ADVANCING U.S. POLAR RESEARCH THROUGH THE ACQUISITION OF A NEW POLAR RESEARCH ICEBREAKER

A REPORT FROM THE ANTARCTIC RESEARCH VESSEL OVERSIGHT COMMITTEE

JUNE, 2006

Executive Summary

The Antarctic Research Vessel Oversight Committee (ARVOC) serves in a formal advisory capacity to Raytheon Polar Services Corporation (RPSC), the principal NSF contractor for support of the U.S. Antarctic Program. ARVOC members serve as volunteers and are elected from the U.S. Polar Science Community. ARVOC provides the U.S. Antarctic Program (USAP) with advice and recommendations regarding its polar research vessels. For the past 4 years ARVOC has been engaged in an assessment and planning effort directed towards making recommendations to the USAP regarding future vessel contracts and the possible construction of a new polar research icebreaker. Two community science workshops were held in 2002 with the goal of anticipating future scientific requirements for Southern Ocean marine research over the next decade and beyond. Workshop products were used extensively by ARVOC members in their deliberations about the justification for, and design of, a possible new polar research icebreaker. To explore possible designs for a new research icebreaker, NSF contracted with the U.S. Maritime Administration (MARAD) and Science and Technology Corporation's polar technology group (STC) in 2003. ARVOC subsequently formed a 15-member special standing committee to work interactively with RPSC, MARAD, STC, and NSF on a feasibility level design study and to collect additional science community input on research vessel design issues. ARVOC organized a series of "Town Hall Meetings" at large national science congresses. We surveyed many additional members of the polar research vessel user community in one-on-one contacts. ARVOC has also collected information through a public access website where questions, comments, and opinions about vessel science mission requirements and design are logged and archived. As of May 1, 2006, ARVOC estimates that more than 270 individuals have provided opinions, comments, and technical design or engineering information related to the design of a next-generation polar research icebreaker. ARVOC members as well as other members of the polar science community that were brought in to participate in the preparation of this report are listed in appendix 3.

While the RVIB *Nathaniel B. Palmer* (NBP) has served the science community well over the past 15 years, there are compelling reasons to plan now for a new research icebreaker to support future U.S. efforts in the Southern Ocean. Specific research requirements that mandate a new vessel for future scientific exploration of the Antarctic seas are as follows:

- Enhanced ice breaking capabilities (4.5 feet level ice at 3 knots)
- Increased endurance (to 80 days)
- Increased accommodation and lab space (for 50 scientists)
- Moon pool for geotechnical drilling and access to the water column through a controlled interface (no ice, limited surge and turbulence)
- Ability to tow nets and research instrumentation from the stern during ice-breaking

- Acoustically quiet vessel with hull form designed for installation and operation of remote sensing instruments.

The first two requirements are directed towards substantially increasing the reach of U.S. researchers into a greater portion of Antarctica's ice-covered seas, as well as throughout the Southern Ocean during all 4 seasons. Increased accommodation space will foster comprehensive and integrative approaches to Antarctic marine research. The moon pool, ice-shedding stern, and acoustic/hull properties are required to take advantage of new tools that have become important for many types of Antarctic research. Taken together, these requirements dictate that the next generation Polar Research Icebreaker will be larger and have a different hull shape than our current polar research vessels.

The scientific rationale leading to these requirements is based in part on the following themes. 1) Understanding Antarctica's role in global change requires access to dynamic areas of the ice sheet margin as well as those areas where heat exchanges between the atmosphere and ocean. Many of these areas are currently inaccessible to the U.S. research community and none of them are accessible year-round. 2) The past history of the ice sheet can inform us about likely scenarios for the future. One of the most useful records of ice shelf and ice sheet activity is preserved in the sediments of Antarctica's continental shelves. These sedimentary archives can be drilled and cored using technologies now in development and from ice-capable vessels adapted for geotechnical sampling. 3) Around the only continent on Earth where there is no terrestrial primary production, the food web and ecosystems of the Southern Ocean emerge as key elements in understanding Antarctica's living marine resources. A process-based understanding requires multidisciplinary and interdisciplinary approaches, both theoretical and in terms of field work. As an example, understanding the controls on primary production in Antarctic waters requires experts in ocean physics, sea ice formation and melting, the surface atmosphere, the light field, trace element chemistry, potential grazing processes, phytoplankton ecology, and cellular biology. Future expeditions to the Southern Ocean will necessarily be more complex and multitasking and will require expanded vessel capabilities.

The single most important factor driving the need for a larger, heavier vessel is the increase in icebreaking capability. A major limitation for current U.S. research in Antarctica is the inability of the RVIB *Nathaniel B. Palmer* to access large areas of high scientific importance because of the distribution of pack and fast ice. A new vessel should be capable of working farther into the ice and be reliable to support year-round science operations in most of the Southern Ocean. Figure 1 (on page 7 of this report) illustrates the areas that are problematic for the RVIB Nathaniel Palmer (rated at 3 feet of sea ice at 3 knots). Figure 2 (also on page 7) illustrates the areas accessible to a new research icebreaker with a 50% increase in icebreaking capability (to 4.5 feet).

ARVOC and the polar science community very strongly endorse the development of detailed guidance drawings and specifications to serve as the basis for issuing a request for construction bids for a polar research icebreaker. This will ensure that scientific needs identified by the ship user community are included at the earliest stage of the design process. Secondly, potential builders will be able to base their bids on an actual new ship design, without the need to engage in their own information-gathering design studies. We expect to receive a larger number of competitive bids by this process.

Background on ARVOC and Future Polar Research Vessel Requirements

The Antarctic Research Vessel Oversight Committee (ARVOC) exists to ensure representation of the scientific community in the management and operation of U.S. Antarctic Program (USAP) research vessels. An important function of ARVOC is to provide advice and make recommendations regarding research vessels, ship scheduling, efficient utilization of shipboard equipment and instruments, and the shipboard computer network and hardware. Meetings are annual, with the option of convening more often if there are critical matters needing discussion. Topics occasionally arise that warrant focused and sustained attention. As part of the ARVOC charter, a standing committee may be formed to study an issue, formulate a position, and make recommendations to ARVOC or report directly to Raytheon Polar Services Corporation (RPSC) and the National Science Foundation/Office of Polar Programs (NSF/OPP).

Discussions about the merits of a 20-year midlife refit of the Research Vessel/Icebreaker (RVIB) *Nathaniel B. Palmer* (*NBP*) versus the acquisition of a replacement research vessel have now been underway for three years. The current *NBP* contract with Edison Chouest Offshore, the vessel owner, terminates in either 2008 or 2012, at NSF's discretion. As part of a community-based planning process designed to better inform future decisions about Antarctic research vessels, two science workshops were held in 2002 with the goal of anticipating future scientific requirements for Southern Ocean marine research over the next decade and beyond. An Antarctic Marine Geology and Geophysics Planning Workshop in March 2002 focused on planning by the Antarctic Earth Sciences community. An Antarctic Oceanography Planning Workshop in June 2002 focused on future science plans and operational needs articulated by chemical, physical, and biological oceanographers working in the Southern Ocean. Participants in both workshops were charged with thinking broadly about the future of Antarctic marine science with an emphasis on integrative science and the leveraging of new and developing technologies. These workshop reports can be found at (http://www.usap.gov/vesselScienceAndOperations/) under the ARVOC heading. They have been used extensively by ARVOC members in their deliberations about the feasibility and design of a possible new PRV. Encouragingly, there was significant overlap in the lists of critical vessel requirements that emerged from these two workshops.

As part of the discussion about a possible 20-year midlife refit of the RVIB *Nathaniel B. Palmer* a Memorandum of Agreement (MOA) between NSF and the U.S. Maritime Administration (MARAD) was signed on February 10, 2003. Under this agreement, MARAD, would provide technical support in connection with a new generation Antarctic Research Vessel (PRV) and other related services as required by NSF. Subsequently, the first tasking under the MOA had the following goals.

(1) To translate an initial set of science and operational requirements into research vessel design criteria taking into account the experience gained by U. S. and foreign vessels engaged in polar research.

(2) To conduct special engineering and design studies to understand the full implications of these requirements.

(3) To produce a feasibility-level ship design with sufficient detail to allow decisions to be made regarding vessel size and its general arrangement, as well as to allow a better informed estimate of vessel cost, for both construction and operation.

In May of 2003, ARVOC met in Washington, D.C. and received a report from a fact-finding team (representatives from NSF, RPSC, MARAD, STC). The team had toured icebreakers in Sweden and Finland, and visited the Alfred Wegener Institute (AWI) in Germany, operator of the research icebreaker *Polarstern*. ARVOC proposed to RPSC and NSF to form a Scientific Standing Committee for the PRV (SSC-PRV) of 15 members, composed of both ARVOC members and invited participants. Invited participants were selected based on their expertise in polar research vessel design or in areas of marine-based polar science where we felt that existing ARVOC expertise was not sufficient. The SSC-PRV was charged with providing guidance regarding the new PRV's performance and design criteria, based on scientific needs as articulated during the 2002 community workshops and from our own discussions.

The SSC-PRV met at the Monterey Bay Aquarium Research Institute (MBARI) in July, 2003 to view an early conceptual or feasibility design for the PRV. We also discussed (1) how best to invite and include active participation by the entire scientific community in the PRV planning process, and (2) the possible use of detailed guidance drawings and specifications to serve as the basis for issuing a request for construction bids for the PRV. Providing detailed drawings and specifications to possible bidders during the RFP portion of the procurement process represents a significant departure from procedures used during the acquisition of the *Nathaniel B. Palmer* and *Lawrence M. Gould*. There are two benefits. This method will ensure that scientific needs identified by the ship user community are included at the earliest stage of the design process. Secondly, potential builders will be able to base their bids on an actual new ship design. Without the need to engage in their own information-gathering design studies, we expect to receive a larger number of competitive bids.

ARVOC recognizes that the time line for the design and procurement of a new ship is long, and it is imperative to keep the science community engaged for the duration of the process. ARVOC members have held “Town Hall Meetings” at several large gatherings of polar marine scientists including the American Geophysical Union (AGU) Annual (2003) and Ocean Sciences (2004) meetings as well as the American Society of Limnology and Oceanography (ASLO) annual meeting in 2004. SSC-PRV members have also surveyed numerous members of the polar research vessel user community in one-on-one contacts during the past 3 years. Additionally, ARVOC has collected information through a public access website where questions, comments, and opinions about vessel science mission requirements and design are logged and archived (see http://www.usap.gov/vesselScienceAndOperations/PRVSection.cfm). We have scheduled additional meetings of the SCC-PRV in 2006, and will host future town hall meetings at several national science conferences in late 2006.

As of May 1, 2006, ARVOC estimates that more than 270 individuals have provided opinions, comments, and technical design or engineering information that has been taken into account during the preparation of this report as well as the current version of the feasibility-level design of a next-generation polar research icebreaker.

Scientific Requirements for a New Polar Research Icebreaker

While the RVIB *Nathaniel B. Palmer* (NBP) has served the science community well over the past 15 years, there are compelling reasons to plan for a new research icebreaker to support U.S. efforts in the Southern Ocean. Aside from the anticipated need to replace an aging ship, there are newly defined specific research requirements that mandate a new vessel for future scientific exploration of the Antarctic seas. Based on the 2002 workshop results, future science support for integrative as well as disciplinary research will require an upgrade of our present research capabilities in the following areas:

- Enhanced ice breaking capabilities (4.5 feet level ice at 3 kts)
- Increased endurance (to 80 days)
- Increased accommodation and lab space (for 50 scientists)
- Moon pool for geotechnical drilling and access to the water column through a controlled interface (no ice, limited surge and turbulence)
- Ability to tow nets and research instrumentation from the stern during ice-breaking
- Acoustically quiet vessel with hull form designed for installation and operation of remote sensing instruments.

The first two requirements are directed towards increasing the reach of U.S. researchers into more of Antarctica's ice-covered seas as well as throughout the Southern Ocean during all 4 seasons. The increased accommodation space will foster comprehensive and integrative approaches to Antarctic marine research. The moon pool, ice-shedding stern, and acoustic properties are required to take advantage of new tools that have become important for many types of Antarctic research. Taken together, these requirements dictate that the next generation Polar Research Icebreaker will be larger and have a different hull shape than our current polar research vessels. In addition the layout of decks and lab facilities needs to accommodate a wide variety of existing and new technologies in oceanography.

The scientific rationale leading to these requirements is based in part on the following themes. 1) Understanding Antarctica's role in global change requires access to dynamic areas of the ice sheet margin as well as those areas where heat exchanges between the atmosphere and ocean. Many of these areas are currently inaccessible to the U.S. research community and none of them are accessible year-round. 2) The past history of the ice sheet can inform us about likely scenarios for the future. One of the most useful records of ice shelf and ice sheet activity is preserved in the sediments of Antarctica's continental shelves. These sedimentary archives can be drilled and cored using technologies now in development and from ice-capable vessels adapted for geotechnical sampling. 3) Around the only continent on Earth where there is no terrestrial primary production, the food web and ecosystems of the Southern Ocean emerge as key elements in understanding Antarctica's living marine resources. A process-based understanding requires multidisciplinary and interdisciplinary approaches, both theoretical and in terms of field work. As an example, understanding the controls on primary production requires experts in ocean physics, sea ice formation and melting, the surface atmosphere, the light field, trace element chemistry, potential grazing process, phytoplankton ecology, and cellular biology. Future expeditions to the Southern Ocean will necessarily be more complex and multitasking and will require expanded vessel capabilities.

As we enter the 21st century, the development and application of new instruments and methods in marine science are facilitating novel multidisciplinary approaches for addressing key questions in polar science. As the primary platforms for marine scientific activities in the U.S. Antarctic Program, the vessels used for research must be technologically up-to-date and compatible with a wide range of new research methods. Examples include: geophysical drilling of the seabed, remote sensing using hull-mounted arrays as well as underwater vehicles, micronutrient-sensitive sampling, fisheries surveys, on-board molecular biological assays, etc.

The ability to range farther and longer into new and unstudied areas of the Southern Ocean will greatly promote all areas of polar research.

Details on the rationale for the recommended design characteristics of a next generation polar research icebreaker are summarized below. Two NSF-sponsored workshops directly addressed potential future science needs and the complementary design requirements of a new Antarctic research icebreaker (Leventer, 2002; Smith and Ackley, 2002). Numerous other workshops (e.g., Aagaard et al., 1999; Bellingham and Reves-Sohn, 2002; Lowenstein, 2003) have identified key issues in polar science that warrant special or immediate attention and would greatly benefit from the availability of a new and improved research vessel (for a more complete listing of NSF OPP workshops, see http://www.nsf.gov/od/opp/opp_advisory/reports.jsp). A workshop to evaluate required upgrades for USCG polar class icebreakers used in research was recently convened by the University National Oceanographic Laboratory System (UNOLS, 2003). The resulting workshop report includes recommendations on improved ship capabilities and scientific justifications for the suggested upgrades.

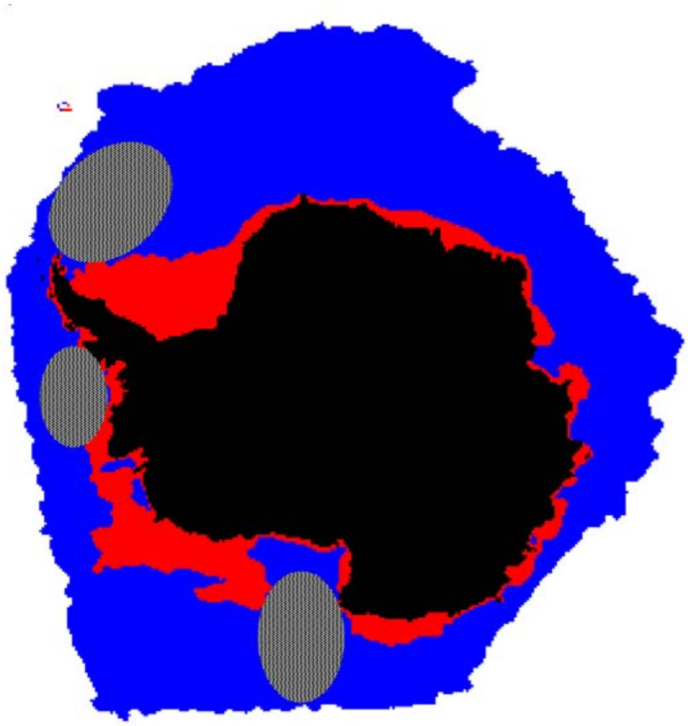
1. Vessel range, cruise duration, and ice-breaking capacity

A major limitation for current U.S. research in Antarctica is the inability of the RVIB *Nathaniel B. Palmer* to physically access large areas of scientific interest because of the distribution of pack and fast ice (Figure 1). The U.S. research community currently lacks an icebreaker capable of carrying out many of the new scientific initiatives being planned. A new vessel should be faster, capable of working farther into the ice and be reliable to support fall, winter and spring science (Figure 2). Aside from a few winter cruises (e.g., individual investigator, Palmer LTER, Southern Ocean GLOBEC), the USAP has not sponsored winter research south of the Antarctic Circle. In fact, a large portion of the year is presently inaccessible for non-peninsular regions of the Southern Ocean. Even in the peninsular region, in some years the NBP has not been able to break into the inner most regions of annual ice (as was the case during Southern Ocean GLOBEC 2002). The winter period coincides with important and as yet, largely unstudied, end-member environmental conditions in Antarctica, in particular the year’s lowest temperatures, strongest winds, highest sea ice cover, and lowest light levels.

In Antarctica, the winter is very different from the late spring and summer seasons when most shipboard research is undertaken. Very little is known about the behavior, physiology, and ecology of marine organisms during this dark period of the Antarctic annual cycle. A 1999 NSF workshop on year-round access to McMurdo Station previously identified a number of scientific questions and issues that require conducting research through the winter months (Priscu, 2001). The workshop report highlights the winter season gaps in knowledge about sea ice formation and the associated development of the sea ice community, plankton dynamics and trophic interactions, the biology of year-round bird and mammal residents (e.g., emperor penguins, Weddell seals), annual patterns of biogeochemical cycles, and the general lack of opportunity to observe unknown transient events that may occur during the winter months.

An increase in the spatial and temporal range of a new research icebreaker will provide new opportunities for increasing our knowledge about the Antarctic seas. Access to Antarctica’s coastal seas and offshore areas all year will lead to a better understanding of Southern Ocean ecosystems and how this region of the world interfaces with global processes in the context of climate change.

Figure 1. Minimum and maximum sea ice extent during calendar year 2000. Areas in red show where ice was present when the sea ice fields started expanding during autumn 2000. Blue shows the sea ice field at maximum extent, in addition to the red. Areas in red are likely to consist of 2nd year or older ice. The *NBP* has had little success penetrating even short distances into areas of multiyear ice. The red region represents the minimum area within which the *NBP* cannot operate. Additional areas that are problematic include the blue region during winter and spring, particularly in areas of sea ice convergence, even if only first year sea ice is present. Hatched areas show where *NBP* operations have been problematic during multiple cruises.



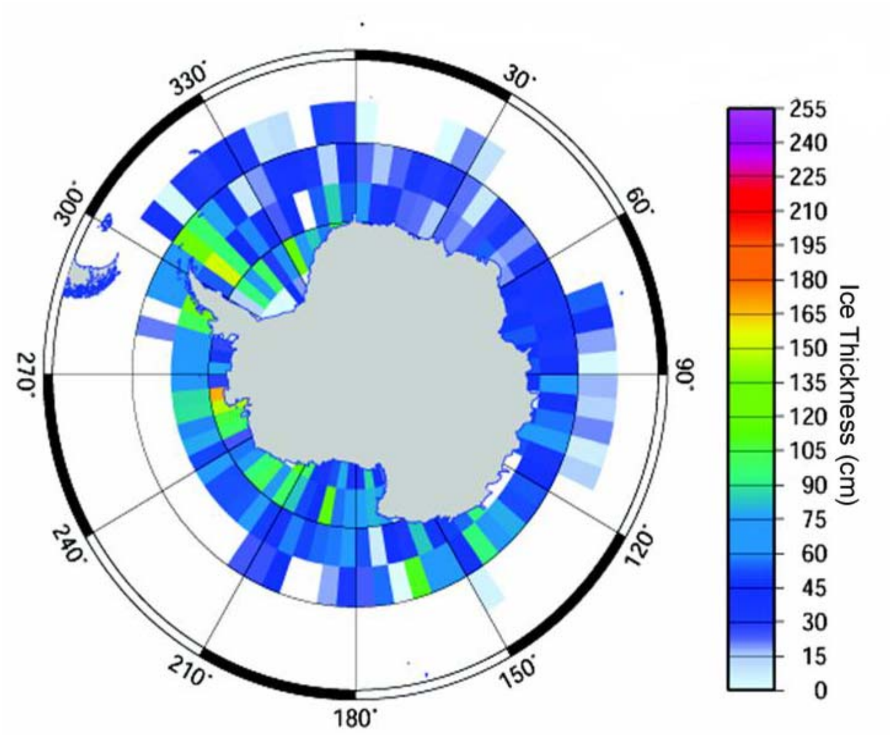


Figure 2. Annual mean sea ice thickness including ridges and open water areas, averaged over 5 x 5º grid cells. Derived from over 18,000 observations extending back 25 years using the ASPect protocols for ice observations. The targeted icebreaking capability of the new polar research icebreaker of 4.5 feet (138 cm) occurs at the green/yellow color transition in this figure. Over 90% of the ice-covered areas of the Antarctic margin will be accessible to the new research icebreaker.

Our understanding of how and when Antarctica was first glaciated, and how its ice sheets have waxed and waned over the past 40 million years is largely based on scientific drilling of seafloor sediments along Antarctica's margin. Offshore scientific drilling began in Antarctica in 1972. Yet as of 2005, only a handful of additional sites have been sampled, making this the least drilled continental margin on Earth. The irony of this simple fact is that because of Antarctica's thick and constantly moving ice sheet, it is the continental margins, below the reach of the glaciers, that offer the only continuous sedimentary records of environmental change on shore. The impediment to offshore drilling in the Southern Ocean is technical. There are few icebreakers that can be equipped with scientific drilling systems and most of these operate exclusively in Arctic waters. The challenges involve drilling in ice-covered areas, where motion of the sea-ice dictates a "drill swiftly and move on approach", as well as in the open ocean where large seas and strong winds make station-keeping difficult. The recent SHALDRIL program has proven the feasibility of geotechnical drilling from the RVIB *Nathaniel B. Palmer*. A larger, more ice-capable vessel with advanced station-keeping capabilities will open up an entirely new archive of Antarctic environmental change to U.S. scientists in the 21st century.

2. Deck layout and lab facilities

Currently, ship-supported sea ice studies are mostly limited to the marginal ice zone with little accessibility to the pack ice interior or regions of fast ice. Various NSF workshops and community feedback to the SSC-PRV committee indicate that there is great interest in studying the physics and biology of ice south of the immediate ice edge and in locations other than the westernmost Ross Sea. Studies of sea ice are vital to our understanding of past, current and future patterns of climate change. Investigations of sea ice require not only the ability of a vessel to enter the ice, but also to be equipped with remotely operated vehicles (ROV's) or autonomous underwater vehicles (AUV's) to facilitate investigations under the ice. Major advances have recently been made in both ROV and AUV technologies and ARVOC anticipates that these instruments will become widely used in all areas of marine science. The case for their deployment in Antarctica is exceptionally compelling as they are ideally suited for scientific exploration under fast ice and floating glacial ice. The deployment, operation, and retrieval of these instruments is not easily facilitated on the RVIB *Nathaniel B. Palmer.* A next-generation Polar Research Vessel should include features conducive to the operation of AUV's and ROV's, such as a large moonpool, Tele-arm style A-frames, and an ROV/AUV instrument hanger.

ARVOC also recommends several design features that will allow for new geotechnical drilling technologies as well as jumbo sediment coring (e.g., SHALDRIL, jumbo piston coring). Large, load-bearing drill rigs are best placed at the center of a research vessel's pitch and roll, an area that is traditionally covered by the ship's superstructure. After considering several different scenarios, ARVOC supports a design with a centerline moonpool amidships and with sufficient open deck space that a 40 to 50 foot drill rig and pipe racker can be installed during geotechnical drilling legs. Drilling, particularly in shallow water, requires advanced station-keeping capabilities, an extra requirement for the vessel's propulsion and position-control systems. The latest generation of ultra-long piston coring systems developed by France and the United States are capable of collecting samples of seabed sediments as long as 80 meters. The recovery of such long cores requires an unusual length of along-the-rail-access on one of the sides of a research vessel. Major modifications of several UNOLS vessels are now underway to permit the deployment of these systems. ARVOC recommends that this feature be included in the design of a next generation polar research icebreaker. Once retrieved by drilling or coring, sediment cores require suitable space for initial processing and analysis. Cores are typically retrieved in 10 or 20 foot sections and are subjected to a variety of rapid-analysis logging sensors before they are cut, photographed, sampled, and stored in refrigerated spaces. The associated labs in the vessel must be sufficient in size and appropriately located so as to allow core movement and processing.

Shipboard biological investigations are rapidly evolving and rely increasingly on molecular-based methods for evaluation of taxonomy and physiology. Sterile and/or certified clean labs and motion sensitive instruments (e.g., ultracentrifuges, fluorescence microscopes) are required for many future research projects. The ability to accomplish onboard processing, or at a minimum, preprocessing, of samples for molecular analyses will greatly benefit studies of polar genomics, proteomics, and metabolic processes. The potential of future polar molecular biology research is outlined in a recent National Research Council report (NRC, 2003).

We also envision a newly expanded capability to support research in the polar atmospheric sciences. Workshop and town hall meeting participants suggested that a new vessel be outfitted to support atmospheric remote sensing instrumentation based on microwave and laser technologies. Unmanned aerial drones are also now proposed for use in atmospheric, sea ice, and glacial ice studies in areas where a polar research vessel will be required to serve at the primary base of operations. The new vessel should be designed to permit the deployment and recovery of aerial drones.

A new polar research icebreaker for the USAP must be multifunctional with modular components that can be assembled and dissembled for specific projects. This is reiterated in both of the NSF ship workshop reports and was a common comment from individual scientists who responded to the SSC-PRV website or attended one of the town meetings.

3. Ice and acoustics

Acoustic instruments are essential in both physical and biological marine research. These include acoustic instrument pack releases, bioacoustic packages for assessing fish and zooplankton, Doppler sonars, acoustic current meters, and positioning and telemetric systems. The performance of nearly all acoustic systems can be severely degraded by radiated noise from a vessel. For hull-mounted instrumentation, acoustic data are affected by ringing (acoustic reverberation inside the transducer well), background noise (e.g., from mechanical vibration or flow conditions), acoustic interference (from other sonars), and acoustic blocking (e.g., bubbles, aerated water or ice). Acoustic blocking and flow noise are generated through complex interactions among factors that include: hull design, ship speed, sea state, heading relative to seas, wind strength and direction (relative to ship and to seas), transducer well design (fluid-filled well, mechanical coupling to the hull, presence of a window, rough edges), transducer placement (the bow gets more bubbles), under hull protrusions and roughness, nearby gratings, holes, or flows (e.g. bow thruster), to name a few.

The following observations made during a acoustics test cruise in October 2004 following the installation of an RD Instruments 38 kHz Ocean Surveyor Acoustic Doppler Current Profiler (ADCP) on the RVIB *Nathaniel B. Palmer* are illustrative of problems with the current ship design. During the test cruise, signal blockage by aerated water was problematic at 12, 9, and 6 knots; the problem was greatly reduced but not eliminated at 3 knots. The duration of each signal blockage increased but the frequency of blockage decreased as the ship speed was reduced from 12 to 6 knots. On station, the predominant issue was the bow thruster, which is located less than 10 meters from the OS38 transducer array and disturbs the water beneath the ship. As a result, on-station acoustic data, especially from the OS38 ADCP, are likely to be of poor quality when the bow thruster is in use.

The largest underway effect on single-ping acoustic data came from acoustic blocking (presumably from bubble sweep down or aerated water). Acoustic blocking renders useless all returns from the outgoing signal. It results in a loss of data at all depths, with the critical exception of a few highly biased bins at the top. The OS38 ADCP was severely affected by this issue; the NB150 less so. More detail can be found in the report, "*Nathaniel B. Palmer* Ocean Surveyor 38 kHz data report", by Jules Hummon and Eric Firing, available at http://currents.soest.hawaii.edu.

There are now well-tested solutions to the problem of how to collect high quality acoustic data from a ship at sea or working in ice. ARVOC endorses the use of a box keel, e.g., a keel that protrudes beneath the vessel's hull and that by design is kept clear of bubble sweep. In addition, the use of common bus electric power generation and podded electric motor propulsors is known to greatly reduce radiated ship's noise which also affects towed acoustic surveys.

4. Increased berthing for science personnel

The RVIB *Nathaniel B. Palmer* can accommodate 32 scientists and 7 contractor technicians. The characteristics and berthing capacities for other polar vessels is shown for comparison in Table 1. For example, the main German research icebreaker, *Polarstern*, can berth 55 scientists and an additional 15 support personnel). As pointed out by both of the ship planning workshops, 32 shipboard scientists has proven to be inadequate for many cruises over the past 10 years, especially for large programs such as GLOBEC, JGOFS, and ROAVERRS. Polar research vessels are used intensively during cruises, with shift work running 24 hours each day. As our science requirements expand to include real-time sample analysis in shipboard laboratories, manpower needs necessarily rise. As we begin to deploy more technically complex instrumentation such as drilling rigs, ROV's, and AUV's, the requirement for larger numbers of seagoing staff with specialized training will also increase berthing demand. In addition, with the anticipated increase in multidisciplinary projects, the problem of berthing will be exacerbated. ARVOC strongly recommends that any new vessel design include the ability to accommodate larger scientific parties (~50 scientists).

Table 1. Characteristics of Icebreakers, Polar Research Vessels, and Research Icebreakers currently operating in Arctic or Antarctic waters.

Name	*Aranda*	*Otto Schmidt*	*Nathaniel B. Palmer*	*Aurora Australis*	*Polarstern*	*Louis St-Laurent*	*USCGC Healy*	*Akademik Federov*	*Endurance*
Registry	Finland	Russia	USA	Australia	Germany	Canadian	USA	Russia	UK
Crew Type	Civilian	Civilian	Civilian	Civilian	Civilian	Govt/Civ	Military	Civilian	Military
Crew Size	12		26		36	59	75	90	35
Addl Persons	26		39		70	13	52	160	91
LOA (ft)	194.36	239.5	308.5	311.38	387.14	392.49	420	463.25	298.56
LBP	167.81		279.75	290.03	335.3	356.5	396.5	421.95	270.67
Max Beam (ft)	45.28	61.02	60	66.6	82.02	79.86	82	77.1	58.73
Draft (ft)	15.09	21.65	21.75	25.75	34.45	31.17	28	27.89	21.33
Displacement(t)	1919	3641	6480	7716	15008	14504	16000	15943	5048
Provisioning (d)	180		90	90		180	65	180	120
Endurance (nm)	15000		15000	25000	10000	23000	16000	20000	50000
Cruising Spd	10.42	14.5	12	11.57	13.04	10.65	12.5	10.42	12
Endurance (d)	60		52.1	90	32	90	53.3	80	173.6
Mission	Research	Research	Research	Supply Research	Supply Research	Research Escort Patrol	Research Patrol	Supply Research	Supply Research
IB Capability	2	2	3	3	4	4	4.5	4	3

Name	*Igenpearl (formerly Bransfield)*	*James Clark Ross*	*Polar Duke*	*Shirase*	*Soya*	*Oden*	*Polar Sea/Star*	*Laurence M. Gould*
Registry	Grenadines	Falklands	Norway	Japan	Japan	Sweden	USA	USA
Crew Type	Civilian	Civilian	Civilian	Military	Military	Civil	Military	Civilian
Crew Size		25	14	136	71	26	155	
Addl Persons		52	26	101		22	30	26
LOA (ft)		324.93	219.16	439.5	323.49	353.67	399	230
LBP	295.28	295.28	190.29	406.72	308.4	305.77	352	212
Max Beam (ft)	60.04	61.84	42.65	91.84	51.18	101.71	83.5	46
Draft (ft)	20.34	20.67	17.06	30.34	17.06	26.25	28	19.42
Displacement(t)	6900	7361	2145	17210	3506	11901	10800	3781
Provisioning (d)			90	60		180	150	75
Endurance (nm)		16500	12000	25000	5700	30000	28875	12000
Cruising Spd	13.5	12	12	15	12	12.4	14	12
Endurance (d)		57.3	41.7	69.4	19.8	100.8	86	41.7
Mission	Supply Research	Supply Research	Supply Research	Supply Research	Supply Research	Escort Research	Patrol Escort Research	Supply Research
IB Capability	1.75	2.5	1.75	5	3.5	5	6	1.25

Current Status of Defining the Scientific and Operation Requirements

The ARVOC SSC-PRV committee, MARAD, RPSC, and NSF have now worked together for over 3 years. The feasibility design study has yielded the size of the ship and recommendations on hull shape and power and propulsion systems. There have been important technical advances in icebreaker design and propulsion/steering systems since the RVIB *Nathaniel B. Palmer* was designed. By incorporating these advances, it will be possible to achieve better performance, in terms of achieving mission goals, at reduced costs. The current design drawings illustrate the current thinking on the desired layout of the ship as well as some of its key science capabilities.

These include:

- A vessel 378 feet in length with level ice breaking capability of 4.5 ft at 3 knots (ABS A3), which permits operations in the central Arctic Basin in summer as well as breaking multi-year sea ice. The 4.5 ft capability was the minimum acceptable due to scientific requirements for additional spatial/temporal range of operation (e.g., Figures 1&2).
- Capable of holding 50 science and science support personnel.
- Endurance of 80 days /20,000 miles at 12 kt open water speed.
- Moon pool of 10 ft by 12 ft for geotechnical drilling, and conduct of AUV/ROV and other operations, especially in ice
- Helicopter hanger

The following is a list of the initial scientific and operation requirements brought forth by the two workshops that have been refined based on specific design studies as well as continued interaction with the scientific community. See attached drawings.

a) The moon pool is currently smaller (10' x 12') and relocated to the box keel, i.e., in the center for drilling and dynamic positioning. These changes were possible because geotechnical drilling is not built in. There is a 6 ft space around the moon pool for the drill rig.

b) The jumbo piston coring setup is similar to a design from WHOI, with a capacity for 50 m, up to 80 m.

c) The concept of diesel-electric propulsion, potentially podded, is endorsed due to enhanced station keeping ability, maneuverability in ice and less ambient ship noise. The concept of podded propulsion needs further research on EMI and reliability.

d) The box keel design for transducers gives the ability to survey during ice breaking.

d) The helo deck and hanger are now on the 02 deck.

e) The vessel design promotes reduced emissions, e.g., a 'greener ship'.

f) The vessel can accommodate 5-6 portable lab containers (2 on 01 deck, 3 to 4 on main deck).

g) There is an 8 ft wide passageway on the main deck and inter-deck elevator.

h) 2 microscope rooms.

i) 2 environmental rooms.

j) There is a walk-in science freezer with a minimum footprint of 200 ft^2.

k) Designed for easy handling of and access to containers in hold.

l) 2-point winch system for large otter trawl.

Recommendations from ARVOC

ARVOC recommends that the design process continue to be driven by the scientific community and based on a forward-looking vision of mission requirements. After many years of experience aboard polar research icebreakers, U.S. as well as foreign vessels, we now have a large cadre of technically astute U.S. scientists that are able to engage naval architects and design specialists in productive conversations. The U.S. polar science community and ARVOC very strongly endorse the development and use of detailed guidance drawings to ensure that mission requirements are effectively folded into the design and procurement process. A spin-off benefit of providing guidance drawings is that it should have the effect of allowing more ship-builders to engage in a competitive bidding process.

ARVOC wishes to specifically comment on the use of performance specifications versus design specifications during the procurement process. Performance specifications give the responsibility of ship design to the bidders for the ship construction project. Ship builders often lack sufficient experience and knowledge about the preferences and requirements articulated by the science community. Without guidance plans and specifications, the up-front proposal development costs by potential bidders will be hundreds of thousands of dollars. It is likely that some potential bidders will opt out of the bidding process because of these high costs and the associated risks. ARVOC endorses the continued development of guidance drawings and a design-based procurement RFP, so as to attract more bidders and to ensure that science needs are met. The science community has stated that it is willing to actively participate in order to reduce the risks of failure in the final product. The overall goal of a new polar research icebreaker is to greatly improve our scientific capabilities in the Southern Ocean, with a view ahead to the key science objectives for the next 20 years.

ARVOC has discussed the issue of vessel operations in both northern and southern polar regions. Recent heavy ice conditions in McMurdo Sound have brought the USCGC *Healy,* normally restricted to the Arctic, into the Ross Sea to aid with channel clearing duties. It seems likely that such dual-use capabilities will remain desirable for all U.S. polar research vessels. ARVOC therefore recommends that the PRV design ensures that it is capable of complementing research activities in the Arctic. However, ARVOC views the mode of alternating cruises between the poles routinely, as is done by the German research icebreaker *Polarstern*, as an inefficient use of the vessel. ARVOC recommends that the PRV be used primarily in support of Antarctic research throughout the year.

References

Aagaard, K., D. Darby, K. Falkner, G. Flato, J. Grebmeier, C. Measures and J. Walsh (ed.). 1999. Marine Science in the Arctic: A Strategy. Arctic Research Consortium of the United States (ARCUS). 84 pp. http://www.arcus.org/Marine_science/index.html

Bellingham, J.G. and R. Reves-Sohn (ed.). 2002. Instrumentation for Arctic Ocean Exploration. National Science Foundation, Monterey Bay Aquarium Research Institute, Woods Hole Oceanographic Institution. 45 pp. http://www.mbari.org/rd/ArcticInstrumentationWorkshop/WorkshopAnnouncement.htm

Leventer, A. (ed.). 2002. Antarctic Research Vessel - Anticipated Needs for Marine Geology and Geophysics. National Science Foundation. 15 pp. http://departments.colgate.edu/geology/faculty/AMGGPWReport.pdf

Lowenstein, R. (ed.). 2003. Antarctic Science and Advanced Computer Networking Workshop. National Science Foundation. 55 pp.

NRC (ed.). 2003. Frontiers in Polar Biology in the Genomics Era. Committee on Frontiers in Polar Biology, National Research Council, National Academies. 186 pp. http://www.nap.edu/catalog/10623.html

Priscu, J.C. (ed.). 2001. Year-Round Access to the McMurdo Region: Opportunities for Science and Education. Special Publication 01-10, Dept. of Land Resources and Environmental Sciences, College of Agriculture, Montana State University, USA. 60 pp. http://www.homepage.montana.edu/~lkbonney/DOCS/Links.html

Smith, W.O. and S. Ackley (ed.). 2002. Antarctic Oceanographic Planning Workshop: Possible Replacement of the R/V Nathaniel B. Palmer. National Science Foundation. pp. http://www.vims.edu/admin/sponpgms/AOPWReport.pdf

UNOLS (ed.). 2003. Polar Class Icebreaker Workshop. University-National Oceanographic Laboratory System. 21 pp. http://www.unols.org/meetings/2003/200306aic/200306aicmi.html

Appendices

Appendix 1: Timeline of work by ARVOC
Appendix 2: Workshop reports
Appendix 3: Roster of ARVOC members and list of attendees at the SSC-PRV meetings
Appendix 4: Drawings of the main deck and 01 deck
Appendix 5: Drawings of the hull shape and box keel for the transducer well

Appendix 1. Time Line of Activities - Defining Scientific and Operational Requirements for the PRV

a) Spring 2002 - Discipline workshops
    - Antarctic Marine Geology and Geophysics Planning Workshop (March 2002), chaired by Amy Leventer
    - Antarctic Oceanography Planning Workshop (June 2002), chaired by Walker Smith and Steve Ackley

b) March 2003: NSF, MARAD, and STC representatives on fact finding tour to observe icebreaking operations in the Baltic Sea with vessels having podded and traditional propulsion machinery.

c) May, 2003: ARVOC meeting
    - Presentation of results of fact-finding tour of group with representatives from NSF, RPSC, MARAD and STC
    - SSC-PRV formed

d) August, 2003: SSC-PRV meeting held at MBARI (Monterey Bay Aquarium Research Institute) to consult the resident AUV/ROV expertise
    - Formation of focus groups
    - Develop strategies for soliciting input from the scientific community and incorporating the input into the scientific and operation requirements (web page, newsletter, and town hall meetings at scientific conferences)

e) November, 2003: SSC-PRV meeting held in Washington, DC
    - Continue refinement of scientific and operational requirements
        - Geo-technical drilling
        - Under-water sampling
        - ROV/AUV
        - SCUBA diving under the ice
        - Jumbo piston coring (deck layout)
        - Net towing (deck layout)
        - Lab vans (portability and exchange)
        - Topside observations (ice, marine mammals, birds)
        - Other
            1. winch arrangements
            2. sample flow through labs
            3. moon pool size and placement
            4. satellite requirements
            5. crane requirements and placement
    - Develop poster and approach for town hall meetings

f) Town Hall Meetings - solicited input from more than 100 scientists. The SSC-PRV was then able to synthesize common issues, and found they were generally on the right track. The attendance highlighted the desire of the scientific community to participate in the development of the scientific and operation requirements.
    - December, 2003, Fall AGU Meeting, San Francisco
    - January, 2004, Ocean Sciences, Portland
    - February, 2004, ASLO, Oahu

g) May, 2004: SSC-PRV meeting held in conjunction with ARVOC meeting in Washington, DC.
    - Update of status of PRV
    - Decision to summarize status of develop of scientific and operation requirements

h) October, 2005: ARVOC meeting in Washington, DC
    - Update on status of PRV planning
    - Update on National Academy of Sciences progress on "Assessing U.S. Coast Guard Polar Icebreaker Roles and Future Needs".
    - Report from MARAD on continuing design studies for the PRV

i) November, 2005: ARVOC delivers PRV-SSC Executive summary to National Academy of Sciences Committee on the Assessment of U.S. Coast Guard Polar Icebreaker Roles and Future Needs.

j) November, 2006: ARVOC Chair delivers testimony and answers questions at National Academy Committee Meeting (Open Session).

k) June, 2006: ARVOC meets in Denver to finalize PRV report.

Appendix 2: Previous Meeting and Workshop Reports

ANTARCTIC MARINE GEOLOGY AND GEOPHYSICS PLANNING WORKSHOP

FINAL REPORT
National Science Foundation Sponsored Workshop

Washington, D.C.
March 23 – 24, 2002

Convener:
Amy Leventer

Participants:
John Anderson
Jay Ardai
Lou Bartek
Scott Borg
Stefanie Brachfeld
Steve Cande
Gail Christeson
Eugene Domack
Jim Holik
Scott Ishman
Tom Janacek
Leah Joseph
Randy Keller
Larry Lawver
Amy Leventer
Kathy Licht
Bruce Luyendyk
Rick Murray
Pat Manley
Suzanne O’Hara
Frank Rack
Al Sutherland
David Tewksbury
Julia Smith Wellner
Woody Wise

Planning the Future of Antarctic Marine Geology and Geophysics
United States Antarctic Program

Mission Statement

The primary goal of this workshop was to initiate discussion about future scientific objectives and technical needs of the Antarctic marine geology and geophysics community, in particular, how these needs relate to Antarctic research vessels. The need for this kind of workshop was twofold. First, it had been about a decade since the community last took a focused look at the long-range science goals and needs for Antarctic marine geology and geophysics, so a new perspective was needed. The need for such a dialogue was also based on the timing of the lease schedule for the current ship support to the US Antarctic Program. Although ship support for Antarctic science is contracted for several more years, the process of developing scientific requirements as planning input for ship support beyond this period takes a considerable amount of time, and it is critical that science users be involved throughout the process. Consequently, the primary goal of the meeting was to produce a document outlining the anticipated future scientific goals and objectives, in a broad fashion, and describing the specific technical needs for marine geologic and geophysical work in the Southern Ocean.

Rather than focus on the design of the current ships and ask the question of whether these ships will meet our future needs; the workshop was more forward looking, forcing Antarctic marine geologists and geophysicists to anticipate the course of scientific research over the next two decades and to address the technology required to meet those needs. Thus the questions guiding this meeting were:

1. As a community, where do we hope to be ten to twenty years from now?
2. What major scientific questions will we want to address?
3. How will we accomplish answering those questions?

In order to answer these questions best, participants were told to “think big” and to “think outside the box” for too often it is easier to work from an existing design than from a relatively blank slate. In the end, we took a combination of these two approaches; recognizing that the current vessel has many outstanding characteristics, but that existing capabilities may be enhanced, and new areas of research may demand changes in current technologies. This report is organized around the scientific framework of future research plans, in the broadest sense, with general scientific rationale outlined first. Based on this scientific framework, specific recommendations for ship design are then presented.

This report, produced from the March 23-24, 2002 workshop, will serve as a planning document and is available as a hard copy (email request to: aleventer@mail.colgate.edu) and on the Internet at the following address:
http://departments.colgate.edu/geology/faculty/AMGGPWReport.pdf

Future Science Directions and Recommendations

1. Continued oversight of vessel plans, design, construction and testing by research scientists.

First and foremost we emphasize the absolute necessity of continued oversight of all future planning for the next research vessel by research scientists with both scientific and technical expertise, in order to be certain that the marine geological and geophysical community is best served by our future research ship. This includes oversight of all planning prior to the development of a Request for Proposals by the Office of Polar Programs, to active participation in all phases of ship design and eventual construction, walk-throughs and testing of shipboard systems. This is the only way that we can be assured of maximizing this opportunity to develop an icebreaker that provides a superior logistical base from which we can conduct our research. We emphasize as well that continued oversight will most likely save money in the long run with far fewer costly changes necessary at later stages of construction and ship use. In order to achieve the degree of oversight we desire, we recommend continued consultation throughout the entire process, with a group of approximately four members of the Antarctic Marine Geology and Geophysical community. This core group is recommended in order to facilitate continued, well-organized, and informed involvement and feedback from our community. This group should be separate from the Antarctic Research Vessel and Oversight Committee (ARVOC), a committee with many additional responsibilities regarding ship use in Antarctica. We also suggest that small working groups may be necessary to address more specific issues such as newer technologies (for example, the use of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs)).

2. Multidisciplinary science programs and their implications for increased space.

We foresee the development and application of more complex technical programs and multidisciplinary approaches to scientific questions; two examples are briefly described below in order to provide a scientific framework for our recommendation of increasing the total space available for a scientific party. Currently we are allocated space on the *NB Palmer* for 32 scientists and 7 technical support employees, for a total of 39 berths. We suggest increasing this to a total complement of fifty scientists and technical support crew. Consideration should also be given to the possibility of "expansion capability,' that is, the possibility of adding temporary extra bunks into spaces normally used for other purposes, such as storage, in the unusual circumstance that this extra berthing space would be required. However, we maintain that an upper limit of fifty scientists and technical support personnel is reasonable. As the number of berths increase, everything else must be scaled up to allow adequate work and living space for the additional participants, including increased laboratory space, galley space and common rooms. In addition, we suggest that more (~3) senior scientist cabins be considered, to accommodate lead scientists on multidisciplinary programs who would be better served with private working areas.

Two examples of the types of multidisciplinary projects anticipated are described below; we emphasize that many other possible programs could be designed:

Many marine sediment-coring programs have been carried out in the Antarctic Peninsula region; these programs have made a tremendous contribution to our understanding of the glacial history of the region and the response of the Peninsula to climate change over several different time scales. However, far fewer ice cores have been drilled, limiting our ability to develop a more coordinated understanding of the complexities of climate change in a region that is clearly experiencing rapid change today. Clearly, climate change records from two different and "independent" sources may provide more insight into the relationship between atmosphere, cryosphere, and ocean conditions during climatic fluctuations. Coordinated marine sediment and ice coring projects in the Antarctic Peninsula region with deployment of ice coring programs via helicopters would bring us forward in this endeavor. We recognize the current logistical constraints of placing ice-coring programs in areas that may be difficult to access by travel over the ice itself or by more traditional forms of Antarctic air support (C-130 for example). However, informal conversations with members of the ice-coring community indicate that helicopter support of an ice-coring program in the Peninsula would be logistically successful. While helicopters are used extensively to support projects in the McMurdo region, they have been used only once from the NB Palmer. The details of how such a program would be coordinated remain to be determined, with logistics ranging from deployment of an ice-coring project completely independent of ship support once deployed, to a program where routine ice-core processing could take place on board ship, in concert with a marine program (see section 5 for comments on clean room capabilities).

Many researchers have already completed projects that integrated multiple disciplinary field techniques on a single cruise, for example, where the project goals ranged from ecosystem monitoring and characterization to evaluation of how water column processes impacted the marine sediment regime. In this case, biological and geological field parties worked together toward a common objective. For example, the ROAVERRS (Research on Ocean Atmosphere Variability and Ecosystem Response in the Ross Sea) had coordinated biological and marine geological objectives. A consequence of the broad scientific objectives of these types of programs is that the number of scientific participants can be quite high. In the past, berthing space has been less than desired and has pushed research groups to prioritize objectives forcing important projects to be cut. In addition, with more berthing space for the scientific party, more researchers would be comfortable adding smaller but related projects on to their cruise. The increased return scientifically, could be great; especially when the ship visits poorly studied regions of Antarctica. With the recognition that even on a cruise with purely marine geological and geophysical objectives, additional physical, chemical and biological data will be of great value in the long run, we recommend increasing berthing space on the ship.

3. Comprehensive programs that cross geographical transitions and correlation between environments -continental to deep sea.

In terms of developing a more integrated view of geological processes in Antarctica, we anticipate larger scale research efforts that are focused on transects of study, potentially reaching from the continent (aeromagnetic work?, ice coring programs?) → shelf processes/deposits → deep sea. The rationale for this kind of work is based on the connections between these subenvironments, with geologic features and processes linked across these boundaries. In the long-term, our science may benefit from focused attention on specific regions of Antarctica and the Southern Ocean (though not at the expense of individual programs). For example, we foresee the possibility of a series of transects from continent to offshore that might coordinate the efforts of programs like ANDRILL (at the edge of the ice shelf or fast ice), SHALDRIL (on the continental shelf) and future ODP-style efforts (primarily though not exclusively open ocean), with an objective of combining results from each program.

Similar to recommendation #2, this type of program may place extra demands upon the research vessel in terms of an increased number of berths and consideration of the logistics for transporting scientists, equipment and samples (such as cores), to and from areas on the continent and/or ice shelves. The use of helicopters and landing craft will most likely be necessary, with implications for ship design and space. This is discussed in more detail below. We emphasize that in the programs described, the ship would not be used solely as a support vessel (not a cost-effective use of a vessel outfitted for research), but as a multi-functional platform. We note that longer-range helicopter support may facilitate shore-based work in restricted areas.

4. Rapid response science and its effect on ship capabilities.

Under many circumstances critical scientific programs may develop in response to an event that even if anticipated in the general sense, may occur at an unanticipated time. Although it is difficult to prepare for the unexpected, an attempt should be made to adapt the ship and the ship-using community to these possibilities. The first may be simpler to accomplish than the second, and we will not attempt to address potential scheduling difficulties and the repercussions of the implementation of rapid response science projects on programs already in progress. However, we will try to address the ways in which ship design can be modified to be the most flexible in accommodating study of events for which we may not get a second chance to sample. In particular, we emphasize the need to get to specific sites relatively quickly and to have a wide range of sampling options available. We use the example of the recent breakup of the Larsen B Ice Shelf as an event that comes under this category. In this case, helicopters and drones would have been critical to support the logistics of a study examining the breakup event. In many cases, these rapid response science projects would be interdisciplinary.

With this single example in mind, two things to consider are first, how easy it would be to get the ship and equipment to the right location in the necessary time period, and second, how to transport scientists to and from the ship. In the first case, we recommend addressing the ship’s maximum speed coupled to its icebreaking capabilities so that a greater portion of the Antarctic margin is accessible. This issue is not limited to rapid response science (see #5 below). In general, access to a greater range of sites along the Antarctic margin is desired, which may necessitate increasing the class of icebreaker from what is currently available to the US Antarctic Program. As well, we note the need to ferry scientists to and from specific sites and the need for both continued dedicated helicopter space in the form a deck and hangar, and for more “sea-worthy” and “landing-worthy” small boats.

5. Sampling needs in currently inaccessible areas of the seafloor, ocean and continent.

Several different types of science and technologies fall into this category. However, specific issues are of paramount importance to all. First, we reiterate addressing the ship's maximum speed coupled to its icebreaking capabilities so that a greater portion of the Antarctic margin is accessible. In general, access to a greater range of sites along the Antarctic margin is desired (areas with heavier sea ice concentrations, for example), which, as stated previously, may necessitate increasing the class of icebreaker from that which is currently available to the US Antarctic Program. Continued dedicated helicopter space (deck and hangar) will facilitate access to currently inaccessible sites, as will expansion of our capabilities with more "sea-worthy" and "landing-worthy" small boats. These will increase our abilities to work in areas that are currently less accessible, such as fjords and locations close to ice margins. The design and deployment of such a small boat would have implications for overall ship design. We understand that the ARVOC also has been considering adding a "smaller" boat to the currently available Antarctic fleet, but there has been debate about its size and capabilities. The Antarctic Marine Geology and Geophysics working group, like ARVOC, needs to consider the size and capabilities of a small vessel in more detail before making a specific recommendation.

We highlight two categories of research efforts that are limited by our inability to conduct the field research necessary to complete particular scientific objectives.

Sub-Ice Shelf / Sub-Sea-Ice Processes. Currently we have very few (if any) ways to address questions regarding sub-ice shelf and sub-sea-ice processes, except along the immediate ice edges. We anticipate an interest in looking "up" (i.e. biologists – example of under sea ice krill study in Weddell Sea, by Brierley et al. 2002, *Science*, 295, 1890-1892, using autonomous underwater vehicle *Autosub*-2; see http://www.soc.soton.ac.uk/autosub/ for a complete description of the instrument) and looking "down" (sediment cores and terrain visualization of areas underneath ice shelves for example). While we addressed the interests of the marine geological and geophysical community specifically, we expect that these types of projects will be of interest to biologists, glaciologists, and chemical and physical oceanographers as well.

Technologically, these types of projects can be approached with a variety of remotely operated vehicles (ROVs) (potentially some with coring capabilities) and autonomous underwater vehicles (AUVs) (with geophysics capabilities). Our brief survey of the literature reinforces that development of these technologies is being pursued actively (for example, http://www.spawar.navy.mil/robots/pubs/oceans2000.pdf, AUV Commercialization – Who's Leading the Pack?, R.L. Wernli). We note that the British Antarctic Survey is using the AUV *Autosub-2* and that the *Healy* recently tested the use of the MBARI-designed ALTEX AUV (see http://www.aslenv.com/reports/OIA%202001%20MBARI%20Tervalon%20Paper.pdf for a brief description). In considering these new technologies that already exist and are being used, and those that certainly will evolve over the next two decades, we must take into account a ship design amenable to the deployment, recovery, and safe on-board storage of these devices. The two main considerations are deck space for storage and deployment devices. We recommend that a large scale "garage-type" space be considered for the ship, similar to the current NB Palmer helo-hanger, but perhaps with some overhead rail systems for easier movement of large and heavy, but delicate equipment. We also recommend that serious consideration be given to how these devices might best be deployed, in terms of both the weight limits and physical placement of A-frames and cranes on the main deck.

Coring capabilities. Coring technologies continue to evolve; we would like the US program to exist at the forefront of these technologies. Three main issues are addressed here: 1) the ability to core/drill sediment lithologies, such as sands and tills that traditionally have been technically problematic, 2) the ability to acquire longer cores, and finally, 3) the ability to acquire cores from ice-covered areas of the continental margin.

> *SHALDRIL* – The rationale for SHALDRIL has been spelled out in great detail in previous documents (http://www.arf.fsu.edu/arfhtml/download/shaldril_hi.pdf), so will not be repeated here. Simply put, “conventional piston and gravity cores cannot penetrate the over-compacted, ~10-m-thick glacial diamicton layer on the continental shelves and upper slopes.” The SHALDRIL initiative is centered on the implementation of a drilling technology that will permit recovery of the records that lie within and beneath the glacial diamictons, in order to develop a better understanding of climate and the history of fluctuations of the Antarctic ice sheet. Shipboard requirements for the SHALDRIL initiative include the presence of a moonpool (76" diameter) through which coring will take place and dynamic positioning abilities for the research vessel.
>
> *Long piston corer* (i.e. 80 meters?) – With the current design for deployment of the Jumbo Piston Corer, our recovery is limited to piston cores of 25 meters in length. Given the potential goldmine of long, ultra-high (annual to decadal scale) resolution sediment records (drift deposits and basinal systems), the ability to acquire longer sediment cores within biosiliceous sediment units is critical. We have had great success with maximizing our recovery using the current system (25 meters), and anticipate that longer cores could be acquired successfully, with some modifications to deployment design. We base our recommendation for jumbo piston cores reaching an 80-meter length on the capability of the French research vessel *Marion Dufresne* to recover cores of this length. We note that although it is possible to recover 80-meter cores, 50-60 meter cores are more commonly acquired by the *Marion Dufresne* in marine pelagic sections. The *Marion Dufresne*, however, does not have the ice-breaking capability to perform in ice-covered seas, so cannot be used to fill this need. The French system (Calypso corer) was designed by Yvon Balut; we recommend discussions be initiated with Balut concerning Calypso core design, as well as discussions with Bill Curry at WHOI, concerning their current plans for a long piston corer on the *Knorr*.
>
> Requirements to be considered here include whether to position the coring horizontally (side rail system as on *Marion Dufresne*) or to rig the core vertically and deploy the coring system through a moonpool. In addition, we must consider how design will affect ship length and main deck layout, the A-frame location, core barrel storage, winch wire storage (thicker wire therefore more storage space, stronger winch, etc.). Many of these considerations have been discussed in a previous report (Domack, E., 1995, A long core facility on the R/V Nathaniel B.

Palmer: Scientific justification and feasibility, A report submitted to the Office of Polar Programs, National Science Foundation by the Polar Earth Science Working Group).

We note as well, that discussion and consideration of other coring devices should remain open. For example, the DOSECC AHC800 drilling rig was recently used on the New Jersey shelf with the *Knorr*. This is a rotary system equipped with active heave compensation, deployed through the *Knorr*'s moonpool. This system achieved sub-seafloor penetration of ~13 meters in interbedded sands and muds. Another example of the successful use of an alternate technology, is the BAS use of vibro-coring technology to core into soft and hard till in the Marguerite Trough.

Additional impacts on ship design for both SHALDRIL and the long coring system include the need for a climate controlled storage space. Even with the shorter 25-meter cores, acquisition of even a relatively small number of long cores necessitates addition of a refrigerated van to the NB Palmer. We recommend as well, the strong consideration of "logical" pathways for movement of core sections around on deck and in and out of labs and storage (i.e. no sharp corners or stairs between deck, laboratory and storage facilities).

Under ice coring – Although addressed briefly previously, we reinforce our interest in acquiring sediment samples (including cores) from underneath ice shelves or impenetrable sea ice. We anticipate that in the future, ROVs and/or AUVs with coring capabilities will exist. We must consider how these instruments will be deployed, recovered and how they will be stored on board ship (i.e. garage-type structure). As stated earlier, it is difficult to plan for the unknown; but maximum flexibility in the organization of deck space will be a critical factor.

In the case of all the systems described, decisions must be made regarding on board processing capabilities, especially since in some cases the immediate examination of cores may be instrumental in making decisions with regard to the cruise track. Whether or not cores should be split on board ship must be considered, as should be the appropriateness of specific measurements (ephemeral property measurements, for example). Our recommendation is that this capability be present. With regard to ship design, these considerations will determine the types and size of laboratory space needed, with an emphasis, again, on space design being extremely flexible. We point out the ODP model of on board core processing, which allows relatively complete core characterization and sample allocation prior to the end of a cruise. Of course, this would necessitate an increase in lab and living space and larger scientific parties. A larger ship with more flexibility in terms of modular lab space would facilitate this capability. Finally, we address the issue of clean space on board the vessel. The decision to bring ice cores on board would require the presence of a clean (and cold) room for packaging of cores without cross-contamination. Special precautions would have to be made with regard to air handling systems and clean access to a clean room.

6. Geophysical needs and implications for ship design.

We recognize the absolute necessity of acquiring high quality geophysical data, from both hull-mounted and towed systems. Consideration of how to accomplish this is critical to the success of our program. These issues are not unique to the design of our ship; we urge consultation with marine architects and others with the technical expertise and experience to provide the best advice. In particular, for any hull-mounted systems, such as a multibeam and chirp sonar, consideration of hull design and shape, and how they impact the generation of bubbles and funneling of ice needs to be considered. *We cannot emphasize the importance of hull design enough*. For towed systems, considerations with regard to ship design are centered on several issues including the need for keeping the stern area as clear of ice as possible, over the greatest distance, as well as a deck configuration with the flexibility to allow longer and multiple MCS streamers and larger air compressors. With regard to the air compressors, appropriate below-deck compressor capability must be built into ship design from the outset. For both hull-mounted and towed systems, we need to consider interference by frequencies generated by the ship's engines as well as the compressors.

In addition, we note that the USAP is falling behind other national Antarctic programs in terms of sea floor mapping capabilities. In particular we point out the use of the ultra-high-resolution seismic TOPAS parametric echosound system by the British Antarctic Survey (BAS), the Germans (Polarstern) and the Spanish Antarctic Program, which provide superior sub-bottom data and the new Simrad swath mapping systems used by BAS and both the Spanish and Italian Antarctic Programs. We do note the recent installation and testing of the *NB Palmer*'s new SIMRAD system, which is a strong step in the right direction, though early reports suggest more work is necessary to bring the system's capabilities in line with our expectations.

Another way to approach the acquisition of geophysical data is through the use of AUVs, which have been briefly discussed already. Two immediate advantages are obvious. First, this would this allow us access to areas that are ice-covered, by either heavy pack ice (as in the Weddell Sea) or ice shelves. Mapping of bottom structures, under the ice, would allow us to observe, for the first time, details of many under ice processes, an important step in understanding processes occurring in this transitional region between the continent and deep sea. Second, if an AUV could be sent off on a mission while the ship is "anchored" on station while performing tasks, such as coring, we could effectively double the amount of science accomplished over that time period. In many cases the AUV would acquire data that would permit short-range planning and site selection during a cruise.

The issues discussed above pertain specifically to the acquisition of the best data sets possible. Several additional issues related to geophysical data sets are also important to consider. For example, we emphasize the need for separation of permanent computing facilities on the vessel, for easy maintenance and longer life of this equipment (i.e. humidity, clean air, climate control, vibration control). In addition, the volumes of data that are being collected force us to consider long-term data archiving, such that our data sets reach their maximum potential scientific value. Much like core material or rocks collected from the continent, swath mapping and other geophysical data sets must be archived permanently through a well-coordinated plan that allows for merging of data to create spatially comprehensive maps. A program dedicated to archiving geophysical data sets clearly is a critical step to be taken as quickly as possible. We note the OPP has just funded a research group to archive multibeam data from the Antarctic.

7. Long-term monitoring of the oceanic environment.

We anticipate the potential of a variety of long term monitoring projects including, but not limited to those that may keep track of earthquakes (ocean floor seismometers), sedimentation (sediment traps) and currents (moored arrays of current meters). Deployment and recovery of instruments is relatively routine. Note that we did not discuss this in depth but recognize that additional conversation may be necessary, particularly in terms of how these programs might affect ship design, as, for example the potential need for a “Baltic type” room on both sides of the ship.

Specific Recommendations

1. Continued oversight of vessel plans, design, construction and testing by research scientists with appropriate technical expertise.
2. Size of ship to accommodate 50 scientists (includes technical support staff).
3. Increase icebreaking abilities (extends workable season and percentage of margin accessible).
4. Continued space for helicopter support (helicopter deck and hangar) – alternate use possible if flexibly designed.
5. Addition of more “sea-worthy” and “landing-worthy” small boat(s).
6. Addition of AUV/ROV support to the ship, with consequent implications for flexible garage-style storage space with overhead track, and consideration of deployment – A frame and crane capacities and placement, along with staff considerations.
7. Presence of a moonpool for coring and potentially deployment of instruments.
8. Increased jumbo piston coring capacity – either horizontal or vertical arrangement.
9. Increased refrigerated storage and core processing capabilities.
10. Consideration of “logical” pathways for routine movement of awkward and heavy pieces of equipment and samples (such as cores).
11. Increased flexibility and overall size of lab space – modular space.
12. Acoustic characteristics of the ship that produces the least interference.
13. Maximum ability of ship to create stern ice-free zone for towed equipment.
14. Separation of permanent computing facilities for easy maintenance and longer life of equipment (i.e. humidity, clean air, climate control, vibration control).
15. Plan for long-term archiving of swath mapping data.

Appendix I
Workshop Program

GENERAL AGENDA

Saturday 3/23/02

8:00 – 9:00	**Continental style breakfast at AGU facilities**
9:00 – 9:15	Welcome and Introduction (Amy Leventer)
9:15 – 9:30	Brief comments by Dr. Scott Borg, NSF-OPP
9:30 – 9:35	Introduction to sediment coring issues (Amy Leventer)
9:35 – 10:05	Shaldril (John Anderson)
10:05 – 10:20	ROV with coring capabilities (Kathy Licht)
10:20 – 10:45	**Break**
10:45 – 11:15	Long coring via the JPC (Amy Leventer, Gene Domack)
11:15 – 11:45	Core processing and storing on board ship (S. Brachfeld, E. Domack, S. Ishman, T. Janacek, R. Murray) Core splitting, Geotek track, Geochemical measurements
11:45 – 12:00	Shore-based support: the ARF and satellite core storage (Tom Janacek and Gene Domack)
11:45 – 12:00	
12:00-12:30	OPEN FORUM
12:30 – 1:30	**Lunch Break (lunch provided for group)**
1:30 – 1:35	Introduction to Geophysical issues (Amy Leventer)
1:35 – 2:00	Seismic issues: high resolution/shallow penetration; deep penetration (Gail Christeson, Steve Cande)
2:00 – 2:30	Multibeam issues – ship-based operations (any volunteers to initiate discussion?)
2:30 – 3:00	Multibeam issues - shore-based support: swath map archive/data distribution center (Eugene Domack)
3:00 – 3:30	Autonomous vehicles and submarines (Bruce Luyendyk)
3:30 - 3:45	**Break**
3:45 – 4:15	Brief agenda items – Site survey requirements for ODP (Gail Christeson) Update on IODP (Frank Rack) Lessons from the Healy (Larry Lawver) Links to other disciplines Links to other initiatives Use of helicopters Rapid response projects
4:15 – 4:45	OPEN FORUM
4:45 - 5:00	Summary (Amy Leventer)

Sunday 3/24/02

8:00 – 9:00	**Continental style breakfast at AGU facilities**
9:00 - 9:30	Review and any new agenda items
9:30 - 10:30	Small group discussion and writing of recommendations
10:30 - 10:45	**Break**
10:45 - 12:30	Presentation of recommendations
12:30 - 1:30	**Lunch Break (lunch provided for group)**
1:30	Adjourn

Appendix I
Participant List

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Antarctic Oceanography Planning Workshop: Possible Replacement of the *R.V.I.B. Nathaniel B. Palmer*

FINAL REPORT

National Science Foundation Sponsored Workshop
Washington, DC
June 25-26, 2002

<u>Conveners</u>

Walker O. Smith, Jr.
Stephen Ackley

<u>Attendees</u>

Stephen Ackley, Clarkson University
Robert Anderson, LDEO, Columbia University
Donald Atwood, Raytheon Polar Services
Terri Chereskin, Scripps Institution of Oceanography
Kendra Daly, University of South Florida
David DeMaster, North Carolina State University
Chris Fritsen, Desert Research Institute
James Holik, Raytheon Polar Services
Bruce Huber, LDEO, Columbia University
Scott Ishman, Southern Illinois University
Deneb Karentz, OPP-NSF
Bernard Lettau, OPP-NSF
Miles McPhee, McPhee Research Co.
B. Greg Mitchell, Scripps Institution of Oceanography
Robin Muench, OPP-NSF
Polly Penhale, OPP-NSF
Robin Ross, University of California, Santa Barbara
Bruce Sidell, University of Maine
Walker Smith, Virginia Institute of Marine Sciences
Al Sutherland, OPP-NSF
Colm Sweeney, Princeton University
Richard Voelker, MARAD
Peter Wiebe, Woods Hole Oceanographic Institution

The workshop's objective was to provide broad community input in the initial stages of design of a new ice breaker designed to replace the *R.V.I.B. Nathaniel B. Palmer*. As such, the attendees consisted of physical, chemical and biological oceanographers, as well as those involved in sampling ice and using remote sensing techniques or remotely operated platforms. As future research directions will drive the needs of the research platform, the workshop also included discussions of future research programs and directions. The major recommendations include the following for a replacement vessel:

- **A larger vessel capable of holding ca. 40 researchers with endurance of up to 90 days;**
- **Modular design for laboratories to allow for efficient multiple use of ship;**
- **Incorporate into the design unique opportunities afforded by operating in a pack ice environment, such as booms and efficient surface access allowing deployment of multiple instrumentation systems simultaneously;**
- **Inclusion of a modular automated underwater vehicle deployment and recovery station to extend ship operations in space and in locations (e.g., under ice) where the ship cannot effectively sample;**
- **A design that forces ice away from the stern area to allow for efficient towing of nets and other gear; and**
- **A design that reduces acoustic noise and which allows for effective acoustic sampling from the hull.**

Additional recommendations were also made that would enable the replacement vessel to clearly be the most capable research ice breaker in the world. It is expected (and desired) that interaction with the oceanographic community as a whole will continue throughout the planning of the vessel to insure that new and novel approaches to the problems of polar research are incorporated in the ship design.

The requirements of the community for the replacement vessel were varied, but in large part were consistent with each other, or at least not mutually exclusive. These fell into overall needs (for example, those dealing with endurance, ice breaking capability, and science personnel needs) and more specific disciplinary needs (e.g., need for trace metal clean flowing seawater, aquaria accessibility). This report treats those separately, and describes the rationale that the group provided for each recommendation. A summary list of all recommendations is provided in Table 1.

General Requirements for Replacement Vessel

The *N.B. Palmer* can presently accommodate 32 scientists and 7 Raytheon Polar Services technicians. While the needs for berthing space for some cruises is not severe, for some (particularly the larger programs such as JGOFS and GLOBEC) berthing space is the ultimate limiting factor in deciding what science objectives can be met. Indeed, both of those programs had up to 50% more requests for berths than they could accommodate. Hence, the scientific output of large, interdisciplinary programs is constrained by the personnel berthing. However, it was mentioned that vessels such as the *Polarstern* (which accommodates up to 55 scientists) often has difficulties in arranging wire time for all groups, and that the competition for the ship within a cruise was unproductive and to be avoided. As such, the group strongly felt that the new ship should be able to hold ca. 40 scientists, along with an increase in the number of RPS technical staff.

Such a ship would necessarily be larger, and it was felt that additional laboratory spaces should be included to make effective use of emerging technologies. For example, a moon pool is quickly becoming a tool that is used by all oceanographic disciplines (as evidenced by the recent addition of a moon pool to the *Palmer*), and that in the future even more use of this sampling system will occur. Simple and effective water-level access to the moon pool is needed (e.g., for nets, diving, AUV and ROV recovery and launching), and its location needs to be included in the early phases of design to allow sampling by all disciplines. Such a pool needs to be able to accommodate a CTD, as well as potentially be used as a means to deploy and retrieve ROVs and AUVs. Additionally, it might also be the site of acoustic sensors that collect data continuously. Design considerations need to take into account the wave generation issue within the pool and the need for proximity to the Baltic room.

Along with berthing capability and new design features, it was felt that the endurance and power (i.e., ice breaking capability) of the vessel need to be somewhat greater than that of the *Palmer*. The maximum cruise length was discussed, and it was felt that generally 75 days is close to the limit of human work capacity. This is near the longest cruise the *Palmer* has conducted, and during that cruise serious concerns were expressed about fuel consumption. Because some interdisciplinary projects and remote locations will require extended cruise deployments, this duration was deemed as the minimum that should be planned. Similarly, the power of the ship should be such that nearly all locations in the Antarctic can be safely and efficiently reached so as no science objectives are eliminated.

Ship design was discussed at length. For example, the present design of the *Palmer* makes it difficult at best to tow surface nets and vehicles while breaking ice, thus effectively precluding various types of studies. The new ship should definitely have a design that pushes ice away from the stern area and keeps this area relatively clean of ice. Similarly, the ship's acoustic noise presents a serious problem to those disciplines that rely on acoustic measurements, and careful attention needs to be paid to reducing the noise to scientifically acceptable levels. The technology presently exists to do so. Finally, alternate means of sampling were discussed, with one example of a new approach being the use of large booms to deploy/retrieve instruments using the ship's cranes. It was suggested that large, outrigger-type booms (30 m in length) could be used on the port side of the ship (the non-CTD side) to more effectively use this side of the ship. Inherent in the use of booms would be the approval to deploy more than one instrument at the same time. Additional materials have been assembled describing recent advances on the design of acoustic systems on modern fisheries research ships and can be viewed within the internet report (www.vims.edu/admin/sponpgms/palmer).

The laboratory design of the *Palmer* is quite acceptable, but it was felt that future needs will require the addition of specialized labs that would not be used for all cruises. Examples of such vans include radioisotope vans (like those now in use), trace metal-clean van (for sampling trace metals at the vanishingly low concentrations found in the Antarctic), and autopsy vans for marine mammal dissection. It is essential that all vans be modular and hence interchangeable with regard to hook-up with the ship. All will need adequate power supplies, fire alarms, intercoms/telephones for safety, computer network connectivity, and plumbing (running fresh water; drainage for sinks). Specialized drains may be required for some vans (e.g., isotope van). Positioning of the vans is also critical and must be considered early in the design phase (e.g., you do not want a radioisotope van placed a great distance from the incubators that hold the samples). Special considerations for some vans also need to be taken into account (e.g., positive pressure for the trace metal van; contained freshwater release from the radioisotope van).

The issue of helicopter use on a new vessel was discussed. Historically the *Palmer* has only rarely had helicopters, largely because of the extremely high costs associated with their operation. In addition, the helicopter hangar is used heavily for storage by all science parties, and the helicopter landing pad is the optimal location for isotope vans and incubators required non-shaded space. In addition, weather often severely limits the use of helicopters in the Antarctic. However, future needs require the maintenance of helicopter hangers and landing areas to allow for access to remote locations that would effectively enhance the operations of the ship. Permanent mounting of helicopters on the ship was not recommended. Both areas should continue to be effectively used by multiple purposes (incubator studies with running seawater; storage of science equipment; preparation of equipment such as sediment traps).

The *Palmer* in general is excellent for use in open waters, but it was recommended that the open water capabilities be improved to allow for year-round operation in the harsh environment of the Polar Front, in addition to the more coastal waters surrounding Antarctica.

Specific Requirements for the Replacement Vessel

New technologies are emerging that will soon be applied to Antarctic science. One of those disciplines is marine molecular biology. To adequately conduct these studies at sea, a gimbaled platform or laboratory is needed upon which centrifuges and electrophoresis equipment can be mounted, allowing samples to be processed in a timely manner. Such a platform might also be useful for on-board microscopy and flow cytometry as well. Some of the wet chemistry associated with modern molecular techniques also dictates that adequate fume hood space be designed into laboratories of the ship.

Maintenance of live animals aboard ship is not only useful for molecular biology but also permits physiological experimentation. To enable this work, good aquarium space should be incorporated into ship design. Overall design characteristics similar to those of the aquarium on the *L.M. Gould* (easily removable tanks, etc.), would permit flexible use of such space for other purposes during cruises that do not require this feature.

Recent studies (some conducted on the *Palmer*) have clearly shown the paramount importance of trace metals (particularly iron) to phytoplankton growth, and it is clear that studies of trace metals will continue to be an active area of research in the Antarctic. To facilitate these studies, not only is a trace-metal clean modular laboratory required, but flow-through water that is uncontaminated by the ship's superstructure is also needed. This flow-through system needs to be delivered to the trace metal clean van, as well as to the main laboratory, with little temperature modification. Furthermore, care must be taken to prevent clogging by ice. A second system of seawater delivery also needs to be maintained to provide water for heating/cooling of deck-board incubators and aquaria.

Much of future research will involve communication between the ship and the land-based laboratory, as well as direct use of the internet. As such, it is imperative that adequate through-hull communication ports be created to allow for complete networking of instruments. Furthermore, communication links to Antarctic stations and US laboratories need to be improved, and internet connectivity needs to be established. All communication links need to be able to deliver large packets of data over short time periods.

Experience with the Palmer has led to several suggestions for improved design or capabilities in a new vessel. For example, the cold rooms need to have better temperature control than on the Palmer, and some cruises may need an additional cold room (to be supplied as a laboratory van). A through-hull XBT launcher is needed to improve accessibility, safety and data integrity. The meteorological tower needs to be tested to insure that the wind velocity field interference is well known and documented. The shipboard ADCP that is presently on Palmer is 20-year old technology. Newer Doppler sonars and multi-frequency Doppler sonars would achieve deep velocity profiling (low frequency) and high resolution velocity profiling (high frequency) at frequencies that are also of biological interest. More and improved hood space is needed in laboratories where volatile chemicals are used (perhaps again in conjunction with a mobile laboratory). A means to transport crates and larger equipment between decks (and perhaps to the holds) is needed, and the concept of a "dumb waiter" was suggested. Within deck transport of gear also needs to be improved. At present the drainage on the decks on each side is inadequate to hold the large volumes of water and sediment that are washed overboard during coring activities, and the drainage capabilities need to be increased. Finally, better science shop facilities are needed to allow for work by scientists on equipment and shipping crates.

Because satellites will be used much more extensively in the coming decades, improved satellite communications are needed on a new vessel.   This parallels the need for improved communication, and is part of that requirement. Satellite receiving capability is needed for both ice and pigment analyses, as well as tracking of AUVs and moorings via Argos. The new design should incorporate the latest satellite telephone capabilities, including communicating with surrounding moorings and buoys via Iridium modem. Implicit in this requirement is the training of RPS personnel to facilitate accessing these data.

It was also suggested that an ice tower be considered for inclusion in a replacement vessel. Such a tower would be able to house meteorological instruments (perhaps providing a less obstructed flow over the instruments), and reduce contamination and interference of the ship's stacks. This also would require enclosed access to monitor and service the instruments.

Conclusions

In general, the *R.V.I.B. Nathaniel B. Palmer* is considered to be the premier oceanographic platform for use in polar waters, and it has been a tremendous asset to the US oceanographic community. It is, however, becoming "middle aged", and it is prudent to consider its replacement early enough to incorporate new technologies into its design. The committee was adamant on one point: ***that the scientific community should be involved not only in the initial stages of design, but throughout the entire design, construction and testing process.*** Errors in the past have occurred as ships were constructed, and it was felt that many of these errors might have been corrected had some group of scientists been consulted during the process of production. Furthermore, we recommend that an independent naval architect be retained as a consultant to the scientific steering group prior to and during the RFP process. While the *Palmer* remains an excellent platform, the opportunity for improving the oceanographic capabilities of the US are substantial, and the recommendations included in this report should facilitate the production of an improved ice breaker that will enhance US science efforts for years to come.

Table 1. List of recommendations of features to be included in the potential *Palmer* replacement vessel.

Number	**Recommendation**
1	Increase size of ship to accommodate 40 scientists, 9 RPS personnel, and have a 75-day endurance capability; have power to sample 98% of all sites in Antarctica
2	Have a substantial number of modular laboratories that can be put in place when needed (e.g., isotope van, trace metal clean van, acoustic van, etc.)
3	Inclusion of an AUV with the capability of multiple sensors, along with simple deployment and recovery
4	Inclusion of a gimbaled platform for microscopy and molecular biology instruments
5	Purchase and outfitting of the following laboratories to be used as needed: trace metal clean van, isotope van
6	Include adequate bulkhead feed-through connections to allow for computer and instrument connectivity
7	Internet capability for a significant portion of the day
8	Have the capability of delivering high-quality, trace metal clean, unaltered seawater to all laboratories
9	Include helicopter pad even though helicopters might not be used on all missions
10	Need in-lab XBT launching capability
11	Need adequate aquarium facilities (temperature control, continuous flow-through seawater) to maintain specimens in good condition
12	Wells that can accommodate bigger transducers
13	Need to have a meteorological tower that is properly tested to define how it alters wind fields
14	Need “dumb waiter” to move boxes between decks
15	Cold rooms need improved temperature control; vans for ice core studies are needed
16	Adequate drainage on all decks, particularly so that they can handle rinsing of sediments and gear
17	Need better construction shop and materials for science use
18	Excellent open water capabilities (motion compensation) also required, particularly for winter work
19	Need improved hood space and ventilation in labs where volatile chemicals are used
20	Need improved satellite receiving capabilities
21	Improve the acoustic characteristics, especially in ice
22	Add multi-frequency Doppler sonars for deep velocity profiling and high resolution profiling at frequencies also of biological interest
23	Hire a naval architect prior to and during the RFP process for independent advice

New Generation Polar Research Vessel

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ABSTRACT

In 2003, the U.S. National Science Foundation (NSF) initiated a program to determine the national requirements for polar marine science in the Antarctic and to assess vessel characteristics for a new generation Polar Research Vessel (PRV). This paper describes the results of that investigation. Science requirements included a need for year-round operations covering a wide range of diverse activities in geographic areas currently inaccessible. These requirements were followed by a series of technical studies that provided an assessment of vessel size, hull form, and power plant to successfully operate in 1.4 m (4.5 ft) level ice.

KEY WORDS: Research vessel; Antarctic; polar; icebreaker.

INTRODUCTION

The United States Antarctic Program (USAP) is managed by the NSF Office of Polar Programs (OPP). The focus of the USAP is the support of science and this is carried out by maintaining land-and marine-based facilities. The three permanent land-based research stations are: Amundsen-Scott South Pole Station, McMurdo Station, and Palmer Station. The marine-based facilities consist of two vessels, the *Nathaniel B. Palmer* (*NBP*) and *Laurence M. Gould* (*LMG*).

NBP began operations in 1992 and is the first modern era U.S. commercially-built and -owned icebreaker. Classed by the American Bureau of Shipping (ABS) as **✠A1**, Ice Class A2, (the bow is equivalent to ABS-A3), it can break 0.91 m (3 ft) of ice at a steady 3 kts. The vessel was designed and built as an icebreaking research vessel and is 94 m (308 ft) in length and operates year-round in all areas of the Southern Ocean. Meanwhile, the newest ship in the USAP fleet, the *LMG*, began operations in 1997 and serves a dual role of research and Palmer Station resupply. This 70 m (230 ft) vessel is classed as an ABS **✠A1**, Ice Class A1, with an icebreaking capability of 0.3 m (1.0 ft) at 3 kts and traditionally operates around the Antarctic Peninsula. Both of these vessels are under charter to NSF-OPP's prime support contractor Raytheon Polar Services Company. With the *NBP* charter expiring in 2012 after 20 years of service, plans are currently being developed for the acquisition of a new generation PRV that will incorporate a variety of expanded roles over that of the *NBP*.

To define the desired scientific and operational capabilities of the new generation PRV, the NSF funded two community science workshops in 2002. The findings of these workshops are available at the following websites: http://www.vims.edu/admin/sponpgms/AOPWReport.pdf and http://departments.colgate.edu/geology/faculty/AMGGPWReport.pdf. Then, using these workshops as guidance, the NSF employed the support of the Antarctic Research Vessel Oversight Committee (ARVOC). This Committee consists of nine members who are active users of the USAP vessels and are representatives of the various scientific disciplines using the ships. (The ARVOC web site is: http://www.usap.gov/conferencesCommitteesAndWorkshops/committeeMinutes/ARVOC.cfm). ARVOC subsequently formed a 15-member Special Standing Committee to provide expertise in scientific areas affecting the vessel and to work interactively with the NSF project team. As such, this Committee provides a continuing opportunity to gather and incorporate input from the broad spectrum of ship users as well as to review and comment on the guidance plans and specifications of the vessel as they are developed. The results have been impressive and include a series of science workshops, "Town Hall Meetings" at large national science congresses, surveys of the PRV user community in one-on-one contacts, and information collected through a public access web site where questions, comments, and opinions could be logged and archived. As of November 2005, ARVOC estimates that more than 250 experts have provided opinions, comments, and technical information related to the next generation PRV.

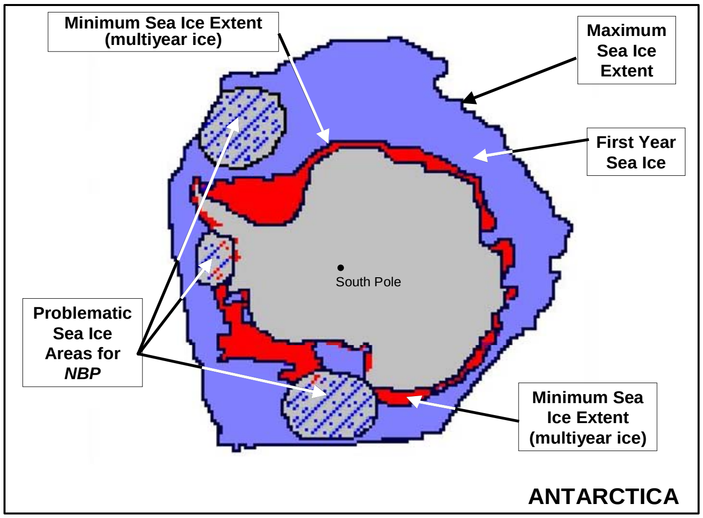
SCIENCE AND OPERATIONAL REQUIREMENTS

While the *NBP* has served the science community well, there are compelling reasons to plan for a new polar research icebreaker. Specific research requirements that mandate a new vessel for future scientific exploration of the Antarctic seas are:

- Enhanced icebreaking capabilities 1.4 m (4.5 ft) at 3 kts
- Increased endurance (to 80 days) and 20,000 miles at 12 kts
- Increased accommodation and lab space (for 50 scientists)

- Moon pool for geotechnical drilling-access to the water column through a controlled interface (no ice, limited surge and turbulence)
- Ability to tow nets and research instrumentation from the stern during icebreaking
- Acoustically quiet
- Hull form designed for the installation and operation of remote sensing instruments during icebreaking

The first two requirements are directed towards substantially increasing the ability of U.S. researchers to operate in a greater portion of Antarctica's ice-covered seas as well as throughout the Southern Ocean during all four seasons. Increased accommodation space will foster comprehensive and integrative approaches to Antarctic marine research. The moon pool, ice-shedding stern, and acoustic/hull properties are required to take advantage of new tools that have become important for many types of Antarctic research. Taken together, these requirements dictate that the next generation PRV will be larger and have a different hull shape than our current PRVs. An example of the benefits to be realized with the PRV's 50 percent increase in icebreaking capability is depicted in Figure 1. It shows the minimum and maximum sea ice extent in year 2000, first year and multiyear ice areas, and hatched areas where *NBP* vessel operations have been problematic during multiple cruises. With the increased capability of the PRV, it will have access to 90 percent of the ice covered areas of the Antarctic margin.



Some additional science and operational requirements include:

Fig. 1: Minimum and maximum sea ice extent during calendar year 2000

- Capability to conduct autonomous underwater vehicle/remotely operated vehicle (AUV/ROV) operations
- Jumbo piston coring (JPC) capacity for 50 m
- Compliance with International Maritime Organization (IMO) guidelines for Arctic vessels
- Reduced air emission from diesel engines and incinerator and other features for a "greener" ship
- Provision for a helicopter flight deck and hangar
- Space for 6 portable lab containers
- 2.4 m (8 ft) wide passageway on the Main Deck and inter-deck elevator
- Aloft, enclosed platform for science observations

Operationally, the PRV may face a wide range of environmental conditions. As such, the vessel will be designed and built for minimum winter air temperature of -46°C (-50°F) and have the capability of enduring a maximum sustained wind speed of 100 kts. Additionally, the combination of cold sea water and air temperatures with high sea states can cause severe topside icing at times. Icing rates of 1.3 cm/hr (0.5 in/hr) can be expected in extreme events.

A notional annual operating profile for the vessel is shown in Table 1 and is representative of the operations of the *NBP* during the last 14 years.

Table 1: Notional Operating Profile

Activity	Days
Transit and science operations away from port	265
In-port preparations for science operations	35
Repairs and maintenance	65
	365

DESCRIPTION OF SEVERAL SPECIAL TECHNICAL STUDIES

The hull form and propulsion plant for the PRV need to satisfy many objectives including efficient performance in level ice, operation in multiyear ice, good maneuverability in ice, excellent station keeping and sea keeping abilities, and low open water resistance. In addition, there is a desire to develop an improved ice-free channel behind the vessel and reduce or eliminate bubble sweep-down and ice pieces from passing under the acoustic array during icebreaking.

Towing in Ice A special study of existing non-conventional hull forms, as well as other various technical solutions for clearing ice from behind the icebreaker, showed it was extremely difficult to tow in ice in a manner comparable to those in open water. The most practical way of reducing the ice concentration in a broken channel is the use of an azimuthal propulsion system that can change the wake direction at the stern. However, the speed and ice thickness in which the ship is operating may limit the effectiveness of this approach. Using special devices or stern arrangements to submerge the towed equipment and minimize their interaction with ice in the ship's track also helps.

Bottom Mapping A box keel has been designed for the vessel to ensure its ability to conduct bottom mapping in open water and during most icebreaking operations. The most successful ship for swath bathymetry in ice has been Germany's Alfred Wegener Institute of Polar and Marine Research vessel *Polarstern*. The design for the PRV, therefore, used a refinement of the *Polarstern* box keel by incorporating in the fore and aft ends of the box keel a bow ice knife and stern skeg to avoid bubble sweep down and help clear ice from the acoustic arrays. Figure 2 shows this arrangement. In essence, this design will cause the ice pieces sliding down the bow or stern to divide and to move laterally.

The acoustic arrays are positioned as far forward as possible. There is potential for damage to the acoustic arrays during ramming because of their very forward location, but the ice knife should prevent the ship from riding up too high on a pressure ridge and, therefore, offer some protection to the arrays. The depth of the keel is 0.9 m (3 ft) and the width of the keel was determined from the width of the arrays. The other acoustic transducers are positioned in the box keel to port and starboard of the longitudinal array.

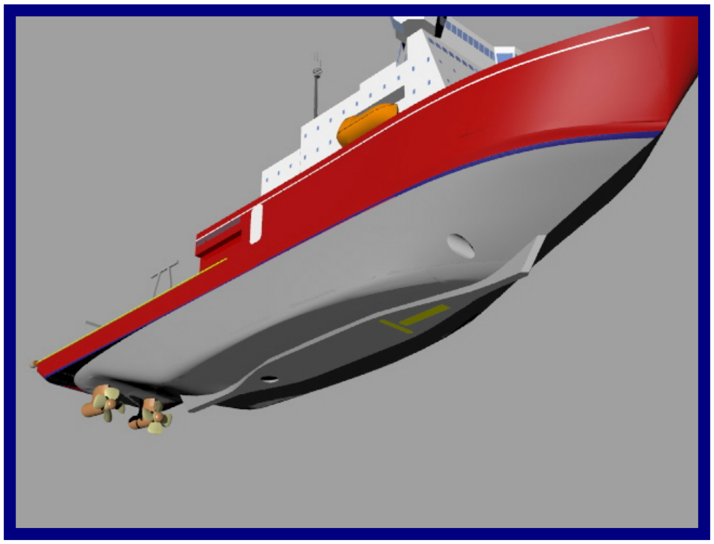


Fig. 2: Underwater view of PRV box keel with bottom mapping sensors

The cross-section of the box keel is similar to the *Polarstern's* with reverse flare on both sides as shown in Figure 3. This reverse flare side on the box keel helps prevent bubble sweep down from occurring across the face of the transducers. The deep draft of the PRV also serves as an advantage during icebreaking operations.

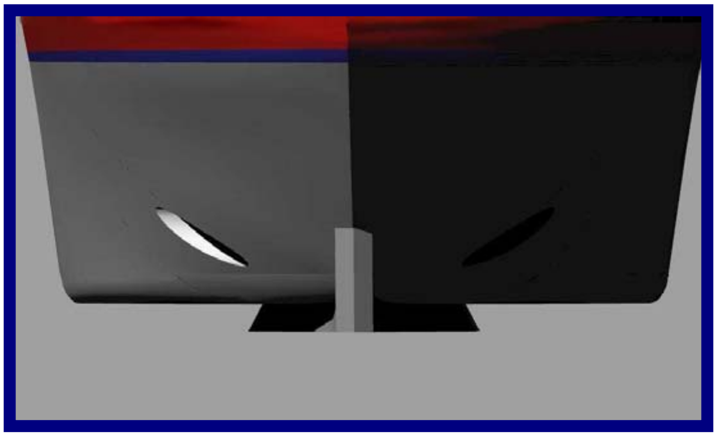


Fig. 3: View of box keel with reverse flare on the sides

Geotechnical Drilling In open water, dynamic positioning will be required to keep the ship on station during drilling operations. The selection of podded propulsors that can be rotated azimuthally was partially based on their good thrusting capability for dynamic positioning. A bow tunnel thruster has been provided to increase maneuverability for dynamic positioning and is located aft and higher compared to the usual thruster mounting in the bow ice knife. This should result in fewer air bubbles sweeping down to the acoustic arrays. The thruster will be effective in open water but will fill with ice in heavy pack. Even if cleared of ice, the bow thruster cannot produce enough thrust to be useful in ice. As such, it will only be used in open water for dynamic positioning and to assist in maneuvering alongside piers.

Moon Pool Operational requirements for the moon pool initially included such diverse activities as geotechnical drilling: conduct of AUV/ROV operations: deployment of rosettes for water sampling; conductivity, temperature, and depth (CTD) measurements; deployment of ocean bottom seismometers (OBS); and diving operations. This resulted in a moon pool size of 6.1 m (20 ft) by 4.9 m (16 ft), with the maximum dimensions based on ROV requirements. Subsequently, the science community decided that the primary function of the moon pool would be geotechnical drilling, but it also could be used to vertically deploy torpedo-shaped AUV's It will be re-sized to between 1.8 and 2.4 m (6 to 8 ft) in diameter, depending upon further study. The moon pool is located on the vessel centerline, close to the longitudinal center of gravity for minimal vessel motion, and it will be capable of being closed at the bottom. AUV/ROV operations can also be conducted off the stern or starboard side of the vessel as necessary.

Icebreaking Capability Operational requirements include enhanced icebreaking capability, 50 percent greater than that of the *NBP*. The proposed hull form has a modified wedge-shaped bow that is fuller than conventional icebreakers. This shape has been shown to be about 25 percent more efficient than some of the ships in service now. The moderate side flare decreases resistance in ice, helps with management of besetment and improves maneuverability in ice. Increasing flare in the stern portions of the ship allows the hull to break ice while turning quickly with the podded propulsors and also reduces the side ice loads. In addition to these features, there is also a need to deploy science equipment in land fast ice including old ice found in some bays of Antarctica. These requirements necessitated a hull and propulsion plant capable of operating in multiyear ice. As a result, the PRV will meet the requirements of the ABS ice classification A3. The vessel will also have the capability for independent operation in Arctic ice along the coastal shelf and into the Arctic Basin in summer. Extended operations in the Central Arctic Basin can be accomplished when escorted by a more capable lead icebreaker.

Open Water Performance A smooth hull form reduces open water resistance and improves endurance over hull forms with knuckles below the waterline that may, however, be easier to build. A stepped shear for high bow freeboard and flare above the water improves sea keeping while keeping the working deck aft at reasonable freeboard for over-the-side operations required of a research vessel.

PRV Machinery and Propulsors An analysis of the many scientific requirements (moon pool, station keeping, towing of nets, and instruments) and operational requirements (low power open water transit and high power icebreaking) led to the selection of a diesel-electric propulsion plant with podded propulsors. The diesel-electric propulsion plant consists of four main diesel generator sets, two of 6050 kW and two of 5100 kW with a total brake power of 22,000 kW. This configuration was selected because it provides greater flexibility as it relates to the physical arrangement on the vessel as well as varying electric power demands. It also provides excellent propeller shaft torque characteristics for operations in ice. Additionally, the diesel-electric generators can be "floated" on isolation mounts for low noise/vibration, thereby reducing the ship's self-generated noise signature to improve acoustic sensor performance.

Propulsors in the current PRV configuration take the form of two azimuthal propeller pods. This system offers enhanced station keeping ability, maneuverability in ice and less ambient ship noise. Each pod contains an 8.4 MW electric motor driving a pulling propeller. They are independently steerable through 360 degrees and provide superior maneuverability in ice and open water (station keeping) without rudders. Each pod drives one stainless steel four-bladed open fixed-pitch propeller of 5.4 m (17.7 ft) diameter. This large propeller rotates at a slow speed and ensures high thrust for icebreaking and low noise in open water, further reducing the ship's self-generated noise signature. It should be noted that conventional line shafting remains an alternative while reliability studies continue on podded systems, as described above.

All electrical service loads including propulsors, bow thruster, winches, cranes, lights, and other general ship service needs are powered from a common bus/integrated electric system.

Low Diesel Exhaust Emissions Diesel engines aboard existing U.S. research vessels, such as the *NBP*, were not subject to emissions regulations when they were built. New engines such as those to be installed on the PRV, must comply with recent U.S. regulatory requirements of the Environmental Protection Agency (EPA) that limit exhaust emissions, particularly nitrogen oxides (NOx). In addition, optional emission reduction equipment employing new technology can be installed to reduce emissions further.

These technologies can be divided into two broad categories. The first category affects the basic combustion process and prevents the formation of undesirable air emissions in the engine. These technologies include fuel selection and treatment, electronic control of fuel injection and valve timing, ceramic coating of combustion parts, exhaust gas recirculation, and the injection of water into the combustion chamber, to name a few. The second category focuses on the removal of undesirable emissions from the exhaust after they form in the engine. These include the use of catalyzed reaction and filtration processes including selective catalytic reduction, diesel oxidation catalysts, and particulate traps.

Emission estimates were made for diesel engines based on various technologies and treatments for NOx, total hydrocarbons (THC), and particulate matter (PM). These estimates are for: (1) commercial "off-the-shelf" regulatory compliant engines after 2007; (2) 2007 engines with currently available, optional technology; and (3) 2007 engines with optional technology that may be available in 2007. As shown in Table 2 and Figure 4 these levels are all compared with the likely emission levels from engines on vessels of the *NBP* vintage. It is clear that the new generation PRV provides an opportunity to significantly reduce diesel engine emissions. However, it is difficult to accurately predict the specific technologies that will be available when the PRV is built due to the rapid changes occurring in the industry.

Table 2: Comparison of emission estimates

Emission Estimates for Various Engine Configurations	NOx + THC (g/kW-hr)	PM (g/kW-hr)
NBP vintage (1990) engines	20	0.50
PRV-2007 engines without optional treatment	9	0.50
PRV-2007 engines with 2003 optional technology	4	0.06
PRV-2007 engines with 2007 optional technology	2	0.03

In addition to reducing diesel engine exhaust emissions, the PRV will have a number of other "green ship" attributes. Among these is the ability to "cold iron" the ship which will allow the vessel to use shore-based electrical power and shut down all ship service generators in port. By the time this PRV begins operation, ultra low sulfur diesel fuel may be available worldwide in the marine market. This will result in a 99.6 percent reduction of sulfur in diesel fuel compared to today's sulfur content. Current U.S. regulations require that sulfur content of marine diesel fuel be reduced by 85 percent by 2007.

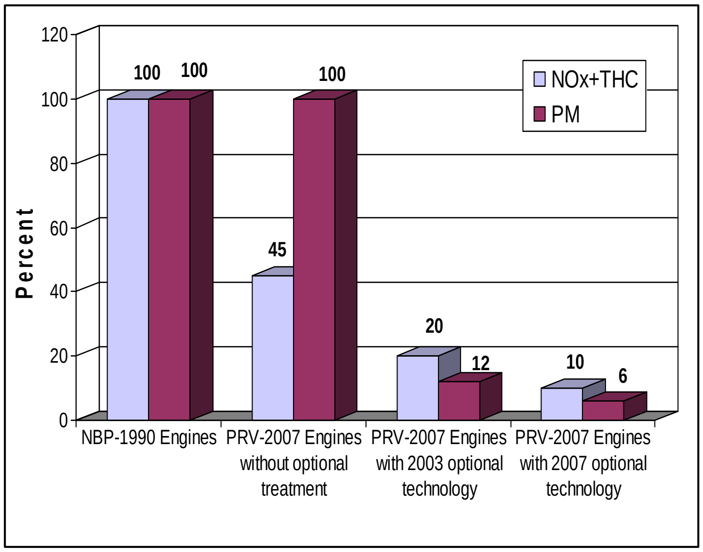


Fig. 4: Emission reduction per horsepower

Other ship requirements Naturally, the PRV will have many of the attributes of an icebreaker capable of year-round operation in the Polar Regions. These attributes include such items as low friction hull coating, heeling and trimming systems, floodlights and deck lights, and facilities for emergency personnel increase, to name a few. In addition to the traditional set of requirements, a service life of 40 years will be designed and built into the ship, taking into account the need for possible replacement of machinery and other components at various times. A preventative maintenance plan and a thorough half-life re-fit at the 20-year mark may be some of the methods used to extend the ship's life span. IMO measures may also be in effect to eliminate or reduce potential harmful exchanges of ballast water and marine organisms from native to non-native habitats and seas.

PRINCIPAL CHARACTERISTICS

Having defined the mission requirements and a feasibility-level technical study of hull and machinery systems, the principal characteristics were determined as shown in Table 3 and a rendering of the vessel as shown in Figure 5. The vessel is configured for primary pilot house control from the starboard bridge wing, which affords a clear view of the open starboard and fantail area. There is no need for a centerline control station as the redundant station will be located in the port bridge wing.

Table 3: PRV principal characteristics

Length, Overall	115.3 m	378.4 ft
Length, Waterline	103.9 m	340.9 ft
Beam	22.7 m	74.5 ft
Draft	9.0 m	29.6 ft
Displacement	11,200 MT	11,000 LT
Propulsion Horsepower (total, twin propellers)	16.8 MW	22,400 HP

ARRANGEMENT OF PRIMARY SCIENCE DECKS

Considerable time and effort have been spent by ARVOC and others in the science community on the current arrangement of scientific spaces on the Main and 01 Decks. These Decks are the primary work areas of the vessel and are shown in Figure 6. The arrangement is somewhat

Fig. 5: Artist's rendering of Polar Research Vessel

similar to the *NBP*, but incorporates changes to reflect operational experience and new needs.

The PRV must be multi-functional with modular designed components that can be mobilized or de-mobilized for specific projects. As an example, investigations in the Polar Regions require not only the ability of a vessel to enter the ice, but also to be equipped with AUVs or ROVs to facilitate investigations under the ice, in the water column and on the sea floor. There are rapid advances being made in technologies for AUVs and ROVs and it is anticipated that these instruments will become standard in all areas of marine science. Storage, deployment, operation, and recovery of modular systems and instruments need to be fully reviewed.

Similar consideration must be given to accommodate new geotechnical drilling and sediment coring. Here again, storage and deployment of drill rigs require careful analysis of their capabilities, planning of deck layout and superstructure as well as ship maneuverability. In addition, biological investigations are rapidly evolving to rely more and more on molecular-based methods for evaluation of taxonomy and physiology. Sterile lab conditions and motion sensitive instruments are routine components of many research projects.

To support the need for this flexibility, the Main Deck area aft of midships provides a significant amount of clear, unobstructed open space, with tie-down fittings to make it suitable for a wide range of investigations. It is also home to many laboratory spaces, scientific stores, and storage for modular lab containers and workshops. The 01 Deck has a variety of control room spaces, winch rooms, 12 two-person staterooms, and the messroom. This latter space was relocated from the Main Deck, because of the noise generated from icebreaking at that location. Additional scientific cabins for one and two-person berthing are located on the 02 Deck.

The 2-person science cabins are approximately 16.7 sq m (180 sq ft) in area and contain the following: fore and aft berthing with an upper berth that can be folded into the bulkhead, a private bathroom, two desks facing outboard with communication and computing facilities, a sofa, spacious storage lockers for clothing, and a window.

MISSION SENSITIVITY STUDY

A sensitivity study of vessel construction cost for various mission requirements was completed. Basically, a synthesis model allowed the determination of vessel characteristics and an estimate of vessel costs without going into many naval architectural calculations. A special

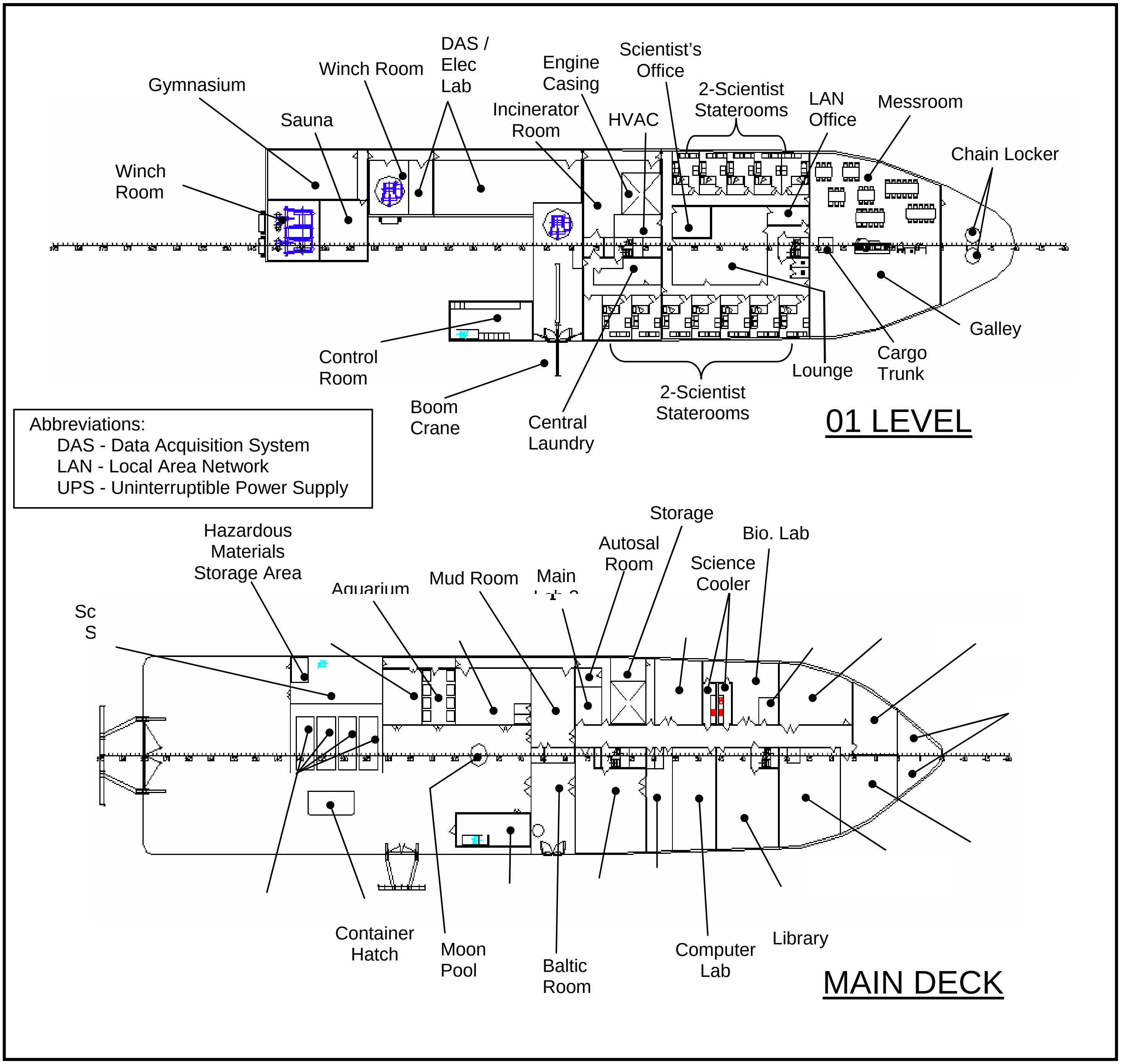


Fig. 6: PRV arrangements for the Main Deck and 01 Deck

feature of the model is that it allows both single and multiple sets of scientific and operational missions to be compared.

As shown in Figure 7, the sensitivity model was systematically varied for several different configurations of science features and icebreaking capabilities. The baseline ship accommodates 37 scientists, an endurance of 60 days, a 0.9 m (3 ft) icebreaking capability, and is comparable to the existing research vessel *NBP*. New scientific mission/capability was then examined for bottom mapping (box keel), double hull, diesel emission reduction, JPC of 50 m (164 ft) and 80 m (262 ft) capability, geotechnical drilling, 80-day endurance, AUV/ROV operations through a moon pool, accommodations for 50 scientists, and icebreaking capability of 1.2 m (4 ft) and 1.4 m (4.5 ft).

The sensitivity study for the PRV revealed that some of the mission requirements are associated with no significant increase in construction cost. Interestingly, a box keel for enhanced bottom mapping capability in open water and during icebreaking actually reduces the vessel construction cost by effectively providing displacement without the significant accompanying structural weight.

In contrast, the mission requirement for increasing level icebreaking capability has a significant construction cost increase. The thicker the ice a ship must break, the more expensive its construction cost. Other mission requirements such as weight allowances for geotechnical drilling capability, inclusion of a double hull and an expanded moon pool contributed little to the vessel cost. In some cases, a mission requirement can either affect the vessel construction cost significantly or not at all. The 80 m (262.4 ft) JPC is the primary example of this. For a 0.9 m (3 ft) icebreaking baseline ship, adding only the 80 m JPC requirement greatly affects the cost because the ship must be significantly longer to accommodate the capability. However, a larger ship, such as one with 1.4 m (4.5 ft) icebreaking capability, already has the length required for the 80 m (262.4 ft) JPC and has little effect on construction cost.

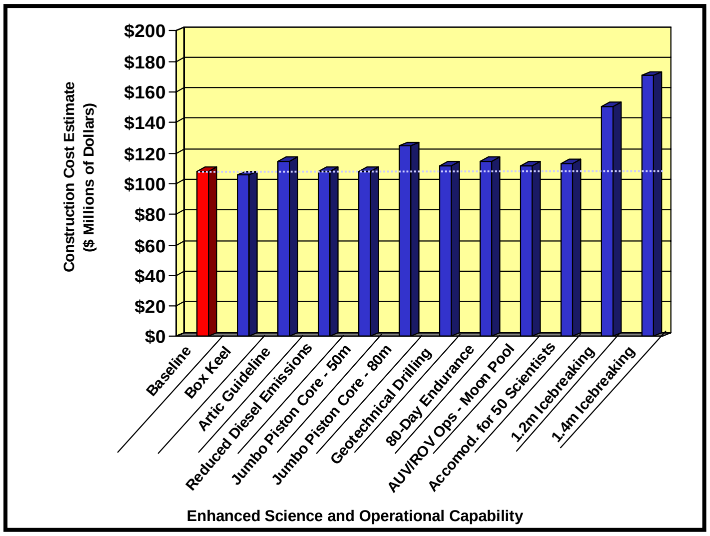


Fig. 7: Significance of individual mission requirements on construction cost

In addition to assessing the cost for individual requirements, many cases were examined for various combinations. For example, the vessel characteristics needed to satisfy 1.4 m (4.5 ft) icebreaking capability, resulted in a cost increase of less than one-half of one percent for inclusion of a double hull, a moon pool, 50 m (164 ft) JPC, a box keel, lower diesel emissions, and geotechnical drilling.

Likewise, a cost increase of 17 percent over the single mission requirement of 1.4 m (4.5 ft) icebreaking provided a vessel that satisfied all scientific and operational needs. These and other cases were examined during the study.

ACQUISITION PLANS

Although detailed acquisition plans for the vessel must still be developed, a likely scenario is for a long-term lease similar to that presently used for the *NBP* and the *LMG*. The terms of the lease would have to be determined, but it is recognized that the longer the lease period, the less the risk to the bidder and thus the greater the competition and the lower the daily charter rate.

A lease-versus-buy study would have to be performed before a final decision could be made, similar to that required for the *NBP*. The *NBP* study, 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. It involved a number of estimates and assumptions including interest rates, discount rate, operating cost, length of lease, and ship value at the end of the lease. While a major factor in the consideration was cost, there were a number of other items that were factors in the decision.

- ✓ 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.
- ✓ Fleet management – the maintenance of the vessel and hiring of the crew is the responsibility of the owner.
- ✓ Construction – there is the potential for diverse views between the owner and shipbuilder. The operator wants a quality ship that can be easily maintained and efficiently run, whereas the shipyard wants to provide a ship that meets specifications at the lowest cost.

It should be recognized that there are several different practices for research vessel ownership and operation in the United States and they vary considerably with the agency or institution supporting the research. The National Oceanic and Atmospheric Administration (NOAA) primarily uses a model of Government-owned – NOAA Corps-operated vessels. The University National Oceanographic Laboratory System (UNOLS) vessels are a combination of Government-owned (Navy and NSF) vessels and University-owned vessels. They are operated by the individual Universities through funding provided primarily by NSF and other Government agencies. Each of the methods of providing research ship support to science varies considerably, and each has advantages and disadvantages; none is necessarily “better” than the other.

As has been done in the past, and prior to release of a request for proposal for the PRV, a series of public meetings with prospective bidders would be held in order to stimulate interest and thus competition. Meetings would also enable industry to provide suggestions on methods to construct the vessel more economically, and with less risk, and consequently more cost effective for the Government. Figure 8 shows an outboard profile of the PRV as a result of the feasibility stage study.

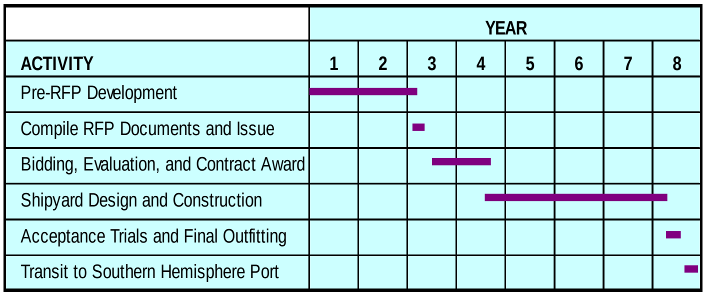
Fig. 8: Outboard profile of the PRV showing dual podded propulsors although traditional line shafting remains an alternative

PRV TIMELINE

A representative schedule for the PRV has been developed based on one of several possible procurement strategies. In particular, Figure 9 shows a schedule based on a strategy of using technical specifications with guidance drawings of the vessel. This approach is based on incorporating the experience, knowledge, and preferences gained from prior polar science operations while still allowing innovation on the part of the vessel owner and shipbuilder. In essence, this strategy provides a framework or guidance for the final design by the shipyard and for vessel construction.

The pre-RFP (Request for Proposal) development activities, where the project is today, requires a little over two years to complete. It is during this time period that the scientific and operational requirements are finalized; a procurement strategy is developed; construction cost sensitivity studies are performed; a number of studies related to the hull, machinery, laboratory arrangements, environmental protection, and the like are conducted; and guidance plans and specifications are developed.

Alternate procurement strategies can either lengthen or shorten the timeline with corresponding changes in risk and cost. In particular, a performance-only based technical specification would probably result in a one year shorter time frame for vessel delivery. However, a contract design technical specification with drawings would add about another two years before delivery of the vessel and severely limit changes to the design after contract award.



	YEAR							
ACTIVITY	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Pre-RFP Development	▬	▬	▬					
Compile RFP Documents and Issue			▬					
Bidding, Evaluation, and Contract Award			▬	▬				
Shipyard Design and Construction				▬	▬	▬	▬	▬
Acceptance Trials and Final Outfitting								▬
Transit to Southern Hemisphere Port								▬

Fig. 9: PRV Timeline

NEXT PHASE

As described in this paper, most of the requirements for the feasibility stage have been completed. The PRV's basic science and operational missions have been determined as well as the vessel size, characteristics, and a construction cost estimate.

The next phase must now fine tune aspects of the vessel such that guidance plans and specifications can be developed for the PRV RFP. From a procurement perspective, some of the key activities include an analysis of the lease-versus-buy alternatives, the conduct of meetings with industry on the procurement, and a wide set of activities related to preparation of the RFP.

From a science point of view, a great deal of time and effort is needed on the arrangement of laboratory and science spaces such that there is proper integration with winches, cranes, storage, and cargo handling equipment. In addition, some of the laboratories will require a more detailed design to assure that they provide the desired flexibility of use for multiple science disciplines. All of these activities will require considerable deliberation and coordination.

From a technical perspective, there is a need to refine the hull and propulsion plant such that a series of model tests (sea keeping, icebreaking, calm water speed/power, and station keeping) can be conducted. The objective of these tests would be to demonstrate or verify, not optimize, that the guidance drawings of the hull and propulsion plant satisfy the requirements. Prospective bidders will then have the option of using this information or attempting to further optimize the configuration as they respond to the RFP. Several additional studies will need to be conducted and these include: the reliability of podded propulsors in ice, acoustic studies and general refinement of the machinery plant.

PROJECT WEB SITE

A project web site has been prepared to serve a number of purposes. Foremost is the fact that the web site will provide an open means to solicit, gather, and incorporate input from the broad community of potential ship users including: scientists, technicians, operators, managers, and all who have a vested interest in the new ship. In effect, this forum will be a project management tool for developing, collecting, and organizing PRV science and technical requirements.

The web site consists of six sections:

- Purpose Statement
- Background/Current Efforts
- Conceptual Design Specifications
- Science Community Participation
- Newsletters
- Multimedia Gallery

Access to the site, and the ability to enter comments, are open to all. However, access to make changes to sections and functionality of the site is controlled.

The web site address is:
www.usap.gov/vesselscienceandoperations/prvsection.cfm

SUMMARY

The NSF has begun planning for the acquisition of a new generation PRV that is intended to serve the needs of the science community in the first half of this century. To aid in this effort, NSF employed the support of ARVOC to develop the science and operational requirements. Some of these requirements are in response to the national need to expand global climate change studies in the polar regions. Computer models point to these areas as critical components for developing forecasts.

After receiving comments and reviews from over 250 experts, the basic requirements were established and formed the basis for generating a feasibility study to determine approximate vessel characteristics. To aid in this effort, a number of special technical studies were performed including a sensitivity study relating mission requirements to vessel construction cost. Subsequently, the issues associated with the acquisition of the PRV, as well as the overall project schedule from today's pre-RFP activities to vessel acceptance, were described. The remaining pre-RFP activities from an acquisition, science, and technical perspective were also presented. The NSF seeks to have the PRV serve as a world-class platform for future decades of research in the polar regions.

REFERENCES

1. Sutherland, A., "United States Antarctic Program Research Vessels," Marine Technology Society Journal, Fall 2001

2. Dunbar, R. (on behalf of the Antarctic Research Vessel Oversight Committee), "Advancing U.S. Polar Research through the Acquisition of a New Polar Research Icebreaker," draft document, January 2006

Appendix 3: Roster of ARVOC and ARVOC PRV meeting attendees

ARVOC members who have worked on the PRV project:

Dr.	**Steven**	**Ackley**	Clarkson University 8 Clarkson Avenue Potsdam,New York 13699	sackley@pol.net
Dr.	**Bob**	**Anderson**	Lamont-Doherty Earth Observatory Rt 9W P.O Box 1000 Palisades, New York 10964-8000	boba@ldeo.columbia.edu
Dr.	**John**	**Anderson**	Rice University Department of Earth Science-MS 126 Houston Texas 77251-1892	johna@ruf.rice.edu
Dr.	**Jamie**	**Austin**	University of Texas at Austin 4412 Spicewood Spring Road Austin, Texas 78759	jamie@utig.ig.utexas.edu
Dr.	**Teresa**	**Chereskin**	University of California San Diego MS 0230 9500 Gilman Drive La Jolla, California 92093	tchereskin@ucsd.edu
Dr.	**Bill**	**Detrich**	Northeastern University Dept. of Biology 414 Mugar hall, 360 Huntington Boston, Massachusetts 02115	iceman@neu.edu
Dr.	**Robert**	**Dunbar**	Stanford University Geological & Environmental Sciences 325 Braun Hall Bldg 320 Stanford, California 94305	dunbar@stanford.edu
Dr.	**Chris**	**Fritsen**	Desert Research Institute Division of Earth and Ecosystem Sc. Reno, Nevada 89512	cfritsen@dri.edu
Dr.	**Chris**	**Measures**	University of Hawaii at Manoa 1000 Pope Road Honolulu, Hawaii 96816	chrism@soest.hawaii.edu
Dr.	**Robin**	**Ross**	University of California Santa Barbara Marine Science Institute Santa Barbara, California 93106	robin@icess.ucsb.edu
Dr.	**Bruce**	**Sidell**	University of Maine at Orono School of Marine Sciences 5751 Murray Hall Room 316 Orono, Maine 04469	bsidell@maine.marine.edu
Dr.	**Janet**	**Sprintall**	UCSD/SIO, 0230 9500 Gilman Drive La Jolla, California 92093	jsprintall@ucsd.edu
Dr.	**Jim**	**Swift**	UCSD/SIO, 0214 9500 Gilman Drive La Jolla, California 92093	jswift@ucsd.edu

Members of the Scientific Steering Committee for the PRV, in addition to the members of ARVOC:

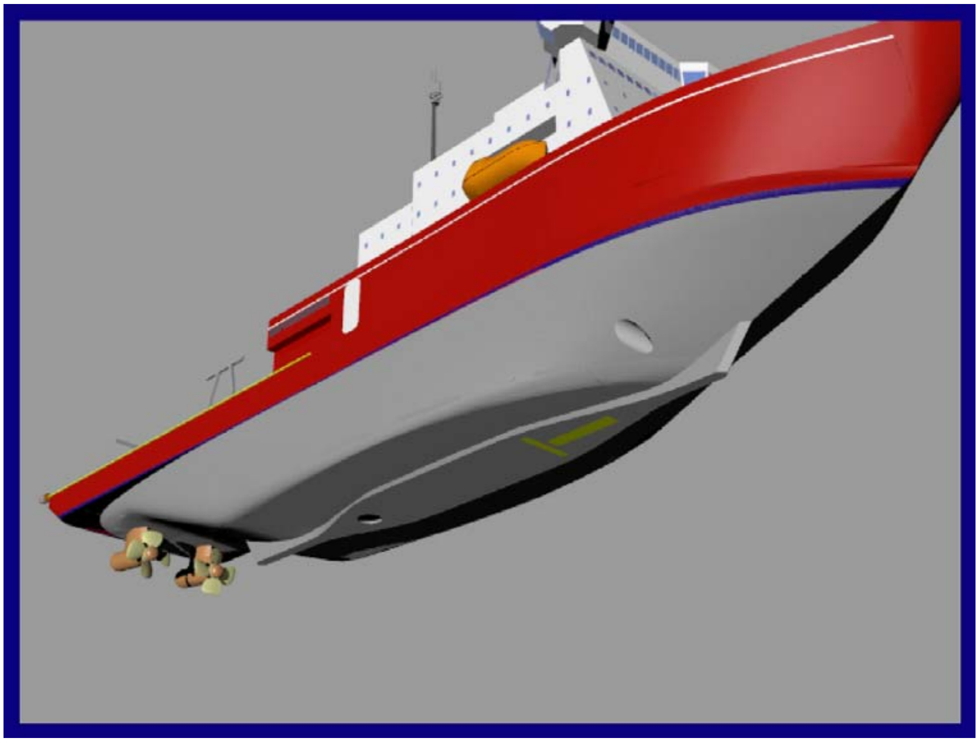
Eugene Domack, Hamilton College
Deneb Karentz, Univ. of San Francisco
Amy Leventer, Colgate University
Bruce Robison, MBARI
Colm Sweeney, NOAA
Barrie Walden, WHOI
Tom Janecek, IODP-IMI
Bruce Huber, LDEO

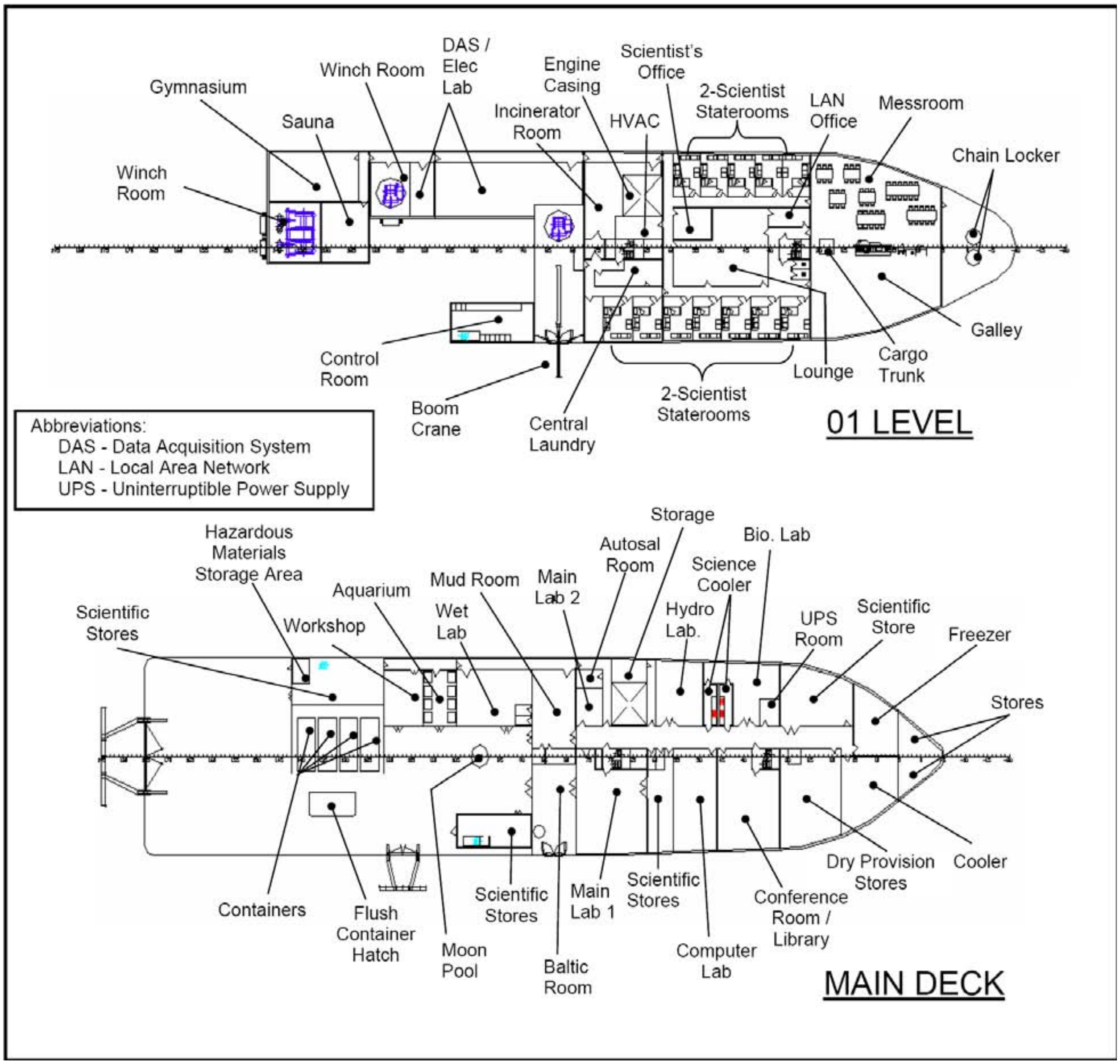
Meeting attendees from MARAD/STC:
Richard Voelker
Jim St. John
Alex Iyerusalimskiy

Meeting attendees from NSF:
Scott Borg
Erick Chiang
Bernhard Lettau
Roberta Marinelli
Polly Penhale
Al Sutherland
Thomas Wagner

Meeting attendees from RPSC:
Steve Dunbar
Jim Holik
Bob Kluckhohn
Paul Olsgaard
Skip Owen
Dawn Scarboro

Appendix 4. Drawings of PRV (Provided by MARAD/STC).




DAS / Elec Lab
Winch Room
Gymnasium
Engine Casing
Scientist's Office
2-Scientist Staterooms
Incinerator Room
HVAC
LAN Office
Messroom
Sauna
Chain Locker
Winch Room
Galley
Control Room
Cargo Trunk
Lounge
Boom Crane
Central Laundry
2-Scientist Staterooms
01 LEVEL
Abbreviations:
DAS - Data Acquisition System
LAN - Local Area Network
UPS - Uninterruptible Power Supply
Storage
Hazardous Materials Storage Area
Autosal Room
Bio. Lab
Science Cooler
Mud Room
Main Lab 2
Aquarium
Scientific Stores
Wet Lab
Hydro Lab.
Scientific Store
Workshop
UPS Room
Freezer
Stores
Dry Provision Stores
Cooler
Containers
Flush Container Hatch
Scientific Stores
Main Lab 1
Scientific Stores
Conference Room / Library
Moon Pool
Baltic Room
Computer Lab
MAIN DECK