ASC RESEARCH VESSEL REPLACEMENT PROGRAM

CONCEPT DESIGN REPORT

PREPARED FOR

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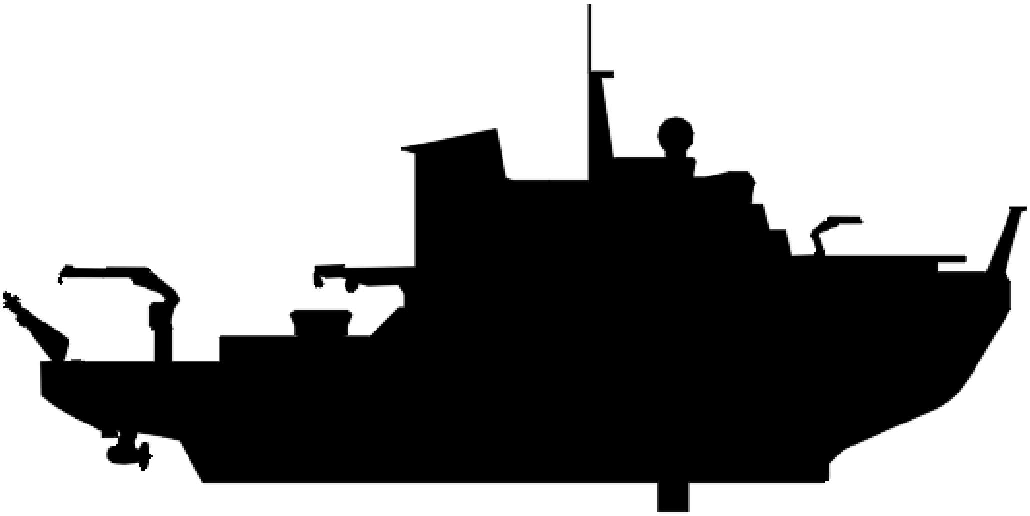

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Acronyms, Initialisms, and Abbreviations

ABS	American Bureau of Shipping
ACCU	Automated Control System Certified for Unattended Engine Room
ADCP	acoustic Doppler current profiler
ARSV	Antarctic Research and Supply Vessel
ASC	Antarctic Support Contract
AUV	autonomous underwater vehicle
CFD	computational fluid dynamics
CFR	Code of Federal Regulations
COI	Certificate of Inspection (obtained from and enforced by the USCG)
CTD	An instrument used to measure water conductivity, temperature, and depth
DNV GL	Det Norske Veritas Germanischer Lloyd
ECA	Emissions Control Area
ECO	Edison Chouest Offshore
EPLA	electrical power load analysis
HVAC	heating, ventilation, and air conditioning
LARS	launch and recovery system
LHS	load handling system
LMG	ARSV *Laurence M. Gould*
MARPOL	The International Convention for the Prevention of Pollution from Ships
MPC	Marine Project Coordinator
MSD	marine sanitation device
NBP	RVIB *Nathaniel B. Palmer*
NOx	nitrogen oxide
NSF	National Science Foundation
OCMI	Officer in Charge, Marine Inspection
PC	Polar Class
RVIB	Research Vessel Icebreaker
SCR	selective catalytic reduction
SOLAS	Safety of Life at Sea
STCW	Standards of Training, Certification, and Watchkeeping
SWBS	Ship Work Breakdown Structure
UAV	unmanned aerial vehicle
UNOLS	University-National Oceanographic Laboratory System
USAP	United States Antarctic Program
USBL	ultra-short baseline acoustic positioning system
USCG	United States Coast Guard
URN	underwater radiated noise
VCG	Vertical Center of Gravity

Revision History

Section	Rev	Description	Date	Approved
All	-	Initial release	5/27/20	TSL
All	A	Revisions based on review comments and follow-on studies	8/11/21	TSL
All	B	Revisions based on Leidos review comments	8/16/21	TSL

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Executive Summary

A concept design was developed for the Antarctic Research Vessel (ARV) that will serve as a replacement for the RVIB *Nathaniel B. Palmer*. The concept design was developed to verify that the threshold requirements identified by the NSF in their 2019 report on research vessel procurement (Reference 1) result in a vessel that is in the desired size and cost range. Additional review comments from NSF and Liedos were incorporated into the concept design and this report.

This report summarizes the concept design philosophy, demonstrates that a vessel meeting the general requirements is feasible, and summarizes the impact on the concept design from several follow-on studies authorized by Leidos/NSF after initial submittal of this report.

The threshold requirements initially developed by the NSF in Reference 1 were refined and prioritized during development of the concept design and after review and discussion with NSF project leadership, which was captured in a capabilities and scoring spreadsheet (Reference 2). Table 1 compares NSF thresholds and objectives from Reference 2 with the ARV concept design.

Table 1 ARV concept design characteristics versus NSF requirements

Characteristic	Threshold	Objective	Concept Design
IACS Polar Class	PC3		Designed for PC3
Range	17,000 nm (70 days * 10 kts)		17,000 nm @ 12 kts, calm water.
Endurance	90 days		90 days[1]
Antarctic diesel oil transport	60,000 gal		60,000 gal
Science Party	45	55	52 -55 (including resident technicians)[2]
~~Helo Deck and Hangar~~	~~Two Bell 412, Sikorsky S-70 or USCG HH60~~		This requirement was eliminated (Reference 3)
Working Deck	4,500 ft^2	5,500 ft^2	5,450 ft^2 aft working deck, 710 ft^2 side working deck, 6,160 ft^2 total
~~Moon Pool~~	~~4 m x 4 m. Closures at top and bottom. Able to be pumped dry. System to clear ice when in use.~~		This requirement was eliminated (Reference 4)
Centerboard(s)	At least one, retractable		One, retractable; 3 working positions, one maintenance position
Containers	20 total, including: 7 aft Main Deck, 2 fwd of Bridge, 4 below deck, space for 6 additional containers with limited service hookups	30 total, including: 7 aft Main Deck, 2 fwd of Bridge, 8 below deck, space for 7 additional, limited service hookups	30 total, including: 15 on aft Main Deck, 4 fwd of Bridge 8 below deck, 3 in lab van bay
Lab Area (Total)	5,700 ft^2	6,500 ft^2	5,900 ft^2 (including 700 ft^2 Baltic Room)

Characteristic	Threshold	Objective	Concept Design
Science Storage	14,000 ft^3	16,000 ft^3	28,000 ft^3 (including cargo hold)
Anti-roll Systems	Passive or active anti-roll devices to allow work thru SS 5.		Two U-tube tanks. Science ops through SS 5.
Wastewater holding capacity	20 days for black water and 60 days for gray water.		60 days of holding (gray and black water, processed through MSD)
Drilling Capability	Over the side		Over the side or seafloor.

1. See discussion of endurance in Section 8.
2. See discussion of science berthing in Section 6.

Section 1 Overview

The RVIB *Nathaniel B. Palmer* (NBP) and the ARSV *Laurence M. Gould* (LMG) have been supporting Antarctic research through a charter arrangement with Edison-Chouest Offshore (ECO) via Leidos, the U.S. Antarctic Program's (USAP's) Antarctic contractor. Both ships are nearing end of contract and the NBP is nearing the end of its design service life. Both USAP vessels are out of date with respect to various regulatory matters, and neither can readily be refit into compliance.

Leidos and Glosten developed a concept design and Performance Specifications (Reference 5) for a replacement vessel for the NBP based on National Science Foundation (NSF) requirements and input. The new vessel is referred to as the Antarctic Research Vessel (ARV). The final goal of this process has been development of Performance Specifications and solicitation for the design and construction of the ARV.

The first step in this process was a review of the NSF Report of the Ad Hoc Subcommittee on the USAP's Research Vessel Procurement (Reference 1), which describes the ARV's capability requirements. These requirements were condensed into a Requirements Matrix (Reference 6) that was organized to focus on items with the greatest effect on the ARV's cost and size and provided recommendations on how to address them.

This report describes the ARV concept design and the basis for design decisions during its development.

1.1 Performance Specifications

Studies were undertaken before and after an initial concept design was developed to validate that adherence to the Requirements Matrix will result in a vessel that is suitable for the needs of the science community and is of appropriate size and cost. The concept design is not intended to be the first iteration of the final design; rather, its purpose is to ensure that design solutions exist that meet the performance requirements. The primary design guidance for the designer in the next phase of this project will come from the Performance Specifications. The Performance Specifications is a document that was reviewed by NSF and Leidos and updated throughout the concept design phase to establish the requirements that a designer will need to meet in a design-bid-build contract. The Performance Specifications and the accompanying Documentation Requirements (Reference 6) will be completed pending final review by the NSF review panel.

1.2 Vessel Particulars

ARV concept design vessel particulars are as follows:

Length, Overall (L_{OA})	335'-9"	102.3 m
Length, Design Waterline (L_{WL})	312'-0"	95.1 m
Beam, Maximum (B_{max})	69'-0"	21.0 m
Beam, Design Waterline (B_{dwl})	68'-7"	20.9 m
Depth, At Side Amidship (D)	38'-0"	11.6 m
Draft, Design Waterline (T)	28'-0"	8.5 m
Displacement (Δ)	10,248 LT	10,412 MT
Estimated Gross Tonnage (ITC)	9,200	
Integrated Electric Power	22,800 hp	17,000 kW
Cruising Speed (knots)	10-12	
Range (NM)	17,000	

Endurance (Days)... 82

Diesel Fuel Capacity (90%) ....471,420 gal.................. 1,785 m^3
Urea Capacity (90%).................................36,500 gal..................... 138 m^3
Potable Water Capacity (100%)................75,000 gal..................... 284 m^3

Science Laboratories....................................5,200 ft^2..................... 483 m^2
Working Deck..6,200 ft^2..................... 576 m^2
Baltic Room ....700 ft^2....................... 65 m^2
AUV Hangar ....460 ft^2....................... 42 m^2
UAV Hangar ....420 ft^2....................... 39 m^2

Science Berths... 52
Crew Berths 29
Containers .... up to 30

1.3 Vessel Size

There are several design requirements that directly impact the size of the current concept design. Table 2 summarizes the primary design requirements that drove the size of the ARV concept design and compares them with the existing NBP. Figure 1 illustrates the size difference between *Sikuliaq* (PC5), NBP, and the ARV concept design. More details about the height of the concept design are given in Section 3.1.

Table 2 Primary vessel requirements driving ARV size compared to NBP

	ARV Requirement	R/V *Nathaniel B. Palmer*
Polar Class[1]	3	Estimated hull strength at PC4/5 but no double hull
Propulsion power	17,000 kW	9,500 kW
Fuel Capacity[1]	471,000 gallons	425,000 gallons
Endurance	90 days at 10 knots	52 days at 12 knots
Range	17,000 nm	15,000 nm
Lab Area	5,700 - 6,500 ft^2	5,300 ft^2
Working Deck Area	4,500 - 5,500 ft^2	4,000 ft^2
Scientists	52	39
Containerss[2]	25 - 30	20 Cargo, 9 Science
Jumbo Piston Core	40 - 50 m	24 m

1. Current Polar Class requires that no polluting fluid, i.e., diesel oil, be stored against the skin of the vessel.
2. Container capacity considers a single vessel replacement of NBP.

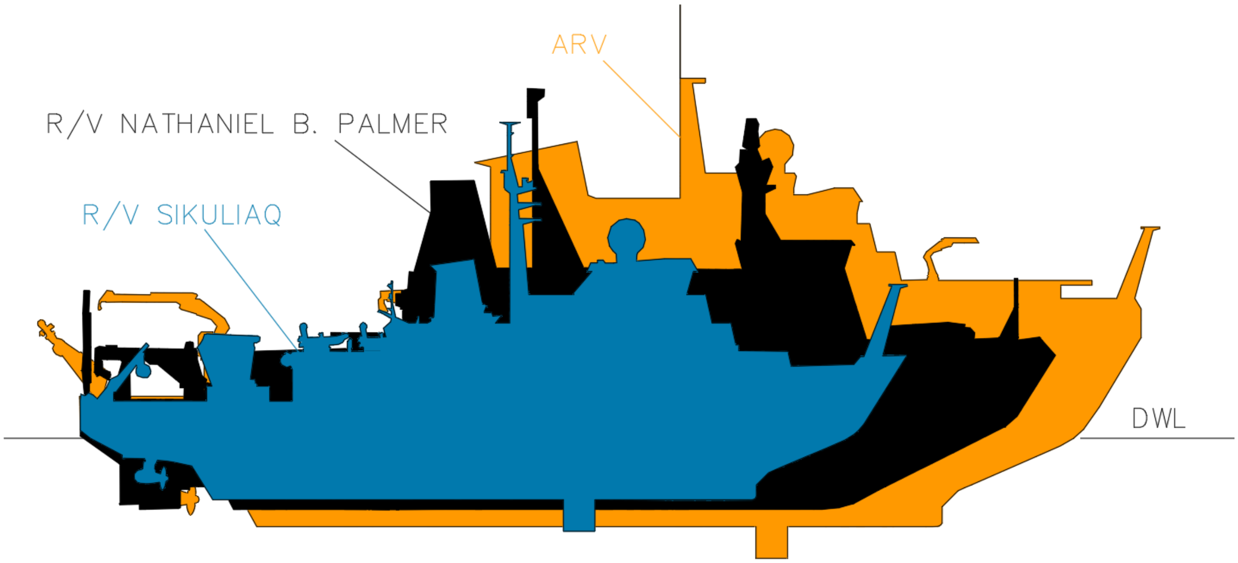


Figure 1 Size comparison: ARV concept design, R/V *Sikuliaq*, and R/V *Nathaniel B. Palmer*

Section 2 Polar Class Definition

2.1 Polar Class Definition

The Requirements Matrix requires Polar Class 3 so that the vessel is capable of year-round navigation in second-year ice conditions, which may include multi-year ice inclusions. This exceeds the capability of the current NSF-chartered vessels.

The following regulations apply to the conditions in this operating area and are relevant to the design and operation of the ARV:

- ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters* (Reference 8). These classification society requirements wholly integrate the IACS Polar Class requirements. Polar Class (PC) refers to the ice class assigned to a ship by a classification society based on the *Unified Requirements concerning Polar Class* developed by the International Association of Classification Societies (IACS). Other classification societies such as DNV-GL have equivalent requirements.
- ABS *Guide for Vessels Operating in Low Temperature Environments* (Reference 9).
- *The International Convention for the Prevention of Pollution from Ships* (MARPOL, Reference 11).

Complying with the relevant regulations requires establishing the operating conditions to which the design will be subject. Reference 9 establishes a design service temperature based on the lowest mean daily average temperature in the vessel's area of operation. A follow-on study (Reference 27) investigated mean daily low temperatures in the intended operating area and recommended a MDLT of -35° C and a Polar Service Temperature of -45° C. Should such notation be desired, this will correspond to an ABS Notation of:

PC3, CCO-POLAR (-35° C, -45° C)

The Climate Study (Reference 27) provides further guidance on the environment and applicable regulatory requirements.

2.1.1 Transiting and Maneuvering

The following ice operation features have been incorporated into the concept design to provide for good ice transiting and maneuvering characteristics:

- Adequate propulsion power, in a diesel electric configuration where maximum torque can be applied over the entire propeller speed range.
- Azimuthing propulsors that will provide excellent maneuverability operating in ice leads and ice cover. The azimuthing drives also provide a means to clear ice from the sides of the vessel. A follow-on study evaluating the trade-offs between azimuthing and fixed shaft propulsion was undertaken (23) with azimuthing propulsors being strongly recommended for the ARV.
- While the hull form has not been fully developed, the hull form used is based on the approach of diverting broken ice outboard away from transducers, reducing propeller-ice interaction and providing a clear ice-free wake.

Sea ice conditions can vary significantly, but design ice conditions for model testing outlined in the NSF Committee Report (Reference 1) are as follows:

- Continuous progress (3 knots) in second year level ice having a thickness of 4.5 ft (1 m) and a flexural strength of 100 psi (700 kPa).
- Speed in thin ice 1.6 ft (0.5 m) or less to be 5-6 knots.
- Speed in level ice astern to be equal to speed in level ice ahead.
- Maneuvering characteristics are as follows:
    - Maximum turning diameter of 4 X LWL in 4.5 ft (1.4 m) level ice.
    - Maximum turning diameter of 3 X LWL in 1.6 ft (0.5 m) level ice.
    - Ability to break out of its own channel in 4.5 ft (1.4 m) level ice.
    - Ability to transit ridges.

2.1.2 Other Polar Class Characteristics

Meeting the ABS and IMO requirements for year-round operations in Antarctica impacted the concept design in several key areas summarized below.

Hull Structure and Arrangements

- Low temperature steel is required for hull structural plating to avoid brittle fracture. Depending on specific characteristics of the steel used, special welding techniques may be required.
- The requirement for a double hull in way of all polluting (e.g., fuel and oil) tanks resulted in minimally dimensioned wing and double bottom tanks.
- Ice-excluding seachests connected to a central sea bay are arranged in accordance with regulatory requirements. This implies a seachest port and starboard with ice excluding baffles and a means to access the upper portion of the seachest above the waterline in order to clear ice blockage. See Section 4.7.

Machinery

- Certain aspects of the machinery installation are needed for operating in low temperature and ice environments such as ice-excluding sea chests, heating of combustion air, over-torque capabilities of the drive motors to withstand propeller-ice interaction. See Machinery Description, Section 4.

Habitability

- Enclosed bridge wings, in accordance with ABS Polar Guide.
- Retaining heat within the vessel requires efficient insulation and vestibules at high traffic exterior access doors.
- Emergency (from emergency generator) heating is required in command/control spaces as well as “refuge spaces”, two or three common spaces such as mess and lounge(s).

Lifesaving

- The concept design accommodates Polar Class enclosed lifeboats and Polar Class inflatable liferafts, as required by ABS and SOLAS. Lifeboats are oversized (125%) to account for people wearing cold weather gear as well as polar survival packs. Lifeboats are stowed in protected areas to avoid spray icing.
- One rescue boat is supplied, as required by SOLAS with a similar workboat located on the opposite side of the vessel. The workboat could conceivably be rated as a SOLAS boat and function as a back-up.
- Additional storage to accommodate the required outfit of polar survival gear and cold water immersion suits to meet Polar Class requirements.

Section 3 General Arrangement

The general arrangement of the concept design, discussed in this section, is illustrated by Drawing No. 19136-000-001 (Reference 12).

3.1 General Design Philosophy

As with most general purpose research vessels, the Main Deck of the concept design is prioritized as the working deck, with labs having highest requirements for low motions located amidship. A heated and enclosed Baltic Room is included to provide a safe area for overside operations, particularly CTD casts, as is typical for vessels working in polar regions. This room is located close to amidships on the working side of the vessel (starboard), where there will be lower relative motions between deck and sea surface.

A long side working deck, typical of most science vessels, particularly those in the UNOLS fleet, provides access to the starboard overside area. Again, lower relative motion here improves overside operability in greater sea states. The side deck length is driven by the requirement to assemble, launch, and recover piston cores up to 50m long.

The aft working deck has relatively low freeboard (10 ft at design draft) and is sized to allow flexibility in the type and location of portable equipment including winches cranes and containers. Portable, bolt-down bulwarks are fitted around the perimeter of the working deck to provide flexibility in mission arrangements. The deck is designed to accommodate portable and bolted mooring eyes, bollards, and other equipment.

The working deck is heated either via circulating fluid or by electric resistance heating elements to enhance operability under polar service conditions. The deck heating arrangement provides zoned heating of all exterior working deck areas on the Main Deck, 01 Deck, and the UAV Deck (04 Deck). All winch rooms are enclosed heated spaces to maintain and protect the winches and to improve equipment maintenance in severe conditions.

The lab container bay on the Main Deck allows the complete integration of up to three 20 ft ISO lab containers into the aft superstructure. The lab containers are loaded and secured via a flush deck rail system and tugger winches, which facilitates moving the containers forward from the open deck to underneath the overhanging 01 Deck. A hydraulically actuated raiseable coaming is located at the aft end of the lab container bay to prevent damage from boarding seas.

Polar service also dictates enhanced lifesaving equipment requirements, including totally enclosed lifeboats rated for polar operations, polar rated liferaft(s), survival packs, cold weather immersion suits, and arrangements allowing unobstructed access to lifeboats and rafts. The concept design is arranged to meet all lifesaving requirements. The lifeboats and rafts are located in protected areas to prevent buildup of snow and ice.

The concept design features greater deck to deck heights than in most research vessels, foreign and domestic: 12 ft for the Main Deck to 01, 10 ft. from 01 to 02 Deck, and 9 ft. above the 02 Deck. The rationale is that most builds struggle to effectively install HVAC, piping, wiring, lights, and insulation in the overheads. This can result in extra cost, more complex routing, more difficult maintenance, and sometimes lower finished ceiling heights. The downsides are that more steel is required to construct a taller vessel and there may be limits with regards to stability. If these higher deck heights are achievable, it will create more desirable interior space.

3.2 Accommodation Spaces Above the Main Deck

Main public spaces are primarily located on the 01 Deck within easy access of on-watch or off-watch personnel. The laboratory and working deck below offer a noise and vibration buffer for the relatively quieter off-duty areas such as the mess, library, and lounges. The mess and relaxation and recreational activity areas are located on this deck to take advantage of the lower motions. Ample galley stores are located in the forepeak and adjacent to the galley. A personnel lift provides convenient access to stores below the Main Deck. A forward stores hatch allows for loading of stores on this deck and the decks below.

All accommodation spaces are located above the 01 Deck, allowing the Main Deck and the 01 Deck to serve as a noise and vibration buffers. There is physical separation of science and crew quarters. The science population tends to be transient, so their staterooms are on the 02 Deck, while the crew, who are more permanent, have their staterooms located on the 03 and 04 Decks. Another consideration for this arrangement is that crews, comprised of professional seafarers, can better tolerate the higher motions of upper decks.

Science staterooms, except for the Chief Scientist and the Marine Project Coordinator (MPC) staterooms, are all double occupancy staterooms. Each stateroom has its own toilet/shower facility and access to light and air via airports. The Chief Scientist and Mission Planner staterooms have adjoining office spaces.

All crew staterooms are single occupancy with toilet and shower modules and comply with Maritime Labour Convention standards (Reference 14). Officers' staterooms are located on the 04 level, with offices adjoining the Master and Chief Engineer staterooms.

All staterooms are arranged with berths running longitudinally. There have been injuries reported due to people falling out of longitudinal bunks in rough seas, primarily beam seas when transiting to and from Antarctica. However, longitudinal bunks are generally preferred for comfort and other safety considerations and are recommended for ABS HAB++. The ARV is a larger vessel than those chartered by NSF, so it should have reduced accelerations. This could be quantified with further study (see Section 10.8 for more details). Additionally, lee boards or lee cloths could be examined as options to prevent bunk injuries. Optionally, the current configuration of the cabins allows for a rearrangement with transverse berths should that become a desired feature.

The Bridge at the 06 level is located as far aft as practical to provide good visibility over the working decks aft. Forward visibility over the UAV Deck was enhanced by raising the Bridge Deck via an interstitial HVAC Deck separating the accommodation block from the Bridge. Bridge wings port and starboard extend far enough outboard to provide the bridge wing station a clear view of the sides of the vessel as well as the track forward of the vessel during ice operations. The starboard bridge wing and starboard science observation area provide good visibility over the side working deck and partial visibility of the aft working deck. Critical overside operations from the aft working deck can also be controlled from the aft science control room located on the 01 Deck.

3.3 Science Spaces Below the Main Deck

A science hold is located below the aft working deck. For cargo loading, it is accessed via a flush centerline hatch with ample size to load a standard 20 ft. ISO container. At least eight 20 ft. ISO containers can be loaded into the hold using a permanently installed gantry system for precisely positioning the containers in two-high stacks. Adequate area is provided forward of the containers locations to accommodate grated container access flats for lab containers. Lab container services are available for each container location below deck. The science hold location below deck is designed to keep major weights low in the vessel to improve stability characteristics. The science hold represents a significant storage volume, resulting in a capacity over and above what is asked for in the requirements matrix. If storing eight containers in the hold is not seen as essential, the tank top level in the hold could be raised, leaving an additional volume that could be used for fuel or urea (see Section 8.1.2).

An oceanographic winch room is located directly below the aft working deck, from which wire is routed, via a sheave tower, to the aft A-frame or either side crane. This location is protected from weather with heavy wire spools located where they will not adversely affect stability.

A transducer room is located below the Main Deck forward of the centerboard well.

3.4 Science Spaces Above the Main Deck

An enclosed, heated winch room containing a direct drive hydro winch and a traction winch is located on the after part of the 01 Deck in alignment with the side A-frame. The winches could also serve the Baltic Room or the be led to the base of the large midship crane via turning sheaves and in the case of the hydro winch via a turntable foundation.

The aftmost portion of the 01 Deck contains the science control room, which provides visibility over the aft and side working deck. The aft part of this deck also accommodates workboats and launch equipment. Portions of the aft 01 Deck area are also designed to accommodate incubators.

An atmospheric lab is located on the forward 02 Deck at the base of the forward instrument mast for convenience. This lab is accessed from the base of the foremast via an inclined ladder and watertight door at the base of the mast.

A UAV flight deck and hangar is located on the 04 level. This deck can also accommodate storage of up to four 20 ft ISO lab containers when not required for missions involving UAVs. These container locations will be provided with services. A five-ton folding knuckle-boom crane is located on this deck to facilitate stores and science gear loading.

A meteorological lab is located on the 07 Deck (Bridge Top). This lab location provides convenient access to instrumentation located above the Bridge on the upper instrument platform and mast above the uppermost deck.

An enclosed and heated mammal observation area is located above the bridge. This area also provides access to the outboard sides of the deck, where big-eye binoculars may be located for bird and mammal observations.

Section 4 Major Equipment Definition

4.1 Propulsion System

4.1.1 General Requirements

The following key concept design requirements drove propulsion system design:

- Cruising speed of 10 to 12 knots in ice-free waters.
- Polar Class 3 from *Unified Requirements Concerning Polar Class* developed by the International Association of Classification Societies (IACS) (Reference 15). ABS and DNV-GL incorporate these requirements in their classification rules.
- Seakeeping:
    - Fully operational in Sea State 4 (SS4).
    - Able to perform most routine operations to Sea State 5 (SS5).
    - Shipboard personnel can safely work to Sea State 6 (SS6).

Calculations were performed in NavCad™ to estimate the calm water resistance at 10 kts and 12 knots. Additional margin was added for resistance in waves to account for operation at SS6 (see Appendix A for resistance calculations). A delivered total power of approximately 6.6MW is required for operation in SS6 at 12 knots, 3.3MW power for each propulsor.

Polar Class 3 requires year-round operation in second-year ice that may include multi-year ice inclusions. Meeting these PC 3 requirements requires significantly more propulsion power than is estimated to be required for operation in open water. The power required in ice was estimated parametrically based on similar Polar Class vessels such as the R/V *Kronprins Haakon* (DNV-GL Polar Class 3), which has two 5.5MW azimuthing thrusters. The Icebreaking Performance Memo (ref) explores the feasibility of increasing main propulsion power should icebreaking performance requirements dictate higher thrust levels. Conceivably a thruster power level of approximately 7.4MW total could be accommodated.

The selected propulsors (see Section 4.1.2) will provide adequate power for icebreaking and will allow the vessel to achieve 12 knots in up to SS6.

4.1.2 Propulsor Selection

The primary alternatives for propulsors are a conventional shaft system or azimuthing propulsion, which could be Z-drives, L-drives, or pods. There are advantages and disadvantages to each alternative. Conventional shafting is simple, proven, and robust, and provides options for either open or ducted propellers. Several recent icebreakers are equipped with azimuthing propulsion, and more ice hardened options are available now than ever before. By the time the ARV is constructed, it is likely that even more advancements will have been made.

For this concept design, twin 5.5 MW azimuthing propellers were selected for the ARV to meet the PC 3 icebreaking requirements as well as the speed requirements. Azimuthing propulsion provides excellent maneuverability, and these types of drives have been in existence for over 30 years, with Z-drives in use on UNOLS vessels for at least 30 years.

Compared to conventional fixed shaft propellers, azimuthing drives have the following advantages:

- Increased maneuverability.
- Ability to clear ice in wake of vessel.
- Ability to clear ice from side of vessel.

The concept design also includes a bow thruster for dynamic positioning and docking. The thruster(s) will provide for improved dynamic positioning.

A propulsor study to evaluate performance and cost trade offs between conventional shafting, Z- or L-drives, and pods has been undertaken (ref) and concludes that azimuthing drives are highly recommended for the ARV. A future study of a triple screw variant is suggested to explore any advantages that accrue to having a centerline fixed pitch propeller optimized around low underwater radiated noise with port and starboard azimuthing podded drives providing steering forces in open water.

4.2 Power Generation

The ARV's diverse mission requirements require variable power loads for propulsion, hotel services, science, and other needs. An integrated diesel electric power plant was selected as the best option to efficiently and reliably supply power during all operating conditions. The benefit of high torque electric motors also makes diesel electric a good choice for ice class vessels. An installed power of 16.2 MWe was selected based on a parametric estimation using similar Polar Class vessels. The power is provided by four 720 rpm medium speed diesel generator sets. Between the four generator sets there are a total of 28 cylinders at 600 kW (mechanical) each:

- 2 x 4.6 MWe generator sets (MAN 8L32/44CR are shown in the GA).
- 2 x 3.5 MWe generator sets (MAN 6L32/44CR are shown in the GA).

There are many suppliers of reliable medium speed generators. Those selected for the concept design are in-line configurations with either six or eight cylinders per engine. All cylinders for both generator sizes are identical, simplifying spare parts inventory and maintenance. The arrangement allows a spare generator to be available in almost any operating condition to ensure reliability, availability, and maintainability for a 90-day endurance. If it is determined that more power generation is required during later stages of design, there is sufficient space for an additional 2.2 MWe by increasing the cylinders of the two smaller generators from six to eight. Alternatively, installed power can be increased up to approximately 20 MWe if other manufacturers and engine models are considered.

The exhaust casing is designed to house silencers, waste heat boilers, selective catalytic reduction (SCR) systems, diesel boiler exhaust, and supply and exhaust ventilation for cooling the engine room.

4.3 Selective Catalytic Reduction

SCR systems are required for operation inside of the North American Emissions Control Area (ECA), which extends 200 miles off the coast of the United States. The SCR systems are connected to the vessel's Global Positioning System (GPS) and activated automatically when inside the ECA. The SCR systems inject a urea solution into the exhaust, where it mixes and evaporates before entering the reactor. In the reactor, the urea reacts with nitrogen oxides (NO_x) and converts most of them to nitrogen gas (N_2) and water vapor (H_2O). The concept design includes a 36,500 gallon urea tank adequate for an entire 90 day mission. See Section 8.1.2 for more details.

4.4 Heating Systems

The concept design utilizes waste heat recovery to improve fuel efficiency. Waste heat boilers supply heat that may be used for deck heating, cabin heating, water making, and other needs for lengthy missions into the Antarctic region. Jacket water heat recovery may also be desirable and should be investigated during the next phase of the design. Waste heat (water or steam) is the most energy efficient deck heating system but is also expensive to build and maintain. Deck heating with electric heat tracing is less expensive to build and maintain but will use more fuel due to the high electric load. The concept design includes a diesel boiler to supply heat when waste heat is unavailable or additional capacity is needed.

4.5 Electrical System

A medium voltage 6.6 kV propulsion bus has been specified for the ARV. Medium voltage is typical for vessels in this size and power range. Smaller diesel electric vessels often use lower voltages for main propulsion (e.g., 690 V) and are often paired with high speed, 1800 rpm engines. For larger vessels with medium speed engines, medium voltage is more appropriate due the decrease in size and weight of the alternators and propulsion motors.

Power is generated at 6.6 kV, 60 Hz with a split bus arrangement. Propulsion motors are tied directly to each side of the bus and operate at 6.6 kV. Auxiliary power is supplied to separate buses through step down transformers at the required voltages for small and medium sized auxiliary equipment (typically 480V, 208V, and 120V). Further details of the electrical system are not specified in the concept design, but space reservations were included to account for the medium voltage architecture. A large electrical equipment space is located on the first platform level aft of the main engine room. The Engineers Operating Station (EOS) is located forward of the main engine room on the first platform level. A reasonable approach would be to house the medium voltage equipment in the electrical equipment space and the lower voltage ship service buses in the EOS.

The emergency generator is located on the aft end of the 02 Deck.

A hydrid diesel-electric wth battery system is recommend in accordance with the Power Systems Study (reference 28). Such a system will allow the diesel generator sets to operate at higher efficiency levels. The concept design incorporates a 2,000 kW-hr capacity battery room at the 2nd Platform Level just forward of the hold. This location allows easy access to the hold for convenient battery replacement operations.

4.6 Machinery Ventilation

Polar Class requires air intakes for machinery and accommodations to be located on both sides of the ship and to be heated. This is to prevent intake air from being blocked due to asymmetrical icing of the intake louvers. Heating can prevent the buildup and ingestion of ice and can be used to heat air being brought into the machinery spaces for cooling and combustion. The concept design has separate intakes for combustion and engine room cooling. The intake, located on the aft end of the 02 Deck, meets the IACS requirements by straddling the centerline of the vessel and provides intakes on both sides. A crossover duct connects the port and starboard intakes, providing protection from weather and minimizing risk of icing. This arrangement has proven successful on Polar Class vessel R/V *Sikuliaq*.

To cool the machinery room, supply air is brought in at the 02 level and drawn through powered fans to the Engine Room. Powered fans at the 03 level Machinery Ventilation Room draw the air up through the casing and exhaust it out the inboard and aft side of the casing. Trunk spaces and openings were sized to exceed requirements based on combustion and ventilation air volumes calculated using Reference 16.

4.7 Machinery Cooling and Seawater Intakes

Polar Class has unique requirements for seawater intakes due to the critical importance of cooling vital machinery and the complications presented by ice conditions. The following general requirements are imposed by IACS:

- Two seachests arranged as ice boxes, each with a volume of 1 m^3 per 750 kW of total installed power.
- Ice boxes are to be designed for an effective separation of ice and venting of air.
- Means shall be provided to recirculate cooling seawater to iceboxes.
- Detachable gratings and manholes are to be provided for ice boxes, with manholes located above the deepest load line; access is to be provided to the ice box from above.

To accommodate the Polar Class requirements, the concept design has two seachests, both arranged as ice boxes with access above the waterline. The seachests protrude into the engine room at frame 71-74 to the tank top level. They are sized to meet the IACS volume requirements noted above. Access from above the waterline is provided on the first platform. The seachest extends above the waterline, and a hatch or watertight opening can be accessed while the ship is in the water to allow for visual inspection and for ice to be cleared. These details are not shown in the concept design, but adequate space was allocated to meet the requirements.

A seabay is located on centerline at the tank top level. The intake pipes from the seachest to the seabay are shown in the arrangement. Sea strainers and isolation valves will be located on each intake pipe. Cooling water is circulated back to the seachests after cooling the engines, raising the water temperature in the seachest to help prevent icing. Water is then circulated to the sea bay where it is drawn to supply machinery, ballast, firefighting, etc. This arrangement has proven successful on R/V *Sikuliaq*. Figure 2 illustrates a seachest and seabay arrangement that is similar to the concept for the ARV.

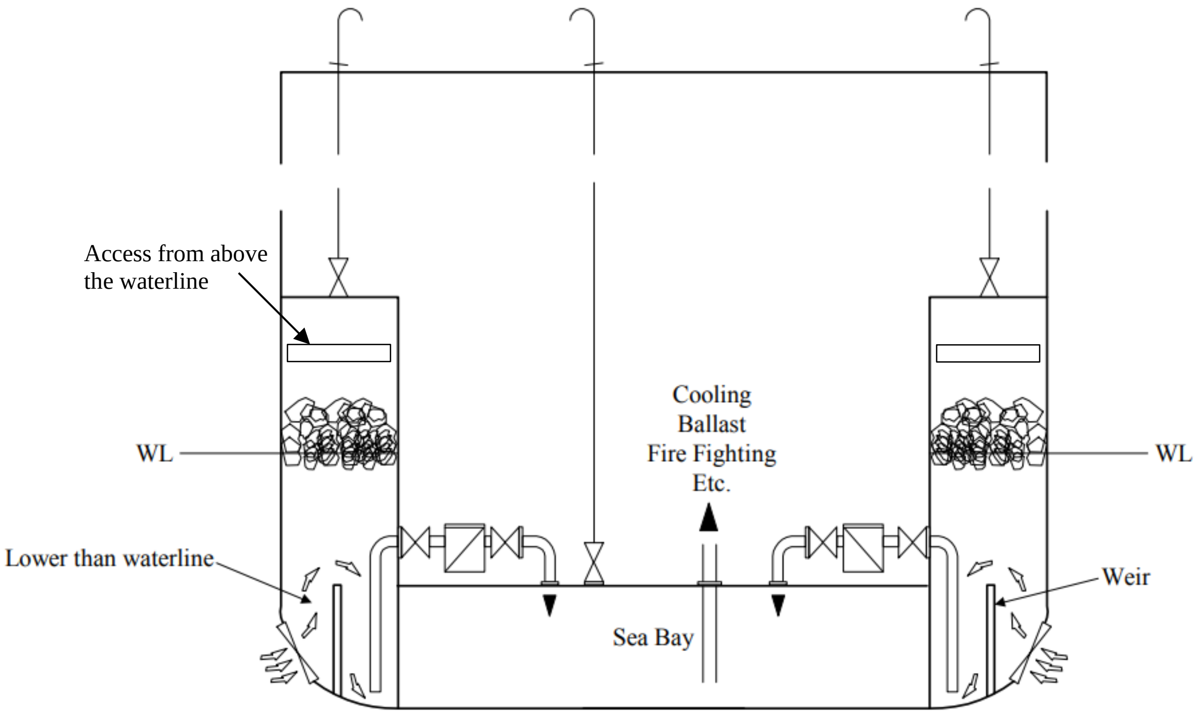


Figure 2 Example seachest arrangement similar to ARV concept design

4.8 Auxiliary Machinery

Several auxiliary machinery spaces are included in the concept design to accommodate the large amount of auxiliary machinery required to support the power plant, hotel services, and science operations. The motor room and thruster room accommodate auxiliary equipment for cooling, lubrication, hydraulics, and other related functions. Roll reduction tanks will require compressors and electronics located in the main engine room.

4.8.1 Accommodation Ventilation

Polar Class requires heated air intakes for accommodations to be located on both sides of the ship. The accommodation air intake is located on the aft end of the 05 Deck, similar in design to the machinery room air intake. The air intakes are directly adjacent to two large HVAC rooms and two trunks. The trunks at Frames 47 and 69 transit from the 05 Deck to the tank top, which will allow for supply or exhaust air to be run the full height of the vessel.

Fan rooms for ventilation and air conditioning were scaled parametrically from similar Polar Class vessels. The fan room locations were selected to be close to mechanical trunks and to minimize overall ducting. There are two smaller fan rooms rather than one larger fan room for the same reasons.

Ducting design is a challenge on research vessels with significant laboratory space. Workspaces and accommodation spaces have significant minimum air change requirements for health and safety. For a Polar Class vessel, the incoming air must be heated before distribution to these spaces. In laboratories, exhaust hoods further increase capacity requirements due to the large amount of exhaust air drawn from the space. One way to minimize these challenges is to heat and cool the air locally (in the laboratory), with only makeup air ducted from the outside. Air handling equipment in the laboratory space reduces usable space but also reduces ducting and improves temperature control. For these reasons, the concept design assumes the use of localized air conditioning equipment for each lab. The server room, located on the Main Deck forward, will require a significant amount of air conditioning, but not a large amount of makeup air. The concept design includes an HVAC room dedicated to the server room.

Accommodation HVAC requires several ventilation spaces to house the air handlers and fans. While central air conditioning systems are possible, other possible solutions can be considered. Local fan coil units that provided recirculated air to a cabin unit could offer advantages in volume and temperature control. Local thermostatic control and integrated heating and cooling water coils minimize the ducting for staterooms to just makeup and exhaust air. Such a system would require a large chilled water and hot water network, but the smaller water pipes mean less interference in the overheads. The concept design provides adequate fan room space for central air conditioning, but it is recommended that decentralized systems be studied further in the next design phase.

4.9 Periodically Unattended Engine Room

Class societies such as ABS offer a notation for different levels of automation, including Automated Control System Certified for Unattended Engine Room (ACCU) notation. ACCU notation pertains to propulsion machinery in periodically unoccupied spaces that is monitored or controlled from the bridge or another centralized location. In addition to the substantial hardware requirements that allow for remote control and monitoring of machinery, the notation requires annual testing of the system.

For US flagged vessels, USCG also enforces regulatory automated control system requirements as part of the CFR governing vessel construction and operation. While the requirements have similarities, differences exist such that both class and USCG requirements must be independently checked and incorporated.

USCG is responsible for establishing minimum crewing requirements. They require that the functionality and reliability of remote control and monitoring systems be demonstrated before approving reduced crewing requirements. The OCMI (Officer in Charge, Marine Inspection):

> ‘C*onsiders the capabilities of an automated system in establishing initial manning levels; however, until the system is proven reliable, a manning level adequate to operate in a continuously attended mode will be specified on a vessel's COI. It remains the responsibility of the vessel's master to determine when a continuous watch is necessary*.’ (Reference 16)

Section 5 Science Missions Systems Definition

5.1 Science Missions Systems Definition

In addition to standard marine science loadouts, requirements included items to facilitate special missions and operations in ice.

The requirement to deploy 40-50m long jumbo piston cores drives the need for an open side deck of similar length. It also requires specialized equipment to handle the loads associated with pulling such a long core out of the sea bed and transferring the core from vertical to horizontal and onto the vessel. These requirements directly impact the layout and length of the vessel.

The initial design guidance from the Requirements Matrix requested a moonpool that could be used to launch and recover science equipment in ice conditions. The advantages and disadvantages of the moonpool requirement were evaluated (Reference 4), and based on this evaluation, NSF guidance was to eliminate this requirement due to the combined adverse effects of cost, increased maintenance, and the significant impact on arrangements below the Main Deck.

The initial requirements also included a helideck and hangar capable of accommodating a relatively large helicopter. The hangar was required to be large enough to store and service two helicopters. The advantages and disadvantages of the helideck and hangar were also evaluated (Reference 3), and based on this evaluation, NSF guidance was to remove this requirement, primarily due to space and cost constraints.

5.1.1 Winches

Using the Requirements Matrix for guidance, the following winch installations are envisioned for the concept design:

- Baltic Room: This space will be the primary operating area for CTD casts, and in accordance with the Requirements Matrix it will have a dedicated CTD winch and LARS or Load Handling System. The space is designed to accommodate a LARS/LHS installation providing "hands-off" launch and recovery of CTDs as well as limited towing capability that can be controlled locally or from the operating station on the 01 Deck. The intent is for a gantry crane or a swing jib boom to be installed to safely move heavy items around in this space. The CTD winch is electric and motion compensated, with capacity for 10,000 m of 0.322 EM cable.
- Upper Winch Room: This space is located on the 01 Deck and will serve the side A-frame. One of the winches in this space could be configured, via turntable, to serve the LHS in the adjoining Baltic Room. In accordance with the Requirements Matrix, each of these winches is electric, motion compensated, and has capacity for 10,000 m of 0.25" to 0.5" cable and are fitted with slip rings. A traction winch and storage reel capable of using heavy heavy synthetic line suitable for use with the jumbo coring system and serving the side A-frame or the large midship crane are located in this space.
- Aft Winch Room: This space is located directly below the aft working deck, with the winches serving the aft deck via a sheave tower extending from the winch room to the 01 level, where wire can be directed to either the aft A-frame or the two aft deck knuckle-boom cranes. Two oceanographic wire storage drums are located in this space, with each drum capable of feeding a traction winch through individual

levelwinds and a wire tensioner. The storage drums, in accordance with the Requirements Matrix, are electric, motion compensated, and have capacities for 10,000 m of 9/16" wire rope and 10,000 m of 0.680 EM cable. Traction winch and storage drums are capable of handling fiber-optic cable.

5.1.2 Overside Handling Systems

The aft working deck over-side handling equipment, in accordance with the Requirements Matrix and the concept arrangements, consists of:

- Large knuckle-boom crane, port side, capable of a Sea State 5 load of 10 tons at a reach of 50 ft.
- Smaller knuckle-boom crane, starboard side, capable of a Sea State 5 Load of 5 tons at 40 ft.
- Large knuckle-boom crane, starboard forward of aft science control room, in-port load capacity of 34 tons at 65 ft and a Sea State 5 load of 10 tons at 30 ft. This crane is used for loading/offloading containers from/to dock to/from aft deck and hold.
- The interface with the proposed new pier at Palmer Station will need to be verified as the pier design is finalized. At the time of this writing, the starboard side to the pier orientation will allow transfer of fully loaded 20 ft ISO containers (gross weight of 33.6 Tons) from the ship's hold (or aft deck with the assistance of the large aft deck crane to port) to anywhere on the outer pier apron. See Reference 13 and Figure 3 below.

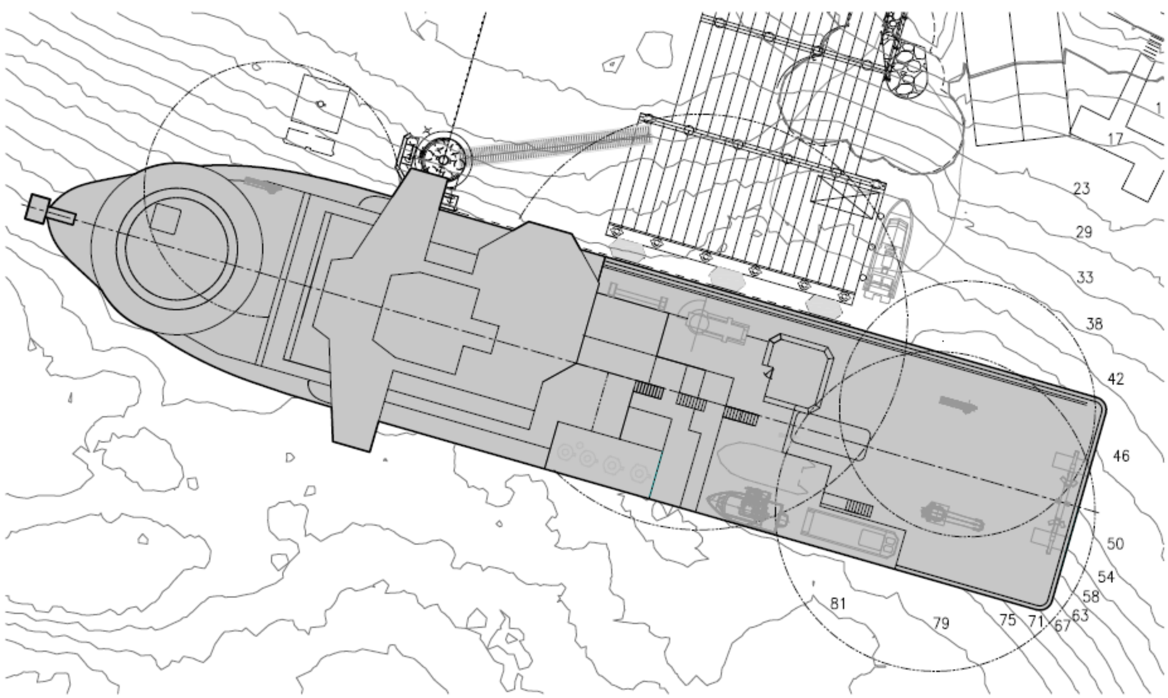


Figure 3 ARV moored at proposed new Palmer Station pier (Reference 13)

- Stern A-frame. A fully articulating stern frame that meets the following NSF requirements is envisioned:
    - Sea dynamic load capability of 30,000 lbs through its full range of motion in Sea State 5.

- Frame structure designed to handle the load from 1.5 times the breaking strength of the largest deployed wire, such as the tether for a large ROV (up to 120,000 lbs breaking strength).
- Minimum 15 ft horizontal clearance and 25 ft vertical clearance.
- At least a 12 ft inboard and outboard reach.
- A forward maintenance position that will put the frame cross structure within easy reach of the deck for servicing.

- Side A-frame. The side A-frame is capable of a Sea State 5 load of 20 tons. Additionally, this frame is used for handling (launch and recovery) of piston core. As such, it has strength characteristics that allow large synthetic line to be used for the piston core.

All cranes are personnel rated and capable of local and remote control from the aft science control room and/or wireless belly packs.

5.1.3 Centerboard

The concept design includes a single raiseable centerboard for use in non-ice covered waters. The centerboard is designed primarily to house the fisheries transducers (EK80 or similar) and be capable of lowering beyond the boundary bubble layer of the ship at cruising speed. The board trunk is fitted with a close-fitting collar that will prevent ice pieces from filling the lower trunk area.

The centerboard has three main deployment positions and one maintenance position:

- Deployed to full depth position, 10 ft below the keel. Used in open water, at speed, for maximum protection from the entrained bubble layer.
- Deployed to a flush position with the bottom of the keel. Used at slow speed – no bubble environment.
- Deployed to a "protected" position 2ft above the keel. Transducers will have some limited viewing cones in this position. Used while in ice.
- Maintenance position. Retracted in trunk well above waterline to allow access to bottom of board for maintaining or replacing transducers.

Similar to R/V *Sikuliaq*, it is assumed that the bottom section could be accessed and replaced to house other transducers.

Some research vessels of this size have dual centerboards. A second centerboard could be advantageous for deployment of an ultra-short baseline (USBL) underwater acoustic positioning installation, with potential spare space. The USBL may be deployed in other ways, such as retractable pole mounted transceivers (e.g. HIPAP), which may provide options for deploying in ice where the centerboard should not be used.

The ARV design has a single centerboard; a dual centerboard approach has a significant impact on vessel arrangement, as the trunk becomes very wide and the supporting equipment to be maintained doubles. There does not appear to be a significant enough advantage to justify the impact to the internal space of a second centerboard.

5.1.4 Transducers

The concept design has a flat of bottom area near the aft end of the ice knife (Figure 4). T his area houses the deep ocean and shallow water multibeam systems, the sub-bottom profiler, and the ADCPs. As discussed in Section 5.1.3, the bioacoustics transducers and possibly the USBL are located on the centerboard. The acoustic release and other hydrophones are intended to be located in areas suitable for mounting. All transducers will have ice windows to help resist impacts to the sensors.

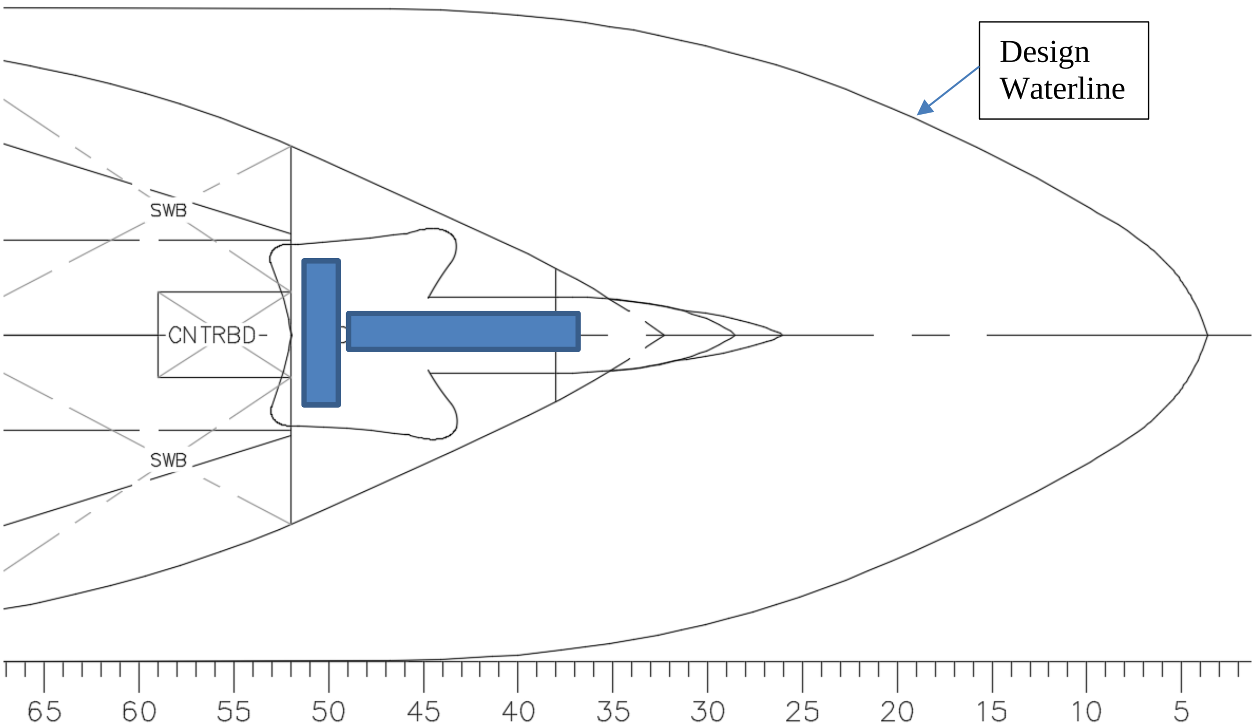


Figure 4 Transducer flat location (deep water multibeam transducers shown)

One disadvantage of icebreaking hull forms is related to bubble sweepdown. The hull shape required for breaking ice is not ideal for controlling the path of bubbles along the hull, and a gondola is not an option due to operations in ice. Fortunately, a vessel of this size has a deep enough draft that bubbles passing over the transducer faces should be minimized.

For this concept, the transducer is partially located in the ice knife. This will provide some additional benefit for bubble sweepdown but does place the transducers close to the bow thruster. However, the bow thruster is not typically used at the preferred speeds for bottom mapping and should not present a noise issue. This location does have good separation from the main machinery room. An expanded discussion of bubble sweepdown relative to the concept design is contained in the Bubble Sweepdown Requirements Study (Reference 1).

While there may be limited options to modify a hull designed to meet PC3 icebreaking to minimize bubble sweepdown, CFD evaluation of flow lines of the bid design is recommended to help verify that the transducers are in the best location possible.

USBL installations are typically separate and located further aft, often on a retractable pole system. The installation of a USBL has not been examined at this level of concept design. An ice capable USBL installation should be examined.

Section 6 Crew and Scientist Berthing

6.1 Summary of Decisions

The ARV is required to accommodate a science party of 45 to 55 and a crew to support them and operate and maintain the vessel on its various missions. The vessel is to provide enough berths to house the crew and the science team, which consists of scientists and technicians. The comfort level is in accordance with ABS HAB++ (Reference 10). A crewing study was conducted to determine minimum and recommended crew levels (not including the science party). A summary of the Crewing Study is presented in Table 3. For more details, see Appendix B.

Table 3 Crewing Study totals and concept design crew and science berths

POSITION	QUANTITY		
	Minimum[1]	Recommended	Concept Design
DECK Subtotal	8	15	
ENGINE Subtotal	5	9	
STEWARDS Subtotal	5	5	
Crew Total	**18**	**29**	**29**

1. Minimum crew size based on minimum requirements by regulations and emergency squad capabilities

The ARV concept design currently has staterooms adequate to house 81 individuals (29 crew and 52 science party). An increased science berthing capacity of 55 appears feasible with judicious reallocation of superstructure areas. A closer examination of space layouts in the preliminary design phase will be needed to verify that a total of 55 sciences berths can be accommodated. The key features of the accommodation's layout are:

- Crew housed in individual rooms.
- Two scientists housed per room.
- Chief scientist and planner housed in individual rooms with adjoining office.
- The individual staterooms allow for a single berth, locker, and desk.
- The two capacity staterooms have bunkbeds, lockers, and a shared desk.
- Each stateroom has a private head and shower.
- All science staterooms are on the 02 and 03 Deck.
- Crew staterooms are on 03 and 04 Decks.
- Staterooms are a higher standard than most of the UNOLS fleet, providing 104 square feet on the lower limit for both single and double rooms.
- The head provided is 22 square feet.
- Master, Chief Engineer, Chief Scientist, and MPC staterooms are larger and have an adjoining office.

6.2 Justifications

The size of the staterooms was determined by allowing adequate width and depth to arrange the berths longitudinally (berths may be placed transversely if desired by Owner), place a desk near natural light, and situate a head and shower within the footprint of the stateroom. Stateroom sizes comply with the Maritime Labor Convention, Reference 14.

A crewing study, presented in Appendix B, provides detail on minimum and recommended crew numbers. The number of berths was determined using the Code of Federal Regulations (Reference 16), recommendations from the Marine Safety Manual (Reference 18), Polar Code (Reference 19), and comparison with other vessels. The recommended crew numbers are based on other research vessel crewing levels and the required endurance of 90 days. The standards and codes used to determine the minimum crew number do not consider vessel-specific missions and are limited to vessel operation, maintenance, and safety. Operating 24 hours per day for the full endurance requires additional crew than the minimum required to support the science team and normal vessel operations.

ABS offers an automation certification known as ACCU, as described in Section 4.9. ACCU notation allows for the propulsion machinery space to be periodically unattended and controlled primarily from the bridge and a centralized control and monitoring station. Although ABS and other class societies provide design requirements and periodic testing to receive the ACCU notation, they do not set crewing requirements. Crewing must be approved by USCG as part of the Certificate of Inspection (COI). The USCG requires that the reliability of an automation system be proven before any crew reductions can be approved. Additional details on ACCU are presented in Section 4.9.

Section 7 Weight Estimate

7.1 Weight Estimate

The weight of the vessel without fuel, ballast, payload, and other removable or consumable items is referred to as the lightship weight. The lightship weight is a good basis for estimating characteristics about the vessel such as cost and stability. A lightship weight estimate of the concept design was developed starting with the one-digit Ship Work Breakdown Structure (SWBS) weight estimate summary for R/V *Sikuliaq*, a PC5-class research vessel previously designed by Glosten. The weight of each SWBS category was scaled to the ARV using appropriate factors.

- The 100s, 400s, 600s, and 700s were scaled by the ratio of vessel cubic numbers (LOA*B*D/100). Cubic number is a rough measure of the internal volume of a vessel and is useful for comparing overall vessel size to other vessels. The cubic number for ARV is 8,803.
- The 200s and 300s were scaled by the ratio of total installed power.
- The 500s were scaled by the average of the two previously described ratios, because this weight category is partially dependent on vessel size (e.g., HVAC) but also dependent on installed power (e.g., cooling systems).
- A final scale factor was applied to the 100s to account for additional structure weight due to Polar Class requirements. This factor was derived using the structural midship section and scantling calculations for *Sikuliaq*. The weight-per-foot of the section was calculated. The scantling calculations were modified as if *Sikuliaq*'s Polar Class rating was increased from PC5 to PC3. The weight-per-foot of the strengthened *Sikuliaq* was calculated, and the ratio of these values was applied as a factor on the 100s weight.

The one-digit SWBS concept weight estimate is summarized in Table 4.

Table 4 Weight estimate summary

SWBS	Description	Weight (LT)
100	Hull Structure	3,984
200	Propulsion	646
300	Electric Plant	438
400	Command and Surveillance	28
500	Auxiliary Systems	716
600	Outfit and Furnishings	641
700	Science Support Equipment	362
TOTAL: Lightship Weight		**6,813**

Note that this ARV lightship estimate is at a concept level, and as it is based on parametric scaling, it should more properly be expressed as a range of 6,000-7,800 LT.

The lightship weight and cubic number of the R/V *Nathaniel B. Palmer* and the ARV concept design are presented in Table 5 for comparison. The concept design is estimated to have 50% more volume and 40% greater lightship weight than the NBP.

Table 5 Size comparison, NBP vs. ARV concept design

	R/V *Nathaniel B. Palmer*	ARV Concept Design
Cubic Number	5,553	8,803
Lightship Weight Estimate (LT)	4,800	6,813

It can be difficult to compare lightship weights from vessels designed at different times, to different rules. The current rules for icebreaking structure result in a more weight-efficient structure compared to the older ABS rules, which may have resulted in NBP being heavier than would be required by current rules. Conversely, there are now requirements for double hulls and increased subdivision that could increase weight by some degree. A detailed breakdown of the NBP lightship weight was not available for a more in-depth comparison.

The lightship vertical center of gravity above baseline (KG) was estimated to be 32.7 ft using the same vertical center to depth ratio (KG/D) as *Sikuliaq*.

For the purposes of cost estimating, the following values were calculated, again based on the *Sikuliaq* weight estimate:

- Piping weight: 118 LT.
- Piping length: 30,767 ft.
- HVAC weight: 126 LT.
- HVAC length: 11,684 ft.
- Cable weight: 148 LT.

Section 8 Endurance

8.1 Endurance

The ARV endurance threshold is 90 days. A concept design endurance of 82 days was achieved, limited by fuel storage capacity. However, this 82-day endurance is based on very conservative assumptions of resistance, including added resistance in high sea states. It is believed that a 90-day endurance could be met with a refinement of assumptions for mission-specific energy consumption. The designer will be required to investigate range and endurance based on an updated hull form and resistance and powering estimates. It is anticipated that more detailed mission profiles will be available to the designer during the next project phase. Mission profile fuel consumption and power demand assumptions are described for the concept design herein. Food stores spaces are sufficiently sized to support a 90-day endurance.

8.1.1 Fuel consumption

Operational profiles for 29 specific missions were developed by ASC's science planners (Reference 20). These mission profiles provide a high-level plan of where the ship will operate and the activities that would be expected within a specific cruise. Power demand values were assigned to each mission activity to calculate fuel consumption.

The power required during open water transit is predominantly due to hull resistance. Vessel calm water resistance was estimated using extrapolated model test data from *Sikuliaq*. Resistance was converted to delivered power using a speed-dependent overall propulsive efficiency also derived from the *Sikuliaq* model tests. The overall propulsive efficiency is very low (0.36 - 0.40) due to the use of quiet, low-cavitation propellers. Added resistance in waves was applied using a factor of 1.6 on delivered power. A constant hotel load of 1.8 MW (estimated as described below for mission activities) was added to the propulsive load to estimate total power demand during transit. Calculations assumed a transit speed of 10 kts based on input from ASC's science planners.

Apart from open water transit, the power demand for each mission activity was estimated as a percent of total installed power based on similar vessels' electrical power load analyses (EPLAs). These values represent the worst case for electrical loading. For example, the EPLA load for dynamic positioning represents the worst-case weather in which the vessel will hold position. For fuel consumption calculations, this value is overly conservative.

A more realistic way to estimate fuel consumption is to estimate average power demand representative of actual operations of the duration of a voyage. Demand factors to reduce the EPLA power to an endurance power were estimated. This demand factor approach reduces over-conservatism in the EPLA values by accounting for loitering time and more typical, rather than worst-case, weather than the EPLA design day. A demand factor of 0.6 was assumed for each mode except open water transit. This value is conservative compared to actual power consumption data obtained for R/V *Thomas G. Thompson*, which suggests a factor of 0.5 from the EPLA values.

Fuel consumption estimates for the 29 mission profiles defined by ASC are summarized below in Table 6. The assumptions used for the fuel consumption calculations are provided in Appendix C. Of the 29 mission profiles, two are not attainable by the concept design. They are: GO-SHIP Expedition (85 days) and GEOTRACES (90 days). The R/V *Nathaniel B. Palmer* currently accommodates these missions in multiple voyage legs, which the concept design could also achieve. According to these calculations, GEOTRACES would be attainable with 10%

reserve fuel if the mission duration is decreased from 90 to 82 days. Therefore, the achieved vessel endurance of the concept design is reported as 82 days.

Table 6 Fuel consumption estimates for ARV mission profiles

Expedition	Duration (days)	Fuel consumed (gal)	Fuel capacity (gal)	Utilization
First Season				
Palmer Station Opening s1	18	90,873	403,800	23%
Peninsula Region Science s1a	54	335,894	523,800	64%
Long Term Ecological Research Expedition	45	261,836	523,800	50%
Peninsula Region Science s1b	30	158,015	523,800	30%
Palmer Station Closing s1	18	125,828	523,800	24%
Peninsula Region Science s1c	64	390,284	523,800	75%
Mid-Atlantic region science	55	322,375	523,800	62%
Second Season				
Palmer Station Opening s2	18	90,873	403,800	23%
Hazardous Waste Transfer s2	23	166,388	523,800	32%
Thwaites Expedition	73	430,073	523,800	82%
GO-SHIP Expedition	85	476,897	523,800	91%
Palmer Station Closing s2	18	125,828	523,800	24%
Third Season				
Palmer Station Opening s3	18	90,873	403,800	23%
Peninsula Region Science s3a	54	351,125	523,800	67%
LTER Grid s3	42	250,413	523,800	48%
Peninsula Region Science s3b	15	123,290	523,800	24%
Dry Dock	42	114,605	523,800	22%
Palmer Station Closing s3	18	90,873	523,800	17%
ECORD	60	443,591	523,800	85%
Fourth Season				
Hazardous Waste Transfer s4	22	162,580	523,800	31%
GEOTRACES	90	517,828	523,800	99%
Peninsula Region Science s4	30	161,822	523,800	31%
Palmer Station Closing s4	18	90,873	523,800	17%
Fifth Season				
Palmer Station Opening s5	18	90,873	403,800	23%
Peninsula Region Science s5a	54	215,769	523,800	41%
LTER Grid s5	45	267,040	523,800	51%
Peninsula Region Science s5b	31	161,822	523,800	31%
Palmer Station Closing s5	18	90,873	523,800	17%
Peninsula Region Science s5c	64	390,284	523,800	75%

8.1.2 Urea consumption

Urea is consumed by the selective catalytic reduction (SCR) system which reduces NOx emissions from diesel engine exhaust. The concept design has a urea storage capacity of 36,500 gal, which is adequate for to cover potential voyages of up to 68 days. However, the vessel is not designed for continuous operation of the SCR for the full 90-day endurance. If the vessel were required to operate the SCR system for its full 82-day endurance, a required urea volume of 44,000 gal estimated.

8.1.3 Provisions

Food stores requirements were estimated by scaling the stores space volumes of RVIB *Nathaniel B. Palmer* for the increased complement and endurance of the ARV concept design. Space volumes, complement, and endurance were obtained from Reference 21. The usable height in storerooms is assumed to be 6.5 ft. Volumes were then scaled on the basis of cubic feet of stores space per person per day of endurance. The ARV assumed endurance for stores volumes is 90 days such that provisions do not limit the vessel's overall endurance. The assumed complement is 83 persons. The achieved stores volumes in the ARV concept design exceed the requirements calculated in this manner. The concept design volumes are summarized in Table 7.

Table 7 Volumes for provisions

	Volume (ft^3)		
Stores type	**NBP**	**NBP scaled to ARV**	**ARV concept design achieved**
Dry stores	2,769	4,243	5,940
Chilled stores	1,742	2,669	2,740
Frozen stores	1,742	2,669	2,980

Section 9 Technical Risks

The risks described in this section are related to design issues that will influence the vessel size, arrangement, capital and operational costs, and technical risk. Having a better understanding of the tradeoffs and developing more detailed and accurate requirements to provide in the design bid tender can help ensure the design will meet the objectives. Additionally, it can help reduce design time by allowing the Owner to make important decisions on some approaches before the contract design effort.

9.1 Near term (Affecting Design Phase)

The concept design has demonstrated that there is at least one design solution meeting the requirements within the desired size range. The effort of refining the requirements and developing the design also illuminated several design risks to acquiring the desired vessel if the requirements are not thoroughly understood and accurately conveyed. Table 8 summarizes these technical risks and recommended studies to mitigate these risks. Section 10 contains more detailed descriptions of the studies undertaken.

Table 8 Technical risks and proposed studies to mitigate risks

Technical Risk Area	Proposed Studies to Mitigate Risks
Carrying fuel as cargo could cause regulatory issues. This is currently addressed by waivers from the USCG, but a goal of the ARV is to eliminate waivers if possible.	A brief description of each study and a summary of impacts to the concept design is presented below. USCG Compliance Study
A minimal and recommended crew size has been determined. There is a risk that the crew size is inadequate to fully support vessel and science operations.	Government Vessel Operations Study
Shipyards working for a fixed-fee contract are incentivized to minimize cost. This incentive can be so great that shipyards sometimes take on excessive risk when designing and constructing the vessel. It is also possible that shipyards identify low-cost design elements that meet the Performance Specifications but fall short of expectations. The goal of this study is to understand what key design elements to impose on shipyards. These could include: Azimuthing thrusters vs. conventional shaft. Alternating frequency power generations. De-icing approaches. Handling of larger size and number of autonomous vehicles.	Propulsor Study Power Systems Study Deck De-icing Systems Study Autonomous Vehicles Study Green Ship Alternatives Study
The Jumbo Piston Core will drive the design in many ways (length, handling equipment size and layout, and core storage). Vague design requirements could negatively impact coring operations.	Piston Coring Study
The ARV will be a larger vessel than the NBP and will have different mooring requirements. There is risk that the ship's mooring systems may not allow adequate mooring at the pier.	Mooring Study

Technical Risk Area	Proposed Studies to Mitigate Risks
Icebreaking and seakeeping performance of the ARV will depend on the requirements related to relevant ice and sea state conditions. Providing the required ice conditions, climate data, and performance measurement reduces the risk of designers using inadequate or erroneous design environment data.	Climate Study Seakeeping Study Ice Environment Study Operability Definition
Underwater radiated noise can have an impact on the science performed on the vessel. However, overly stringent requirements considering the intended vessel missions would increase the cost of the vessel unnecessarily.	Underwater Radiated Noise Requirements Study

9.2 Long-Term (Affecting Construction)

Long term technical risks fall into three basic categories:

1. **Inadequate funding / contingency.** Construction bids for the specified vessel exceed the available budget.
2. **Potential changes to regulations.** In particular, anticipated risks include changing environmental regulations for operating in and around Antarctica.
3. **Unintended consequences from requirements**. Especially in performance specifications, there may be loopholes or gray areas.

To help reduce the funding risk and best evaluate the requirements, the concept design has taken the approach of providing the objective criteria wherever possible rather than just meeting the threshold. This is to help ensure adequate funding is requested to support construction of the desired vessel.

New regulations normally take several years to come into force, particularly international regulations that require ratification by multiple countries. Currently, there are no known regulatory changes in process that could significantly affect the ARV. However, given the substantial length of time between bid tender and keel laying, regulations should be monitored to ensure that any regulatory changes are addressed in the design phase rather than the build phase, when they are almost always much costlier.

Prior to contract signing, shipyards building to a fixed-fee contract are incentivized to maximize the contract value. After contract signing, they are incentivized to minimize cost and risk. An example of the unintended negative consequences of this is vessels being delivered significantly under weight when there are penalties for being overweight, due to use of excessive margins in the design. These potential effects should be considered throughout the development of the Performance Specifications and shipyard contract.

Section 10 Follow-On Studies

A series of studies were undertaken to mitigate some of the technical risks discussed in Section 9. These studies are listed in Table 9.

Table 9 Follow-on studies

Study	Reference
A brief description of each study and a summary of impacts to the concept design is presented below. USCG Compliance Study	22
Propulsor Study	23
Deck De-icing Systems Study	24
Underwater Radiated Noise Requirements Study	25
Piston Coring Study	26
Concept Design Update	
Climate Study	27
Seakeeping Study	28
Ice Environment Study	29
Power Systems Study	30
Green Ship Alternatives Study	31
Autonomous Vehicle Handling Study	32
Bubble Sweepdown Study	1

A brief description of each study and a summary of impacts to the concept design is presented below.

10.1 USCG Compliance Study

RVIB *Nathaniel B. Palmer* (NBP) currently operates with a waiver that allows it to carry cargo to Antarctica despite it being a research vessel. It is preferable to operate without a waiver as waivers are subject to change or non-renewal.

The USCG Compliance Study (Reference 22)determined options for notation, allowing the ARV to operate as a research vessel and perform the necessary cargo operations without waivers.

The goal of the study was to develop a requirement and/or provide guidance to vendors for a combined notation, if there is an option.

The study concluded pursuing a dual certification as a research vessel and a cargo/tank vessel is not practical due to a number of adverse arrangement impacts such as adding a dedicated cargo pump room, segregated cargo tanks and hazardous zones.

At this time the Concept Design remains unchanged and the question of obtaining a waiver is left to future discussions with USCG.

10.2 Propulsor Study

Vessel performance and hull shape in the stern are influenced by the choice of either azimuthing drive propulsion or conventional shafted propulsion. The Propulsor Study (Reference 23) compared azimuthing and conventional propulsion options to determine if it is appropriate to require one approach over the other.

This study considered characteristics such as maneuvering / dynamic positioning, fuel efficiency, icebreaking performance, and capital and life-cycle costs.

The goal of the study was to determine if there is a clearly preferred propulsor type to achieve the desired performance. Including a clear preference as a requirement can help ensure consistent performance of proposed options. Predetermination of basic propulsion configuration can also help reduce design phase schedule.

The study concluded that azimuthing propulsion is strongly recommended, either Z-drives or podded drives, due to advantages gained in both open water and ice performance. As the concept design currently incorporates azimuthing Z-drives, no changes to the concept design resulted from this study.

10.3 Deck De-icing Systems Study

The Deck De-icing Systems Study (Reference 24) examined the life cycle costs and benefits of various de-icing approaches. Items studied included:

- Stability and safety requirements for de-icing (defines the extent of de-icing required).
- Approaches to de-icing surfaces, including use of electrical heating, waste heat, etc.
- Life-cycle cost of each approach. Deicing systems require significant amounts of energy, so fuel costs were a portion of this estimation.

The goal of this study was to determine best practice for deicing and establish areas to have built-in deicing to achieve desired safety and operability.

The concept design already shows stack boilers on main propulsion machinery as well as a back-up boiler. The assumption for the concept design was that waste heat could be used for heating of all or some of the working decks. The study outlined various options including waste heat and possibly electric heating coils (especially for upper decks where weight is a concern). No changes to the concept design result from this study.

10.4 Underwater Radiated Noise Requirements Study

The goal of this effort was to identify achievable and economically feasible underwater radiated noise (URN) requirements that will help meet scientific and environmental goals. The Underwater Radiated Noise Requirements Study (Reference 25) evaluated the scientific needs to achieve the desired low-noise missions and a maximum allowable URN curve was developed.

The URN curve developed is based on the machinery configuration of the concept design: it assumes twin azimuthing drives. No changes to the concept design were required as a result of this study.

10.5 Piston Coring Study

A stated goal of the ARV is the ability to retrieve piston cores up to 40-50 m long. Obtaining 40-50m long cores requires a long open side deck and specialized equipment that will affect the arrangement and potentially the size of the vessel.

The goal of the Piston Coring Study (Reference 26) was to establish a process for handling of these long piston cores. This was accomplished by working with UNOLS coring experts to understand the state-of-the-art in coring technology. A primary concern was sizing of the tension member. Tension members designed to limit stretch tend to be very strong and require over the side handling equipment that can support the breaking strength.

It was assumed that the handling system will be designed per USCG requirements for the equipment to have strength greater than the breaking strength of the line. It was recommended that USCG be approached to see if the design can be based on the safe working load of the intended operation given the over sizing of the line.

The result of this study was a process and requirements definition to be provided to the designer. This will help ensure the vessel design incorporates a system capable of meeting all science objectives.

The concept design main deck arrangement was driven in part by the requirement to handle a 40-50m core. No changes to the concept design are required as a result of this study.

10.6 Concept Design Update

Following NSF review of the design, Glosten worked with Leidos to update the design to address NSF comments and findings from the other studies. Drawing 19136-000-001, Rev -, *ARV Concept Design General Arrangement* (Reference 12) incorporates these comments.

This model and renderings produced from it include primary features and a consistent level of detail throughout.

10.7 Climate Study

The ARV must be able to perform its mission in challenging climatological conditions around the world. To ensure the bid designer is designing to appropriate extreme climate conditions, the Climate Study (Reference 27) was conducted to investigate and report these data.

A sea state distribution was developed that forecasts sea states during the life of the vessel, which was used to evaluate seakeeping and estimate anti-roll tank sizing in the Seakeeping Study.

Icebreaking capability requirements, assuming a Polar Class 3 designation were presented. Ice accretion calculations for stability were recommended.

Design low and high water and air temperatures were recommended. The study recommended a change to the ABS Polar Design Temperature from -30°C to -35°C. This has been updated on the lead sheet of the concept design drawing, 19136-000-001, Rev -, *ARV Concept Design General Arrangement* (Reference 12).

Design wind and current speeds were recommended.

10.8 Seakeeping Study

Using sea state data developed in the Climate Study above, the Seakeeping Study (Reference 28) analyzed the motions of the concept design to ensure the requirements in the specification are reasonable for a vessel of its size. Updated seakeeping requirements were recommended.

The study also provided information on the rough size of an anti-roll tank that will be required to achieve motion requirements. Understanding the roll tank size and the efficacy allows for more diligent design review during early-stage design of the ARV.

The size and location of the anti-roll tank suggested by this study have been incorporated into the concept design.

10.9 Ice Environment Study

The goal of the Ice Environment Study (Reference 29) was to evaluate the ice conditions, including strength, thickness, etc. to be incorporated in the vessel requirements, including the ice conditions in which the vessel will need to be tested. Stating the ice environment more explicitly provides greater certainty that the vessel will meet the icebreaking performance required.

The results of the study as well as subsequent consultation with Leidos and NSF firmly establish ABS Polar Class 3 as a requirement. This has been noted on the lead sheet of the concept design drawing, 19136-000-001, Rev -, *ARV Concept Design General Arrangement*.

10.10 Power Systems Study

This study (Reference 30) evaluated options for power generation and distribution, including fixed and variable speed generators and the potential for battery hybrid solutions.

This study considered fuel efficiency, emissions, and capital and life-cycle costs. The goal was to determine if there is a clearly preferred solution to add as a requirement.

The study recommended that a battery hybrid power system be installed. The concept design includes this system.

10.11 Green Ship Alternatives Study

There are many technologies available to help reduce the vessel's fuel consumption and environmental impact. The Green Ship Alternatives Study (Reference 31) analyzed technologies including:

- Variable frequency drives.
- Permanent magnet motors.
- Waste heat recovery.
- Fuel monitoring.
- Fire suppression agents.
- Non-ozone depleting refrigerants.
- Environmentally acceptable lubricants.
- Additional insulation.

This study evaluated the cost and benefit of the above items at a minimum and where appropriate recommended items to include in the vessel requirements. There is no incentive for shipyards to increase capital cost in exchange for reduced operating costs in a cost competitive bid, unless explicitly required.

Several suggestions for inclusion in the concept design as well as the specifications resulted from this study. However, many of the suggestions from this report will be more properly considered in the next cycle of the design. Those suggestions having a significant impact on the current concept design and therefore incorporated in the latest concept:

- Add harbor generator set.

- Electric winches.
- Space for waste management equipment.
- Energy storage batteries (Hybrid propulsion system).
- Waste heat stack boilers.

10.12 Autonomous Vehicle Handling Study

The use of autonomous vehicles for research activities is increasing, including the use of undersea, surface, and aerial vehicles. This study (Reference 32) reviewed handling systems to support the efficient launch and recovery of multiple vehicles.

In addition to handling autonomous vehicles, this study evaluated the requirements for the storing and charging of their batteries, power requirements, and regulatory obstacles. Storage and charge of vehicle batteries is an important topic due to space and arrangement requirements.

Recommendations from this study that impacted the concept design include confirmation that the forward 04 Deck is the desired location for UAV ops. Additionally, the hangar size was confirmed as adequate to meet projected UAV requirements.

10.13 Bubble Sweepdown Requirements Study

When a ship is moving through the water, air bubbles from the water surface can be pulled underneath the hull and potentially interfer with sensitive instrumentation such as sonar transducers. Optimizing a hull form to avoid bubble sweepdown conflicts with optimizing a hull form for icebreaking. The Bubble Sweepdown Requirements Study (Reference 1) was conducted to ensure that the right balance is struck between the two competing requirements.

In addition to defining the relative importance of the competing requirements, recommendations were made for how to improve the specifications to mitigate the risks of performance issues related to bubble sweepdown.

Appendix A Resistance Calculations

ARV Resistance estimate

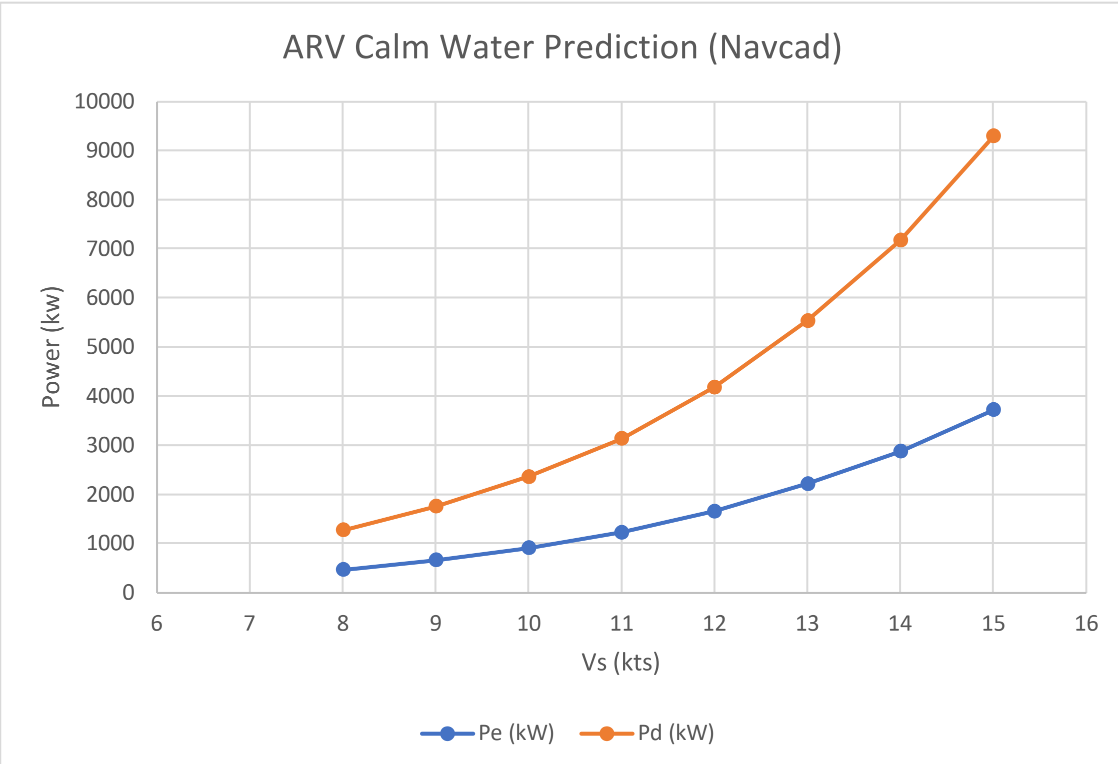
19136_312x69x28.hcnc
DCZ 3/9/2020

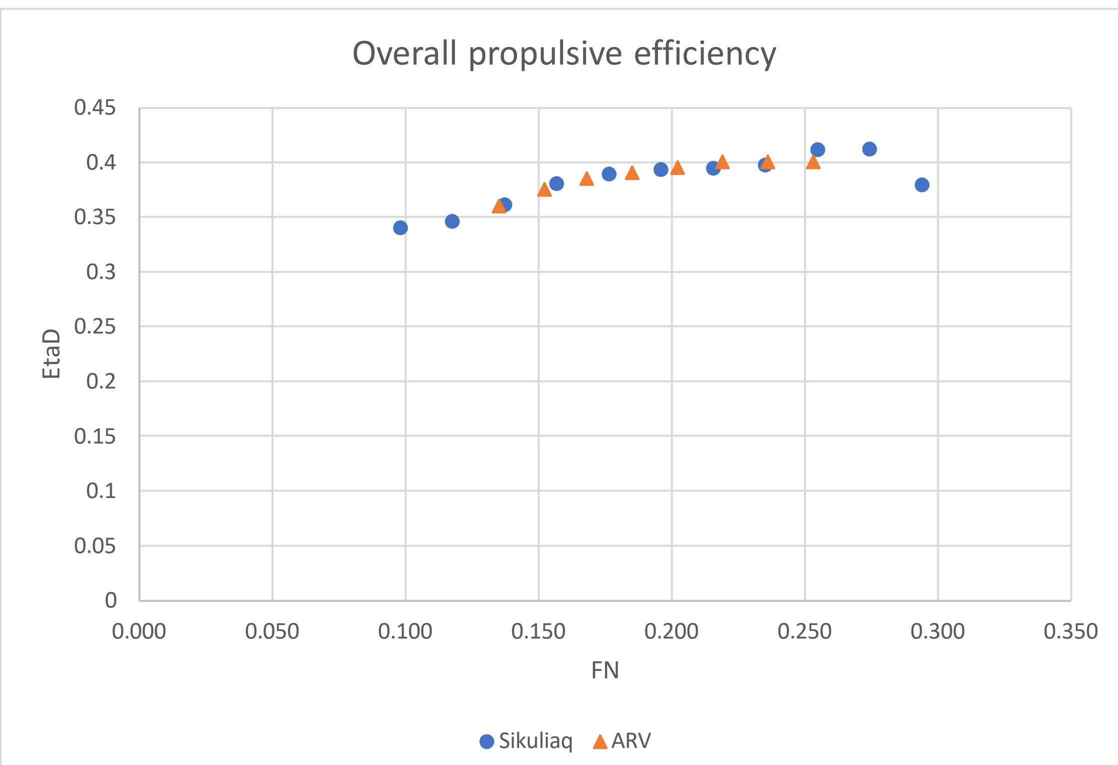
This resistance curve data comes from Navcad
The Sikuliaq MARIN full scale prediction was input to Navcad as Defined resistance and saved
Then the Sikuliaq data was referenced into a new Navcad file for ARV
The calm water resistance for ARV was extrapolated using ITTC-78 Scale from test option
There is no added wind or wave drag, nor is there a sea margin
Calculation for delivered power assume similar overall propulsive efficiency to Sikuliaq
(The overall prop. efficiency is very low due to quiet / low cavitation propellers)

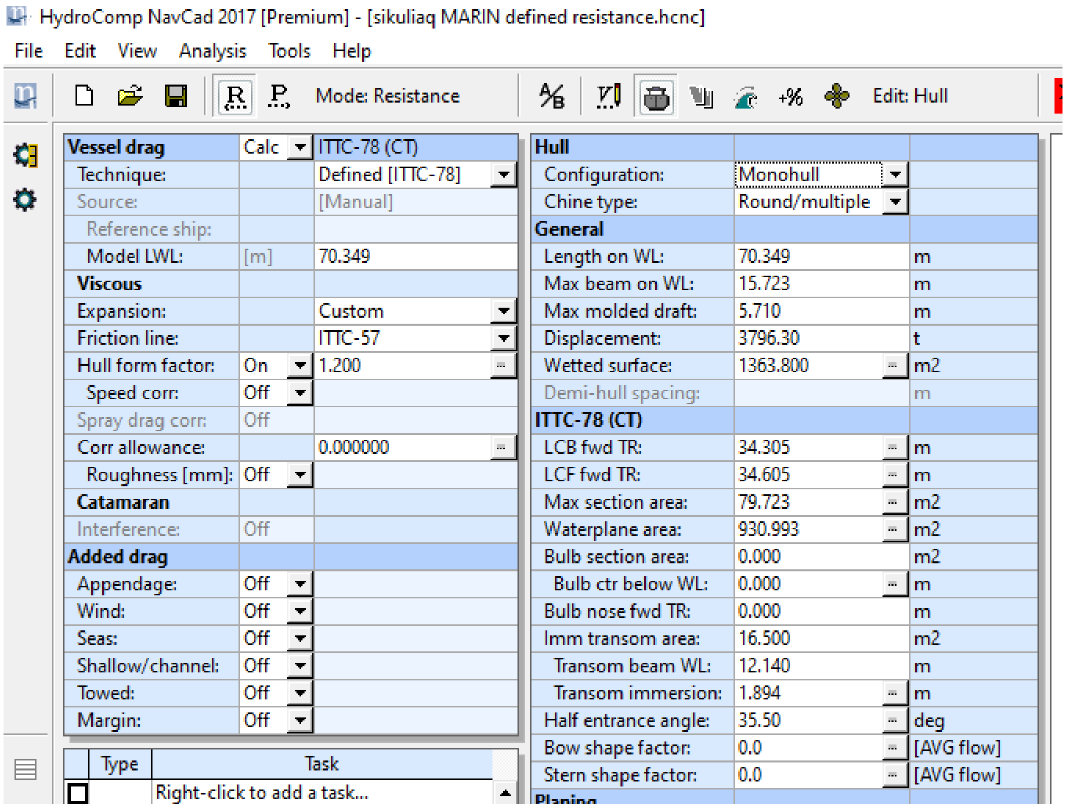
Vs (kts)	FN	RT (kN)	Pe (kW)	EtaD	Pd (kW)
8	0.135	112	459.8	0.36	**1277**
9	0.152	142	656.9	0.375	**1752**
10	0.168	176	906.7	0.385	**2355**
11	0.185	216	1221.5	0.39	**3132**
12	0.202	267	1649.9	0.395	**4177**
13	0.219	331	2212.9	0.4	**5532**
14	0.236	398	2867.2	0.4	**7168**
15	0.253	482	3716	0.4	**9290**

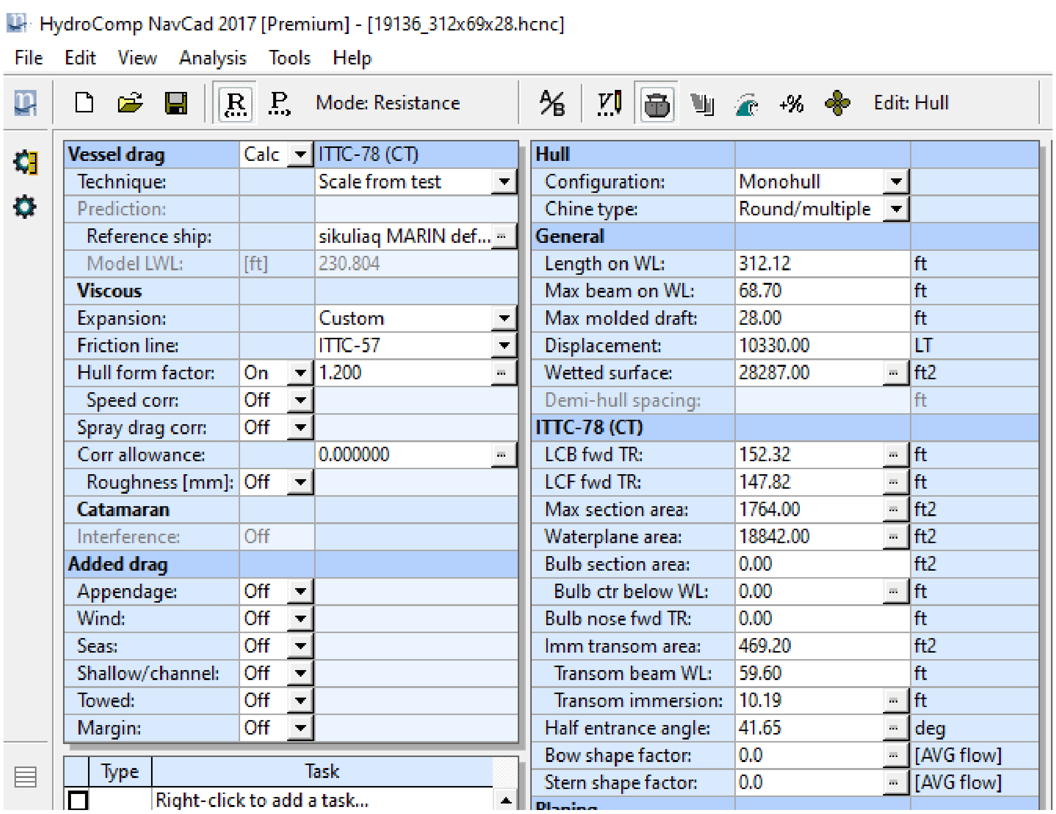
Added resistance in waves: climatology not yet decided. More severe sea state than TRV (39%
increase in SS4 15 kts) but less severe than 200'-LWL Sikuliaq VTT (84% increase 12 kts SS5/6

Vs (kts)	Pd (kW)	Factor R_aw	Pd aw (kW)
10	2355	1.6	**3,768**
11	3132	1.6	**5,011**
12	4177	1.6	**6,683**


ARV Calm Water Prediction (Navcad)
Power (kw)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
6
7
8
9
10
11
12
13
14
15
16
Vs (kts)
Pe (kW)
Pd (kW)


Overall propulsive efficiency
EtaD
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
FN
Sikuliaq
ARV


HydroComp NavCad 2017 [Premium] - [sikuliaq MARIN defined resistance.hcnc]
File Edit View Analysis Tools Help
Mode: Resistance
Edit: Hull
Vessel drag | Calc | ITTC-78 (CT)
Technique: | Defined [ITTC-78]
Source: | [Manual]
Reference ship:
Model LWL: | [m] | 70.349
Viscous
Expansion: | Custom
Friction line: | ITTC-57
Hull form factor: | On | 1.200
Speed corr: | Off
Spray drag corr: | Off
Corr allowance: | 0.000000
Roughness [mm]: | Off
Catamaran
Interference: | Off
Added drag
Appendage: | Off
Wind: | Off
Seas: | Off
Shallow/channel: | Off
Towed: | Off
Margin: | Off
Type | Task
Right-click to add a task...
Hull
Configuration: | Monohull
Chine type: | Round/multiple
General
Length on WL: | 70.349 | m
Max beam on WL: | 15.723 | m
Max molded draft: | 5.710 | m
Displacement: | 3796.30 | t
Wetted surface: | 1363.800 | m2
Demi-hull spacing: | | m
ITTC-78 (CT)
LCB fwd TR: | 34.305 | m
LCF fwd TR: | 34.605 | m
Max section area: | 79.723 | m2
Waterplane area: | 930.993 | m2
Bulb section area: | 0.000 | m2
Bulb ctr below WL: | 0.000 | m
Bulb nose fwd TR: | 0.000 | m
Imm transom area: | 16.500 | m2
Transom beam WL: | 12.140 | m
Transom immersion: | 1.894 | m
Half entrance angle: | 35.50 | deg
Bow shape factor: | 0.0 | [AVG flow]
Stern shape factor: | 0.0 | [AVG flow]


HydroComp NavCad 2017 [Premium] - [19136_312x69x28.hcnc]
File Edit View Analysis Tools Help
Mode: Resistance
Edit: Hull
Vessel drag | Calc | ITTC-78 (CT)
Technique: | Scale from test
Prediction:
Reference ship: | sikuliaq MARIN def...
Model LWL: | [ft] | 230.804
Viscous
Expansion: | Custom
Friction line: | ITTC-57
Hull form factor: | On | 1.200
Speed corr: | Off
Spray drag corr: | Off
Corr allowance: | 0.000000
Roughness [mm]: | Off
Catamaran
Interference: | Off
Added drag
Appendage: | Off
Wind: | Off
Seas: | Off
Shallow/channel: | Off
Towed: | Off
Margin: | Off
Type | Task
Right-click to add a task...
Hull
Configuration: | Monohull
Chine type: | Round/multiple
General
Length on WL: | 312.12 | ft
Max beam on WL: | 68.70 | ft
Max molded draft: | 28.00 | ft
Displacement: | 10330.00 | LT
Wetted surface: | 28287.00 | ft2
Demi-hull spacing: | | ft
ITTC-78 (CT)
LCB fwd TR: | 152.32 | ft
LCF fwd TR: | 147.82 | ft
Max section area: | 1764.00 | ft2
Waterplane area: | 18842.00 | ft2
Bulb section area: | 0.00 | ft2
Bulb ctr below WL: | 0.00 | ft
Bulb nose fwd TR: | 0.00 | ft
Imm transom area: | 469.20 | ft2
Transom beam WL: | 59.60 | ft
Transom immersion: | 10.19 | ft
Half entrance angle: | 41.65 | deg
Bow shape factor: | 0.0 | [AVG flow]
Stern shape factor: | 0.0 | [AVG flow]

Appendix B Crewing Study

CREWING STUDY

POSITION	IMO EQUIVALENT	QUANTITY		REGULATORY REFERENCES	IMO REGULATORY REFERENCES	INTERPRETATIONS / ASSUMPTIONS	STATION BILL DUTIES		
		MIN[1]	Recommended				FIRE & EMERGENCY DUTIES	ABANDIN SHIP DUTIES	Watch
Master	Master	1	1	46 CFR 15.805(a)(1) & 815(a)	STCW-95 Reg II/2	'Every self-propelled, seagoing documented vessel of 200 gross tons and over.'	On Bridge, In Command of All operations	On Bridge, In Command of All operations	N/A
Ice Pilot	Ice Pilot	1	1	IMO Polar Cade	STCW A-II/2 and A-11/3	Voyage, planning and navigation: ice' Could be accomplished with a Mate holding an endorsement or a dedicated Pilot.			
Chief Mate	Chief Officer (Chief Mate)	1	1	46 CFR 15.810(b)(1)	STCW-95 Reg II/2&3	'Vessels of 1000 gross tons or more - three mates', Ice Pilot Endorcement	1st: On Sceene - In Charge Communications	1st: On charge of Boat deck Operations	1
Second Mate	Officer in Charge of a Navigational Watch (OICNW)	1	1	46 CFR 15.810(b)(1)	STCW-95 Reg II/2&4	'Vessels of 1000 gross tons or more - three mates'	2nd: on Bridge, helm or GMDSS,	2nd: Lifeboat #1	2
Third Mate	Officer in Charge of a Navigational Watch (OICNW)	1	1	46 CFR 15.810(b)(1)	STCW-95 Reg II/2&5	'Vessels of 1000 gross tons or more - three mates'	3rd: Fire Team #1 Nozzleman	3rd: Lifeboat #2	3
Able Seaman	Able Seafarer Deck (AS-D)	3	6	46 CFR 15.840(a) and Marine Safety Manual Vol. 3, Part B4 D.1	STCW-95 Reg II/5	At least 65% of the deck crew of these vessels, excluding individuals serving as officers, must be able seamen.' Each watch will have helmsman and lookout based on mission requirements.	on Bridge, helm or Messenger Fire Team #2 - Nozzleman Fire Team #1 - Hoseman Fire Team #2 - Hoseman	On Bridge, Helm or Communications Lifeboat #3 Liferaft #1 Liftraft #2	
Ordinary Seaman	Rating forming part of a Navigational Watch (RFPNW)	0	4	46 CFR 12.25-1 and Marine Safety Manual Vol. 3, Part B4 D.1	STCW-95 Reg II/4	65% of deck crew must be AB's, therefore remaining compliment can be Ordinary Seamen	Fire Team #1 - Valveman Fire Team #2 - Valveman	On bridge, helm or Messenger Report to Chief Mate, Messenger	
DECK		**8**	**15**						
Chief Engineer	Chief Engineer (CE)	1	1	46 CFR 15.820(a)(1)	STCW-95 Reg III/3	'Seagoing or Great Lakes vessels of 200 gross tons and over.'	In charge engine room	in charge engine room	1
Assistant Engineer	Officer in Charge of an Engineering Watch (OICEW)	3	3	46 CFR 15.825	STCW-95 Reg III/1	Licensed Assistant Engineer(s) required; OCMI determines quantity based on level of automation. (over 200 GT) Must have one licensed engineer per watch.	Report to Emer. DG - Standby Report to Engine Room Assist as needed - Fire Pumps	Report to Emer. DG - Stand By Lifeboat #2 - Motorman Lifeboat #1 - Motorman	2,3
Electrotechnical	Electro-technical Officer (ETO)	1	2		STCW-95 Reg III/6				
Oiler (QMED)	Able Seafarer Engine (AS-E)	0	3	Marine Safety Manual Vol. 3, Part B4 E.5	STCW-95 Reg III/5	Billet not specifically required by CFR. No unlicensed watchstander required in engine room with "deadman" alarm.	Report to Emer. DG Rm, Assist as Directed Report to EOS, Assist as Directed Report to Chief Mate, Assist as Directed	Report to Emer DG Rm. Assist as Directed Report to EOS, Assist as Directed Liferaft #3 - In charge	
Wiper	Rating forming part of an Engineering Watch (RFPEW)	0	0	Marine Safety Manual Vol. 3, Part B4	STCW-95 Reg III/4	Billet not specifically required by CFR. No unlicensed watchstander required in engine room with "deadman" alarm.			
ENGINE		**5**	**9**						
Chief Steward	Chief Steward/Purser	1	1	46 CFR 12.25-1 & -2		Billet not specifically required by CFR. Must be food handler endorsed.	In charge at designated Muster Station Take Muster	In charge at designated Muster sstation, Take Muster	
Cook	Cook/2nd Steward	2	2	46 CFR 12.25-1 & -2		Billet not specifically required by CFR. Must be food handler endorsed.	Assist at Designated Muster Station, Sweep Vessel; Assist as Directed	Liferaft #2 assist as Directed; Liferaft #3 assist as directed	
Mess Assistant	Steward	2	2	46 CFR 12.25-1 & -2		Billet not specifically required by CFR. Must be food handler endorsed.	Assist as directed	Assist as directed	
STEWARDS		**5**	**5**						
Total Crew		**18**	**29**						

1. Minimum crew size based on minimum requirements by regulations and emergency squad capabilities.
2. One electrician/tech will have lifeboatman/MMD certification.

Appendix C Endurance Study

ARV Fuel Consumption

By: DCZ 4/28/2020

Assumptions:

1) Mission profiles are from "Expedition Mission Profile Scenarios.pdf" received 20 March 2020.
2) Specific fuel consumption 180 g/kWh (175 g/kWh at 85% MCR per Bergen diesel)
3) The overall generator efficiency is 95% (conversion of engine bkW to ekW)
4) One gallon of diesel weighs 3224.5 g
5) ARV total installed power is same as Haakon, 15 MW
6) ARV transit powering estimate comes from "IBRV Resistance.xlsx" dated 17 March 2020, reproduced here.

Sea margin	1.6	added resistance in waves estimate for ARV, based on Sikuliaq and TRV model tests
Hotel load during transit	12%	of installed power
Efficiency of motor	97%	
Efficiency of drive	97%	

V (kts)	Pd (MW)	Pd sea (MW)	P hotel (eMW)	Total, transit P (eMW)
10	2.4	3.8	1.8	5.8
11	3.1	5.0	1.8	7.1
12	4.2	6.7	1.8	8.9

7) Power estimates for each mission activity are as shown below.
   EPLA design values are estimated using % of installed power based on similar vessels.
   Demand factor reduces overconservatism in EPLA values by accounting for loitering time and better weather than the EPLA design day.

	Activity	% installed	EPLA design P (MW)	Demand Factor	Endurance P (MW)	e.g.
1	Open Water Transit	*see above*				
2	Ice breaking	80%	12.0	0.60	7.2	
3	On Station	30%	4.5	0.60	2.7	CTD survey, mammal survey, field science, diving
4	On Station, DP	60%	9.0	0.60	5.4	AUV/ROV deployment, coring, drilling
5	Deployment	50%	7.5	0.60	4.5	Mooring operations, net tows, acoustic survey
6	Hotel only	20%	3.0	0.60	1.8	Port calls
7	Ice transit	30%	4.5	0.60	2.7	Speed <= 6 kts

8) The total fuel carrying capacity of ARV is 523,800 gal
   of which, the amount retained as cargo is 120,000 gal
   leaving a vessel fuel storage capacity of 403,800 gal
   The reserve amount (unusable for missions) is 10%
   The usable volume including cargo fuel is 471,420 gal
   The usable volume excluding cargo fuel is 363,420 gal

First Season

Palmer Station Opening s1

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call		6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit		1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL			**18**				**90,873**	1,920

Peninsula Region Science s1a

Science Operation	Activity	7	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
AUV/ROV Deployment	On Station		3	5	0	2.7	324,000	19,038	0
CTD survey	On Station		3	7	0	2.7	453,600	26,654	0
Diving	Ice leads/ On Station		3	8	7	2.7	518,400	30,462	1,344
Mooring Operations	Deployment		4	3	5	5.4	388,800	22,846	360
Sea Ice Sampling	Ice breaking/ Ice leads		2	7	7	7.2	1,209,600	71,077	1,176
Seal Tagging	On Station		3	7	0	2.7	453,600	26,654	0
Transit	Open Water Transit		1	17	10	5.8	2,368,308	139,163	4,080
	TOTAL			**54**				**335,894**	6,960

Long Term Ecological Research Expedition

Science Operation	Activity	9	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Acoustic Survey	Deployment		5	3	5	4.5	324,000	19,038	360
AUV Deployment	On Station		4	3	0	5.4	388,800	22,846	0
CTD survey	On Station		3	5	0	2.7	324,000	19,038	0
Hotel only	Palmer Station Port Call		6	4	0	1.8	172,800	10,154	0
Marine Mammal Sampl	On Station		3	7	0	2.7	453,600	26,654	0
Mooring Operations	Deployment		5	3	5	4.5	324,000	19,038	360
Net Tows	Deployment		5	3	5	4.5	324,000	19,038	360
Penguin Survey	On Station		3	3	0	2.7	194,400	11,423	0
Transit	Open Water Transit		1	14	10	5.8	1,950,371	114,605	3,360
	TOTAL			**45**				**261,836**	4,440

Peninsula Region Science s1b

Science Operation	Activity	5	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
CTD survey	On Station		3	4	0	2.7	259,200	15,231	0
Field science/island visi	On Station		3	10	0	2.7	648,000	38,077	0
AUV Deployments	Survey		3	3	10	2.7	194,400	11,423	720
Transit	Open Water Transit		1	10	10	5.8	1,393,122	81,861	2,400
UAS	On Station		3	3	0	2.7	194,400	11,423	0
	TOTAL			**30**				**158,015**	3,120

Palmer Station Closing s1

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call		6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit		1	8	12	8.9	1,709,373	100,444	2,304
	TOTAL			**18**				**125,828**	2,304

Peninsula Region Science s1c

Science Operation	Activity	7	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Acoustic Survey	Deployment		5	9	5	4.5	972,000	57,115	1,080
Field science/island visi	On Station		3	3	0	2.7	194,400	11,423	0
Fishing	Deployment		5	20	5	4.5	2,160,000	126,923	2,400
Hotel only	Palmer Station Port Call		6	7	0	1.8	302,400	17,769	0
Mooring Operations	Deployment		5	5	5	4.5	540,000	31,731	600
Net Tows	Deployment		5	10	5	4.5	1,080,000	63,461	1,200
Transit	Open Water Transit		1	10	10	5.8	1,393,122	81,861	2,400
	TOTAL			**64**				**390,284**	7,680

Mid-Atlantic region science

Science Operation	Activity	3	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Multibeam Survey	Survey		3	25	5	2.7	1,620,000	95,192	3,000
Dredging	Deployment		5	10	1	4.5	1,080,000	63,461	240
Transit	Open Water Transit		1	20	10	5.8	2,786,245	163,722	4,800
	TOTAL			**55**				**322,375**	8,040

Second Season

Palmer Station Opening s2

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call		6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit		1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL			**18**				**90,873**	1,920

Hazardous Waste Transfer s2

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Transit	Open Water Transit		1	18	10	5.8	2,507,620	147,349	4,320
	Ice Transit		7	5	5	2.7	324,000	19,038	600
	TOTAL			**23**				**166,388**	4,920

Thwaites Expedition

Science Operation	Activity	8	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
AUV Deployment	On Station		4	10	0	5.4	1,296,000	76,154	0
Coring	On Station		4	15	0	5.4	1,944,000	114,231	0
CTD survey	On Station		3	10	0	2.7	648,000	38,077	0
Field science/island visi	On Station		3	8	0	2.7	518,400	30,462	0
Mooring Operations	On Station		3	3	0	2.7	194,400	11,423	0
TMC CTD Operations	On Station		3	10	0	2.7	648,000	38,077	0
Transit	Open Water Transit		1	13	10	5.8	1,811,059	106,419	3,120
	Ice Transit		7	4	5	2.7	259,200	15,231	480
	TOTAL			**73**				**430,073**	3,600

GO-SHIP Expedition

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
CTD survey	On Station		3	50	0	2.7	3,240,000	190,384	0
Transit	Open Water Transit		1	35	10	5.8	4,875,928	286,513	8,400
	TOTAL			**85**				**476,897**	8,400

Palmer Station Closing s2

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call		6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit		1	8	12	8.9	1,709,373	100,444	2,304
	TOTAL			**18**				**125,828**	2,304

Third Season

Palmer Station Opening s3

Science Operation	Activity	2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call		6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit		1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL			**18**				**90,873**	1,920

Peninsula Region Science s3a

Science Operation	Activity	8	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
AUV/ROV Deployment	On Station		4	5	0	5.4	648,000	38,077	0
CTD survey	On Station		3	7	0	2.7	453,600	26,654	0
Diving	Ice leads/ On Station		3	8	7	2.7	518,400	30,462	1,344
Mooring Operations	Deployment		5	3	5	4.5	324,000	19,038	360
Sea Ice Sampling	Ice breaking/ Ice leads		2	7	7	7.2	1,209,600	71,077	1,176
Seal Tagging	On Station		3	7	0	2.7	453,600	26,654	0
Transit	Open Water Transit		1	5	10	5.8	696,561	40,930	1,200
Transit	Open Water Transit		1	12	10	5.8	1,671,747	98,233	2,880
	TOTAL			**54**				**351,125**	6,960

LTER Grid s3

Science Operation	Activity 9	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Acoustic Survey	Deployment	5	3	5	4.5	324,000	19,038	360
AUV Deployment	On Station	4	3	0	5.4	388,800	22,846	0
CTD survey	On Station	3	5	0	2.7	324,000	19,038	0
Hotel only	Palmer Station Port Call	6	4	0	1.8	172,800	10,154	0
Marine Mammal Sampl	On Station	3	7	0	2.7	453,600	26,654	0
Mooring Operations	Deployment	5	3	5	4.5	324,000	19,038	360
Net Tows	Deployment	5	3	5	4.5	324,000	19,038	360
Transit	Open Water Transit	1	6	10	5.8	835,873	49,116	1,440
	Open Water Transit	1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL		**42**				**250,413**	4,440

Peninsula Region Science s3b

Science Operation	Activity 3	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Field science/island visi	On Station	3	4	0	2.7	259,200	15,231	0
Hotel only	Palmer Station Port Call	6	3	0	1.8	129,600	7,615	0
Transit	Open Water Transit	1	8	12	8.9	1,709,373	100,444	2,304
	TOTAL		**15**				**123,290**	2,304

Dry Dock

Science Operation	Activity 2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Drydock	idle	n/a	28	0		0	0	0
Transit	Open Water Transit	1	14	10	5.8	1,950,371	114,605	3,360
	TOTAL		**42**				**114,605**	3,360

Palmer Station Closing s3

Science Operation	Activity 2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call	6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit	1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL		**18**				**90,873**	1,920

ECORD

Science Operation	Activity 3	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Transit	Open Water Transit	1	10	10	5.8	1,393,122	81,861	2,400
	Ice Transit	7	5	5	2.7	324,000	19,038	600
Drilling	On Station	4	45	0	5.4	5,832,000	342,692	0
	TOTAL		**60**				**443,591**	3,000

Fourth Season

Hazardous Waste Transfer s4

Science Operation	Activity 2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Transit	Open Water Transit	1	18	10	5.8	2,507,620	147,349	4,320
	Ice Transit	7	4	5	2.7	259,200	15,231	480
	TOTAL		**22**				**162,580**	4,800

GEOTRACES

Science Operation	Activity 3	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
TMC CTD Operations	On Station	3	40	0	2.7	2,592,000	152,308	0
Transit	Open Water Transit	1	40	10	5.8	5,572,489	327,443	9,600
	Ice Transit	7	10	5	2.7	648,000	38,077	1,200
	TOTAL		**90**				**517,828**	10,800

Peninsula Region Science s4

Science Operation	Activity 5	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
CTD survey	On Station	3	9	0	2.7	583,200	34,269	0
Field science/island visi	On Station	3	5	0	2.7	324,000	19,038	0
Hotel only	On Station	6	3	0	1.8	129,600	7,615	0
Mooring Operations	Deployment	5	3	5	4.5	324,000	19,038	360
Transit	Open Water Transit	1	10	10	5.8	1,393,122	81,861	2,400
	TOTAL		**30**				**161,822**	2,760

Palmer Station Closing s4

Science Operation	Activity 2	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call	6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit	1	8	10	5.8	1,114,498	65,489	1,920

	TOTAL		**18**				**90,873**	1,920

Fifth Season

Palmer Station Opening s5

Science Operation	Activity *2*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call	6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit	1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL		**18**				**90,873**	1,920

Peninsula Region Science s5a

Science Operation	Activity *3*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
CTD survey	On Station	3	25	0	2.7	1,620,000	95,192	0
Diving	Ice leads/ On Station	3	25	0	2.7	1,620,000	95,192	0
Mooring Operations	Deployment	5	4	5	4.5	432,000	25,385	480
	TOTAL		**54**				**215,769**	480

LTER Grid s5

Science Operation	Activity *6*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Acoustic Survey	Deployment	5	8	5	4.5	864,000	50,769	960
CTD survey	On Station	3	10	0	2.7	648,000	38,077	0
Hotel only	Palmer Station Port Call	6	4	0	1.8	172,800	10,154	0
Mooring Operations	Deployment	5	3	5	4.5	324,000	19,038	360
Net Tows	Deployment	5	8	5	4.5	864,000	50,769	960
Transit	Open Water Transit	1	12	10	5.8	1,671,747	98,233	2,880
	TOTAL		**45**				**267,040**	5,160

Peninsula Region Science s5b

Science Operation	Activity *5*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
CTD survey	On Station	3	10	0	2.7	648,000	38,077	0
Field science/island visi	On Station	3	5	0	2.7	324,000	19,038	0
Multibeam Survey	Survey	3	5	5	2.7	324,000	19,038	600
Transit	Open Water Transit	1	10	10	5.8	1,393,122	81,861	2,400
UAS	On Station	3	1	0	2.7	64,800	3,808	0
	TOTAL		**31**				**161,822**	3,000

Palmer Station Closing s5

Science Operation	Activity *2*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Hotel only	Palmer Station Port Call	6	10	0	1.8	432,000	25,385	0
Transit	Open Water Transit	1	8	10	5.8	1,114,498	65,489	1,920
	TOTAL		**18**				**90,873**	1,920

Peninsula Region Science s5c

Science Operation	Activity *7*	Activity #	Days each	Speed (kt)	P (MW)	Energy (kWh)	Fuel consumed (gal)	Distance (nmi)
Acoustic Survey	Deployment	5	9	5	4.5	972,000	57,115	1,080
Field science/island visi	On Station	3	3	0	2.7	194,400	11,423	0
Fishing	Deployment	5	20	5	4.5	2,160,000	126,923	2,400
Hotel only	Palmer Station Port Call	6	7	0	1.8	302,400	17,769	0
Mooring Operations	Deployment	5	5	5	4.5	540,000	31,731	600
Net Tows	Deployment	5	10	5	4.5	1,080,000	63,461	1,200
Transit	Open Water Transit	1	10	10	5.8	1,393,122	81,861	2,400
	TOTAL		**64**				**390,284**	7,680

Results summary:

Expedition	Duration (days)	Fuel consumed (gal)	Fuel capacity (gal)	Utilization
First Season				
Palmer Station Opening s1	18	90,873	403,800	23%
Peninsula Region Science s1a	54	335,894	523,800	64%
Long Term Ecological Research Expedition	45	261,836	523,800	50%
Peninsula Region Science s1b	30	158,015	523,800	30%
Palmer Station Closing s1	18	125,828	523,800	24%
Peninsula Region Science s1c	64	390,284	523,800	75%
Mid-Atlantic region science	55	322,375	523,800	62%
Second Season				
Palmer Station Opening s2	18	90,873	403,800	23%
Hazardous Waste Transfer s2	23	166,388	523,800	32%
Thwaites Expedition	73	430,073	523,800	82%
GO-SHIP Expedition	85	476,897	523,800	91%
Palmer Station Closing s2	18	125,828	523,800	24%
Third Season				
Palmer Station Opening s3	18	90,873	403,800	23%
Peninsula Region Science s3a	54	351,125	523,800	67%
LTER Grid s3	42	250,413	523,800	48%
Peninsula Region Science s3b	15	123,290	523,800	24%
Dry Dock	42	114,605	523,800	22%
Palmer Station Closing s3	18	90,873	523,800	17%
ECORD	60	443,591	523,800	85%
Fourth Season				
Hazardous Waste Transfer s4	22	162,580	523,800	31%
GEOTRACES	90	517,828	523,800	99%
Peninsula Region Science s4	30	161,822	523,800	31%
Palmer Station Closing s4	18	90,873	523,800	17%
Fifth Season				
Palmer Station Opening s5	18	90,873	403,800	23%
Peninsula Region Science s5a	54	215,769	523,800	41%
LTER Grid s5	45	267,040	523,800	51%
Peninsula Region Science s5b	31	161,822	523,800	31%
Palmer Station Closing s5	18	90,873	523,800	17%
Peninsula Region Science s5c	64	390,284	523,800	75%