the importance of an "active and influential" U.S. presence in Antarctica in support of U.S. leadership in the Antarctic Treaty governance process and as a geopolitical statement of U.S. worldwide interests. Currently, 45 countries have acceded to the Antarctic Treaty and have established research programs. The operation of the treaty is by unanimous consent, and the one country-one vote approach has meant in recent years that the influence of the United States has diminished and its leadership is challenged on a regular basis. However, as the lead proponent of the original treaty, the United States has established an influential presence in Antarctica. The nation has served a critical role in maintaining the integrity of the Antarctic Treaty, fostering an atmosphere of international cooperation and partnership.

The U.S. presence in Antarctica is established principally by the year-round occupation of three stations: McMurdo, Palmer, and South Pole. This presence secures the influential role of the United States in the treaty's decision-making system and maintains the political and legal balance necessary to protect the U.S. position on Antarctic sovereignty. Many view the permanent year-round presence of the United States as a major deterrent to those countries that might otherwise wish to exercise their territorial claims. The South Pole Station is of particular importance to sovereignty concerns because the South Pole is at the apex of the areas claimed by the seven countries that assert territorial claims. Thus, scientific activity in the Antarctic is an instrument of foreign policy and should be conducted to support that policy.

The U.S. research presence in Antarctica currently relies on shipborne resupply, with the majority of fuel and cargo for the U.S. Antarctic Program (USAP) delivered to McMurdo Station by tanker and container ship. Fuel and supplies are used either in McMurdo or are delivered to South Pole Station and to USAP's various remote field locations by aircraft or overland traverse vehicles. The amount of fuel and cargo is so large (8,400,000 gallons of fuel [58,600,000 pounds] and 14,200,000 pounds of cargo in 2004-2005) that the only cost-effective means of transport with minimal risk is by ship.

Presently two ice-strengthened ships operated by the Military Sealift Command (MSC) bring in cargo and fuel and remove refuse. These ships *require* that large icebreaker(s) first open a shipping channel through the shorefast ice to McMurdo Station, which in recent years has been up to 80 miles long and provide close escort to and from the ice pier. Ice conditions on the final 12 miles of the sea approach are typically challenging due to the presence of thick, multiyear ice. During the past six years, the break-in through McMurdo Sound has become increasingly more challenging. Until 2006, large icebergs in the Ross Sea blocked wind and currents from clearing the ice from McMurdo Sound, and the blockage increased the amount of harder, thicker, multiyear ice in the sound. The last six seasons have generally required two icebreakers to break and groom the channel and to escort transport ships through the channel.

Over the past several years, severe ice conditions in the Ross Sea necessitated two icebreakers to break the channel to McMurdo Station. In 2002-2003, POLAR STAR was not mission capable and the HEALY was diverted on short notice to assist the POLAR SEA in the McMurdo channel clearing. Use of the HEALY in the Antarctic in 2003 reduced the in-port maintenance time between completion of its extensive 2002 science missions and its redeployment for spring 2003 missions. Due to competing interests for science missions in the western and eastern Arctic, the National Science Foundation (NSF) tasked the NATHANIEL B. PALMER to its first Arctic mission in summer 2003 since the reduced ice that year was suitable for its ice strength. It should be noted that this option would likely not have been possible with the heavy 2006 summer ice, where multiyear ice extended south past Barrow, Alaska, in July.

In 2004-2005, unusually heavy ice conditions again necessitated use of two heavy icebreakers. At this time, the POLAR SEA was in dry dock and not mission capable. The NSF contracted the services of the Russian icebreaker KRASIN, operated by the Far East Shipping Company to assist the POLAR STAR.

Concerned about the reliability of POLAR STAR, NSF hired the KRASIN to break the channel to McMurdo Station for the 2005-2006 resupply mission, and the POLAR STAR remained on "standby" in port in Seattle to assist the KRASIN if needed. The KRASIN attempted the break in alone, but broke a propeller blade (which Navy divers could not repair) before successfully escorting the tanker and container ship through difficult ice conditions. The POLAR STAR was dispatched from standby in Seattle and made a direct 23-day transit to McMurdo Sound. When refueling commenced, McMurdo Station had only five days of fuel remaining.[1] These events highlight the difficult ice conditions, the aging condition of the only two U.S. icebreakers powerful enough to perform the McMurdo break-in, and the questionable condition of icebreakers that can be chartered on the open market. These conditions make future resupply missions vulnerable to failure.

With the importance of the U.S. interests in Antarctica and the role that physical presence plays in supporting and protecting those interests, logical questions arise. Is there a better logistics site than McMurdo Station to serve the USAP resupply? Perhaps an alternative site could be found that is not routinely surrounded by thick summer sea ice requiring Polar class icebreaking capabilities for access. Guided by the findings from previous in-depth studies and the committee's own evaluation, the answer is no. While some alternative locations may provide improved support for certain aircraft, or reduction in required icebreaking, they do not provide both. In addition, these alternate sites do not address other vital U.S. criteria, such as support for South Pole Station or specific science activities.

If McMurdo remains the best choice for the foreseeable future, can resupply be intermittent; that is, if McMurdo Sound ice conditions make break-in too difficult, can resupply be skipped for a year? A National Science Foundation advisory subcommittee answered yes to this question. To make it possible to skip one year of resupply, NSF would have to increase fuel reserve tanks on continent, reduce the logistical dependence of the South Pole Station on McMurdo, and reduce USAP personnel at McMurdo and South Pole when appropriate.

Would preparing to skip one annual resupply materially affect the issues being addressed by this committee? The answer is no. Once resupply has been skipped for a year, it is mandatory in the next year, or skeletal staffing (or abandonment) of McMurdo Station, and perhaps the South Pole Station, may become necessary. The latter alternative is not acceptable. Despite these changes in logistics, the NSF subcommittee concluded that shipborne resupply, supported by icebreakers that can reliably break the required channel into McMurdo Station dock, remains the best mode of logistics for the USAP. Thus, the nation must have icebreaker ships that permit break-in any year it is deemed necessary. This reality requires reliably controlled icebreaker capability that can be ensured over decades. Annual charter—commercial or from another nation—provides insufficient assurance of successful resupply for the long term.

The committee concludes that for the purposes of the single mission of McMurdo resupply, the icebreakers do not necessarily need to be operated by the U.S. Coast Guard, but to best meet mission assurance requirements they should be U.S. flagged, U.S. owned, and U.S. operated. Without specific proposals it is difficult to evaluate the cost-effectiveness or the possibility that other nations might partner to invest in a Polar class icebreaker with the United States.

Ice conditions will be increasingly difficult until a considerable portion of the multiyear ice in the sound is removed by natural processes. For the foreseeable future, two polar icebreakers will be needed to support the resupply mission at an acceptable level of risk. U.S. icebreaking assets must be sized to handle the most difficult ice conditions in McMurdo Sound.

Recommendation 2: The United States should continue to project an active and influential presence in the Antarctic to support its interests. The nation should reliably control sufficient icebreaking capability to break a channel into and ensure the maritime resupply of McMurdo Station.

SUPPORT OF U.S. POLAR RESEARCH

The history of polar research is tied directly to the geopolitical circumstances following World War II and the subsequent Cold War era. In the south this was evidenced by the deployment of nearly 3,000 personnel to Antarctica in the U.S. commitment to the International Geophysical Year (IGY) in 1957-1958. While polar research was seen as important, it also provided a mechanism to project U.S. global

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[1] Erick Chiang, National Science Foundation, personal communication, June 1, 2006.

presence and power in a manner that served U.S. interests. Construction of the Distant Early Warning (DEW) Line radars looking toward the former Soviet Union necessitated a year-round presence, creating a need for a better understanding of the Arctic environment and improvement in our ability to work and live in the extreme cold. The establishment of research facilities in Barrow was an outgrowth of political and military necessities of the time.

Fundamental advances resulting from polar research have directly benefited society. Polar research led to the identification of the presence and cause of the "ozone hole," leading to society's widespread discontinuance of the use of chlorofluorocarbons. Understanding how both polar regions affect global ocean circulation affects the understanding of climate. The study of Weddell seals, which dive to great depths and cease breathing for long periods, led to better understanding of how such mammals handle gas dissolved in blood during and after deep diving events. This has contributed to advances in understanding sudden infant death syndrome (SIDS). The study of mammals, insects, and plants that endure freezing temperatures yet prevent the formation of ice crystals in their internal fluids is aiding in the design of freeze-resistant crops and improved biomedical cryopreservation techniques.

The Arctic and Antarctic are natural laboratories whose extreme, relatively pristine environments and geographically unique settings enable research on fundamental phenomena and processes that is not feasible elsewhere. Today, researchers seek better understanding of how new ocean crusts form, how organisms adapt to the extremes of temperature and seasonality (light conditions), how ice sheets behave, and how the solar wind and the earth interact. Unexplored, subglacial lakes in the Antarctic that have been sealed from the atmosphere for millions of years are soon to be sampled. Beneath the South Pole Station, a cubic kilometer of clear ice is being instrumented with 5,000 detectors to observe high-energy neutrinos that may tell us about phenomena such as supernovae. Pristine ice cores that span centuries give direct data about temperature changes and atmospheric gas concentrations.

As global climate has garnered worldwide attention, the polar regions have been found to react acutely to fluctuations in climate and temperatures. The 40 percent reduction in Arctic sea-ice thickness over the past four decades is one of the most dramatic examples of recent changes. Because ice tends to reflect solar radiation and water absorbs it, melting in the polar regions can exert a strong influence on both atmospheric climate and ocean circulation. Huge reservoirs of water are held in massive ice sheets and glaciers; substantive release would create major climate and social dislocations. Thus, research in these regions that play a pivotal role in global Earth systems is of critical importance. Scientists have declared 2007-2008 the International Polar Year. Multinational collaboration and new polar research activities are planned.

The health and continued vitality of polar research are intimately linked to the availability of the appropriate infrastructure and logistical support to allow scientists to work in these harsh environments. Conducting research in the polar regions is as complex and challenging as conducting research in space. Access to the polar regions is essential if the United States is to continue to be a leader in polar science. To operate reliably and safely in these regions necessitates a national icebreaking capability. Icebreakers enable resupply of the land-based stations and field camps in the south. Lack of availability of polar icebreakers has precluded some research in the Southern Ocean where ice is heavy. Access to the central Arctic Basin is essential to a variety of explorations, including some data collection for UNCLOS claim-related interests. While other assets and platforms such as airplanes and spaceborne sensors are useful technological tools, surface ground-truth and in situ sampling cannot be replaced. There are no land sites in the central Arctic. Only an icebreaker can support a research program of sustained scientific measurement. The availability of adequate icebreaking capabilities will be essential to advancing research in the polar regions.

Recommendation 3: The United States should maintain leadership in polar research. This requires icebreaking capability to provide access to the deep Arctic and the ice-covered waters of the Antarctic.

RENEWAL OF THE NATION'S POLAR ICEBREAKING FLEET

Projecting an active and influential presence in the polar regions requires that the United States be able to access polar sites at various time of the year, reliably and at will. It is the judgment of this committee that this need is only partially fulfilled by airborne, spaceborne, and submarine assets and that a physical surface presence is necessitated by geopolitics. In recent correspondence to the committee, the Department of State, the Department of Defense, and the Department of Homeland Security further validated that icebreaking capability is necessary to protect national interests in the polar regions. Assured access to the polar regions is therefore a key tenet: The United States needs to maintain a national capability to break heavy, multiyear ice in the northern and southern polar regions. Based on these broad missions, the committee believes that the core of the icebreaking fleet must be the multimission ships operated by the U.S. Coast Guard, a military organization.

Only polar icebreakers can ensure this vital access, reliably and at will. Since the Second World War, the United States has possessed a capable, world class icebreaker fleet that afforded wide access to the polar regions. The current seagoing U.S. fleet of four ships includes three multimission ships operated by the U.S. Coast Guard and one ship, the PALMER, dedicated to scientific research and appropriately operated by the National Science Foundation. One of the three multimission ships, the HEALY, was commissioned in

1999 and its performance has exceeded design specifications. The HEALY's operating time is dedicated to the support of Arctic research. While capable of performing many additional U.S. Coast Guard missions including search and rescue, sovereignty, presence, and law enforcement, HEALY cannot operate independently in the ice conditions of the central Arctic and McMurdo Sound. The HEALY was built to complement the Polar class ships.

Now, however, the two most powerful U.S. polar icebreakers are both at the end of their 30-year designed service lives. Over the last decade, no major service life extension program has been planned to extend their operation, and no replacement vessels have programmed. As a consequence, U.S. icebreaking capability is today at risk of being unable to support national interests in the north and the south.

The committee believes that the nation continues to require a fleet that includes a minimum of three multimission ships. This conclusion is consistent with the findings of an earlier study, the 1984 United States Polar Icebreaker Requirements Study (PIRS) conducted by U.S. Coast Guard, Office of Management and Budget, National Science Foundation, National Oceanic and Atmospheric Administration (NOAA), Department of Defense, Maritime Administration, and Department of Transportation. It is also consistent with a 1990 Presidential Report to Congress that reiterated that polar icebreakers were instruments of national policy and presence and that three (multimission) polar icebreakers were necessary to meet the defense, security, sovereignty, economic, and scientific needs of the nation (together with a fourth, dedicated research ship, the PALMER). The committee agrees with the findings of the two previous reports. In addition, the committee notes that icebreaking needs have increased since 1990 and will continue to increase into the foreseeable future. This projected increased demand is a direct effect of a changing climate facilitating increased human presence in the Arctic.

Although the demand for icebreaking capability is predicted to increase, the committee believes that the application of the latest technology, creative crewing models, wise management of ice conditions, and more efficient use of the icebreaker fleet and other assets can meet increased requirements while maintaining the number and configuration of the icebreaker fleet the same as today—two Polar class ships, HEALY and PALMER. The demand for icebreaking capability in support of research is also increasing. Today, the National Science Foundation leases the PALMER for research in Antarctic at the ice edge and in light ice. NSF may replace the PALMER in the not too distant future (possibly to acquire more icebreaking capability and thus greater access in the Antarctic), but it will first construct a new ice-strengthened ship, the Alaskan Region Research Vessel, for Arctic research. The icebreaking capabilities of the Alaskan Region Research Vessel will be those of a light icebreaker, for example designed to be able to work safely in young ice and the marginal ice zone. Thus, that ship will not be a "polar icebreaker" in the sense of this report. The committee concluded that the demand of the science community for dedicated research vessels with a variety of icebreaking capabilities will greatly increase in both polar regions. When used in conjunction with the polar icebreakers, research ships will be able to venture into waters that they could not safely transit alone, maximizing the return on the nation's investment in science and the icebreaking fleet.

One new polar icebreaker is insufficient for several logical reasons. First, a single ship cannot be in more than one location at one time. No matter how technologically advanced or efficiently operated, a single polar icebreaker can be operational (on station) in the polar regions for only a portion of any year. An icebreaker requires regular maintenance and technical support from shipyards and industrial facilities, must reprovision regularly, and needs to effect periodic crew change-outs. These functions cannot be conducted practically or economically "in the ice" and therefore require transit time to and from polar operating areas. A single icebreaker, therefore, could not meet any reasonable standard of active and influential presence and reliable, at-will access throughout the polar regions.

A second consideration supporting the need for more than a single polar icebreaker is the potential risk of failure in the harsh conditions of polar operations. Icebreakers are the only ships designed to collide regularly with hard objects and to go independently where no other surface vessels can survive. Despite their intrinsic robustness, damage and system failure are always a risk and the U.S. fleet must have enough depth to provide backup assistance. Being forced to operate with only a single icebreaker would necessarily require the ship to accept a more conservative operating profile, avoiding more challenging ice conditions because reliable assistance would not be available. A second capable icebreaker, either operating elsewhere or in homeport, would provide assured backup assistance and would allow for more robust operations by the other ship.

From a more strategic, longer-term perspective, two new icebreakers will far better position the nation for the increasing challenges emerging in both polar regions. Building two new icebreakers will ensure maintenance of this level of capability. A second new ship would allow the U.S. Coast Guard to reestablish an active patrol presence in U.S. waters north of Alaska to meet statutory responsibilities that will inevitably derive from increased human activity, economic development, and environmental changes. Other unplanned situations can include search-and-rescue cases, pollution incidents where initial response and U.S. Coast Guard monitoring are necessary, and assistance to ships threatened with grounding or damage by ice. The likelihood of these situations will increase as the number of ice-strengthened tankers, tourist ships, and other vessels in the polar regions grows.

Moreover, a second new ship will leverage the possibilities for simultaneous operations in widely disparate geographic areas (such as concurrent operations in the Arctic and Antarctic), open additional solutions for conducting Antarctic logistics, allow safer multiple-ship operations in the most demanding ice conditions and areas, and increase opportunities for international expeditions. Finally, an upfront decision to build two new polar icebreakers will allow economies in the design and construction process and provide a predictable cost reduction for the second ship.

The committee was asked to consider alternative ship ownership options. Considering the McMurdo break-in mission alone, the committee found that only a U.S.-flagged, U.S.-owned, and U.S.-operated ship provides sufficiently reliable control. While that ship might be leased commercially through a long-term lease-build arrangement, from a total fleet perspective it may be more cost-effective if science missions users only pay incremental costs—as has been the case in the past—and if U.S. Coast Guard provides McMurdo resupply support from the multimission icebreaker fleet. Also, the sovereign presence of the United States is not well served by a "leased ship." Commercially or internationally leased ships may not provide a practical backup for a uniformed service ship that is not owned by the United States government. Such commercial or international arrangements do not ensure that the United States could assert its foreign policy at times and places of its choosing. Increasing world demand for polar icebreakers to support Arctic oil and gas exploration and development has significantly reduced the number of available ships, making long-term lease of an existing ship difficult.

The U.S. Coast Guard has a legacy of almost 140 years of supporting the nation's icebreaking needs in the polar regions. The U.S. Coast Guard has the overarching missions to protect the public, the environment, and U.S. economic interests throughout the maritime environment, including ice-covered waters. The committee finds that the U.S. Coast Guard is the best federal agency to operate polar icebreakers in continued support of vital national interests in the rapidly changing polar regions. In this, the committee agrees with the PIRS 84 study that concluded, "An icebreaker fleet is essential to the national interest" and "should be operated by the U.S. Coast Guard."

The committee concludes that the research support mission and other U.S. Coast Guard missions can, in many cases, be compatibly performed with a single ship. The two existing Polar class ships and the HEALY are equipped to support research and have productively served that mission. The committee believes that it is advantageous to configure the U.S. Coast Guard ships with appropriate science facilities as well as facilities for the Coast Guard's more general missions. In the long run, constituting the nation's icebreaking fleet as a single fleet of complementary ships will yield more capability and should be more cost-effective than if each agency independently acquires icebreaking ships. This approach is in line with the long-held belief that the nation can gain the greatest economy from the sharing of assets across agencies and programs when appropriate and feasible and that those users should share in the incremental increase in cost associated with directed usage of national assets.

The committee was asked in what manner to acquire ships. The benefits of constructing a new ship were compared to overhauling and extending the life of POLAR STAR or POLAR SEA. A so-called service life extension program (SLEP) involves wholesale replacement of the propulsion plant and auxiliary, control, and habitation support systems. While the cost of a new hull could be avoided, the retrofit of most systems would be costly and limited by the constraints of the existing hull. The committee recommends new construction for several reasons. First, the new ship could be designed to incorporate the desired mix of mission capabilities without the constraints of the existing Polar class hull. There are very effective new technologies, particularly new hull designs (such as the double-acting hull), that could offer improvements in efficiency and effectiveness. Rough estimates provided to the committee indicate that the cost of reconstruction (SLEP) would be substantial, perhaps approaching that of new construction. A newly designed ship would also meet more stringent environmental standards than the current ships.

Recommendation 4: National interests in the polar regions require that the United States immediately program, budget, design, and construct two new polar icebreakers to be operated by the U.S. Coast Guard.

TRANSITION TO A NEW POLAR ICEBREAKING FLEET

Even under the best conditions, the new polar icebreakers will not enter service for another 8 to 10 years until the program, budget, design, construction, and test phases are completed. During this time, the United States needs a transition strategy to ensure a minimum level of icebreaker capability. To meet this need, the committee recommends a maintenance upgrade strategy to keep the POLAR SEA mission capable until at least the first new polar ship enters service. The renewal and maintenance costs to keep this ship mission capable are much lower than a service life extension program. The resulting capability, an upgraded POLAR SEA and a fully capable HEALY, is less than this committee believes the nation needs, but it is a cost-effective strategy that emphasizes new construction rather than maintenance of aging ships. The committee also advises that the POLAR STAR continue to be kept in caretaker status, with minimal crew and indefinitely moored at the U.S. Coast Guard pier. If the POLAR SEA has catastrophic problems, the POLAR STAR could be minimally upgraded and brought back into service within a year or so.

This strategy carries some risk, and that risk comes from a decade of inaction. The strategy would permit the United States to locate an icebreaker (POLAR SEA and HEALY*)* in each polar region as needed. By operating together the two ships could reinforce each other in the most challenging ice conditions, such as on a central Artic mission or in McMurdo Sound. The NSF may have to supplement the POLAR SEA with a commercial or internationally chartered ship when the McMurdo break-in is particularly difficult as is expected in the coming year. For example, an arrangement with Sweden might make the ODEN available. This strategy is not ideal and it carries significant risk, but due to the long lead time for new ships there are no alternatives.

Execution of this transition strategy has already commenced. The POLAR SEA completed sea and ice trials in August 2006 after undergoing repair work at a cost of approximately $30 million. The POLAR SEA should be capable for the 2007 McMurdo break-in but will likely need the assistance of a second ship due to severe ice conditions. These repairs however are not sufficient to sustain the ship long term; they will keep the POLAR SEA in operating condition only for several years.

Keeping the POLAR SEA mission capable to roughly 2015 or so will require another significant round of maintenance and repair of aging shipboard systems. The U.S. Coast Guard should determine the best way to do this work. One strategy is for the POLAR SEA to be taken out of service for a year of shipyard work around 2012, at a cost of roughly $40 million. An alternative maintenance strategy that avoids having the POLAR SEA out of service for a year is to perform the work in year-by-year increments when the ship is in port. Careful planning would be required for the U.S. Coast Guard to determine which upgrade strategy is better. (These issues are discussed in more detail in Chapter 10.) Possibly by 2012, it would be prepared to skip McMurdo resupply for one year, or the NSF might arrange for an alternative icebreaker to perform the break-in during a year that the POLAR SEA is in the shipyard.

If risk reduction is paramount to national needs, maintenance work to return the POLAR STAR to operating condition could be accomplished over the same time period. The committee has developed a time line showing transition alternatives from the current fleet of U.S. Coast Guard and NSF icebreakers to the "new" fleet, from the present through 2020.

Recommendation 5: To provide continuity of U.S. icebreaking capabilities, the POLAR SEA should remain mission capable and the POLAR STAR should remain available for reactivation until the new polar icebreakers enter service.

MANAGING THE NATION'S POLAR ICEBREAKING FLEET

Both icebreaker operations and maintenance of the polar icebreaker fleet have been underfunded for many years. Deferring long-term maintenance and failing to execute a plan for replacement or refurbishment of the nation's icebreaking ships have placed national needs in the Arctic and Antarctic at risk. The recent transfer of budget authority for the polar icebreaking program by the Office of Management and Budget (OMB) from the U.S. Coast Guard to NSF did not address the basic problem of underfunding routine maintenance or providing funds for U.S. Coast Guard non-science icebreaker missions. The transfer has increased management difficulties by spreading management decisions related to the polar icebreakers across two agencies.

The NSF now has fiscal control over all direct costs associated with the polar icebreaking program, including personnel, training, operation, and maintenance costs. Under a Memorandum of Agreement negotiated between the U.S. Coast Guard and NSF, the U.S. Coast Guard must submit a yearly plan for approval by the NSF. The NSF is now fiscally responsible, and making decisions, for missions outside its core mission and expertise. Without budget authority, the U.S. Coast Guard has been put in a situation in which it has the role of operating a ship for which it does not have full budget and management control.

The committee believes that the total set of U.S. Coast Guard icebreaking missions transcends the mission of support to science, despite the fact that the majority of icebreaker usage at the current time is to support research. The U.S. Coast Guard should have the funds and authority to perform the full range of mission responsibilities in ice-covered waters of the Arctic. There is strong evidence that national need for polar icebreaking in the Arctic will increase over the next several decades. Orders for commercial ice-strengthened tankers will double the worldwide fleet of these vessels. Most are slated to operate in the western Arctic along the Northern Sea Route, but expansion of hydrocarbon development activities to the Alaskan North Slope and Canadian Beaufort Sea is proceeding. With this added human presence, a robust U.S. Coast Guard polar icebreaker fleet will be needed for regular patrols of our coastal waters to increase U.S. presence in international Arctic waters. This will require resumption of regular patrols of coastal waters and an increased U.S. presence in international Arctic waters by the nation's multimission icebreaker fleet. It is not sufficient to provide funds to only maintain the fleet; it is necessary to provide funds to operate it effectively. The committee strongly believes that management responsibility should be aligned with management accountability.

When NSF, NOAA, or another "user" agency employs a U.S. Coast Guard icebreaker to support some directed activity, the user agency should pay only incremental costs associated with direct mission tasking. This arrangement has worked well for decades, although it would be useful for the financial arrangement to be clarified and reasserted by the administration. If the U.S. Coast Guard is funded to operate a vessel, then direct tasking reimbursement would typically include the cost of fuel for extended transit beyond patrol, and on-ship engineering and habitation costs that derive from research activities. The committee distinguishes between direct mission tasking of a science voyage and science of opportunity where scientists or educators are aboard at the invitation of the U.S. Coast Guard on voyages planned for Coast Guard patrol missions. The committee encourages the U.S. Coast Guard to invite researchers and educators on planned patrols to conduct science of opportunity. Only direct tasking should result in reimbursement to the U.S. Coast Guard above its congressionally appropriated operational funds.

Recommendation 6: The U.S. Coast Guard should be provided sufficient operations and maintenance budget to support an increased, regular, and influential presence in the Arctic. Other agencies should reimburse incremental costs associated with directed mission tasking.

CLARIFICATION OF NATIONAL POLICY

The U.S. need for polar icebreaking has been studied several times over the past two decades. This committee has reviewed these studies and believes the essential conclusions remain the same. As a nation with citizens in the Arctic and a significant, continuing investment in the Antarctic, the United States has a clear obligation to assure the welfare of these citizens and to protect its interests in the polar regions. The polar icebreaker fleet has been described as a national asset that is capable of meeting multiple missions. The committee concurs with previous studies and strongly supports renewal of the nation's polar icebreaking capability.

The last declaration of presidential-level policy regarding the U.S. requirements for polar icebreaking was a Presidential Report to Congress in 1990. While recognizing the national need for polar icebreaker operations, that report does not adequately address current and future issues.

Immediate policy action is needed for several reasons: wholesale ship obsolescence in the fleet; lack of adequate U.S. Coast Guard capability in the Arctic; increased human presence and economic activity in the Arctic region; and threats to Native Alaskan communities due to accelerating environmental changes. Clear direction for sustaining these capabilities needs to be asserted to ensure that the United States does not find itself without adequate polar icebreaking capability in the future as it has in the past and as it does today. If the multimission ships are to be used most effectively as a national asset, then the agency with the core mission to support the polar icebreaking needs of the nation—the U.S. Coast Guard—must have adequate budgetary authority and operational control of these ships. The committee has reviewed laws and statutory authorities related to U.S. polar icebreaking and finds these to be adequate. There is a need, however, for policy clarification within the Executive Branch. The U.S. Coast Guard operational mission in the ice-covered waters of the Arctic needs to be reaffirmed.

Recommendation 7: Polar icebreakers are essential instruments of U.S. national policy in the changing polar regions. To ensure adequate national icebreaking capability into the future, a Presidential Decision Directive, should be issued to clearly align agency responsibilities and budgetary authorities.

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A

Statement of Task

Polar icebreakers are essential for the United States to conduct operations in the Antarctic and the Arctic regions. This study will provide a comprehensive assessment of the current and future roles of Coast Guard polar icebreakers in supporting U.S. operations in the Antarctic and the Arctic, including scenarios for continuing those operations and alternative approaches, the changes in roles and missions of polar icebreakers in the support of all national priorities in the polar regions, and potential changes in the roles of Coast Guard icebreakers in the Arctic that may develop due to environmental change. Specifically, this study will:

1. Assess the roles of U.S. Coast Guard icebreakers (heavy, medium, and light) in supporting U.S. operations in the Antarctic and the Arctic and provide an analysis of the overall demand for icebreaking services, including:

    a. Describe present uses of polar icebreakers with respect to the relevant missions in the Antarctic and the Arctic, including national defense, homeland security, support of economic activity, law enforcement, search and rescue, environmental protection, and the support of and conduct of science.
    b. Describe expected future needs for polar icebreakers, such as where and when the polar icebreakers will be expected to operate and what capabilities will be needed in order to accomplish all missions in the polar regions.
    c. Determine the approximate number and types of Coast Guard polar icebreakers needed in the future and when and where they might be expected to operate to meet national priority concerns in the polar regions.

2. Present and analyze a small number of feasible scenarios for continuing polar icebreaker operations in the polar regions, including service life extension of existing Coast Guard icebreakers, replacement of existing Coast Guard icebreakers, and alternate methods of meeting identified needs (e.g., resupply of McMurdo Station and availability of platforms for marine research), including use of ice-strengthened vessels, foreign vessels, and other options that do not use Coast Guard services.
3. Describe potential changes in the roles and missions of Coast Guard polar icebreakers in support of future marine operations in the Arctic that may develop due to environmental change.
4. Review existing laws governing Coast Guard polar icebreaking operations and present recommended changes based upon potential missions and new operating regimes.

This study will be conducted in two phases. The committee will deliver an interim report by November 30, 2005, that provides the foundation materials needed for urgent decision making. In addition it will deliver a final, detailed report in the summer of 2006 that meets the requirement for a comprehensive study, which cannot be accomplished in the initial timeframe. In phase one, the committee will focus on conducting the demand analysis (Task 1) and outlining the nature of the feasible scenarios for continuing operations, including identification of those that seem most promising (starting on Task 2) for additional analysis. The potential for environmental change (Task 3) is one variable that will be considered when identifying promising scenarios, although details will be developed and provided in phase two.

B

Summary from Interim Report

At the request of Congress in PL 108-334, the U.S. Coast Guard (USCG) provided funds to the National Research Council of the National Academies to establish the Committee on the Assessment of U.S. Icebreaker Roles and Future Needs. The Committee's Statement of Task (Appendix A) charges it to provide a comprehensive assessment of the current and future roles of U.S. Coast Guard polar icebreakers in supporting U.S. operations in the Antarctic and the Arctic, including scenarios for continuing those operations and alternative approaches, the changes in roles and missions of polar icebreakers in the support of all national priorities in the polar regions, and potential changes in the roles of U.S. Coast Guard icebreakers in the Arctic that may develop due to environmental change. The committee was asked to provide a brief interim report to highlight the most urgent and time-dependent issues, and this report fulfills that request. The committee will provide a final report covering the full scope of its tasks and more detailed analysis in the late summer of 2006.

In this interim report, the committee describes present and expected future uses of the polar icebreakers (POLAR STAR, POLAR SEA, and HEALY) with respect to relevant U.S. Coast Guard missions in the Antarctic and the Arctic, including national defense, homeland security, support of economic activity, law enforcement, search and rescue, environmental protection, and the support of and conduct of science, as part of an overall demand for icebreaking services. This report also addresses potential changes in the roles and missions of U.S. Coast Guard polar icebreakers in support of future marine operations in the Arctic that may develop due to environmental change. The committee addresses what it believes are the most time-dependent issues for decisions makers, focusing in particular on the urgent, short-term need for reliable icebreaking support. Longer-term issues will be covered in detail in the committee's final report.

The committee appreciates the presentations and supplementary materials provided by the U.S. Coast Guard, National Science Foundation, Arctic Research Commission, Department of State, National Oceanic and Atmospheric Administration, and others in the marine transport and science communities. The committee's findings and recommendations are based on its analysis of the materials and briefings received, and the committee's expert judgment. The committee members have expertise in ship design and operations, national defense, naval architecture, marine transport–shipping industry, polar ship technologies, icebreaker command and operations, science management, oceanography, glaciology, sea ice dynamics, paleoclimatology, and Antarctic policy.

Congressional staff and Office of Management and Budget (OMB) examiners spoke with the committee and they indicated a need for management decisions regarding the polar icebreakers. The committee was told that the findings and recommendations in this report could be useful for informing FY07 budget decisions. Although the Statement of Task does not request the committee to make management recommendations, it explicitly instructs the committee to provide materials for urgent decision making. Thecommittee believes that management recommendations are useful to both Congress and OMB to help in resolving the U.S. Coast Guard icebreaker issue for FY07 and until a long-term solution can be found. The committee hopes that the interim findings and recommendations will inform decision making while it proceeds to carefully develop recommendations for a long-term solution. The committee identifies four overarching issues for which findings and recommendations are made. These issues are icebreaking needs for the Antarctic and for the Arctic, the current status of the U.S. Polar Class (heavy) icebreakers, and managing the nation's icebreaking assets.

ICEBREAKING NEEDS IN THE ANTARCTIC

The need for icebreaking in the Antarctic is primarily a result of a succession of national policy statements and Presidential Decision Directives, which assert that the United States has strategic interests in the Antarctic related to foreign policy and security, environmental protection and scientific research. The United States asserts strategic interests in Antarctica through the year-round residence of American researchers at three permanent scientific stations. The presence of the South Pole Station, in particular, helps protect the U.S. position on sovereignty in Antarctica, providing for a unique research platform at a location that assures U.S. participation in the Antarctic Treaty system.

Despite some missions of opportunity, the primary use of U.S. heavy icebreakers (POLAR STAR and POLAR SEA), at present, is to break a channel into McMurdo Station to aid the resupply that is critical to the continued functioning of both the McMurdo and South Pole Stations. By using an altered logistics strategy, the National Science Foundation (NSF) has determined that it may be possible to maintain operations at the McMurdo and South Pole Stations while occasionally skipping annual channel break-in and ship-borne portion of the McMurdo resupply to avoid a break-in under extraordinarily heavy ice conditions. Nevertheless icebreaker support of the break-in to McMurdo Station is required for the foreseeable future. Based on these findings, the committee recommends:

- **Recommendation #1**: The United States should reliably control (by ownership or other means) at least one heavy icebreaker that is available and capable of breaking a channel into McMurdo Station.

The committee will investigate in the next several months how the icebreaker assets should be controlled to meet the nation's icebreaking needs, and recommendations will be provided in the final report.

ICEBREAKING NEEDS IN THE ARCTIC

Because of the geographic location of Alaska, the United States is an Arctic nation with significant geopolitical, security, economic, and scientific interests in the Arctic, and U.S. interests must be protected in this region. The U.S. Coast Guard has the overarching missions of maritime safety, maritime security, national defense, and protection of natural resources in this region where icebreaking capabilities are sometimes required. Although the HEALY is primarily devoted to fulfilling the U.S. Coast Guard mission to support scientific research, this ship is also available to support the overarching U.S. Coast Guard missions in the Arctic. If this ship is tasked to the Antarctic, as it was in 2002-2003, the federal icebreaker presence in arctic waters is reduced significantly.

In the winter, the entire Alaskan northern coast and a substantial portion of the Alaskan western coast is ice-covered. In the summer months, the Arctic sea ice margin retreats northward creating open waters around the entire Alaskan coastline for several weeks to several months. Arctic sea ice extent over the next several decades in early spring and late summer (shoulder seasons) is expected to be even further reduced, creating more broken ice along the Alaskan coastline. Greater spatial and temporal variability in sea ice extent and thickness throughout the Arctic is expected, which may influence the capability needed to break ice of differing thicknesses in certain regions of the Arctic.

Economic activity appears to be increasing and moving northward as a result of dramatic ice margin retreat over recent years. These economic activities involve fishing fleets, native Alaskan hunting and fishing expeditions, cruise ships, and increased interests in more northerly natural resource exploitation. Increased activity would imply a greater human presence in these regions, where risks are increasing due to changing ice edge environments and more broken ice in open waters. In addition, possible ratification of Article 76 of the U.N. Convention on the Law of the Sea would require extensive mapping of the U.S. continental shelf off the coast of Alaska, if the United States wishes to use the treaty to extend its economic zones and counter claims by other Arctic nations.

The potential increase in human activity in northern latitudes will likely increase the demand on the U.S. Coast Guard to have a greater presence in and around the ice margin to perform its security and law enforcement missions. Assuming that the U.S. Coast Guard is to continue to support scientific research in the Arctic as well, icebreaking capability is required, including occasional heavy icebreaking. The committee recommends:

- **Recommendation #2**: The United States should maintain dedicated, year-round icebreaker capability for the Arctic to support national security interests as well as science.

CURRENT STATUS OF THE U.S. POLAR CLASS ICEBREAKERS

Ships with icebreaking capabilities are currently required for multiple missions in the Arctic and the Antarctic and likely in the future. The two existing heavy icebreakers, POLAR STAR and POLAR SEA, have operated in both polar regions for 29 and 28 years, respectively, and are near the ends of their design service lives. Both ships are inefficient to operate because they now require substantial and increasing maintenance efforts to keep vital ship systems operating, and their technological systems are becoming increasingly obsolete. These conditions are increasing the risk of operational failure and are placing national programs and missions at risk.

Currently, only one U.S. Coast Guard heavy icebreaker, the POLAR STAR, is capable of supporting the resupply operation in Antarctica. The NSF and U.S. Coast Guard have identified funds for restoring POLAR SEA to interim operational capability by the fall of 2006. However, this is not a long-term solution because the age, condition, and expense of maintaining a Polar Class, heavy icebreaker on a yearly basis puts the annual Antarctic resupply at significant risk of failure. Providing an icebreaker capable of handling the rigorous ice conditions in McMurdo Sound is a critical problem in the short term, which the committee has defined as the next 4 to 8 years. This is an optimistic estimate of the time required to either build a new ship(s) or extend the service life(ves) of the current ship(s). Although the HEALY is capable of supporting the McMurdo break-in, it is primarily tasked to support Arctic science, and its removal directly impacts Arctic missions. A reliable and fully operational HEALY is essential to successful executions of many science missions in the Arctic.

Since 2005, the NSF has twice negotiated a contract with a private company, the Far East Shipping Company (FESCO), to hire the Russian icebreaker ship, KRASIN, to break a channel to McMurdo Station. Contracting ships of other nations on *a year-by-year basis* is not a dependable long-term solution. Only a few icebreakers are capable of supporting this mission in a timely manner, and many of these ships have been contracted for the next several years due to emerging resource exploitation in northern latitudes. A long-term contract for icebreaking operations with an operator other than the U.S. Coast Guard is a viable option to be considered, although this arrangement may have long-term implications for U.S. control of icebreaking capabilities and the availability of icebreakers to the United States in the Arctic.

A short-term plan is needed to provide a bridge to a long-term solution. This long-term solution must ensure the integrity and operation of the icebreaking assets necessary to meet U.S. needs in both the Arctic and the Antarctic. Regardless of the ultimate long-term solution, full implementation will require on the order of 4 to 8 years. Based on these findings, the committee recommends:

- **Recommendation #3**: In the short term, the required maintenance should be performed to make at least one polar class ship mission capable over the next 4 to 8 years.

MANAGING THE NATION'S ICEBREAKING ASSETS

Significant long-term maintenance of the heavy icebreakers has been deferred over the past several years. This, coupled with the lack of a plan for replacement or refurbishment of the nation's icebreaking ships, has put meeting national needs in the north and south (as outlined above) at risk.

Recently, OMB assigned budget authority for the U.S. Coast Guard polar icebreaking program to the NSF, and Congress sustained this action. Now the NSF has fiscal control over all direct costs associated with polar icebreaking program, including personnel, training, operation and maintenance costs. Under a Memorandum of Agreement (MOA) negotiated between the USCG and the NSF, the USCG must submit a yearly plan for the NSF approval. Although the MOA identifies funds for traditional U.S. Coast Guard missions (e.g., search and rescue, law and treaty enforcement), the cost of training for these USCG missions must be included in the plan and is therefore subject to approval by the NSF.

The immediate problem is that given the current mode of operation, activity is underfunded. Moving budget authority for the icebreaking program to the NSF does not address the base funding problem and increases the difficulty of management because management decisions related to the polar icebreakers are now spread across two agencies. Currently, the polar icebreakers are dual purpose ships, meeting both the NSF and the USCG mission responsibilities. The U.S. Coast Guard reports that over 90 percent of the ship deployment time is in support of science primarily utilized by the NSF, although NOAA has recently used roughly 30 percent of available time on the HEALY. These ships, however, are necessary to support other U.S. Coast Guard traditional missions (e.g., national and homeland security, maritime safety, search and rescue), and these missions will increase in the future if human presence in the Arctic increases due to climate changes and emerging economic opportunities. The U.S. Coast Guard reports that limited budgets keep these ships in port unless other agencies provide deployment funds.

Having been given budget authority over the icebreaking program, the NSF is now fiscally responsible for missions outside its core mission and expertise. Without budget authority, the U.S. Coast Guard has been put in a situation in which it has the role of operating a ship for which it does not have full management control. Issues such as how to fund or choose among crew training alternatives for non-science missions are not fully under USCG control.

The committee believes that the U.S. Coast Guard icebreaking mission transcends the support of science despite the fact that the majority of icebreaker usage at the current time is to support science. There remains a need for USCG operations to support its other missions, and this need may increase in the future in the Arctic. The committee strongly believes that management responsibility should be aligned with management accountability and therefore recommends:

- **Recommendation #4**: In the short term, the management of the U.S. polar icebreakers should reside with the U.S. Coast Guard, and it should have the appropriate operational and maintenance budget to fulfill U.S. Coast Guard missions that require icebreaking.

- **Recommendation #5**: In the short term, the NSF should revert to being a user and should continue to negotiate financial agreements to pay for icebreaker services when U.S. Coast Guard ships are employed.

GOALS FOR THE COMMITTEE'S FINAL REPORT

Having identified both basic uses and needs for polar icebreakers and described how the roles and missions of these ships may change in response to changing environmental conditions in the Arctic, over the next several months the committee will investigate the mix of icebreaking capabilities and numbers of icebreaking ships that are required to meet these needs over the *long term*. The committee will consider this mix in light of the multiple, divergent missions of the polar icebreakers, how the operational mode of the U.S. Antarctic Program might be modified to reduce dependence on icebreaking assets and the potential for increasing icebreaker needs in the Arctic. Specifically, the committee will investigate whether multipurpose or single purpose assets are required to efficiently meet the nation's long-term icebreaking needs and identify a range of options to efficiently manage and operate these ships over the next several decades.

Although the Statement of Task charged the committee to outline feasible scenarios for continuing icebreaking operations and identify those that seem most promising, the committee determined that it was not feasible to conduct this analysis in the three months the committee had to deliver this interim report. In the final report, the committee will investigate the options for acquiring icebreaking capabilities, including, but not limited to, a full service life extension program for one or both existing heavy icebreaking ships, construction of one or more new ship(s), and alternate methods of meeting identified needs (e.g., use of ice-strengthened vessels, hiring foreign vessels, and other options that do not use U.S. Coast Guard services). The committee will specifically investigate the future needs for polar icebreaking to support national security issues, especially in light of the potential environmental and economic changes in the Arctic. The committee will also review existing laws governing U.S. Coast Guard polar icebreaking operations and present recommended changes in these laws based upon potential missions and new operating regimes that seem most promising to meet the nation's long-term icebreaking needs.

The committee wishes to emphasize that the issue before them is the viability and need for icebreaking capabilities to support U.S. needs in the polar regions. Although the Committee's Statement of Task emphasizes the U.S. Coast Guard role, and this role has been crucial in the past, it is uncertain whether the future will hold the same type of nearly exclusive emphasis on the U.S. Coast Guard to meet the nation's full polar icebreaking needs. The committee will investigate a wide range of models to determine how to best meet the nation's needs for icebreaking and address this central issue in its final report. These findings and recommendations will be focused on providing direction for meeting the nation's long-term icebreaking needs for the next several decades.

C

U. S. Coast Guard Polar Icebreaking Authority and Policy

BASIC STATUTORY AUTHORITIES

The legislative authorities for Coast Guard missions are contained in Title 14 of the United States Code; other Titles contain relevant authorities affecting various aspects of Coast Guard responsibilities. None of the Coast Guard's basic missions are limited to ice-free waters. The following U.S.C. sections pertain to particularly polar icebreaking and potential future changes in the polar regions.

14 U.S.C. 2 specifies icebreaking as one of several basic Coast Guard functions and notes a national defense connection: "The Coast Guard shall develop, maintain, and operate with due regard to the requirements of national defense, aids to navigation, icebreaking facilities, and rescue facilities for the promotion of safety on and over the high seas and waters subject to the jurisdiction of the United States; and pursuant to international agreements, operate icebreaking facilities on waters other than high seas and waters subject to the jurisdiction of the United States." 14 U.S.C. 2 also specifies one of the duties of the Coast Guard is to engage in oceanographic research.

14 U.S.C. 81 authorizes the Coast Guard to maintain aids to navigation, some of which require the use of icebreaking facilities.

14 U.S.C. 88 generally authorizes the Coast Guard to aid persons and property in distress on and under the high seas and waters over which the U.S. has jurisdiction, or imperiled by flood. Distress may be caused by, among other things, vessels beset in ice.

14 U.S.C. 93 authorizes the Coast Guard to maintain icebreaking facilities. It generally authorizes the Coast Guard to conduct experiments and investigations to assist in the performance of its duties, and to establish shore facilities.

14 U.S.C. 94 requires the Coast Guard to conduct oceanographic research and to cooperate with other government agencies as may be in the national interest.

14 U.S.C. 141 authorizes the Coast Guard to utilize its personnel and facilities to assist, among others, federal and state agencies. Under this authority the Coast Guard provides icebreaking services to user agencies such as the Department of Defense and the National Science Foundation; upon proper request, the Coast Guard conducts icebreaking in harbors and channels to relieve flooding conditions.

14 U.S.C. 147 authorizes cooperation with the National Oceanic and Atmospheric Administration (NOAA) for meteorological observations and services.

15 U.S.C. 4101 states: "The United States has important security, economic, and environmental interests in developing and maintaining a fleet of icebreaking vessels capable of operating effectively in the heavy ice regions of the Arctic."

15 U.S.C. 4109(b)(2) states: "The Office of Management and Budget shall seek to facilitate planning for the design, procurement, maintenance, deployment, and operations of icebreakers needed to provide a platform for Arctic research by allocating all funds necessary to support icebreaking operations, except for recurring funds associated with specific projects, to the Coast Guard."

16 U.S.C. 2431(a)(6) states: "The United States has important security, economic, and environmental interests in developing and maintaining a fleet of icebreaking vessels capable of operating effectively in the heavy ice regions of the Antarctic."

16 U.S.C. 2441(c) states: "Icebreaking.—The Department of Transportation shall facilitate planning for the design, procurement, maintenance, deployment, and operations of icebreakers needed to provide a platform for Antarctic research. All funds necessary to support icebreaking operations, except for recurring funds associated with specific projects, shall be allocated to the United States Coast Guard."

33 U.S.C. 1254 authorizes the Coast Guard to cooperate with the Environmental Protection Agency in research related to the removal, prevention, control, and elimination of oil and hazardous substance pollution.

33 *U.S.C.* 1441-1442 requires the Coast Guard, jointly with the Environmental Protection Agency and the Department of Commerce, to conduct research on ocean dumping as may affect oceanic and coastal waters, and the Great Lakes and its connecting waters.

46 U.S.C. 738-738d authorizes the Coast Guard to provide the patrol services required for the International Ice Patrol established therein and to annually report on the services so rendered.

49 U.S.C. 101 establishes as National Transportation Policy, the facilitation of commerce.

TREATIES AND INTERNATIONAL AGREEMENTS

The following treaties and agreements affect U.S. icebreaker responsibilities and operations. A variety of other international conventions and protocols address general maritime issues such as safety at sea and, especially, maritime pollution prevention and response. In general, these protocols and conventions apply to ice-covered waters of the polar regions.

The Antarctic Treaty (1959) provides the fundamental basis for U.S. policy and presence in Antarctica. The 27 countries with consultative status have adopted over 200 recommendations and five separate international agreements, which together constitute the Antarctic Treaty System. The five international agreements are:

- Agreed Measures for the Conservation of Antarctic Fauna and Flora (1964).
- Convention on the Conservation of Antarctic Seals (1972).
- Convention on the Conservation of Antarctic Marine Living Resources (1980).
- Convention on the Regulation of Antarctic Mineral Resource Activities (1988).
- Protocol on Environmental Protection to the Antarctic Treaty (1991).

United Nations Convention on the Law of the Sea (UNCLOS). 157 nations have signed the UNCLOS, which entered into force in 1994. Although the United States has not ratified the treaty, no significant U.S. objections remain and action by the Senate Foreign Relations Committee to ratify is expected. Under Article 76 of the treaty, a coastal state may claim jurisdiction over the seabed and subsoil of "submerged extensions of the continental margin" beyond their current exclusive economic zone (EEZ). An Article 76 claim is based on a set of limit lines defined from the depth and shape of the seafloor, the thickness of the underlying sediments, and other geophysical evidence such as gravity or magnetics. This UNCLOS article is particularly relevant to the Arctic Ocean basin, which features a pronounced but poorly mapped continental margin and is subject to conflicting claims by Arctic nations (including the United States). USCGC HEALY has mapped ice-covered Arctic Ocean bathymetry with its bottom-mapping sonar during two cruises (2003 and 2004).

Agreement Between the Government of the United States of America and the Government of Canada on Arctic Cooperation. This agreement, signed on January 11, 1988, resulted from USCGC POLAR SEA's transit of the Northwest Passage in the summer of 1985. POLAR SEA proceeded from east to west through the Canadian Archipelago as the most expeditious route to homeport in Seattle following operations around Greenland; the transit was not intended to reinforce the U.S. view that the passage is an international strait, but it aroused significant Canadian media interest. Many in Canada believed the U.S. was purposefully flaunting Canadian sovereignty. The agreement was fashioned to allow future icebreaker operations while allowing both nations to reserve their positions on the status of the Northwest Passage. It has been used successfully in subsequent years for U.S. icebreaker transits.

The agreement reads as follows:

1. The Government of the United States and the Government of Canada recognize the particular interests and responsibilities of their two countries as neighbouring states in the Arctic.

2. The Government of Canada and the Government of the United States also recognize that it is desirable to cooperate in order to advance their shared interests in Arctic development and security. They affirm that navigation and resource development in the Arctic must not adversely affect the unique environment of the region and the well-being of its inhabitants.

3. In recognition of the close and friendly relations between their two countries, the uniqueness of ice-covered maritime areas, the opportunity to increase their knowledge of the marine environment of the Arctic through research conducted during icebreaker voyages, and their shared interest in safe, effective navigation off their Arctic coasts:

> —The Government of the United States and the Government of Canada undertake to facilitate navigation by their icebreakers in their respective Arctic waters and to develop cooperative procedures for this purpose;
>
> —The Government of Canada and the Government of the United States agree to take advantage of their icebreaker navigation to develop and share research information, in accordance with generally accepted principles of international law, in order to advance their understanding of the marine environment of the area;

—The Government of the United States pledges that all navigation by U. S. icebreakers within waters claimed by Canada to be internal will be undertaken with the consent of the Government of Canada.

4. Nothing in this agreement of cooperative endeavor between Arctic neighbours and friends nor any practice thereunder affects the respective positions of the Government of the United States and the Government of Canada on the Law of the Sea in this or other maritime areas or their respective positions regarding third parties.

5. This agreement shall enter into force upon signature. It may be terminated at any time by three months' written notice given by one Government to the other.

Memorandum of Understanding Between the Department of Transportation of the United States of America and the Ministry of Transport of Canada Concerning Research and Development Cooperation in Transportation. This broad agreement was signed on June 18, 1970, and has served as the basis for a variety of cooperative transportation projects by the two countries. In 1993, the agreement served as the formal instrument for the exchange of icebreaking services in the Arctic. In 1993, Canadian Coast Guard icebreakers provided standby icebreaker support for ships resupplying Thule Air Base in northwestern Greenland, eliminating the need to send a U.S. Coast Guard icebreaker from Seattle every summer. In return, the U.S. Coast Guard has agreed to provide icebreaking support in the western Arctic, an area where Canadian ships operate only sporadically, upon request by Canada.

PRESIDENTIAL EXECUTIVE ORDERS AND MEMORANDA

Executive Order 7521 (1936) directs the Coast Guard to undertake icebreaking operations for harbors and channels, "in accordance with the reasonable demands of commerce." This executive order has constituted the basic authority for what has generally been called "domestic icebreaking" in mid-Atlantic and northeastern U.S. and on the Great Lakes. Ice-strengthened Coast Guard cutters and icebreakers have traditionally provided assistance to commercial vessels, especially to facilitate movement of critical cargoes such as fuel oil, assisted remote communities isolated by abnormal ice conditions, and responded to persons and vessels in distress.

National Security Decision Memorandum 71 (July 10, 1970) documents a Presidential decision that "the Antarctic program should be continued at a level which maintains an active and influential United States presence in Antarctica and which is responsive to United States scientific, economic and political objectives." Budget authority is transferred from the Department of Defense to the National Science Foundation, which shall "draw upon logistic support capabilities of government agencies on a mutually acceptable reimbursement or non-reimbursement basis." NSF is to use "commercial support and management facilities where there are determined to be cost effective."

National Security Decision Memorandum 318 (February 26, 1976) reaffirms NSDM 7521. Changes include an amplification of using commercial support and management facilities, which must be not only cost effective but also determined by "the Antarctic Policy Group not to be detrimental to the national interest." In addition, NSDM 318 states that "the use of logistic support by the Department Defense—assisted by the Coast Guard—gives the U.S. an important flexibility and reach to operate in that area." The DoD and Department of Transportation are to "maintain the capability to provide the logistic support requested by the National Science Foundation."

Presidential Memorandum 6646 (February 5, 1982) reaffirms the provisions of NSDM 318, but clarifies U.S. presence to include "the conduct of scientific activities in major disciplines; year-round occupation of the South Pole and two coastal stations; and availability of related necessary logistics support."

Presidential Decision Directive/NSC-26 (March 9, 1996) provides a comprehensive summary of U.S. national interests in Antarctica (expanding the background and rationale for the U.S. Antarctic Program beyond that contained in the earlier presidential memoranda) and specifically authorizes funding for rebuilding the South Pole Station.

Other U.S. Government Policy Instruments and Agreements

United States Polar Icebreaker Requirements Study (11 July 1984). Directed by the Office of Management and Budget, this multiagency 400-page report resulted from a comprehensive review of national requirements at a time when the World War II-era Wind class icebreakers and GLACIER were at the end of their useful service lives. The increasing needs for polar research were a notable part of the study. Alternatives to using icebreakers were evaluated. The study concluded: "An icebreaker fleet is essential to the national interest" and "should be operated by the Coast Guard." Significant study recommendations included:

- The Coast Guard should maintain a fleet of four polar icebreakers to meet stated requirements.
- Design of a new icebreaker should begin immediately, which would enhance research while retaining escort and logistics capabilities, with icebreaking capability "between a *Wind* and a *Polar*-class."
- Capital costs of a new icebreaker should be funded by the Coast Guard.
- The interagency reimbursement system should be reexamined.
- Crewing and operating day standards should be evaluated.

- The science capabilities of existing icebreakers (the Polars) should be improved.

Polar Icebreaker Requirements, Presidential Report to the Congress (October 1990). Required by the Coast Guard Authorization Act of 1988 (Public Law 100-448), this report updated the 1984 Polar Icebreaker Requirements Study. Agency requirements for polar icebreaker support were reviewed quantitatively, and various acquisition alternatives were discussed. The report contained a one-sentence conclusion: "Based on this analysis, the Administration has concluded that in addition to the Coast Guard's two existing polar icebreakers and the National Science Foundation's ice-capable research vessel, the U.S. currently requires one additional Coast Guard polar icebreaker." The 1990 report cleared the way for funding of USCGC HEALY.

Revised Memorandum of Agreement Between the Department of the Navy and the Department of the Treasury on the Operation of Icebreakers (1965). Although dated, this agreement has never been cancelled and provides basic authority for Coast Guard icebreakers to support peacetime, wartime and contingency operations in high latitudes. In addition, it states that the Coast Guard will provide icebreaking services to meet the reasonable demands of commerce in United States ports, harbors, and inland waterways.

Memorandum of Agreement Between the United States Coast Guard and the National Science Foundation Regarding Polar Icebreaker Support and Reimbursement (August 9, 2005). This agreement is the latest of a series (the last dated May 25, 1999) addressing the use of USCG polar icebreakers in support of NSF Arctic and Antarctic programs. This latest agreement was necessitated by the transfer of all icebreaker budget funds from the Coast Guard to NSF. Provisions include an annual scheduling process that, in addition to NSF requirements, considers "all national priorities" and the needs of other government agencies. The need for icebreakers to conduct "traditional USCG missions" such as search and rescue and enforcement of laws and treaties is noted and is to be funded from the "program base." In a reversal of past practice, NSF is required to reimburse the Coast Guard for actual icebreaker costs.

Memorandum of Agreement between United States Coast Guard, United States Navy and National Oceanic and Atmospheric Administration (July 21, 2005). This agreement establishes procedures for the jointly operated National Ice Center and commits the participating agencies to provide "the highest quality strategic and tactical ice services tailored to meet the operational requirements of U.S. national interests." The Coast Guard provides staff, on-scene observations, and other oceanographic support as inputs to the National Ice Center and uses ice information for icebreaker planning and operations. Ice services include polar and subpolar areas as well as ice coverage in the continental U.S.

Memorandum of Agreement Between the Department of Defense and the National Science Foundation for Operational and Logistics Support of the National Science Foundation's Polar Programs (effective April 1, 1999). This agreement provides detailed arrangements for DoD support to the National Science Foundation, especially to the Antarctic Program. It notes that the Coast Guard will provide icebreaker support and indicates that Coast Guard icebreakers supporting logistics operations in McMurdo Sound will be under the tactical control (TACON) of the Commander, Operation Deep Freeze.

Vice Chairman, Joint Chiefs of Staff Memorandum dated 14 June 1990. Documenting a review by the Joint Requirements Oversight Council, the memo states "the requirement for two polar icebreakers to conduct resupply operations in support of air bases in Greenland remains valid," but beyond this, "no significant military missions have been identified." While the memo states the Department's wartime requirements can be met by two polar icebreakers, a handwritten note indicates "other *non-DoD* Polar Icebreaking requirements justify a fleet of four polar capable icebreakers." The memo states classified requirements documentation is available.

INTERNAL COAST GUARD DIRECTIVES AND POLICY

The U.S. Coast Guard has no internal directives or policy documents that specifically address polar icebreaking operations. However, general guidance is included in operation orders issued for each polar deployment. The following policy guidance is typically included to authorize or direct the commanding officer of the icebreaker to take action as appropriate.

- Sampling of the continental shelf of any foreign nation, or trenches contained within the shelf, is prohibited without specific permission from the nation involved.
- Foreign nations must be notified of marine research which will occur within their exclusive economic zones (EEZ). The EEZ is composed of those waters within 200 nautical miles of the nation's coastal boundaries, or as defined by international agreement. The responsibility of requesting Department of State notification rests with the project sponsor.
- The icebreaker's aircraft are authorized to carry personnel and materials as necessary, including foreign nationals.
- Depending on the areas of operations, the icebreaker may be authorized to participate in civic action projects in foreign ports, exchange personnel and exercise with foreign services and agencies for training and familiarity, host diplomatic events in concert with State Department requests, and collect information of interest.

D

Biographical Sketches of Committee Members

Anita K. Jones is a professor at the University of Virginia. She received her Ph.D. in computer science from Carnegie-Mellon University (CMU) in 1973. Dr. Jones left CMU as an associate professor when she cofounded Tartan Laboratories. She was vice president of Tartan from 1981 to 1987. In 1988 she joined the University of Virginia as a professor and the chair of the Computer Science Department. From 1993 to 1997 Dr. Jones served at the U.S. Department of Defense where, as director of defense research and engineering, she oversaw the department's science and technology program, research laboratories, and the Defense Advanced Research Projects Agency. She received the U.S. Air Force Meritorious Civilian Service Award and a Distinguished Public Service Award. Dr. Jones served as vice chair of the National Science Board and cochair of the Virginia Research and Technology Advisory Commission. She is a member of the Defense Science Board, the Charles Stark Draper Laboratory Corporation, the National Research Council Advisory Council for Policy and Global Affairs, and the MIT Corporation. She is a fellow of the Association for Computing Machinery and the Institute of Electrical and Electronics Engineers, and the author of 45 papers and two books. Dr. Jones is a member of the National Academy of Engineering.

Albert J. Baciocco, Jr., retired from the U.S. Navy in 1987 after 34 years of distinguished service, principally with the nuclear submarine force and directing the Department of the Navy research and technology development enterprise. He graduated from the U.S. Naval Academy in 1953 with a B.S. in engineering, and subsequently completed graduate-level studies in nuclear engineering as part of his training for the naval nuclear propulsion program. He served as chief of naval research from 1978 to 1981, and as the director of research, development and acquisition, the senior military Research, Development and Acquisition official in the Department of the Navy, from 1983 to 1987. Upon retirement, he established The Baciocco Group, Inc., a technical and management consulting practice, and has since been engaged in a broad range of business and pro bono activities with industry, government, and academe, including memberships on the Naval Studies Board and the Army Science Board, and service on the Boards of Directors of several corporations, both public and private. He is a trustee of the South Carolina Research Authority and serves as Director of the Foundation for Research Development at the Medical University of South Carolina. He is a member of Tau Beta Pi, a national engineering honor society and the recipient of an Honorary Doctorate in Engineering from Florida Atlantic University. Vice Admiral Baciocco is a senior fellow of the Potomac Institute for Policy Studies, Arlington, Virginia, and has been designated a lifetime national associate of the National Academies by the Council of the National Academy of Sciences.

Julie Brigham-Grette is a professor in the Department of Geosciences at the University of Massachusetts, Amherst. Dr. Brigham-Grette received her Ph.D. from the University of Colorado's Institute for Arctic and Alpine Research. After postdoctoral research at the University of Bergen, Norway, and the University of Alberta, Canada, with the Canadian Geological Survey, she joined the faculty at the University of Massachusetts in the fall of 1987. Dr. Brigham-Grette has been conducting research in the Arctic for nearly 24 years, including eight field seasons in remote parts of northeast Russia since 1991, participating in the science program as well as dealing with difficult logistics. Her research interests and experience span a broad spectrum dealing with Arctic paleoclimate records and the Late Cenozoic evolution of the Arctic climate both on land and offshore, especially in the Bering Strait region. She was a member of the Arctic Logistics Task Force for the National Science Foundation (NSF) Office of Polar Programs (OPP) in 1996-1999 and 2000-2003, and was a member of the external OPP Office Advisory Committee in 2002-2004. She chaired the U.S.

Scientific Delegation to Svalbard for Shared Norwegian-U.S. Scientific Collaborations and Logistical Platforms in 1999. Dr. Brigham-Grette is currently chair of the International Geosphere/Biosphere Program's Science Steering Committee on Past Global Change (PAGES) with an international program office in Bern, Switzerland, and president of the American Quaternary Association. She also serves as one of two U.S. representatives to the International Continental Drilling Program.

Rita R. Colwell received her Ph.D. in oceanography from the University of Washington. Dr. Colwell is the chair of Canon U.S. Life Sciences, Inc., and distinguished university professor at the University of Maryland, College Park, and at the Johns Hopkins University Bloomberg School of Public Health. Dr. Colwell was the first woman to be named director of the National Science Foundation (NSF), where she served with distinction from 1998 to 2004. In her capacity as NSF Director, she served as cochair of the Committee on Science of the National Science and Technology Council. Dr. Colwell has held many advisory positions in the U.S. government, nonprofit science policy organizations, and private foundations, as well as in the international scientific research community; she is a member of the American Philosophical Society, American Academy of Arts and Sciences, and National Academy of Sciences.

Hajo Eicken is associate professor at the Geophysical Institute and the Department of Geology and Geophysics at the University of Alaska, Fairbanks. Before joining the University of Alaska, Dr. Eicken was a senior scientist at the Alfred Wegener Institute where he was the head of a research group for sea-ice physics and remote sensing. He received his Ph.D. in geophysics at the University of Bremen. Dr. Eicken's research interests include studies of the growth, evolution, and properties of sea ice in the Arctic and the Antarctic. He is particularly interested in determining how microscopic and macroscopic properties affect larger-scale sea-ice processes and their role in the climate system. Dr. Eicken has participated in several icebreaker expeditions in both hemispheres. He is serving on a number of national and international scientific and technical committees.

Jeffrey M. Garrett has been a maritime affairs consultant since retiring from the U.S. Coast Guard in 2005 after 31 years of service. Graduating from the U.S. Coast Guard Academy in 1974, he served multiple assignments in the polar icebreaker fleet, in the commissioning crew of POLAR STAR, aboard the Wind class icebreaker BURTON ISLAND, again in POLAR STAR as executive officer, as commanding officer of POLAR SEA, and as commissioning commanding officer of HEALY during delivery, shakedown operations, and ice trials. These shipboard assignments included multiple deployments to the Arctic and Antarctic in support of research, defense, and other national interests. He had additional operational duty at the Vessel Traffic Service in Prince William Sound, Alaska; commanding officer of MOBILE BAY in the Great Lakes; and as executive officer of ACTIVE. Staff experience included multiple headquarters assignments in ice operations and programming and budgeting, and chief of operations in the Pacific Area staff. As director of resources at headquarters he was responsible for the Coast Guard's budget, long-range planning, and policy development. He holds a master of science in management degree from the Naval Postgraduate School and was a research fellow while attending the Industrial College of the Armed Services. His last assignment was as commander, 13th Coast Guard District, overseeing all Coast Guard activities in the Pacific Northwest.

Jacqueline M. Grebmeier is a research professor and project director at the University of Tennessee, Knoxville. Her research interests include pelagic-benthic coupling, benthic carbon cycling, and benthic faunal population structure in the marine environment; understanding how water column processes influence biological productivity in Arctic waters and sediments; understanding how materials are exchanged between the seabed and overlying waters; and documenting longer-term trends in ecosystem health of Arctic continental shelves. Some of her research includes analyses of the importance of benthic organisms to higher levels of the Arctic food web, including walruses, gray whales, and diving sea ducks, and studies of radionuclide distributions of sediments and within the water column in the Arctic as a whole. Over the last 20 years she has participated in 33 oceanographic expeditions on both U.S. and foreign vessels, with more than 500 days on icebreakers alone. She is a member of the Polar Research Board, served previously as a member of the U.S. Arctic Research Commission, and has contributed to coordinated international and national science planning efforts such as the International Polar Year and Shelf-Basin Interactions project. Dr. Grebmeier earned her Ph.D. in biological oceanography in 1987 from the University of Alaska, Fairbanks.

Mahlon C. Kennicutt II is the director of sustainable development and team leader for the Sustainable Coastal Margins Program, Office of the Vice President for Research, at Texas A&M University. Dr. Kennicutt earned his Ph.D. in oceanography in 1980 from Texas A&M University. Dr. Kennicutt has worked as an oceanographer for 25 years, spent more than 500 days at sea, including on various ships in Antarctica, and is familiar with the logistics operations at McMurdo Station as well as University-National Oceanographic Laboratory System (UNOLS) ship operations. In addition, Dr. Kennicutt is a vice president of the Scientific Committee for Antarctic Research (SCAR) of the International Council for Science (ICSU), an international committee that serves as the formal science advisor to the Antarctic Treaty Consultative Parties. In this role he is familiar with the Antarctic Treaty and especially its environmental protocols. As the U.S. delegate to SCAR, he accompanies the U.S. Department of State delegation to treaty meetings. As a scientist, his research interests include environmental monitoring; fate and effects of contaminants; environmental impacts of offshore energy exploration and exploitation; coordination of the social and physical sciences to address environmental issues; and all aspects of the sustainable development of coastal margins. He served on the National Research Council's Committee to Review the Oil Spill Recovery Institute and the Committee on Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. Dr. Kennicutt is a member of various professional organizations including the American Geophysical Union, the American Association for the Advancement of Science, and the American Society of Limnology and Oceanography.

Ronald K. Kiss is president emeritus of Webb Institute, a private four-year college providing B.S. degrees in naval architecture and marine engineering. Prior to joining Webb Institute, he was vice president of SYNTEK, assisting the U.S. Navy on the Joint Navy-Defense Advanced Research Projects Agency arsenal ship program and the Navy's aircraft carrier and surface combatant programs. He served as deputy assistant secretary of the Navy for ship programs in the Office of the Assistant Secretary of the Navy (Research, Development and Acquisition) and as executive director of the Amphibious, Auxiliary, Mine and Sealift Directorate at Naval Sea Systems Command. Mr. Kiss spent nearly 20 years with the Maritime Administration, culminating as acting associate administrator for shipbuilding and ship operations. He holds a B.S. degree in naval architecture and marine engineering from Webb Institute, and an M.S. in naval architecture from the University of California-Berkeley; he has participated in a number of postgraduate programs at institutions including Harvard University and the Massachusetts Institute of Technology.

Douglas R. MacAyeal is a professor in the Department of the Geophysical Sciences at the University of Chicago. Dr. MacAyeal's field efforts in Antarctica, including the Ross Ice Shelf and the Ross Sea, yield a range of physical models concerning the dynamics of large ice masses. His work in the past has focused on the processes of ice-stream flow and the nature of the subglacial boundary layer that facilitates ice-stream basal lubrication. These models of ice streams were subsequently built upon to determine the role of ice-stream surging in abrupt climate change of the North Atlantic. Dr. MacAyeal's current research interest involves the break-up of ice shelves and the subsequent transport of icebergs into the surrounding ocean. He received his Ph.D. from the Geophysical Fluid Dynamics Laboratory at Princeton University. Dr. MacAyeal has been the chief editor for the *Journal of Glaciology* and a member of the Committee of Advisors for the Office of Polar Programs at the National Science Foundation.

Robert C. North retired from active duty with the U.S. Coast Guard in April 2001. He is presently serving as the president of North Star Maritime, Inc., a marine industry consulting firm specializing in international and domestic maritime safety, security, and environmental protection regulatory issues. Rear Admiral North's U.S. Coast Guard career spanned nearly 35 years and culminated with service as the U.S. Coast Guard's assistant commandant for marine safety, security and environmental protection, where he directed national and international programs for commercial vessel safety, merchant mariner licensing and documentation, port safety and security, and waterways management. In that capacity, he led U.S. delegations to the International Maritime Organization and also served as a member of numerous classification society committees and the Sealift Committee of the National Defense Transportation Association. Previously, he served as chief of acquisition involving major systems such as the U.S. Coast Guard's newest polar icebreaker, the HEALY, and the replacement programs for the U.S. Coast Guard's buoy tender and patrol boat fleets. Earlier assignments included first lieutenant and deck watch officer on the WESTWIND, a polar icebreaker involved in ice escort, resupply, and search-and-rescue operations in the Arctic and Great Lakes regions. He is a graduate of the State University of New York Maritime College at Fort Schuyler and the U.S. Army War College, Carlisle, Pennsylvania.

Raymond J. Pierce obtained his master mariner (H.T.) certification in 1976, his Canadian Coast Guard command in 1977, and his master's foreign going certification in 1981. During this period he held positions of increasing responsibility on various Canadian Coast Guard ships operating in the Atlantic, Pacific, and Arctic Oceans. In 1979 he was promoted to the rank of commanding officer and later assigned to headquarters as superintendent, operational requirements and polar icebreaking. Captain Pierce has worked for BeauDril Ltd. as a shipmaster, port captain of Arctic operations, marine superintendent, and manager. He was also active in the field of advanced navigation and electronic charting with Offshore Systems International of Vancouver. He was an adviser to and director of this emerging public company. After his work in the private sector Pierce rejoined the Canadian Coast Guard where he has served as regional director ship safety, regional director general of the northern central and arctic regions. Captain Pierce is currently executive director of departmental renewal at the Canadian Coast Guard.

Steven T. Scalzo is the chief operating officer of Marine Resources Group, Inc., a holding and support company for investments in tug, barge, and ancillary marine service companies. Mr. Scalzo joined Foss Maritime, a subsidiary of Marine Resources Group, in 1975. He is a graduate of the

U.S. Merchant Marine Academy and received a master's degree in law and commerce from Gonzaga University. Mr. Scalzo is a past member of the National Research Council Marine Board, and he is active in international, national, and local public policy and legislative and regulatory issues affecting the safety of marine transportation, including service as past chairman of the U.S. Department of Transportation Towing Safety Advising Committee and the State of Washington Puget Sound Marine Safety Committee. He has also served as chairman of the American Waterway Operators, the tug and barge industry national trade association, and he is currently a board member of the American Steamship Owners Mutual Protection and Indemnity Association, Inc. (the American Club) and the Coast Guard Foundation.

David G. St. Amand has more than 30 years of maritime industry experience, the last 20 of which have been as a management consultant. He is a maritime economist-business analyst specializing in commercial shipping. He holds a B.S. in naval architecture and marine engineering from Webb Institute and an M.B.A. from the Amos Tuck School of Business Administration at Dartmouth College. His industry experience covers a wide range of activities, including transportation planning, marketing, finance, operations, and engineering. Mr. St. Amand has extensive experience consulting to most sectors of the maritime industry. He has served bulk vessel owner-operators, liner companies, tug-barge firms, industry organizations, marine service firms, cruise lines, ferry operators, terminal operators, and port authorities. These assignments included strategic planning, asset-business valuation, organization analysis, market planning, benchmarking, and regulatory analysis. His strategic planning experience includes tanker owners, liner companies, ferry-cruise operators, tug-barge companies, and port authorities. Mr. St. Amand has been named an expert witness on vessel economics and damages in numerous proceedings. He has also done extensive analysis of the Jones Act, the Oil Pollution Act of 1990 (OPA 90), the 1984 Shipping Act, and the Ocean Shipping Reform Act of 1998 (OSRA) for individual carriers and industry organizations.

James H. Swift is a research oceanographer and academic administrator at the University of California, San Diego Scripps Institution of Oceanography (SIO). He received his Ph.D. in physical oceanography from the University of Washington. Dr. Swift has been on 25 blue water and icebreaker expeditions in the Atlantic, Pacific, Arctic, and Southern Oceans. His primary scientific interests are Arctic water masses and circulation, the global thermohaline circulation, and ocean measurement and interpretation. Dr. Swift is scientific adviser to the SIO Oceanographic Data Facility and coordinator for academic institutions involved in the U.S. Global Ocean Carbon and Repeat Hydrography program. He is also director of the World Ocean Circulation Experiment (WOCE) Hydrographic Program Office (now known also as the Climate Variability and Predictability (CLIVAR) and Carbon Hydrographic Data Office). Dr. Swift was the founding chair of the University-National Oceanographic Laboratory System Arctic Icebreaker Coordinating Committee, which oversaw science-related aspects of the construction and testing of the research icebreaker HEALY, and whose long-term mission includes promoting a productive and successful working relationship between the U.S. Coast Guard and the science community using icebreakers. He now serves on the U.S. Antarctic Research Vessel Oversight Committee, is chair of the NSF Office of Polar Programs Advisory Committee, and chairs its Subcommittee on the McMurdo Antarctic Resupply, which presently relies on icebreaker support.

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Acronyms

ABS	American Bureau of Shipping
ACIA	Arctic Climate Impact Assessment
AICC	Arctic Icebreaker Coordinating Committee
AIS	automatic identification system
AMVER	Automated Mutual-assistance Vessel Rescue
ARCDEV	Arctic Demonstration and Exploratory Voyage
ASPPR	Arctic Shipping Pollution Prevention Regulations
BPXA	British Petroleum Exploration Alaska, Inc.,
CLCS	Commission on the Limits of the Continental Shelf
DEW	Distant Early Warning Line
DHS	Department of Homeland Security
ECO	Edison Chouest Offshore
EEZ	Exclusive economic zone
FESCO	Far East Shipping Company
FOS	full operating staffing
FOSC	federal on-scene coordinators
FY	fiscal year
GISP 2	Greenland ice sheet project
Hp	horsepower
IACS	International Association of Classification Societies
ICSU	International Council of Scientific Unions
IGY	International Geophysical Year
IMO	International Maritime Organization
IPY	International Polar Year
ITASE	International Trans-Antarctic Scientific Expeditions
LEDET	law enforcement detachment
LRIT	Long Range Identification and Tracking
LTER	Long Term Ecological Research
MARAD	Maritime Administration
MDA	Maritime domain awareness
MMS	Minerals Management Service
MOA	Memorandum of Agreement
MSC	Military Sealift Command
NEWP	Northeast Water Polynya project
Nmi	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System

NSC	National Security Council
NSDM	National Security Decision Memorandum
NSF	National Science Foundation
NSTC	National Science and Technology Council
NWP	Northwest Passage
OAC	external OPP Advisory Committee
OCS	outer continental shelf
OMB	Office of Management and Budget
OPP	Office of Polar Programs
PAME	Protection of the Arctic Marine Environment
PIRS	Polar Icebreaker Requirements Study
PRV	PALMER Replacement Vessel
SAR	search and rescue
SHEBA	Surface Heat Budget of the Arctic Ocean
SIDS	sudden infant death syndrome
SLEP	service life extension program
UNCLOS	United Nations Convention on the Law of the Sea
UNOLS	University-National Oceanographic Laboratory System
USAP	United States Antarctic Program
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
VOSS	Vessel of Opportunity Skimming System
VRAM	vessel rehabilitation and modernization
VTS	vessel traffic service