National Science Foundation and Science Community Needs for Polar Ice Breakers

Introduction

The Arctic and Antarctic are premier natural laboratories whose extreme environments and geographically unique settings enable research on fundamental phenomena and processes not feasible elsewhere. In addition, changes in polar regions are tightly coupled to the global earth system, with changes in one strongly impacting the other. Advances in polar research 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. Many areas in the Arctic and Antarctic are only accessible by ship. As the primary supporter of fundamental research in these regions NSF is a key customer of polar icebreaker and ice-strengthened vessel resources.

NSF also bears responsibility for management of the U. S. Antarctic Program, including environmental stewardship and the manifestation of U. S. policy. These activities also depend heavily on polar icebreakers and ice-strengthened ships. Finally, NSF chairs the Interagency Arctic Research Policy Committee (IARPC), created under federal statute to coordinate Arctic research sponsored by federal agencies.

Science and the Research Community

NSF assesses the needs of the research community that require polar icebreakers, through a variety of mechanisms, including external peer review of proposals from scientists, workshops, input from the IARPC and the OPP Advisory Committee, from NAS/NRC reports, and a variety of other sources. The approximately 3,100 proposals that were peer reviewed over the last five years resulted in support for more than 1,500 researchers annually. Research proposals provide near-term guidance on science community needs, while workshops and other reports provide information on future directions for polar science. A major planning activity conducted by the IARPC over the last several years resulted in formulation of the coordinated research program, Study of Environmental Arctic Change, or SEARCH, a synopsis of which can be found on the web at: http://www.arcus.org/SEARCH/index.php. Additional resources include:

- A listing of workshops supported by NSF, available at: http://www.nsf.gov/od/opp/opp_advisory/workshops2004.xls.
- Recent influential NAS/NRC reports, which include: *Frontiers in Polar Biology in the Genomics Era* and *A Vision for the International Polar Year 2007-2008*, available at: http://lab.nap.edu/nap-cgi/discover.cgi?term=frontiers+in+polar+biology&submit.x=1&submit.y=12.

Examples of the kinds of current and recommended research currently being supported by NSF in polar regions include:

- Understanding Earth and its systems. Goals include achieving better understanding of polar regions' influence on and response to global heat distribution in the oceans and the atmosphere, adaptations of organisms to polar extremes, and the valuable records of past climates and atmospheric constituents in ice cores, polar ocean sediments, and other indicators.
- Exploring the geographical frontier. Many fields of science are exploring the still unevenly understood polar frontiers. For example, the central Arctic Ocean and the Southern Ocean are the least studied of the earth's oceans.
- Performing science enabled by the polar setting. Polar conditions can enable research either not possible elsewhere or less effective elsewhere. For example, the extremely dry atmosphere and high altitude of the South Pole makes it the ideal window for astrophysical study of the origins of the universe, while the polar environments provide a natural laboratory for the study of terrestrial and marine ecosystems under extreme conditions.

As noted above, ships able to operate in ice are essential to meeting these and the other needs of the research community. These ships serve a variety of roles, as research platforms, as icebreakers clearing shipping channels in Antarctica for ice-strengthened resupply vessels, as cargo and fuel transport vessels, and as research and support platforms docked in the ice. NSF has met the need for these capabilities in support of the science community through a variety of mechanisms, including tasking U. S. Coast Guard icebreakers under reimbursement arrangements, securing construction to NSF specifications of private ships for long-term lease to NSF, chartering Military Sealift Command capabilities, short-term charters of foreign ships, arranging multi-ship coordination with other nation's science programs, and securing funding for ships operated by University-National Oceanographic Laboratory Systems (UNOLS). Each of these arrangements has specific advantages and they will be discussed below.

Arctic Research

NSF supports research on the Arctic Ocean, atmosphere, and land areas, including their peoples, and marine and terrestrial ecosystems. In addition to research in individual disciplines, support is provided for interdisciplinary approaches to understanding the Arctic region, including its role in global climate. It has become widely recognized that the Arctic is in the midst of a change over the last decade. Changes have been measured in the ice cover, atmosphere, some terrestrial parameters, and northern ecosystems. Residents of the North are seeing these environmental changes affecting their lives. It is important to determine whether these changes are correlated with a short-term shift in regional atmospheric circulation or whether they signal long-term global change.

In the Arctic, science on land and in coastal areas tends to be based at a few sparsely distributed, remote outposts, and in many cases access by ship is the most advantageous means, even for projects that are not inherently oceanographic. So far, research that uses icebreakers has focused either on ocean or coastal processes, although there is clearly another potential use in employing an icebreaker to bring sophisticated science assets to remote terrestrial localities. In the few years of its service, the Coast Guard icebreaker *Healy* has supported amongst others biology, sea ice research, marine geology and geophysics, cartography, physical and chemical oceanography and atmospheric science. (See Appendix A: *US Arctic Research Platform Needs*)

As the requirements of forefront research have become more demanding, NSF has increasingly relied on coordinated international multi-ship expeditions. For example, the USCGC *Healy* does not have the capability to work alone in the deep Arctic, making multi-ship arrangements necessary in lieu of an icebreaker research platform with more robust capabilities. International collaborations also have become necessary, as the demands for research aboard the *Healy* have intensified. Recent international partnerships with Sweden involving their icebreaker, the *Oden*; and with Germany and their icebreaker, the *Polarstern*; have been highly successful, as have collaborations by NSF, NOAA and other agencies with various Canadian, Chinese, Russian and other ships (*See Appendix A*).

Ship Availability and Requirements

According to information provided by the Coast Guard in 2002 and 2003, NSF used approximately 90 percent of the 200 days that the USCG *Healy* could spend at sea. The *Healy* is 128 meters long and designed to conduct a wide range of research activities, with accommodations for up to 50 scientists (exclusive of the 85-person USCG crew). Science programs are limited by the ship time available on the USCGC *Healy.* Additional information on the ship's capabilities can be found in USCG contributions to the Committee.

The *Healy* operating period has been spring, summer, and fall, using the full 200 days available for tasking. The 200-day limit on days at sea is set by USCG policy. Spring work, north of Alaska (2002, 2004 and 2005) has been at, or just beyond the limit of Healy's icebreaking capability, with the Healy being beset for several days in 2004 and 2005.

Plans have been underway for several years for construction of a new ice-strengthened ship that would serve research needs in the waters around Alaska. NSF has assigned high priority to securing funding to build this ship. Designated the Alaska Regional Research Vessel (ARRV), it would likely be operated by a university as a UNOLS vessel, and would be designed for the purpose intended, replacing the *Alpha Helix* in conducting research cruises year round in waters of the Gulf of Alaska and southern Bering Sea, and in the summer as far north as the Chukchi and Beaufort Seas during minimum ice cover. In order to meet science requirements in the seasonal ice zone of the Bering Sea, the ARRV would be designed to work in ice up to 3 feet in thickness. There is substantial need for such a vessel. A major research effort has been formulated to study the relation between ecosystem changes and climate drivers in the Bering Sea. During heavy ice periods in the Bering Sea, the ARRV would probably need the assistance of the *Healy*.

Finally, better access to the deep ocean is needed in the Arctic. Options for supporting research in the deep Arctic should be integral to any study of future icebreaker needs.

Antarctic Research

NSF provides approximately 85 percent of the U.S. funding for fundamental research in the Antarctic and the southern ocean. This research addresses a wide array of topics across many disciplines. For instance, research includes the evolution of the ozone hole to how extreme environments affect gene expression; the effects of ultraviolet radiation on living organisms; changes in the ice sheet and impacts on global sea level, global weather, climate, and ocean circulation; the role of Antarctica in global tectonics and the evolution of life through geologic time; and the early evolution of our universe, as well as its current composition. This research requires access throughout the southern ocean as well as access to the continent, both of which depend on capable and reliable icebreakers and ice-strengthened ships. (*See Appendix B: US Antarctic Research Program – Requirements for Ice Breaking*)

Antarctic Ship-Based Research

U.S. Antarctic Program ship-based research is supported primarily by two vessels, the *Laurence M. Gould* (LMG) and the *Nathaniel B. Palmer* (NBP). (A few research projects have also been supported by the USCG Polar class vessels from time-to-time, on a not-to-interfere basis with the primary re-supply mission.)

Nathaniel B. Palmer

The NBP is leased by the NSF's prime contractor, currently Raytheon Polar Services Company (RPSC), from the Louisiana based shipping company, Edison Chouest Offshore (ECO). The vessel was built to specifications developed on the basis of input from the science community. The ship is an ABS A2 icebreaker capable of breaking 3 feet of level ice continuously at 3 knots, with 13,000 shaft horsepower and a displacement of 6,800 long tons. The vessel is 308 ft. long and can berth 39 scientists and support staff (exclusive of the 22 person ECO marine crew). She is outfitted with all of the winches and A-frames necessary for deploying and retrieving oceanographic. She is fully instrumented with on-board oceanographic instrumentation and a networked computer suite, including multi-beam sonar and has 5,900 ft^2 of lab space and 4,076 ft^2

of open oceanographic working and staging area. (*See Appendix C, Research Vessels, for additional details on the ships capabilities)*

The NBP averages 300 days a year underway in support of science. A brief overview of the research cruises conducted last year on the NBP is listed in *Appendix D.* Additionally, a listing of the cruises supported by the NBP and the Principal investigators for those cruises may be found on the web at:
(http://www.polar.org/science/marine/sched_history/nbp/nbp_history.pdf)

Laurence M. Gould

As is the case for the NBP, the LMG is leased by the NSF's prime Antarctic contractor, from Edison Chouest Offshore (ECO). Also like the NBP, the vessel was designed and built on the basis of input from the science community. The ship is smaller than the NBP and has less ice breaking capability. This is because the LMG is designed to operate in the more benign ice regions surrounding the Antarctic Peninsula, the most northerly part of Antarctica. The ship is an ABS A1 ice-strengthened vessel with 4,600 shaft horsepower and a displacement of 3,400 long tons and can break one foot of level ice at a continuous 3 knots. The vessel is 230 ft. long and can berth 28 scientists and support staff (exclusive of the 16 person ECO marine crew). She, too, is outfitted with all of the winches and A-frames necessary for deploying and retrieving oceanographic instruments. She is fully instrumented with on-board oceanographic instruments and a networked computer suite. The LMG has 2,425 ft^2 of lab space and 2,400 ft^2 of open oceanographic working and staging area. Short-term occupancy berthing vans are used for transporting scientists and support staff to Palmer Station thus accommodating an additional 10 people. The LMG has the dual purpose of supporting oceanographic science and providing re-supply to Palmer Station, located on the Antarctic Peninsula. (*See Appendix C, Research Vessels, for additional details on the ships capabilities)* The LMG also serves an environmental duty, carrying waste back from Palmer to the U.S.

The LMG averages 320 days a year underway in support of science and science logistics. A brief overview of the research cruises conducted last year on the LMG is listed in *Appendix D.* Additionally, a listing of the cruises supported by the LMG and the Principal investigators for those cruises may be found on the web at:
http://www.polar.org/science/marine/sched_history/lmg/lmg_history.pdf

Icebreaker Support for On-Continent Antarctic Research

Current NSF-supported on-continent Antarctic research demands nearly year-round access to Palmer Station in the Antarctic Peninsula region, where the ice is generally less than 3 feet thick. This access is provided by the LMG and the NBP under the charter arrangement noted above.

For support of research at South Pole Station and McMurdo Station, and throughout the interior of the continent, NSF must open a supply channel through the sea ice in the southwest Ross Sea to McMurdo Station. This ice exert from McMurdo ranges from a norm of about 15 nautical miles to the extreme of over 80 nautical miles, which was experienced last year. The ice in this channel can be from 5 to 10 feet in thickness and has, in several recent years, exceeded that. Opening the channel requires the deployment of either one or two icebreakers for approximately 130 days per year. Of this time, 60 days are typically spent in transit to and from Antarctica and approximately 70 days are devoted to icebreaking and escort. In most previous years, this channel was opened by one U.S. Coast Guard Polar Class vessel (either the *Polar Star* or the *Polar Sea*), but more recently two icebreaking vessels have been needed due to extreme ice conditions and concerns about the reliability of the aging Polar class vessels. The unusual ice conditions are thought to be caused by the presence of huge icebergs calved during the last five years. The icebergs have now moved north and no longer hinder movement into McMurdo Sound. Once the channel is opened, the icebreaker escorts two vessels, a tanker and a freighter, to and from the ice pier at McMurdo. These re-supply vessels are ice-strengthened commercial vessels chartered by the Military Sealift Command (MSC). (The Navy used to operate all of their own tankers and freighters but more recently has depended on commercial staffing for operations, construction and maintenance in view of its cost-effectiveness. MSC now charters virtually all of the tankers and freighters used by the DoD either through a direct industry charter or through a government-owned, contractor-operated (GOCO) arrangement.)

The military vessels, *Polar Star* and *Polar Sea* are not rated by ABS but are roughly equivalent to an ABS A5 icebreaker capable of breaking 6 feet of level ice at 6 continuous knots, with shaft horsepower of 18,000 diesel and 75,000 turbine and a displacement 13,400 tons. The vessels are 399 feet long and can berth 20 scientists and support staff (exclusive of the crew of 145-person crew).

Last year, because the *Polar Sea* was undergoing extensive repair and could not assist the *Polar Star* with the break in, NSF chartered the Russian icebreaker *Krasin.* The situation for the coming year is again similar. *Polar Sea* continues to be unable to assist due to on going maintenance. The experience with the two icebreakers last year illustrated how differences in design impact icebreaking capability. Both vessels proved fully ice-capable, although the *Polar Star* suffered an extended breakdown.

Russian Register Icebreaker, *Krasin* is a LL2 (roughly equivalent to ABS A4) capable of breaking 6 feet at 3 continuous knots, with shaft horsepower of 35,500 and a displacement 20,000 tons. The vessel is 443 feet long and has a 65-person crew and no science support. In comparison, the *Polar Star* is about two-thirds the displacement of the *Krasin*, but the *Star* has twice the horsepower. The vessels have similar limits of ice breaking capability although in the back and ram mode *Star* may be quicker to cycle due to the increased acceleration speed provided by the higher horsepower. This high horsepower does come with the disadvantage of heavy fuel consumption. In fact, Star does not take on ballast water as fuel is expended because all of her tankage is needed for fuel. Thus, fuel must be frequently added to add weight (displacement) to the vessel. The *Krasin* is significantly more fuel-efficient than the *Star.*

U. S. Policy for Antarctica

Antarctica is governed under an international treaty according to which the requirement for participation in the governing process is the conduct of an active and influential scientific program there. Twenty-seven nations currently enjoy that status. The U. S. Department of State represents the U. S. in the international governance process. The State Department intends to provide the Committee with a fuller description of U. S. policy and its implications at a later date.

Presidential Memorandum 6646 (1982) tasked NSF with managing the U. S. Antarctic Program on behalf of the U.S. government. The Memorandum also tasked NSF to develop and fund the associated research program; to draw upon logistic support capabilities of government agencies on a cost reimbursable basis; and to use commercial support and management facilities where these are determined to be cost effective and not detrimental to the national interest.

In accord with this policy, NSF has drawn upon the resources of the Coast Guard, chartered the *Krasin* to enable resupply of the McMurdo and South Pole stations, and commissioned the construction and commercial operation of the *Laurence M. Gould* and the *Nathanial B. Palmer*.

Presidential Decision Directive NSC 26 (1994), articulated the four basic objectives of U.S. policy in Antarctica as follows:

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) *Assuring the conservation and sustainable management of the living resources in the oceans surrounding Antarctica.*

The Committee on Fundamental Science of the President's National Science and Technology Council (NSTC) reviewed U. S. activity in polar regions and confirmed in 1996 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." (*United States Antarctic Program, Committee on Fundamental Science, NSTC (Appendix IV), April 1996*, http://www.nsf.gov/pubs/1996/nstc96rp/start.htm)

In 1997, a Blue Ribbon panel chaired by Norman Augustine also endorsed NSF management of the USAP and made a number of recommendations to improve the program, most of which have now been implemented. (*Report of the U.S. Antarctic Program External Panel, April 1997, pg. 87*, http://www.nsf.gov/publications/pub_summ.jsp?ods_key=antpanel)

Ship Availability and Requirements for Resupply

It is widely recognized that the USCG has completed its icebreaking mission for many decades but only with increasing difficulty in recent years. Its two Polar class icebreakers are within a few years of their estimated lifetime and are becoming increasingly difficult and costly to keep in service. The need to charter the *Krasin* has already been mentioned. During the break-in last year, the *Polar Star* developed a leak in a propeller hub that threatened environmental impacts at McMurdo Sound. Pursuant to U.S. commitments for environmental protection, the *Polar Star* had to be taken out of service until the leak could be repaired, a period of 10 days. Given this state of affairs, NSF initiated a study of resupply alternatives and asked the OPP external Advisory Committee to form a subcommittee to oversee and guide the development and analysis of alternatives and provide recommendations to achieve long-term, resupply capabilities. The Report of the Subcommittee on the U.S. Antarctic Program Resupply has now been completed and adopted by the Committee. A copy of the report can be found at: http://www.nsf.gov/od/opp/opp_advisory/final_report/oac_resupply_report_081205.pdf. (See also the briefing material provided to the Committee by Professor Sridhar Anandakrishnan.) NSF is now initiating a more detailed study of the options identified in the Report and will work with the OPP Advisory Committee when it meets in October 2005 in order to further assess the options and their costs. Congress has asked for a report on NSF's assessment of options and costs by the end of this calendar year.

Use of Commercial Ships and Models/Modes of Operation

A variety of models have been used by the U.S and other countries for meeting polar icebreaker needs. The U.S. Coast Guard and the Chilean and Argentinean Navies operate their icebreakers using military personnel. Some countries build their ships to meet military specifications and others do not. The German research icebreaker, the *Polarstern* is owned by that government, but operated by a private contractor. The Swedish government's operational arrangements for the *Oden* are similar to the German model. Both the *Oden* and the *Polarstern* are able to operate in excess of 300 days annually as a consequence of ship design and mode of operation. The Arctic Regional Research Vessel will be operated by civilian crews contracted to University-National Oceanographic Laboratory Systems (UNOLS).

NSF employs a contractor to operate and maintain the privately owned *Laurence M. Gould* and *Nathanial B. Palmer*. The ships were built under a long-term lease agreement between the ship-owners and the government, such that the construction costs are partially amortized over the duration of the lease (with the ship reverting to the owner at the government's option at the end of the lease). These ships also operate in excess of 300 days annually.

Finally, as noted previously, the U.S. Military Sealift Command, meets its needs (and those of NSF's for transport to McMurdo Station) either through commercial charter of ship and crew or government owned, contractor operated arrangements.

Further analysis of the pros and cons of these models/modes, informed by UNOL's experiences, as well as those of colleagues in Sweden and Germany, will be important in deciding how to meet future needs for polar icebreakers.

Future Needs

There is a worldwide shortage of modern icebreakers essential for the support of scientific research in polar regions. Like the U.S., Germany, Japan, Korea, and the Russian Federation are in the process of grappling with the need to replace obsolete equipment. In addition, there is anecdotal evidence that oil companies are chartering available ice-capable ships for exploration purposes, resulting in competition for these resources.

International cooperation to provided icebreaker research platforms will surely increase, both in arranging multi-ship expeditions and in sharing use of platforms. As Germany and the European community follow through in construction of the planned *Aurora Borealis*, NSF will seek to arrange mutually beneficial partnerships.

NSF's commitment to polar research and its responsibility for management of the U.S. Antarctic Program remains constant and therefore perpetuates the need for an icebreaker to open the shipping channel through the Ross Sea to enable the resupply of the McMurdo and South Pole stations. Because opening the channel to McMurdo requires only a fraction of the time a modern icebreaker can operate annually, there may be interest among shipbuilders in providing icebreaker services to the government under a contract in which, the builder can lease the ship to others (other countries or private firms) during the remainder of the year. The NSF OPP Advisory Committee has noted the need to diversify the USAP logistics chain, as well as to rethink how icebreaker support is arranged. The twin goals are to eliminate the current single point of failure mode and to increase the reach of scientific research efforts. We will study the full range of the Committee's recommendations in detail over the coming months.

Access to Palmer Station in the Antarctic Peninsula will continue to be needed. And of course, NSF-supported Antarctic research will require nearly year-round access to the ice-covered water surrounding Antarctica. Reflecting the changing requirements for working at the scientific forefront, NSF has recently supported several community workshops to probe science community requirements for next-generation icebreaker research platforms. The associated workshop reports can be found at: http://www.vims.edu/admin/sponpgms/AOPWReport.pdf and http://departments.colgate.edu/geology/faculty/AMGGPWReport.pdf.

Clearly, the economics and efficiencies of the various acquisition and operating models, merit further study. The analysis should include a comparison between a military constructed and operated vessel vs. that of either a straight commercial charter or a government owned, contractor operated charter. The OPP Office Advisory Committee in its report on Antarctic resupply, commented that, " ...a non-military model of operation for polar ice breakers can potentially provide substantial benefits in terms of economy of operation and retention of experienced personnel as compared to the military model...the Subcommittee recommends further investigation of this option for present and future US polar ice breaking support."

For research in the Arctic, the *Healy* should be a mainstay for many years to come, though its utility is restricted primarily by its 200-day operational limitation and its inability to access the deep Arctic during periods of heavy ice cover. The ARRV, once in service will be a valuable additional resource. Of equal importance, is the need for an icebreaker research platform that is capable of supporting deep Arctic research.

The entire staff of the NSF Office of Polar Programs looks forward to working with the NAS/NRC Transportation Research Board, as you develop your advice for the U.S. government. Your recommendations and conclusions will have great impact for the future of polar research.

Appendix A

Non-published, internal NSF document

US ARCTIC Research Platform Needs

Driver: Why Arctic Science Needs Icebreakers.

The Arctic comprises an ocean basin surrounded by land, with much of the terrain and adjacent shoreline difficult to reach because of ice and challenging access logistics. Routes to the coastal areas are all from the south, there are few if any roads, rail or airports, and there is often little or no support at the coast. Thus science on land and in coastal areas tends to be based at a few sparsely distributed, remote outposts, and in many cases access by ship is the most advantageous means, even for projects that are not inherently oceanographic.

So far, research that uses icebreakers has focused either on ocean or coastal processes, although there is clearly another potential use in employing an icebreaker to bring sophisticated science assets to remote terrestrial localities. In the few years of its service, the Coast Guard icebreaker *Healy* has supported amongst others biology, sea ice research, marine geology and geophysics, cartography, physical and chemical oceanography and atmospheric science.

Biology - major biological research activities employing the *Healy* and other icebreakers have centered on a multi-year NSF- and ONR-funded study on biological production and transport of carbon from the Bering and Chukchi Sea shelves to the ocean basin north of Alaska. This shelf-basin transport is poorly known and has significance for the global carbon balance. Ancillary activities have included work on marine mammals and physical oceanography. Other significant activities have included NOAA-funded work on Arctic Basin biodiversity studies that is part of the Exploration of the Seas and the Census of Marine Life efforts. Key assets used for this are sophisticated water samplers, a seawater pumping system, remotely operated vehicles and the advanced laboratory facilities found on *Healy*. Access to the ship’s helicopter has been valuable for remote deployment onto the ice.

Marine Geology and Geophysics - The *Healy*'s first trip was a significant success in a joint effort with the German research vessel *Polarstern* to explore the Gakkel Ridge, the only spreading center found in the Arctic and one that turned out to be exciting as the slow spreading end-member of the global spreading center spectrum. Current research efforts include a geophysical transect across the Arctic Basin and a return to the Gakkel Ridge area. Key assets for current and future geological research include the multi-beam sonar, piston and gravity corers, remotely operated vehicles, and lowered cameras.

Cartography. The International Law of the Sea Treaty enables countries to lay claim to ocean areas for economic activities, but requires that these claims be based on seafloor configuration and on relations to terrestrial land features. This is determined through examination of ocean bottom topography, usually using multi-beam sonar profiling. The Arctic Basin is one of the poorest known basins for sea-floor topography, so the expeditions of the *Healy* have routinely employed the multi-beam sonar on most voyages. There have also been a few NOAA-sponsored expeditions with the purpose of establishing 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 are important supportive data for any US claims. The key asset used for this at present is the multi-beam sonar and the ability to break ice at adequate speed. The use of towed seismic arrays for sub-seafloor imaging will become more important in the future.

Physical and Chemical Oceanography. The Arctic Basin is poorly sampled from the standpoint of physics and chemistry. There appear to be significant changes occurring in the balance between waters of Pacific and Atlantic origin, and this may threaten key features of the thermohaline profile that are thought to prevent much of the surface ice from melting. It is thus viewed as critical that there be more physical exploration of the Arctic. Some of the main expeditions so far have focused on the deep circum-Arctic circulation, support work for the biological effort in the shelf basins study and work examining the flux of material out of the Arctic through the Canadian Archipelago. There is currently a trans-basin expedition underway for both physics and tracer chemistry, but this could not be supported by the *Healy* as it was already in use for a geological expedition, so this work is being carried out on the Swedish Icebreaker *Oden*. Much of the other work has been supported by submarines, or ice-based work supported by aircraft. This works well, but there are severe limitations on payload, and thus on the kinds of data obtainable. The *Healy* is ideal for this kind of work because of the advanced electronics laboratory support capability. It is also a much safer working environment.

Sea Ice. Research on physics, chemistry and biology in the oceanic sea ice environment is dependent on icebreakers, submarines or sea ice camps. Access from submarines for the civilian research community is gone and sea ice camps are not frequent, so icebreakers are the most effective platform. Because the sea ice is the interface between the atmosphere and the 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, for efforts that need geographic coverage, icebreakers or submarines are the only viable mechanisms. There is currently a trans-basin expedition underway that includes sea ice work.

Terrestrial Ecology and Social Science. There has been almost no work from US vessels on terrestrial ecology and social science, but the ability to cover a large range of environments from an icebreaker base has been recognized in other countries. Sweden has supported several expeditions that have, over the years, nearly circumnavigated the Arctic, using the *Oden* as a residence and laboratory base from which researchers reach land study sites by helicopter. There is significant potential for the same approach using the *Healy*. There is currently a trans-basin expedition underway, but this could not be supported by the *Healy* as it was already in use for a geological expedition, so this work, and some physical work, is being supported on the Swedish Icebreaker *Oden*.

Other US vessels. Plans have been underway for several years for an Alaska Regional Research Vessel (ARRV) that would serve research needs in the waters around Alaska. This vessel is envisioned as ice strengthened, but not ice breaking, in its capability. It would probably be operated by a university as a UNOLS vessel, and would be designed for the purpose intended, replacing the *Alpha Helix* in conducting research cruises year round in waters of the Gulf of Alaska and southern Bering Sea, and in the summer as far north as the Chukchi and Beaufort Seas during minimum ice cover. There is substantial need for such a vessel, and in fact there is a major research effort ready to study the relation between ecosystem changes and climate drivers that will begin work in the Bering Sea soon, however this is not a vessel that would replace the function of the *Healy*. In fact, a Bering Sea program would probably need the assets of the *Healy* during heavy ice periods.

Summary. In short, in an environment that is harsh for humans and consists mostly of ice-covered water, a safe, warm, technologically sophisticated floating laboratory that is capable of covering the entire environment is pretty much indispensable. The Arctic Ocean is so poorly known that US science programs have required every day of shiptime available on *Healy*. Given that requests for *Healy*'s use have often been deferred to icebreakers of other countries, it is clear that the community could use more time if it were available.

Historical & Current Use of US research capable icebreakers.

The first 5 years of *Healy* deployments to the Arctic give a good perspective of the type of activity the NSF funded researchers require for US Arctic icebreaking research platforms.

2001
- Gakkel Ridge Marine Geology and Geophysics
- AUV testing

2002
- Shelf-Basin Interactions, Physical, Biochemical studies Chukchi and Beaufort Seas
- Marine Paleoscience, Bering and Chukchi Seas

2003
- Canadian Archipelago Freshwater Flux focusing on the Nares Strait
- Shelf-Basin Interactions, Chukchi and Beaufort Seas

2004
- Shelf-Basin Interactions, Chukchi and Beaufort Seas
- Cartographic studies funded by NOAA

2005
- Marine Geology and Geophysics, Chukchi Sea and cross-basin transect
- Ocean Exploration (Census of Marine Life) funded by NOAA

The operating period has been spring, summer and fall using the full number of days available for tasking which is about 200 per year – a limit set by USCG policy. Spring work north of Alaska (2002, 2004 and 2005) has been at, or just beyond the limit of *Healy*'s icebreaking capability, with the *Healy* being beset for several days in 2004 & 2005. In the first year, *Healy* was accompanied by *Polarstern* and this year, 2005, *Healy* will work with *Oden* during the crossing of the Arctic Ocean (although in the early part of the transect they will work independently).

Work in the Atlantic sector of the Arctic usually will require transits either to or from the science areas using the Panama Canal. This has occurred in 2001, 2003 and 2005.

In addition to *Healy*, *Polar Star* supported 2 physical oceanographic research cruises in 2002, and the *NB Palmer* supported an SBI survey cruise in 2003.

US research use of foreign research capable icebreakers

Canada

During the last 5 years NSF has funded Canadian Coast Guard support either directly or through research grants to support NSF funded research in the Bering, Chukchi and Beaufort Seas, the Mackenzie Delta, Baffin Bay and Davis Strait. The work is usually conducted collaboratively with Canadian scientists.

Russia

NSF and NOAA both routinely funded ship time and research teams to work on Russian icebreakers, usually to work within Russia's EEZ where access for non-Russian ships is unpredictable

Sweden and Germany

US scientists often work on Europe's most capable icebreaking research platforms *Oden* and *Polarstern* in collaboration with their Swedish and German colleagues.

International Ocean Drilling Program (IODP)

US researchers worked with IODP Arctic Drilling activity in 2004.

Future plans

It is expected that IPY science efforts, principally the establishment of a SEARCH observing network and the Bering Ecosystem Study, will drive requirements during the next 4 years. Beyond IPY it is hard to predict, in a proposal-driven environment, which of the scientific theme areas noted in the first section will drive requirements but it is clear there is very high demand. New technology, such as the HROV (Hybrid Remotely Operated Vehicle), which requires a surface support platform, will also increase demand for icebreakers by U.S. Arctic researchers.

Appendix B

Non-published, internal NSF document

US Antarctic Research Program – Requirements for Ice Breaking

Why Antarctic Sciences Needs Icebreakers

The principal reason that Antarctic Science needs icebreakers is to provide logistical access to the continent via McMurdo Station, and to support science in the Southern Ocean and Antarctic Peninsula regions. Access to the interior of the continent requires support of a coastal station, McMurdo, that in turn supports a myriad of activities that advance knowledge about Antarctica and about the universe. Ice breaking research vessels support marine sciences throughout the Southern Ocean and support USAP programs at Palmer Station in the Antarctic Peninsula.

Antarctica is an integral part of the Earth system. It holds important records of Earth's climate and of life as it has evolved. The ice sheet, along with the surrounding ocean and overlying atmosphere is an integral part of the heat engine of Earth, i.e. it both affects and is affected by conditions elsewhere in the world. As a result, understanding the Antarctic is an essential part of understanding the Earth and its changing climate.

The Antarctic continent constitutes almost 9% of the continental crust on Earth. As such, it contains very important records of Earth's deep time history that bear on topics ranging from continental tectonics to evolution of Earth's biota to climate change and early ice sheet growth. The thick Antarctic ice sheet both records Earth's climate over the last several hundred thousand years and acts as a thermal buffer to global climate change.

The Antarctic constitutes an important natural laboratory for the study of life and ecosystems in an extreme environment. Organisms, and thus ecosystems, exist, and in some cases thrive in conditions of extreme seasonality and cold temperatures. Biological research has the challenge of discovering these special adaptations and then determining how these adaptations have occurred.

The high Antarctic Plateau affords unrivalled conditions for certain types of astronomy and the clear ice of the East Antarctic Ice Sheet has made possible the opening of the new field of neutrino astronomy.

The US Antarctic Program is a world leader in many aspects of Antarctic research. This leadership role exists because NSF empowers the scientific community to determine the most promising research directions through workshops, professional conferences, and other community based activities, and then supports the highest priority research based on open competitive review of proposals. While the university community carries out most of this research, the USAP works with other federal agencies, often in projects involving collaborations with university researchers, on high priority research as well.

This leadership role in Antarctic science would not be possible without the logistical infrastructure that enables access to virtually any part of the continent and the Southern Ocean depending only on the scientific need. Access to Palmer Station and the Southern Ocean, even during the austral winter, is made possible by NSF's use of chartered ice-capable research vessels, the RVIB N.B. Palmer and the RVIB L.M. Gould. Within our current mode of operations, the scientific efficiency of the RVIB Palmer is enhanced considerably by the ability to refuel at McMurdo Station, or from the tanker as it approaches McMurdo during its annual mission to deliver fuel. Access to USAP's South Pole Station and to all areas of the continental interior is possible only with the logistical support enabled by McMurdo Station. Based from McMurdo, helicopters support research in the nearby Dry Valleys region of the Transantarctic Mountains, Twin Otters and LC-130 aircraft support work at a wide array of sites in the interior and at South Pole Station. In turn, ice breakers are essential to the operations and maintenance of McMurdo Station and so are essential to the US Antarctic Program overall. Hence, icebreaker support to enable the resupply of McMurdo is an essential component of the USAP.

Ongoing research supported by the US Antarctic Program falls into 5 major disciplinary areas: Biology and Medicine, Geology and Geophysics, Ocean and Climate Systems, Aeronomy and Astrophysics, and Glaciology. The following paragraphs offer examples, though not intended to be comprehensive, of on-going research in the Antarctic.

Biology – much of the current biological research in Antarctica focuses on three broad themes: adaptation of organisms to the extremes of temperature and seasonality; characteristics, structure, and functions of both marine and terrestrial ecosystems; and responses of organisms and ecosystems to global change. Work over the last few decades has shown that there is significant biodiversity in both the marine and terrestrial environments. Much of this diversity arises from unique functional adaptations that allow organisms to survive and thrive in the region. The current challenge is to use modern molecular biology methods to understand the genetic basis for these adaptations. For example, research concerning genes for cold tolerance and freeze avoidance in fish may provide insights into evolution and adaptation of other organisms to extreme environments. Some of this research results in discovery of new compounds and molecules that might be useful to society. The Southern Ocean marine environment is one of the most biologically productive in the world. This ecosystem has fewer trophic pathways than tropical marine systems, and thus is easier to study both its components and the whole. However, it also is characterized by extensive seasonal variation in light and extent of sea ice that exert different pressures on seemingly similar organisms. For instance, some penguin species thrive in regions of extensive and persistent sea ice, yet others need more open water conditions. As a result, changes in sea ice in the Antarctic Peninsula associated with global change are resulting in shifts in breeding areas and reproductive success of some penguin species. The Antarctic terrestrial environment supports a sparse but hardy biota. Work at the Dry Valleys Long Term Ecological Research (LTER) site, a "cold desert" end-member of the LTER network, is elucidating how seemingly depauperate systems respond to both short-term events as well as longer term global change. The new Microbial Observatory in the McMurdo Dry Valleys is helping to use new genomic methods to understand the genetic basis for microbial adaptation to the harsh conditions.

Geology and Geophysics – research in this general field covers a very broad spectrum of activities ranging from paleontology which reveals the history of life as it evolved in

Antarctica – including the presence of dinosaurs and large marine reptiles – to studies of the Earth's deep interior through seismic observations that are not possible elsewhere in the world. Of particular importance, however, is research aimed at recovery and interpretation of sediment records from the continental margin regions. These sediments provide information about changing conditions in the oceans over geological time. In some instance, these sediment records are complementary to ice cores records and together form a powerful approach to studying the changing Earth. The USAP has just embarked on ANDRILL, an international collaboration with Italy, Germany, and New Zealand, to recover and study sediment cores that span important intervals of time as Earth transitioned from a greenhouse world to an icehouse world. These records will reveal the direct history of ice sheet development on the continent and thus will build 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 with airborne sensors. These studies have revealed important characteristics of the sub-ice 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. One recent project produced the most comprehensive view of a large lake beneath the ice sheet – Subglacial Lake Vostok – and revealed the possibility that this lake could harbor a viable ecosystem.

Ocean and Climate Systems - research in this program area encompasses both oceanography and lower atmospheric research. Within oceanography, a particularly important area of research relates to the formation and distribution of cold-water masses that affect the global circulation in the oceans. Processes of production and flow of so-called Antarctic bottom water are intimately tied to the annual formation of sea ice and are important for circumpolar circulation. Southern Ocean circumpolar currents combined with air mass and heat exchange in the overlying atmosphere affect climate on a regional global basis. In addition, atmospheric and oceanic research is important for understanding overall ice sheet behavior. One active research area is specifically aimed at determining the effect of ocean circulation (including melting) on ice shelves. This is an important component of overall ice sheet behavior because ice shelves form when fast moving glaciers go afloat in the ocean and coalesce to form thick floating glaciers that have a buttressing effect on the ice upstream. Without the ice shelves, inland ice would move faster and thinning of the ice sheet could occur. Balancing this loss of ice is precipitation of new snow on the ice sheet. Research is also underway to understand how precipitation has changed over time and how recent precipitation patterns relate to global phenomena such as El Nino and La Nina events.

Aeronomy and Astrophysics – research in this program covers a spectrum of activities including solar-terrestrial interactions and the Earth's magnetosphere, as well as astronomy and astrophysics. The polar regions are uniquely suites 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. The observations made at USAP stations and at remote sites are essential to understanding phenomena such as space weather. Observations of the upper atmosphere are also made – in particular – to understand ozone destruction, and to couple in situ atmospheric observations with satellite-based observations of total ozone composition. 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, ultra low moisture content, and long periods suitable for observations. These conditions enable discoveries that are not possible elsewhere in the world. Pioneering efforts in radio astronomy have 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 – to study high-energy neutrinos that can tell us 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 Pole 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 5000 detectors to find these elusive particles and determine their source in the universe.

Glaciology – much of the research in glaciology focuses on two areas – studies of climate variation through ice cores, and studies of the ice sheet to understand how it works and how it might change in the future. Earth's climate has changed dramatically geological time. The more recent changes can be directly studied by extracting both direct and proxy records from snow and ice cores. These records can be used for understanding how the Antarctic has responded to, and how it has been a forcing factor in, climate change over a variety of time scales covering the last 500,000 years of Earth history. Work in the past on the Vostok ice core produced, in collaboration with the French and Russian Antarctic programs, a spectacular record of changes in temperature and atmospheric gas concentration over the last 4 glacial-interglacial cycles. Recent work under an international collaboration called the International Trans-Antarctic Scientific Expeditions (ITASE) is revealing detailed records at a large number of sites over the last several hundred years to understand changes in climate during the transition from low to high anthropogenic greenhouse gas production. Over the next several years, the USAP will undertake a project to drill a deep ice core in central West Antarctica (WAISCORES) with the expectation that this will produce records of climate and atmospheric gases over the last 120,000 years or so for understanding change in Antarctica but also for comparison with a similar record from central Greenland for understanding inter-hemispheric variations. In addition, substantial research is being done to understand the dynamics of the ice sheets – how do they change and how fast can they change. Achieving good prognostic models for ice sheet behavior is important because of the large effect that changes in the ice sheet have on global sea level. Important recent work in this field was supported in the 04/05 austral summer 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. Important on-going research is aimed at understanding the effects that ocean tides can have on ice shelves and ice streams far into the interior of the ice sheets.

Federal Cross-Agency Research

In addition to science supported by the Foundation, the USAP facilitates mission research of other agencies. Some examples include:

- Support for the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) at South Pole Station. This is one of five benchmark sites spread across the globe and run by NOAA as key monitoring sites.

- Support for NASA's Long Duration Balloon Program. This program offers the ability to fly instruments in near-space conditions at a fraction of the cost. It also offers the ability to have instruments at altitude for several weeks as compared to flights in temperate latitudes that last only several hours.
- Support for the NSF/NASA/Smithsonian US Antarctic Meteorite Program. This program collects and curates Antarctic meteorites for use by scientists around the US and the world. Meteorites offer important information about the early history of our solar system and, though rare, some are samples of the Moon and Mars.
- Support for NASA's satellite launch tracking system at McMurdo that provides useful post-launch information as payloads transition into orbit.
- Joint NSF/NASA programs in exploitation of satellite data for glaciological studies.
- Support for NOAA-sponsored marine mammal research in the Antarctic Peninsula.
- Joint NSF/USGS programs in geodesy, cartography, hydrology, ice core science, geographic information support, and related topics.

Appendix C

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United States Antarctic Program
Research Vessels

Alexander L. Sutherland
Office of Polar Programs
National Science Foundation

Abstract

The U.S. Antarctic Program (USAP), funded and managed by the National Science Foundation (NSF), has provided dedicated research vessel support for four decades. This paper briefly reviews the impetus to provide such research support, discusses some of the vessels used over the past 40 years and concentrates on the present vessels the *Nathaniel B. Palmer* and the *Laurence M. Gould.*

Antarctica and the Southern Ocean

The Antarctic has been an allure to ships since Medieval Cartographers introduced the concept of Terra Australis Incognita onto nautical charts. Ships seriously exploring for the Antarctic started with those of Cook (1772-75) and later Weddell (1823). These early sailors, and ones that followed, observed icebergs obviously formed by the calving of land based glaciers. Providing further evidence, they noticed that some of the glaciers had entrained rock and soil that could only have come from land. They, however, could not penetrate the pervasive sea ice far enough south to observe any land. U.S. exploration began in the 1820's. Sealers and whalers lured by the lucrative oil and fur trade began hunting the abundant seal and whale populations in antarctic waters. These taciturn hunters of the sea explored the islands north of the Antarctic Peninsula and doubtless made numerous charts and oceanographic measurements of things such as presence and counts of wildlife, tides, current, temperature, and depth. However, their motivation was the highly competitive seal and whale industries and, as such, their discoveries were most often closely guarded. Nathaniel B. Palmer a young, 20 year old sailed as Captain of the 14.3-meter (47-foot) sloop *Hero*, one of the ships in a large whaling fleet out of Stonington, Connecticut. In the summer of 1820, while working in the Shetland Islands south of South America, he ventured further south than his companions in the fleet and made the first recorded observation of the Antarctic Continent in an area now known to be part of the Antarctic Peninsula. (The Russian, Bellingshausen, and the British Bransfield, have also been credited as first sighting the continent). [1]

The first major U.S. oceanographic expedition in Antarctic waters was that of Wilkes in 1838-42. Wilkes explored the Antarctic waters South of Australia and India between approximately 90E and 160E Longitude along what is now known as Wilkes Land. In addition to numerous recorded oceanographic measurements, his sightings of land throughout this broad expanse clearly demonstrated that the extensive land mass was large enough to be classified as a continent.

Although oceanographers for years have referred to the oceans surrounding the Antarctic as a separate and distinct body of water, it has only recently been officially named the "Southern Ocean". A spring 2000 decision by the International Hydrographic Organization delimited a fifth world ocean from the southern portions of the Atlantic Ocean, Indian Ocean, and Pacific Ocean. The new ocean extends from the coast of Antarctica north to 60 degrees south latitude, which coincides with the Antarctic Treaty Limit. The Southern Ocean is now the fourth-largest of the world's five oceans (after the Pacific Ocean, Atlantic Ocean, and Indian Ocean but larger than the Arctic Ocean).[2] It is an inhospitable ocean with an annual ice advance and retreat that has been described as the greatest seasonal event on earth. Storms proceed around the southern ocean in a relentless clockwise (west to east) fashion with very little interval between them. Vessels now regularly operate in these seas but their numbers are few. The primary ship traffic is tourism and ships supporting national Antarctic programs in logistics and oceanographic research (see International Association of Antarctic Tour Operators (IAATO) website http://www.iaato.org/ and Council Of Managers of National Antarctic Programs COMNAP website http://www.comnap.aq).

United States Antarctic Program Research Vessels - History

The United States Antarctic Program (USAP) is managed by the National Science Foundation, Office of Polar Programs. Since the time of Nathaniel Palmer and up until the International Geophysical year of 1957/58, U.S. ships have been conducting some level of oceanographic research, but that was often peripheral to their mission. The first USAP vessel solely dedicated to oceanography was the *Eltanin* from 1962-1972. The 81-meter (266-foot) *Eltanin* circumnavigated the Antarctic in an exploratory fashion with each cruise being a systematic multi-disciplinary survey. [3] In 1968 another USAP vessel with the familiar name of *Hero* joined the *Eltanin* in oceanographic research. This *Hero*, although much larger than her predecessor, was still a throwback to an earlier time. The 38-meter (125-foot) vessel was a sail assisted, diesel driven vessel of wooden construction. The ship was built in South Bristol, Maine and was designed similar to that of a New England trawler. Like Nathaniel Palmer's *Hero*, the successor vessel operated in the waters of the Antarctic Peninsula. It supported Palmer Station, the small USAP research station in the Peninsula and unlike the *Eltanin* it concentrated on hypothesis driven research cruises rather than systematic surveys.[4,5] The *Hero* was retired in 1985 and replaced by the much more capable *Polar Duke*. The *Duke* flag was originally Canadian and then was changed to Norwegian. She is 66-meters (218-feet) long and is a Baltic "Sealer" ice class, which makes her capable of breaking .3-meter (1-foot) of ice at a continuous forward progress. The *Duke*, owned and operated by Reiber of Norway, was originally designed for oil field support work in Eastern Canada. She was modified for oceanographic work and chartered to the USAP for work primarily in the Peninsula – expanding the role of the *Hero*. The *Duke* played a dual role of being a supply vessel for Palmer Station and that of an oceanographic research vessel. The *Duke* served the USAP for 13 years completing its charter in 1997[6].

The present era in USAP oceanography started with the *Nathaniel B. Palmer*. The *Palmer,* launched in 1992, is the first modern era U.S. commercially built and owned icebreaker. Classed at ABS-A2, it can nominally break 1-meter (3-feet) of ice at a steady 5.6 km/hr (3 knots). The ship was built from keel up as an ice breaking research vessel. The 94-meter (308-foot) vessel operates year around in all areas of the Southern Ocean and is presently on its second circumnavigation of the Antarctic. The newest ship in the USAP fleet is the *Laurence M. Gould.* The 70-meter (230-foot) *Gould* is classed as an ABS A1 Icebreaker with roughly the same ice breaking capability as that of the *Duke.* Unlike the *Duke*, however, the *Gould* was purpose built, rather than retrofitted, for the dual role of research and Palmer Station supply. The *Gould* typically operates around the Antarctic Peninsula and is named after the Chief Scientist of the second Byrd Antarctic Expedition who was a diplomat, college president, member of the National Science Board, and Chairman of the Polar Research Board in addition to being an eminent scientist.

The U.S. Coast Guard (USCG) icebreakers have also supported Southern Ocean science. Currently USCG support is provided by the *Polar Star* and *Polar Sea*. These vessels are 122-meters (399-feet) long, with a nominal icebreaking capability of 2-meters (6-feet) of ice at 5.6 km/hr (3 knots). This is roughly equivalent to ABS A5 (although military vessels do not have formal ABS ratings). The primary mission of these vessels when operating for the USAP is logistics. Each year one of these vessels on an alternating basis deploys to the Ross Sea. There they break the channel into McMurdo Station, the largest station operated by the USAP and the staging point for almost all U.S. inland research on the Continent, including the Amundsen-Scott, South Pole Station. In addition to breaking the channel, the *Star* or *Sea* is responsible for providing fuel to a remote helicopter airfield and escorting a tanker and a freighter that annually supply McMurdo. This leaves little time for supporting research, but each year a few short term projects are supported on the south or north bound deployment legs or during the busy time while working in McMurdo Sound. (See Berkson in this volume of the MTS Journal for an article on USCG science support in the Arctic.)

Southern Ocean Science

The worlds most under explored oceans are those closest to the poles. The track line chart of geophysical cruises published by the National Geophysical Data Center (NGDC) shows huge gaps in our knowledge of the Southern Ocean whereas the geophysical track lines in areas between 60°S and 60°N have virtually filled the chart. While exploratory work still must be done, there are also compelling scientific questions that need to be answered. The Antarctic Circumpolar Current, reportedly the mightiest of the ocean's currents, is a key to understanding rapid changes in world ocean circulation and its effect on global climate change. The leaching of brine out of the sea ice surrounding Antarctica forms very cold, very dense, very saline water. This water sinks to the ocean bottom and begins a long, slow voyage to the Northern Hemisphere where it surfaces. Understanding the movement and ultimate surfacing of oceanic deep waters is another key to understanding global climate change. The ozone hole, which annually occurs over Antarctica, allows the penetration of harmful ultraviolet-B radiation into the sea. Studying the effects of this UV-B on phytoplankton, and other members of the food chain, may help to understand the level of harm that can be expected from continued UV-B penetration. The Ross Sea is thought to be the location of one of the world's largest blooms of phytoplankton. Understanding the massive uptake and release of carbon by these microscopic organisms will give insight to the worlds global carbon balance. Assessing the population status of krill and fin fish provides data to aid in the regulation of commercial fishing. Studying the geology and geophysics of the ocean bottom in the seas surrounding Antarctica will provide knowledge of pre-historic climate cycles. The ebb and flow of grounded icebergs leave indelible evidence on the floor of the Antarctic Continental Shelf. Understanding and dating these phenomena will help piece together a clearer understanding of paleoclimates. The plate tectonic movement of the world's continents can only be understood if the tectonic motion of the Antarctic Continent, by deep penetrating ocean seismic experiments, is also studied. These and many other compelling scientific questions have kept the USAP oceanographic research ships fully booked well into the future.

Contractual Arrangements

Starting with the *Eltanin* and continuing through the present day, USAP ship operations have been contractor operated. The present two ships the *Palmer* and the *Gould* continue in that method of operation. The NSF employs a prime contractor to operate most of the USAP facilities in the Antarctic. This includes chartering of major facilities operations such as ships and aircraft. The present prime contractor is Raytheon Polar Services Company (RPSC). RPSC, in turn, charters the *Palmer* and the *Gould* from a Louisiana based corporation, Edison Chouest Offshore (ECO). ECO owns and operates a fleet of over 300 vessels that perform offshore and specialty operations. A major factor in the consideration of lease vs. buy was cost. A lease versus buy analysis, using a method prescribed by the government's Office of Manpower and Budget, resulted in a determination that a lease was most advantageous to the government. This type of analysis is far from precise. It involves a number of estimates and assumptions including interest rates, discount rate, operating costs, length of lease, and ship value at the end of the lease. Cost, however, was not the only factor in the decision to lease. There are a number of other items that were factors in the decision:

1. Risk – With a lease, the owner is financially responsible for building the vessel. Lease payments begin only upon delivery and acceptance of the vessel. Shipyard cost and time over-runs are at the risk of the owner.

2. Fleet management – The maintenance of the vessel and the hiring of the crew is the responsibility of the owner. A vessel owner that operates a large fleet, such as ECO, has the corporate capability to manage the logistics necessary to keep ships running in remote locations. Crew, for unique and demanding vessels, such as antarctic research vessels, are first proven on other less demanding vessels in the fleet and come to the USAP as proven individuals with the demonstrated capability of independent, difficult operations.

3. Construction – In the case of the *Palmer* and the *Gould*, the ship owner, ship builder and ship operator are all one company. This can have significant advantages to the charterer. In more typical situations in which the owner/operator is separate from the ship yard there is often a conflict of economic drivers. The operator wants a quality ship that will be easily maintained and efficiently run. The shipyard wants to provide a ship that meets specification at the lowest cost. Any operator-instituted changes in specification to improve operational capability or maintainability that occur during shipyard construction are likely to be extremely expensive. With an operator that owns the shipyard, these conflicts typically do not arise and changes that improve the ship's capability and maintainability are readily incorporated.[7]

The business practices of research vessel ownership and operation vary considerably with the agency or institution supporting the research. The USAP and NSF's Ocean Drilling Program (ODP) use the contractor owned and operated model. The National Oceanographic and Atmospheric Administration (NOAA) primarily uses a model of government owned - NOAA Corps operated, but they also contract for some of their ship time. The Coast Guard owns their vessels and operates them with Coast Guard sailors. University National Oceanographic Laboratory System (UNOLS) vessels are a combination of government (Navy and NSF) owned vessels and University owned vessels. They are operated by the individual Universities through funding primarily provided by NSF and other government agencies. Each of the methods of providing research ship support to science varies considerably, and each has both advantages and disadvantages. None is necessarily "better" than the other and all are a reflection of the standard means of operation of the particular agency or institution.

ARVOC

The USAP employs the support of the scientific community in the design and operation of its major facilities. There are oversight committees for each of the major, land-based antarctic stations: McMurdo, Amundsen-Scott South Pole, and Palmer. Likewise there is an oversight committee for the research vessels: the Antarctic Research Vessel Oversight

Committee (ARVOC). The ARVOC and its precursor have been involved in provision of design specifications, staffing, equipment recommendations and general operating policy of the USAP ships. The committee consists of nine members who are active users of the USAP vessels and are representative of the various scientific disciplines using the ships. The ARVOC meets once or twice per year. Design specifications of both the *Palmer* and *Gould* relied heavily upon UNOLS specifications for large and intermediate research vessels and added special enhancements for Polar operations. During construction of each of the vessels, the ARVOC met regularly at the shipyard in LaRose LA. and provided invaluable guidance regarding design, construction and recommended modification. Presently the ARVOC is reviewing the possibility of adding another vessel to the USAP fleet, a relatively small vessel (37-46 mtr.(120-150 ft.)) for close support of Palmer Station. The ARVOC works closely with the UNOLS Arctic Icebreaker Coordinating Committee (AICC). Each committee a liaison member who attends the other's meetings. Past Chairs of ARVOC (and its precursor) have been: Capt. Robertson Dinsmore (Woods Hole Oceanographic Institution) (2/90 – 2/92) ; Dr. Douglas Martinson (Lamont-Doherty Earth Observatory) (4/94 – 12/97); and Dr. David Karl (University of Hawaii) (1/98 – 12/00). The present Chair is Dr. Robin Ross (University of California at Santa Barbara) (1/01 – 12/03). (The ARVOC web site may be viewed at: www.polar.org/science/marine/arvoc/arvoc.htm)

NATHANIEL B. PALMER

The contract for construction of the *Palmer* was signed on February 26, 1990. The ship was completed and commissioned on March 15, 1992. Since that time the *Palmer* has operated on a year around basis in the Southern Ocean. She has completed her second circumnavigation of the Antarctic Continent. Cruises have been intense and varied. A number have been in support of major multidiscipline and international oceanographic programs such as Global Ecosystems Dynamics (GLOBEC), the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), the Antarctic Pack Ice Seal study (APIS), the Antarctic Zone Flux experiment (ANZFLUX) and the Long Term Ecological Research program (LTER). The *Palmer* has worked deep in the Ross and Weddell Seas during the harsh antarctic winter. In fact, the *Palmer's* first cruise was in the austral winter in support of a joint US-USSR (now Russia) ice camp deep in the Weddell Sea. The cruise track taken by the *Palmer* paralleled that of the ill-fated cruise of Sir Earnest Shackelton when his ship the *Endurance* was crushed in the grips of the Weddell Sea ice. The *Palmer*, because of her icebreaker rating of ABS A2, was not subject to a similar fate. The *Palmer* is equipped for biology, chemistry, geology, ecology and both ocean bottom and sea ice geophysics.

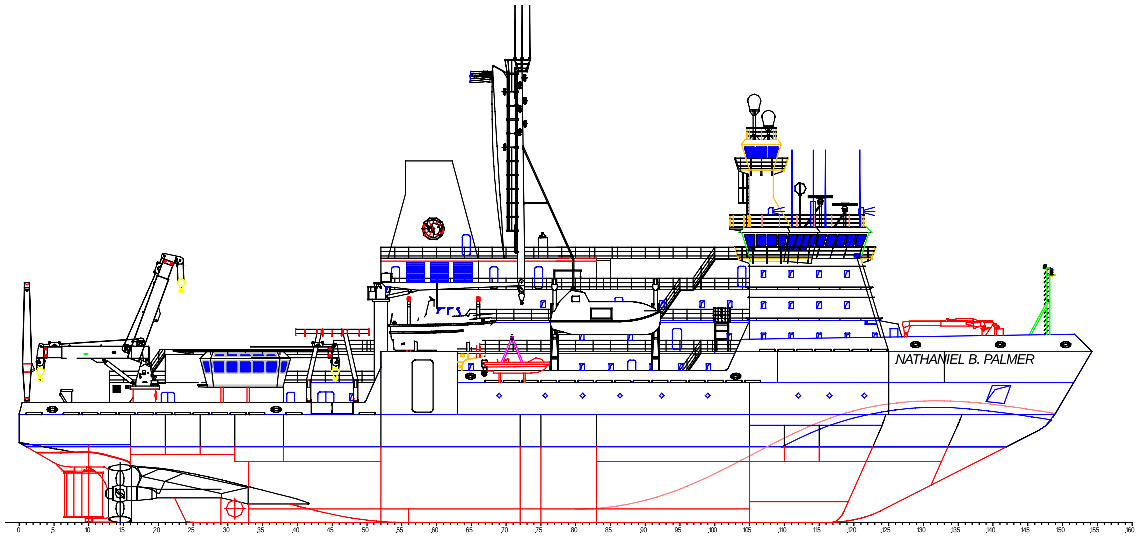

Figure One: Outboard Profile of *Palmer*

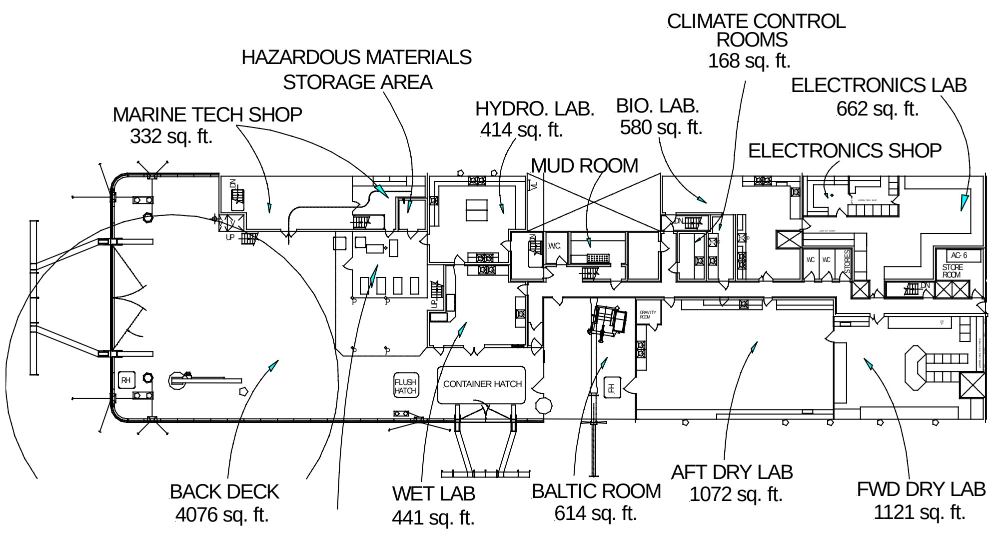

Figure Two: Main Deck Layout of *Palmer*.

A new contract for an additional charter of the *Palmer* was signed on April 10, 2001. It includes a six-year initial term with a four-year optional extension and goes into effect starting March 16, 2002. The new charter will includes: replacement or upgrade of the existing multibeam survey system, fabrication of a moonpool capable of supporting a geotechnical drill rig, an upgrade of the dynamic positioning system, increased berthing, a larger crane, improved workboat characteristics, enlargement of the bio-chemistry lab and extensive renewal of laboratory furnishings and utilities.

The particulars of the *Palmer* are shown below in Table 1. [6,7]

Length	94 m (308 ft)
Breadth	18 m (60 ft)
Design Draft	6.9 m (22' 6")
Displacement	6900 MT (6800 LT)
Horsepower	12,720 SHP from four mains 1,500 HP Bow thruster 800 HP Stern Thruster
Propellers	2 – Variable pitch in Kort Nozzles
Rudders	2 – High Lift
Berthing	39 Science and support technicians
Ice Class	ABS-A2 (nominally break 1 m of ice at 5.6 k/hr (3ft of ice at 3kts))
Winches	Markey, DUSH-5, (Baltic Rm) 10,000m .818cm E-M (33,000ft, .322") Markey, DUSH-5-5WF, 10,000m .818cm E-M & 10,000m .635cm 3x19 WR (33,000ft, .322"; 33,000ft, ¼") Markey, DUSH 9-11, 10,000m 1.72cm E-M & 10,000m 1.43cm 3x19 WR (33,000ft, .680"; 33,000ft, 9/16"
A-Frames	Stern – 11.8 MT, 9m clearance (12 ton, 30') Starboard –11.8 MT, 6.1m clearance (12 ton, 20') Baltic Room – Boom – 5.4 MT (6 ton)
Workboat	7.9m (26ft) steel hull
Compressors	2 @ 566 ltr/sec, 140kg/cm^2 (1200-scfm, 2000 psi)
Lab Space	548 m^2 (5,900 ft^2)

Table 1 – Ship's Particulars, *Nathaniel B. Palmer*

The *Palmer* was specifically designed for year around antarctic operations. The ABS-A2 classification enables operation in almost all antarctic ice regimes. For multi-year ice, that is ice that has survived more than two years melt cycle, a higher ABS class would be warranted. Multi-year ice is common in the Arctic but is far less common in the Antarctic. In the Arctic, an ocean surrounded by continents, ice located close to the North Pole doesn't melt much in summer and can survive a number of years before ocean circulation ultimately drives it into lower latitudes. As sea ice ages, salt leaches out of the ice in the form of highly saline brine. The remaining ice becomes continually less saline and becomes much harder than salt water ice. Also as it ages without thawing it becomes much thicker. In contrast, the Southern Ocean is an ocean surrounding a continent. First year ice is the product of the annual growth and decay of sea ice around the Antarctic. There are areas deep in the Ross and Weddell Seas, the two seas that penetrate to the most southerly latitudes, that form ice that survives one year melt. However there are gyres in both the Ross and the Weddell that circulate this ice out to higher latitudes before the two-year ice is officially classified as multi year ice.

The *Palmer's* ice class ensures the hull strength, horsepower and structural integrity of rudders and propellers to operate in the ice covered areas of the Southern Ocean. In addition to ice class, the vessel has other features that are unique to polar oceanography. The oceanographic staging hangar, or Baltic room, has proved to be extremely effective in temperatures as low as -30°C. The room is equipped with a large, hydraulically operated, watertight door that opens directly to the sea from the skin of the ship on the starboard side. Inside the Baltic room is an overhead telescoping boom and a Markey DUSH 5 winch. The room is heated by three 440-volt heavy-duty electric blower heaters to a near shirtsleeve environment. Sensitive instrumentation such as CTD rosettes can be assembled and tested in comfort prior to opening the door to the environment and extending the boom to deploy the instrument. Total time to deploy and retrieve such instrumentation into and out of the water is a matter of a few minutes, thus avoiding potentially disastrous freeze-up of sensitive instruments or water bottles.[8] Another feature unique to polar oceanography is the heated exterior main working deck. This deck has been proven to keep the decks ice free and safe in temperatures below –30°C. Finally, unique to polar oceanography, a helicopter deck and hangar are available. Cost consideration has prevented significant use of helicopters, but their use in ice covered waters can extend the range of the science and the operation of the ship considerably.

Because of the remote location and the extended shipping time necessary to get scientific equipment to the *Palmer,* the ship is extensively outfitted with oceanographic and scientific measurement instruments and a fully networked computer system. Information regarding this suite of instruments may be found on the Web at: www.polar.org/science/marine/nbp .

LAURENCE M. GOULD

The *Gould* follows in the tradition of the *Polar Duke* by being both a research vessel operating primarily in the Antarctic Peninsula region and a re-supply vessel for USAP's Palmer Station, located in the Peninsula, on Anvers Island, about 120 miles north of the Antarctic Circle.

The *Gould's* contract is for an initial five year with options to extend to ten years. It was signed on April 18, 1995 and the ship was commissioned on January 16, 1998.

The *Gould* is a fully capable ice-breaker, rated at ABS-A1. It is smaller and has less icebreaking capability than the *Palmer*, but it is very well suited for work in the

Peninsula, the most northerly region of Antarctica where ice conditions in the surrounding ocean are less severe than in other regions. The ABS-A1 rating nominally means that the ship can break one foot of ice at continuous forward motion. Backing and ramming, the ship can break far thicker ice. In the Peninsula, in all but the winter season, there are typically open leads in the pack and often no pack at all. Infrequent conditions when the pack is highly consolidated and under pressure by persistent winds has caused the *Gould* to become beset. The structural integrity of the hull is such that there is no concern for safety and it is only a matter of waiting for wind patterns to shift to reduce the pressure and allow the *Gould* to continue.

The particulars of the *Gould* are shown in Table 2. Like the *Palmer*, the *Gould's* general oceanographic specifications are derived from UNOLS specifications for large and intermediate research vessels.

Length	70 m (230 ft)
Breadth	14 m (46 ft)
Max Draft	5.8 m (19 ft)
Displacement	3411 LT (3468 MT) (1599 GRT)
Horsepower	4575HP from two mains 800HP Bow thruster
Propellers	2 Variable Pitch in Kort Nozzles
Rudders	2 High lift
Berthing	28 Science and support technicians plus10 more short term in berthing vans
Ice Class	ABS-A1 (nominally 1 ft of ice at continuous forward motion)
Winches	Markey, DUSH 5, (in Baltic Room) 10,000m, .818cm E-M (33,000ft, .322") Markey, DUSH 6 interchangeable drums, 6,000 m 1.27cm 3x19 WR & 2,800m, 1.72cm E-M (19,700ft, ½" WR & 9,200ft, .680 E-M) Markey, DUSH 4, interchangeable drums 6,300 m, .818cm E-M & 7, 000m .635cm 3x19 WR (20,700ft, .322" E-M & 23,000ft, ¼" WR)
A-Frames	Stern: 10MT, 7.5 M clearance (11 ton, 24'7") Starboard: 5MT, 19'6" clearance (5.5 ton, 19'6") Baltic Room Boom: 5MT (5.5 ton)
Compressors	118 ltr/sec, 149kg/cm^2 (250cfm, 2000psi)
Lab Space	225m^2 (2425 ft^2)

Table 2 – Ship's Particulars, *Laurence M. Gould*

The dual mission of the *Gould*, that of research and re-supply of Palmer Station, dictates a configuration and a normal cruise schedule that is somewhat different from that of pure research vessels. Typically there are 10 to 12 cruises per year. All are in the general area of the Antarctic Peninsula with Punta Arenas, Chile as the typical port of embarkation/debarkation. Most of these cruises will stop at least once at Palmer Station and sometimes twice to handle south and north bound Station cargo and personnel. The *Gould* can carry 9 standard, 20 ft shipping containers (4 in the hold). There are also 2 berthing vans that each carry five persons. The berthing vans are carried in the hold. Both the hold and the vans were required to have special fire protection and communications connections to be Coast Guard certified for the personnel habitation.

These vans are carried aboard as necessary and are only occupied for the transit to/from Palmer Station.

The research mission of the *Gould* is multipurpose. Because the Peninsula is the location of an abundant and varied collection of antarctic flora and fauna, there tends to be a majority of biological, bio-chemical and ecological cruises. However, the ship is also capable of supporting geology and geophysics (e.g. coring, single channel siesmics (with installed 250cfm Price compressors) and physical oceanography. The ship has a 3 ft diameter moonpool that is used for transducer installations and is the source location for drawing ice free uncontaminated seawater. Like the *Palmer*, the *Gould* has a Baltic room. Additionally, like the *Palmer*, and because of the remoteness and long shipping time from the U.S. to Punta Arenas, the *Gould* carries and extensive inventory of onboard sensors, instrumentation, computers and oceanographic equipment. (See website: www.polar.org/science/marine/lmg). Unlike the *Palmer*, the *Gould* does not have a helicopter platform or heated decks.

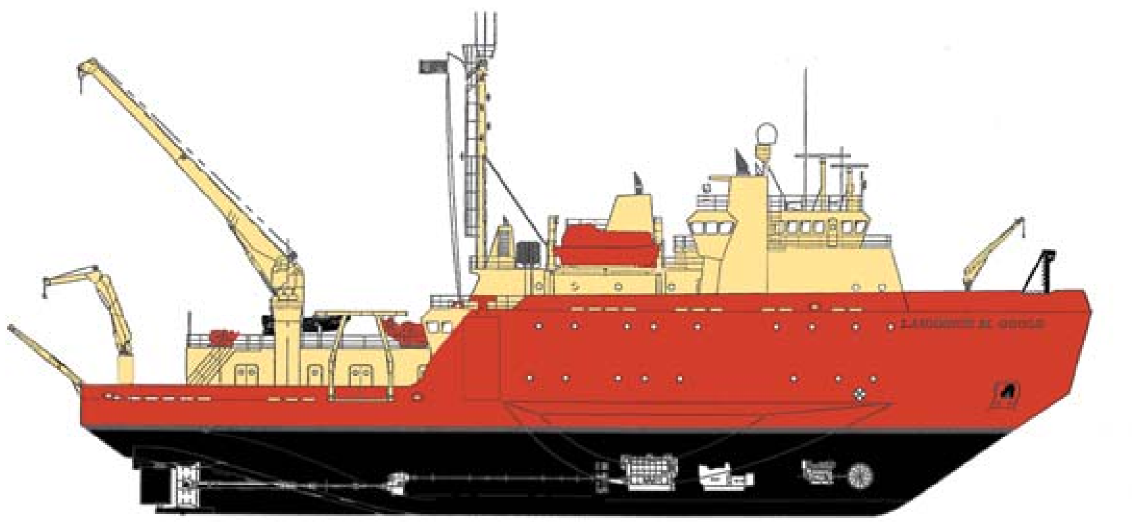

Figure Three: Outboard Profile of *Gould*

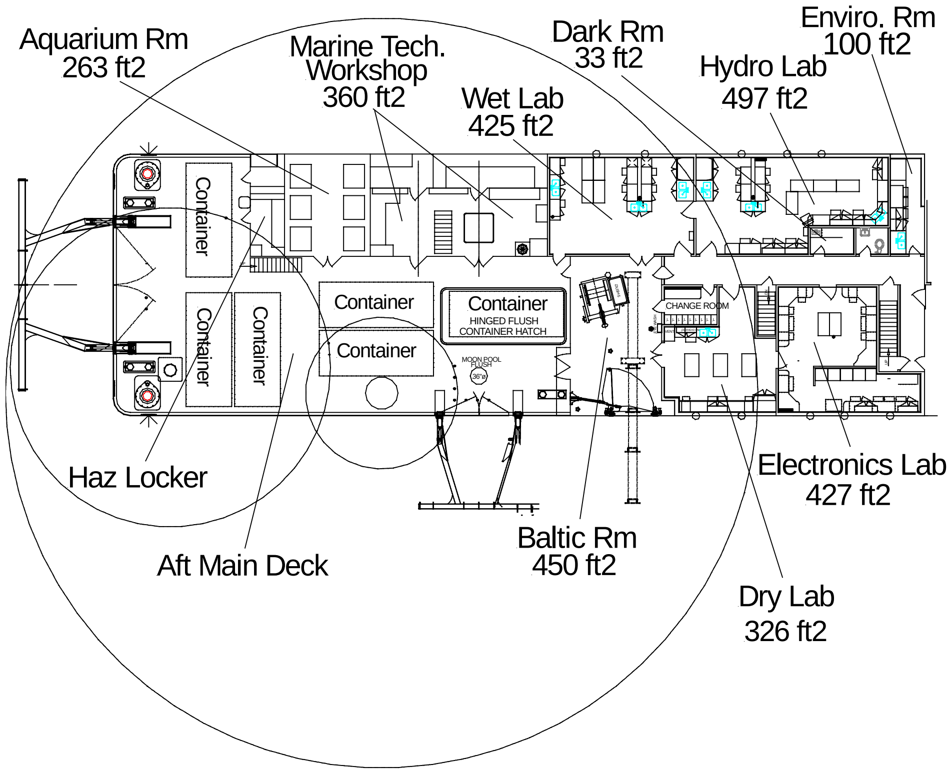

Figure Four: Main Deck Layout of *Gould*

CONCLUSION

The tradition of U.S. support for oceanographic research in the Antarctic is being upheld to this day. Both the *Palmer* and the *Gould* are providing excellent service to the USAP and are enabling significant contributions to our understanding of the biology, chemistry, physical oceanography and geology of the Southern Ocean and the its role in understanding global processes. The charter for the *Gould* will continue until 2002 and can be extended until 2007. The *Palmer's* present charter expires in 2002, and a new charter is in place to extend period until 2008 with options to extend further until 2012.

Figure Five: Picture of *Palmer* and *Gould* together at Palmer Station dock.

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Appendix D

Synopses of the Research Cruises Conducted aboard the *Nathaniel B. Palme*r in 2004

- May – July 2004 "Icefish" cruise - 60 day cruise from Punta Arenas, Chile to Capetown South Africa - Internationally sponsored with 7 nations providing participants - fisheries biology cruise censusing sub-antarctic fish.
- August – September 2004 Transit from Capetown to Aukland and 20 day Dry Dock in Auckland
- October – December - 65 day cruise - Physical Oceanography cruise in the Northern Ross Sea – bottom water formation, global ocean circulation
- December – January 2005 - 39 day cruise – Biological Oceanography in the Southern Ross Sea – phytoplankton bloom, gaseous sulfide emissions and contribution to global climate. Cruise ended in McMurdo.
- January – February – 18 day cruise – Mixed discipline, underway geophysics, Physical Oceanography Mooring Recovery Biological Oceanographic Mooring recovery. Cruise ended in New Zealand
- February - Maintenance – 14 Days in New Zealand
- March - Transit to Punta Arenas Chile - 21 days – Underway geophysics, multibeam, magnetics
- April – "Shaldril" – 24 day cruise near South Shetland Islands and in the Western Weddell Sea. Installation of a geotechnical drill rig that drills through a moonpool in the vessel's hull
- May – June – 46 day open period (no funded science)
- June – July – 22 day cruise in Chilean Fjords – geophysics, seismics, multibeam, piston coring, land based investigations on glaciers
- July – Sept - 60 day cruise, Physical Oceanography, deep ocean mixing events in the Southern Ocean in winter - global ocean circulation, instrumented ice flows, water column chemistry sampling

Synopses of the *Laurence M. Gould* Activities in 2004

- July 2004 – 26 days – Northbound cruise to Louisiana to return hazardous waste generated aboard ship and at Palmer Station to the United States. This return of waste to the U.S. is an obligation of the U.S. under the precepts of the Antarctic Conservation Act.
- August – 21 days – Louisiana – dry dock.
- August - September – 26 days – south bound back to Chile
- September – October 15 days – change over Palmer Station winter and summer crews - re-supply Palmer

- October – 13 days – open penguin study field camp on King George Island, South Shetland - bring science and support crews and supplies to Palmer Station.
- November – 12 days – Open two more wildlife study field camps on King George Island and the Peninsula – re-supply stop at Palmer
- November – December - 29 days - Biological Oceanography cruise – study of salps which comprise a significant amount of the biomass in the Southern Ocean and their contribution to biogeochemical cycles in the ocean – also stop at Palmer Station
- January – February 2005 – 39 days - Long Term Ecological Research Cruise – long term study of the regional ecology and its changes over decadal periods – stop at Palmer
- February – March – 28 days – Geology Geophysics cruise - Western Weddell Sea in vicinity of the Larson Ice Shelf, which spectacularly disintegrated the previous year. Mapping and sampling of sea bottom that had been heretofore inaccessible.
- March – 14 days - Palmer re-supply and field camp pull out.
- April - 13 days – Whale sound recording mooring pick-up and Palmer re-supply.
- April – June – 2, 22 day cruises – biological oceanography – collection of Antarctic fishes and studies of their physiology and protein structure compatible with life at body temperatures of approximately 0 degrees C.
- June – August – Hazardous waste to U.S. and return.