Antarctic Research Vessel (ARV)

Engineering Report: Design Summary Report

Document No.: 5E1-003-R001

Revision: P3

Prepared by the Antarctic Support Contractor
for the
National Science Foundation Office of Polar Programs

Revision History

Revision #	Date	Section (if applicable)	Author/Editor	Change Details
P0	September 30, 2022	All	C. Bracker	Initial draft for ASC peer review
P1	December 23, 2022	All	C. Bracker	Revised based on P0 comments from ASC
P2	January 25, 2023	3.5, 3.6, 5, Appendix 2	C. Bracker	Updated figures to represent most recent drawings. Updated Weight Summary and Design Margins Appendix based on the P3 Design Weight Estimate.
P3	August 16, 2023	All	C. Bracker	Updated to reflect post-PDR design progress

Prepared by:

Claudia Bracker	Claudia Bracker	7/11/2023
Signature	*Print Name*	*Date*

Claudia Bracker, Engineer II, Gibbs & Cox

Checked by:

Cheryl Blanchard	Cheryl Blanchard	7/12/2023
Signature	*Print Name*	*Date*

Cheryl Blanchard, Principal Engineer, Gibbs & Cox

Engineered/Managed by:

Allison Vella	Allison Vella	7/14/2023
Signature	*Print Name*	*Date*

Allison Vella, Assistant Department Manager, Gibbs & Cox

Approved by:

Dave Rosenthal	David Rosenthal	8/16/2023
Signature	*Print Name*	*Date*

David Rosenthal, Assistant Vice President, Gibbs & Cox

Table of Contents

List of Figures

List of Tables

1. Executive Summary

This report details the Preliminary Design of the Antarctic Research Vessel (ARV) and includes a summary of vessel particulars, hull development and optimization studies, and technical details of each Ship Work Breakdown Structure (SWBS) group.

The ARV is being designed to meet three primary Key Performance Parameters (KPP) as shown in Table 1. The ARV will be classed by the American Bureau of Shipping (ABS) as a Polar Class 3 (PC3) vessel and will be designed to meet the full suite of other notations identified in Section 3.3.

Table 1: Key Performance Parameters

Parameter	Requirement	Threshold Value	Objective Value	Science Mission Requirement (SMR) Reference
Icebreaking	The capability to independently break ice	≥ 4.5 ft at ≥ 3 kts (Polar Class 3)	≥ 4.5 ft + 1 ft of snow at ≥ 3 kts	D.2.3.1
Endurance	Maximum endurance without replenishment	≥ 90 days underway	N/A	D.2.3.2
Science & Technical Personnel	Provisions for messing, berthing, sanitation, and scientific workspaces	Crew and science and technical personnel ≥ 55	N/A	D.2.2.1

The ARV has evolved from Concept Design that was started January 2022 through the presently completed Preliminary Design. Throughout the design process, the ARV hull design has gone through multiple iterations to optimize the design and to ensure compliance with the Performance Specification, Reference (1). These design iterations are illustrated in Table 2.

Table 2: Design Iterations

Date	Design Iteration	Hull Dimensions	Development	Strengths	Weaknesses
January 2022	Concept Design	335 ft x 70 ft x 28 ft	Developed in parallel to design requirements definition		Meeting KPPs & P-Spec Requirements
April 2022	Design Review 1	345 ft x 73.3 ft x 28 ft	Draft restricted to 28 ft based on Palmer Station	KPP compliance for icebreaking & accommodations	Range, endurance KPP, inadequate machinery & engine room space
August 2022	Design Review 2	345 ft x 73.3 ft x 28 ft	Initial endurance calculations identified likely KPP deficiencies, but further analysis was necessary before changing length	KPP compliance for icebreaking & accommodations	Stability, insufficient tankage to support endurance & range requirements
October 2022	Design Review 3	365 ft x 80 ft x 32.5 ft	Hull sizing study determined that ship length of 365 ft was required, beam was increased to 80 ft. Further investigation found that Palmer Station could support a deeper draft than 28 ft, but the turn of the	All KPPs met	Bubble sweep-down performance

			bilge must begin at 28 ft draft		
January 2023	Design Review 4	365 ft x 80 ft x 32.5 ft	Complete cycle through design spiral with 365' x 80' vessel to support PDR	All KPPs met	Bubble sweep-down performance
August 2023	Design Review 5	365 ft x 80 ft x 32.5 ft	Hull Variant 11 developed to mitigate bubble sweep-down	All KPPs met, improved bubble sweep-down performance, reduced ice resistance, reduced open water resistance	None

As shown in Table 2, the ARV Preliminary Design effort has succeeded in defining a baseline ship configuration that satisfies KPPs, as well as, producing converged design documentation. The Ship Design Team used the 365 ft x 80 ft hull to converge the design for Preliminary Design Review (PDR). However, there were several technical gaps that the Ship Design Team identified going into PDR that must be addressed post-PDR. One of these gaps included undesirable bubble sweep-down performance that was observed during model testing. This was addressed by performing an additional hull optimization resulting in the development of Hull Variant 11, which was validated during model testing. Other identified technical gaps have been addressed during Design Review 5. These resolutions continue to develop as the design advances toward final design.

Appendix 1 provides a list of Preliminary Design Drawings and Reports. Appendix 2 is the Design Margin Plan that provides the approach and plan for managing design margins with respect to risk and uncertainty. Appendix 3 provides a list of drawing reservations. Appendix 4 provides a list of design documents that require further convergence.

1.1. Acronyms

ABS	American Bureau of Shipping
ACCU	Automatic Centralized Control Unmanned
ADA	Americans with Disabilities Act
ADCP	Acoustic Doppler Current Profiler
AIP	Approval in Principle
Aloft Con	Aloft Control Station
ARV	Antarctic Research Vessel
ATO	Authority to Operate
AUV	Autonomous Underwater Vehicle
AWE	Accepted Weight Estimate
B-SPEC	Builder's Specification
BOSL	Beginning of Service Life
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
ConMod	Contract Modification
CPVC	Chlorinated Polyvinyl Chloride
CTD	Conductivity-Temperature-Depth

DD&B	Detail Design & Build (margin)
DD&C	Detail Design & Construction
DPS	Dynamic Positioning System
DR1	Design Review 1
DR2	Design Review 2
DR3	Design Review 3
DR4	Design Review 4
DR5	Design Review 5
DRM	Design Reference Mission
DWE	Design Weight Estimate
ECR	Engineering Change Request
EDG	Emergency Diesel Generator
EHP	Effective Horsepower
eKW	Electrical Kilowatts
EOSL	End of Service Life
EPLA	Electric Plant Load Analysis
FFP	Firm Fixed Price
GFI	Government Furnished Information
GFM	Government Furnished Material
HM&E	Hull, Mechanical, and Electrical
HPU	Hydraulic Power Unit
HSI	Human Systems Interface
HV	High Voltage
HVSA	Hamburgische Schiffbau-Versuchsanstalt
HVAC	Heating, Ventilation, and Air Conditioning
IBC	Intermediate Bulk Containers
IBS	Integrated Bridge System
IMACS	Integrated Machinery Automation Control System
IMO	International Maritime Organization
IPT	Integrated Product Team
IT	Information Technology
KG	Vertical Center of Gravity Above Keel
KPP	Key Performance Parameter
L/B	Length/Beam
LAN	Local Area Network
LCB	Longitudinal Center of Buoyancy
LCF	Longitudinal Center of Float
LCG	Longitudinal Center of Gravity
LARS	Launch and Recovery System
Li-ion	Lithium Ion
LOA	Length Overall
MAC	Multi-Beam Advisory Committee
MBSE	Model Based Systems Engineering
MEL	Master Equipment List
MVR	Marine Vessel Rules
MWh	Megwatt Hour
NCE	Noise Control Engineering

NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
PC3	Polar Class 3
PD	Preliminary Design
PDR	Preliminary Design Review
ppm	Parts per Million
P-SPEC	Performance Requirements
PSO	Protected Species Observatory
RAM	Reliability, Availability, and Maintainability
RHIB	Rigid Hull Inflatable Boat
ROV	Remotely Operated Vehicles
RVM	Requirements Verification Matrix
SASC	Science Advisory Subcommittee
SAWE	Society of Allied Weight Engineers
SCOAR	Scientific Committee on Oceanographic Aircraft Research
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
SLA	Service Life Allowance
SME	Subject Matter Expert
SMR	Science Mission Requirements
SOC	Science Operations Center
SOD	Science Observation Deck
SOLAS	Safety of Life at Sea
SPS	Special Purpose Ships
SWBS	Ship Work Breakdown Structure
UAV	Uncrewed Aerial Vehicle
UNOLS	University-National Oceanographic Laboratory System
URN	Underwater Radiated Noise
USBL	Ultra-Short Baseline
USCG	United States Coast Guard
VCG	Vertical Center of Gravity
VFI	Vendor-Furnished Information
VOIP	Voice Over Internet Protocol
VSAT	Very Small Aperture Terminal
WG	Working Group

2. Overview

2.1. Organization

The ARV Design Team is made up of numerous individuals across various organizations within Leidos, augmented by the support of key subcontractors, including:

- ARV Project Management Team
- Gibbs and Cox – Ship Design
- Maritime Systems Division – Systems Engineering
- ASC Mission Support
- Consultants / Subcontractors:
  - Noise Control Engineering (NCE)
  - Glosten
  - Dan Oliver (Vessel Operator Consultant)
  - Marc Willis (Vessel Construction Consultant)
  - Tim Gates (Gates Acoustics)
  - Spar Associates
  - Hamburgische Schiffbau-Versuchsanstalt (HSVA) – Model Test Basin
  - American Bureau of Shipping (ABS)

The ARV Design Team Program Manager, Mr. Chris Chuhran, is responsible for coordination and completion of the ARV program. The Hull, Mechanical, and Electrical (HM&E) team is led by the Ship Design Manager, Mr. Clark Thompson, who is responsible for the design of the vessel. The Systems Engineering (SE) organization is responsible for coordination of SE activities as defined in the Systems Engineering Management Plan (SEMP), Reference (2), and includes requirements management, risk management, safety, reliability, modeling, interface management, testing, and cybersecurity. The team is also made up of representatives from the Leidos Antarctic Support Contract, who support the United States Antarctic Program and are experts in the required operations of science research vessels. Additionally, the National Science Foundation (NSF) Science Advisory Subcommittee (SASC) Members review and provide comments against the design products to provide deeper understanding of the scientific mission needs to the design team.

Per the Preliminary Design (PD) Systems Engineering Plan, Leidos developed the SEMP, which included requirements for Integrated Product Teams (IPTs) and Working Groups (WGs). The following is the list of IPTs and WGs established to support development, plan for test, and commissioning of the ARV:

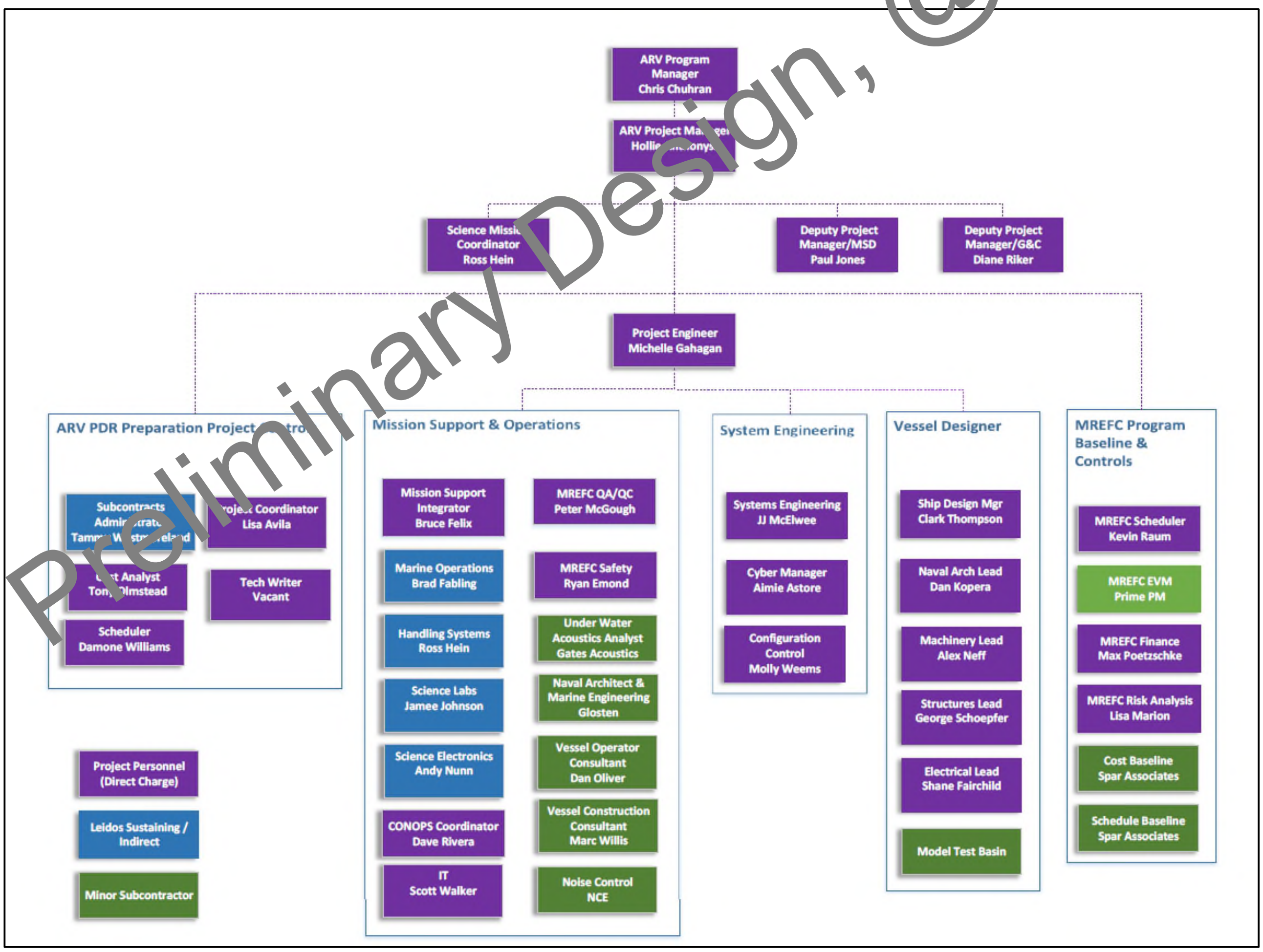
- Science Systems IPT
- Hull, Mechanical, and Electrical IPT
- Systems Engineering IPT
- Cybersecurity IPT

- Safety IPT
- Reliability, Availability, and Maintainability WG
- Aloft Control Station Special WG
- Lab Layout Academic Review WG
- Uncrewed Aerial Vehicle (UAV) Deck and Hangar WG, including University-National Oceanographic Laboratory System (UNOLS) Scientific Committee on Oceanographic Aircraft Research (SCOAR)
- Deep Water Multi-Beam WG, including UNOLS Multi-Beam Advisory Committee (MAC)

These IPTs and WGs will provide visibility across the engineering disciplines and allow Subject Matter Experts (SMEs) to engage and ensure requirements are flushed out, achievable, documented, and reflected in the ARV PD.

The full ARV organization chart is outlined in Figure 1.

Figure 1: Organization Chart



2.2. Design Engagement Philosophy

The design of the ARV has been guided by a singular goal: Support the Science. Not a decision is made on this design without contemplating how that decision impacts the science capabilities of the ship. Through the requirements, Science Advisor Meetings, Internal Design Reviews, IPT Reviews, and through SASC comments, the design team has gained a deep understanding of the technical demands that science missions place upon this ship. This was very important since it provided the design team insight into the operational tempo above and beyond just the requirements.

Through Safety IPT meetings, the Design Team learned of typical injuries encountered on research ships, and how to avoid them. Through Cyber IPT meetings, the team discussed the multiple networks required onboard the ARV, and how those networks' distributed equipment will be utilized by science and ship operators. Through the Science Systems IPT meetings, the team reviewed and coordinated science system equipment selection, installation feasibility, and integration into the vessel infrastructure design. Through Systems Engineering IPT meetings, the team worked through evolving requirements and found how to ensure the needs of the science missions are correctly incorporated into the Performance Specification (P-SPEC), Reference (1), and Builder's Specification (B-SPEC), Reference (3). Additionally, there has been a series of focused working group meetings across disciplines of the design team to determine use cases and design influences on various operational needs of the vessel.

These meetings all generated new actions, so the team was able to take their understanding of the science mission requirements and exchange that information with equipment vendors. The vendors have in return provided details of their equipment solutions so that the team can assess how this equipment will support the ship and support the science operations. It shall be noted that no down selection of vendors has been accomplished at this time. The shipyard will be reasonable to select, negotiate, and control the vendors during detail design and construction.

Additionally, Reliability, Availability, and Maintainability (RAM) plays an important part in the design process to maximize the ship's ability to operate in all expected environments. This is accomplished by developing the requirements within the Build Specification and logistics plan to maximize quality, efficiency of maintenance, and minimize downtime periods. RAM analysis began in the preliminary design process and will continues to be taken into consideration through final design and the construction period. This process was evident in design iterations during preliminary design which resulted in improving the vessel's General Arrangement, machinery plant, etc., within the boundaries of the P-Spec. An analysis of RAM for the ARV design is detailed within the RAM Plan, Reference (4).

2.3. Requirements Verification

NSF has developed and maintains the ARV Science Mission Requirements (SMRs), Reference (5), which forms the baseline for the ARV P-Spec. Traceability between the Performance Specification and the Science Mission Requirements is maintained by the ARV SE Team within the Cameo Model Based Systems Engineering (MBSE) tool. The ARV Requirements Verification Matrix (RVM), Reference (6), tracks and documents vessel design compliance against the P-Spec and is also a product of the Cameo model.

The RVM reports out the current RVM compliance status as Pass, Fail, or Not Verified for all requirements analyzed and assessed in this phase of design. For any items assigned a "Fail", planned resolutions have been identified. Some of these “Failed” requirements may be resolved with simple updates to design products, updates to the P-Spec Requirement Model to incorporate Engineering Change Requests (ECR) that have been approved, or re-design of vessel compartments or systems to meet stated requirements. Post-PDR, the Verification team continues to work with vessel design activity to review and track outstanding and new requirements and bring the RVM to closure.

2.3.1. Builder’s Specification

Technical contribution from the ARV SE and ship design team was used to populate the requirement list. ARV P-Spec requirements are used as the primary input to the B-Spec requirements. The SE team also conducted a review of the National Oceanic and Atmospheric Administration (NOAA) Agor and NOAA Class B build specifications and extracted requirement text where applicable to the construction of ARV. The B-Spec is compiled from a list of requirements developed in Cameo and exported from the Cameo model using an in-built report template. The report template in Cameo allows content updates to be made quickly and offers traceability to the parent P-Spec requirements where applicable.

The current revision of the B-Spec is P2, Reference (3), and continues to undergo reviews and subsequent changes, additions, and deletions to the requirements and document structure prior to a final version being issued.

2.3.2. Open Issues

In the previous submittal of this report, the design team identified several open issues that were planned to be resolved during the post-PDR phase. These open issues are considered relatively low risk at this phase in the design and have follow-on actions and assessments to ensure that they are addressed post-PDR. The open issues from PDR, how they were resolved, and follow-on actions are presented in Table 3. This list has also been expanded to identify any new open issues that have developed since PDR.

Table 3: Open Issues

Issue	Issue Description	Next Steps / Resolution
Anti-Roll Tank	The Anti-Roll Tank configuration and arrangement has not been finalized. This will be addressed post-PDR.	The size of Anti-Roll Tanks has been confirmed with the vendor; the tanks have been incorporated into the Roll Tank Drawing.
Bubble Sweep-down	The Bubble Sweep-down performance is pending completion of model test results. Model test results are preliminary at this time and additional hull optimization is required post-PDR.	Bubble sweep-down has been improved through new Hull Variant 11. See Section 3.4.1 for additional details.
Deck Equipment Supplier	MacGregor has withdrawn from research boat market and an alternate deck equipment supplier needs to be identified. The team is reviewing potential vendors and will engage with several post-PDR.	Multiple vendors have been identified and engaged indicating that the design supports solutions from various vendors and allows for a best value decision in a later design phase.

Issue	Issue Description	Next Steps / Resolution
Aloft Control Station	Further development of Aloft Control Station is required, including assessing whether the Pilot House and the Protected Species Observatory (PSO) can be moved forward. See Section 3.4.2 for further detail.	An Aloft Control Station has been incorporated in the General Arrangement drawing, P4. See Section 3.4.2 for additional details.
Winch Reeving	Further development of winch reeving is required. Winch reeving details will be taken to a higher level of resolution post-PDR and will continue to be refined through Final Design. This design detail will remain open through production design as specific equipment vendor selection is to be left open for the shipyard to compete with various vendors.	The solution has been vetted through an experienced vendor and a reeving solution has been incorporated into Handling Systems drawings. Continued collaboration will further evolve this design to ensure reeving arrangement aligns with winch priority operations.
Main Crane Interference	Main cranes present many interferences. A more detailed structural and deck equipment design specific to vendors will allow for working out the interferences posed by the current design. Furthermore, crane design loads are driving a very large crane design at this time and these requirements should be relaxed in the post-PDR phase. Both factors will enable a more specific detail design of the crane.	The superstructure design has been modified to better accommodate cranes and an ECR has been initiated to moderate the crane requirements.
Side A-Frame Rating	Strength member is oversized to limit strain. According to ABS Rules, this will drive the A-Frame design to excessive strength and weight. This issue has yet to be resolved with ABS.	Continue discussions with ABS and American Petroleum Institute.
02 Level Catwalk	02 Level catwalk for starboard A-frame service needs refinement. The 02 Level catwalk design will take advantage of detail structural design of the house in support of the A-frame and work in conjunction with the detail design of the Starboard Main Crane interface. This catwalk is planned to provide a walkway between the lifeboat deck and the 02 Level Aft Deck and allow for ease of service for the starboard A-frame top block.	02 Level Catwalk has been refined in the General Arrangement drawing, P4. This allows for safe and easy access to the A-Frame top when A-Frame is in vertical position.
Landing Craft	Landing craft needs to be represented in General Arrangement. Specifics of the landing craft will be provided to Munson so that Vendor-Furnished Information (VFI) can be created and applied to the General Arrangement.	Landing craft VFI has been obtained and incorporated into Handling Systems drawings.

Issue	Issue Description	Next Steps / Resolution
Incubator Location	The current incubator location is shaded by deck equipment. The flight deck is a potential location that is unshaded, however, better to find a location near the Aft Working Deck. This will be reviewed in greater detail post-PDR.	This issue is OBE through revised design of deck house, allowing additional deck area on an aft 02 deck for incubator use.
Added Fuel	Added fuel has pulled the longitudinal center of gravity (LCG) forward, causing a 0.23-degree exceedance of the 0.5-degree P-Spec trim limit. Post-PDR, this can be fixed by reassigning or reducing tanks or shifting the Longitudinal Center of Flotation (LCF) and Longitudinal Center of Buoyancy (LCB) forward for the Hull Variant 8-11 optimization work.	This has been mitigated through the development of Hull Variant 11 which increased the capacity of lower fuel tanks, allowing removal of fuel capacity held on the 1st Platform.
Transformer Sizing	The current transformers are too large to fit in the Battery Room with the full battery supply. Active front end type transformers will allow a decrease in the size of this equipment. Greater refinement of the required propulsion load and detailing of the load-shedding system will allow for correct sizing of these transformers.	The Battery Room has been relocated to accommodate the transformer sizes and to co-located batteries and battery transformers as can be seen in Revision P3 of the Machinery Arrangement.
Small Boat Docking	Develop small boat docking solution/platform for alongside operations and free vehicle grappling. There are yacht and cruise ship systems that are attractive for this purpose. These systems will be investigated in greater detail post-PDR.	This topic is still under development and requires additional study. Architectural concepts were examined to determine if there were largescale changes needed to be incorporated to ARV structure to support a waterline access solution. The preferred architectural concept includes a removeable cantilevered platform that would be bolted to the Aft Working Deck. This concept was developed in coordination with the Science Mission Coordinator and will be presented to the customer prior to DR5.

Issue	Issue Description	Next Steps / Resolution
Transducer Room	Revision P4 of the General Arrangement depicts a 4' inner bottom height IWO the Sonar Array Flat. Through development of the conduit design, it has been found that this height is insufficient for proper runs of conduit. At DR5, the SES Arrangement drawing diverges from the P4 General Arrangement by raising the inner bottom height between frame 61 and 69 to a height of 6'. This is projected to reduce fuel capacity in the above fuel tank by approximately 16 LT.	General Arrangement, Rev P5-1, which will be presented at the DR, does reflect this change. This change should converge through all impacted products in Post-RFP and Final Design Phases.
Structural Design	There are minor changes to structural design that are not reflected in the P4 General Arrangement, including addition of stanchions and shifting of hatches and doors.	Structural changes will be included within General Arrangement, Rev P5-1.
Battery Capacity	Multiple deliverables reflect space available for only 18 batteries, which equates to approximately 2MWh and is insufficient to serve as an in-port generator over a 10-year lifespan.	Battery placement for 28 batteries will be finalized in the next phase of design.
Stack Gas Analysis	At certain wind speeds and directions, there is a risk of stack gas impinging upon the upper decks.	This risk will be further quantified with a detailed CFD in future studies.
Forward Hangar	Forward Hangar gantry use cases need to be identified to determine footprint of gantry to inform extent of Forward Hangar height increase.	P-Spec requirement shall be defined, and Design Team will adjust design to meet the requirement.
Mooring Arrangement	Mooring does not meet Panama Canal Passage requirements.	Investigate options with Panama Canal Authority and provide supporting design as necessary.
Emergency Load Factors	Emergency loads currently have a load factor of 1, which may be revised based on USCG review and input. This may lead to an inaccurately sized electric plant.	Discussions with USCG Marine Safety Center to ensure the use of load factors less than 1 are acceptable for non-46 CFR emergency loads.
Picture Windows	Picture windows in the Mess, Lounge, and Conference Room on the 01 Deck are not specifically identified in DWE and present a risk to the design margins.	Perform structural design for the windows and assign weight in weight estimate.
ABS Approval in Principle (AIP) Comments	During DR5, ABS provided comments as a part of an Approval in Principle review of a select number of ARV drawings. Discussions were held with ABS regarding the comments which led to closure of four comments. All other comments remain open.	Path forward for incorporation of open ABS comments, including ongoing discussion of applicability of Special Purpose Ships (SPS) Code, has been determined. See Section 3.3.1 for additional detail.

Issue	Issue Description	Next Steps / Resolution
Deliverable Convergence with General Arrangement	Several design documents have identified factors within the P4 General Arrangement Drawing that do not allow ideal development of the product. In such cases, the discrepancy has been identified within the General Notes of the said document. At the Design Review 5, General Arrangement P5-1 will be presented which will address the aforementioned discrepancies. The Design Weight Estimate will be a notable misalignment that must be addressed in Final Design.	General Arrangement, Rev P5-1 will be displayed at DR5.
Deliverable Convergence for Products Not Revised in DR5	Only select drawings were updated to accommodate the DR5 timeframe allotted. Therefore, there are several drawings that would require revision to suit changes to the DR5 package.	Appendix 4 provides the design documents that were not revised in DR5 and indicates the nature of the change needed. Extent of changes needed and impact of changes varies between deliverables.

2.4. Key Developments from Concept to Preliminary Design

Throughout the Preliminary Design phase, the ARV has evolved from a Concept Design to a fully converged design meeting all three program KPPs. The initial Concept Design developed a 335 ft Length Overall (LOA) design, which upon further investigation during Preliminary Design did not sufficiently meet the ARV KPPs. Preliminary Design followed the design spiral process to achieve KPP compliance, convergence of the design configuration, and agreement between all design artifacts. Additionally, the ARV project team down selected three of the Design Reference Missions (DRMs) proposed by the Antarctic Sciences Section that best illustrates the required ARV performance requirements, identifying typical environmental conditions, and providing a tool for predicting the time necessary in each mission mode. The ARV project team then selected the “Thwaites Glacier/Pine Island Bay” as the representative DRM for ARV. This DRM and the selection is detailed within the DRM Study, Reference (7). Notable developments during Preliminary Design are described in more detail below. Specific details of each design review can be found in the design review presentations and meeting minutes.

2.4.1. Design Review 1

Design Review 1 (DR1) utilized a parallel approach to achieve design convergence in support of model testing. During DR1, the hull was increased 10 ft. longer and 3 ft. wider than the Concept Design hull. DR1 design development aimed to move towards agreement of the hull design, propulsion design, fuel capacity, weights, power requirements, area and volume, and the P-Spec requirements. The General Arrangement and other studies, including Speed and Powering, Electric Plant Load Analysis (EPLA), Machinery Arrangement, Endurance/Tankage, Area/Volume, and the Design Weight Estimate, were advanced utilizing the 345 ft. hull form. During DR1, focus was also placed on the science mission spaces on the Main Deck to improve workflow through science labs and support spaces, ensure aft deck functionality with the placement of cranes, and optimize site lines from control stations to working decks.

2.4.2. Design Review 2

Hull optimization has been ongoing throughout the Preliminary Design phase. For Design Review 2 (DR2), the ship length was initially set to a length of 345 ft, with a maximum draft of 28 ft to suit Palmer Station mooring capabilities. Further investigation of this requirement found that Palmer Station pier could support a deeper keel draft than 28 ft, but the turn of the bilge must begin at 28 ft draft. These constraints were used to develop a new hull form with hull shapes and features designed within the available trade space to satisfy icebreaking and open water requirements. However, upon design development and arrangement of the 345 ft hull, it was determined that the hull envelope did not support a design that met all three KPPs and other controlling P-Spec requirements.

The 345 ft ARV hull size failed to meet all KPP and range requirements as defined in the P-Spec. In addition, intact stability was identified as deficient. The bow form was sufficient to break the required 4.5 ft of ice with a properly sized propulsion plant. However, the restricted 345 ft hull had limited ability to support the ship weight, size of the larger azimuth thrusters, and larger machinery. The 345 ft hull form failed all endurance and range requirements. The volume available for fuel allowed a range of 14,203 nm, below the required 17,000 nm at 11 knots. Additionally, the ARV failed to meet the three DRM endurance requirements.

The 345 ft hull displayed significant intact stability deficiencies. The hull geometry and onboard systems significantly constrained the allowable Vertical Center of Gravity (VCG) calculated in the initial stability assessment. Limiting factors in the stability assessment included a low working deck freeboard of 10 ft which restricted the margin line immersion, and the Anti-Roll Tank which contributed to a high free surface correction. Additionally, the design weight margin was low, indicating a high-risk design.

Additional emphasis during DR2 was placed on further design of the science mission space to improve workflow through labs and arrangement of the centerboard and box keel equipment.

2.4.3. Design Review 3

Due to the shortcomings of the DR2 hull, during Design Review 3 (DR3), a hull resizing study was carried out to maintain ship stability and support the necessary equipment and fuel capacity to achieve the KPPs. The objective of the hull resizing study was to determine the minimal increase in length and beam to provide a compliant ship. Additional details of the hull size increase study can be found in the Hull Form Trade-Off Study, Reference (8).

To determine the smallest increase to accommodate the requirements, the team investigated hull length increases of 10 to 20 ft in 5 ft increments. Beam was increased for each variant to maintain the existing Length/Beam (L/B) ratio of 4.7, resulting in three new variants. Each variant was evaluated for speed/power, fuel load, weight, and intact stability. The hull form would be considered compliant when the hull displacement could support the new ship weight and the required fuel to meet the range and DRM requirements. None of the variants were deemed compliant; Table 4 presents the three variants and the rational for eliminating them as a viable hull size.

Table 4: ARV Sizing Study Initial Hull Variants

LOA (ft)	Beam (ft)	L/B	Reason for Elimination
355	75.5	4.7	Inadequate displacement and FO capacity balance + Stability
360	76.6	4.7	Inadequate displacement and FO capacity balance + Stability
365	77.7	4.7	Stability

The initial approach of maintaining the L/B ratio did not yield a solution to pass stability. To improve the stability limits, the beam would need to be increased beyond the 4.7 L/B ratio. The decision was to increase the beam to 80 ft, resulting in a 4.56 L/B ratio. Additionally, the freeboard height of the working deck was initially 10 ft. However, due to stability concerns, the freeboard at the main working deck was adjusted to 13 ft. This increase in height preserved the ability for science overboard missions close to the water while increasing stability margins and improving crew safety from onboard seas.

The resulting 365 ft x 80 ft hull form with a 13 ft freeboard achieved compliance with the icebreaking requirement, range, and endurance and satisfies stability requirements specified in the P-Spec, Reference (1). The full stability results are detailed within the Intact and Damage Stability Report, Reference (9). Icebreaking, range, and endurance results are further detailed within the Icebreaking Report and the Range and Endurance Calculations Report, References (10) and (11), respectively.

This increased vessel size provides additional non-KPP areas of opportunity including:

- Reduce vertical profile of superstructure allowing lower VCG
- Creates suitable weather deck area for desired incubation areas and for small boat complement
- Alleviate interference of accommodation ladder and lifesaving appliances
- Improves habitability spaces and allows for more single staterooms
- Along with engine size change, allows for the stack to be moved to port

In addition to hull-resizing, additional detail in DR3 was placed on developing the overboard handling system design.

2.4.4. Design Review 4

Design Review 4 (DR4) focused on convergence of the design to the P3 General Arrangement and provided a complete technical documentation Preliminary Design Review (PDR) package. Additional emphasis was placed on finalizing the direct requirement traceability from the SMRs to the B-Spec and evaluating initial Pass/Fail assessment for the RVM.

2.4.5. Preliminary Design Review

The primary purpose of the Preliminary Design (PD) Phase was to advance prior ARV conceptual design into a more mature ship design. The ARV PD effort succeeded in defining a baseline ship configuration that satisfies KPPs as well as producing internally consistent design documentation. The design is well converged to support the Science Mission Requirements. The PDR panel agreed that the ARV design is sufficient and ready to advance to the Final Design Phase. However, there were open issues in the design that had not yet been fully analyzed (see Section 2.3.2) and additional design and deliverable development are required before shipyard bids can be solicited.

2.4.6. Design Review 5

The PD phase of the ARV program included schedule and budget to continue design development after deliverables were submitted for the PDR. The goal of the post-PDR portion of the period of performance was to allow the team to close open issues and advance the ARV design towards the level of detail needed for a bid design package. The ultimate end goal (to be achieved during the Final Design phase in a future effort) is for the design package to contain enough information to enable a shipyard to develop a Firm Fixed Price (FFP) quote and schedule for construction.

A hull form improvement study was performed post-PDR to assess bubble sweep-down performance for seven (7) new hull variants. The hull variant characteristics varied by displacement, draft, longitudinal center of buoyancy (LCB), and various icebreaking angles. The variants were analyzed using Computational Fluid Dynamics (CFD) to evaluate bubble sweep-down performance and a single optimal hull variant was down selected and used for final PD Phase model testing. Additional details of the hull form optimization are presented in Section 3.4.1. In addition to hull form optimization, significant effort was focused on the general arrangement and machinery arrangement to improve the design. Significant changes to the general arrangement include improvement of sightlines, modifications to the superstructure, revised main mast design. Science spaces were modified to improve access. In the machinery arrangement, multiple electronic compartments were relocated to fit the batteries and battery transformers, as well as collocate the low voltage switchboards.

2.4.7. Bid Design Package

The bid design is the package that will be provided to shipyards for the purposes of bidding on construction of the ARV during the Final Design phase of the ARV program. The bid design includes specifications, drawings, and other data in sufficient detail to enable competing shipbuilders to prepare bids including cost of construction and schedule to perform detail design and construct and deliver the ARV. The preliminary design is a low-risk solution that is at the level of maturity necessary to begin final design.

3. Whole Ship Design

3.1. Overview

The ARV will serve as an oceanographic research vessel serving NSF's Antarctic operations. The ARV will be a platform for science with a mission of conducting scientific experiments and collecting high quality data in a safe and cost-effective way with minimal impact to the local environment.

The vessel will serve the science community in the Southern Ocean and Antarctic areas year-round for 40 or more years. The primary mission of the ship is to support multi-disciplinary science efforts including:

- Marine Geology, including coring
- Marine Geophysics
- Marine Chemistry
- Marine Physics
- Marine Biology
- Antarctic Engineering
- Atmospheric and Aerosols Sampling
- Hydrography

In addition to work at sea, the ARV will support off-vessel fieldwork on the ice, in work boats, and on islands and other land-based field camps and stations. Therefore, the vessel shall support the transport of personnel, supplies, and equipment to stations and field camps.

3.2. Key Performance Parameters

The threshold KPPs for the ARV are detailed in

Table 5. The KPPs and additional requirements for the ARV are detailed within the ARV Performance Specifications, Reference (1).

Table 5: Key Performance Parameters

Parameter	Requirement	Threshold Value	Objective Value	SMR Reference
Icebreaking	The capability to independently break ice	≥ 4.5 ft at ≥ 3 kts (Polar Class 3)	≥ 4.5 ft + 1 ft of snow at ≥ 3 kts	D.2.3.1
Endurance	Maximum endurance without replenishment	≥ 90 days underway	N/A	D.2.3.2
Science & Technical Personnel	Provisions for messing, berthing, sanitation, and scientific workspaces	Crew and science and technical personnel ≥ 55	N/A	D.2.2.1

3.3. Classification

The ARV will be classed by the ABS as a Polar Class 3 (PC3) vessel and will be a United States Coast Guard (USCG) inspected vessel under the Code of Federal Regulations (CFR) Subchapter U - Oceanographic Research Vessel. The ARV will be designed to meet the additional class notations outlined in Table 6.

Table 6: Class Notations

Threshold	Objective
ABS A1 Oceanographic	
AMS	
ACCU	
Unrestricted service	
Meet DPS-1 performance requirements	Obtain DPS-1 notation
Ice Class PC3	
CCO-POLAR (-35°C, -45°C)	
HAB+(WB)	HAB++(WB)
Meet NBLES performance requirements	Meet NIBS performance requirements
Meet CS-1 performance requirements	Meet CS-2 performance requirements
BWT	BWT+
ENVIRO	ENVIRO+
UWILD	
ESS-LiBATTERY	
HYBRID IEPS	
ILM	ILM +P

Correspondence between ARV team and ABS is documented in the Regulatory Body Communications and Correspondence Report, Reference (12).

3.3.1. ABS In-Progress Deliverable Review

Prior to PDR, a select number of deliverables were submitted to ABS for preliminary review. The purpose of this review was to gain an initial assessment of the design from a regulatory perspective and identify any issues that will need further attention/discussion. As a result of this initial review, ABS provided 44 total comments, four of which were closed as a result of discussions held with ABS. All comments and queries from ABS based on their review of deliverables are discussed further in the Regulatory Body Communications and Correspondence Report, Reference (12).

3.4. Trade-Off Studies

Trade-off assessments and studies are a key tool for evaluating the cost and capability of design alternatives for the ARV and have been performed across all ship design disciplines. ARV trade-off studies have been an ongoing part of the program since Concept Design. Table 7 lists the trade-off studies that have been performed for ARV during PD and the reports in which the results of the study are documented. All trade-off studies performed during PD not documented in a dedicated report are detailed within the Trade-Off Studies Report, Reference (13).

Table 7: Preliminary Design Trade-Off Studies and Reports

Trade-Off Topic	Report
Hull Form Dimensions	5E1-051-R001 Hull Form Trade-Off Study
Structural Framing Scheme	5E1-061-R001 Structural Design Report
Main Propulsion Selection	5E1-062-R001 Propulsion System Report
Centerboard Trade Off	5E1-052-R201 Centerboard Trade Off Study
Dedicated Harbor Generator	5E1-062-R101 Electric Propulsion Architecture Trade-Off Study Report
Bow Tunnel Thruster Size and Quantity	5E1-052-R001 Trade-Off Studies Report
Bow Azipod	5E1-052-R001 Trade-Off Studies Report
Working Deck Heating	5E1-052-R001 Trade-Off Studies Report
Aloft Control Station	5E1-052-R001 Trade-Off Studies Report
Exhaust Stack Location	5E1-052-R001 Trade-Off Studies Report
Aft Deck Freeboard	5E1-052-R001 Trade-Off Studies Report

3.4.1. Hull Optimization

The hull form went through multiple iterations to develop a set of balanced hull lines that support the ARV primary missions, including icebreaking and open water requirements. The optimization of the hull was determined using a combination of best practices, VFI, and utilizing software to verify the hull performance. The trade space that hull form optimization was prioritized included several factors: fuel capacity was the primary driver for hull size, icebreaking capability was the primary driver for hull shaping, bubble sweep-down drove additional hull shaping below the ice-belt, and open-water resistance used what was left of the trade space. Hull form optimization is further detailed in the Hull Form Trade Off Study, Reference (8).

3.4.1.1. Design Considerations

To meet the icebreaking requirements, the hull features typical icebreaker geometry which influence the bow hull form angles, entrance angle, stem angle, and flare at the forward perpendicular. This is followed by the midship angle and finished with the aft flare and rake angles along the aft perpendicular. These angles dictate the waterline area. The draft for ARV is dependent on the available piers and their draft restrictions. As stated earlier, the draft was believed to be restricted to 28 ft, due to Palmer Station mooring capabilities. However, a detailed review of the seabed around Palmer Station revealed a drop off in the seabed to a water depth of 36 ft, allowing for a deeper draft to be used in the design.

The hull form had considerable design changes after PDR to mitigate turbulence caused by bubble sweep-down that was identified as a risk during the initial model testing. Initially, the ARV incorporated a box keel below the hull bottom which would house the science mission package and attempt to keep the waterflow around the sides of the box keel, and above the bottom plating of the box keel.

Prior to DR4, a total of six variants of the box keel design were analyzed using CFD:

- Variant 1: sloped side walls to prevent the turbulent flow from continuing downwards below the bottom of the box keel, entrapping any bubble along the seam of the box keel and the hull bottom.
- Variant 2: vertical walls to determine if the depth of the box keel below the hull was enough to isolate the sensors away from the bubble sweep-down effects.
- Variant 3: utilized the existing bow with a widened ice knife and a deadrise hull bottom. The design intended for the bubbles from the hull surface to reach the widened ice knife, which would push it outboard past the furthest extents of the sonar equipment.
- Variant 4: followed the same approach with the widened ice knife and deadrise but included a fuller spoon bow. The fuller spoon bow was designed to help direct the bubble flow outboard before it reached the ice knife.
- Variant 5: included a 1.5 ft deep box keel, resulting in a total draft of 31 ft. Additionally, the 6-degree deadrise angle was included in the design, which also incorporated the new hull dimensions with a length of 365 ft and beam of 80 ft.
- Variant 6: maintained the same deadrise, but extended the box keel to 3 ft in depth, resulting in a total draft of 32.5 ft, incorporating the new hull dimensions with a length of 365 ft and beam of 80 ft.

Initial model testing showed the box keel design was not sufficient to keep the waterflow from passing over the edges of the box keel. Following DR4, the ARV hull optimization study was further continued using CFD analysis to identify opportunities to improve bubble sweep-down performance, open water resistance, and wake fraction while maintaining icebreaking performance. Four (4) primary hull variant studies were conducted, with a total of seven (7) new hull form models tested in CFD:

- Variant 7: isolation of box keel performance impacts.
- Variant 8: ice knife location and softer bilge radius.
- Variant 9: incorporate bottom deadrise.
- Variants 10, 10A, 10C, 11: incorporation of S-curves and removal of box keel.

3.4.1.2. Results

Following the hull resizing study, the ARV hull form achieves the ice breaking objective of 4.5 feet of ice and 1 foot of snow. The snow is equivalent to an additional 0.33 ft of ice thickness, resulting in ice breaking capability of 4.83 ft.

The resulting ARV hull form has a maximum length of 365 ft, total beam of 80 ft, and a total draft of 32.5 ft. This was determined to be the minimal hull size required to meet the extensive range and endurance requirements defined in the P-Spec, Reference (1), as well as support the required science missions, crew, machinery and propulsion systems to break the required 4.83 ft of total ice breaking. Table 8 displays the Principal Characteristics of the ARV.

Table 8: Principal Characteristics

Description	Value
Length, Overall	365 ft
Beam, Overall	80 ft
Draft	32.5 ft

Once the bubble sweep-down performance issues identified in Hull Variants 6 through 9 were mitigated in Hull Variants 10 the team began further optimization. Variant 10 included deep S-curves for flow redirection, Variant 10A included shallower S-curves to reduce complex curvature, Variant 10C relocated the ice knife for reduced hull volume to address stability, and Variant 11 increased length of the S-curve channel for improved flow redirection. Overall, it was concluded that Variant 11 continue into post-PDR model testing as the best balance of factors considered in the study. The hull angles for Variant 11 are shown in Table 9.

Table 9: Hull Angles

Angle	Value (deg)
Stem	20.0
Half Entrance	63.4
Flare at Stem	7[illegible].7
Flare at Midship	[illegible].4

The full CFD results are outlined in the Bubble Sweep-down CFD Report, Reference (14). New hull lines were drawn to reflect the larger hull and are shown in Reference (15). Seakeeping performance, speed and power, and maneuvering performance is documented in the Seakeeping Performance Report, Reference (16), the Speed and Power Analysis Report, Reference (17), and the Maneuvering Performance Report, Reference (18), respectively.

3.4.1.3. Model Testing

ARV model testing was performed in the HSVA model testing facility, in Hamburg, Germany and completed in May of 2023. Physical model testing of the ARV hull form in open water and ice was required to validate the hull form design. These tests were performed in accordance with the tests defined in the Model Test Program Plan, Reference (19). The tests included thruster open-water, bubble sweep-down, open-water resistance and propulsion, wake survey, ice resistance, and propulsion tests. These tests were conducted to assess compliance with requirements in the ARV Performance Specification, Reference (1).

The ARV hull form was tested in a model basin twice. The first test was performed on Hull Variant 3A. The bubble sweep-down tests indicated undesirable bubble interference with sonar operations for bubbles originating in a narrow band of the centerline of the hull. After additional hull form optimization, as described in Section 3.4.1, further testing was performed using the updated Variant 11 hull. During model testing, Hull Variant 11 was found to improve bubble sweep-down, improve ice shedding, reduce hull resistance, and have minimal impact on other considerations, such as, stability, ballast, and seakeeping. The model testing also demonstrated the ARV's ability to clear ice for the over boarding science packages and from the hull, as well as, preventing it from traveling under the ARV and past the bottom shell-mounted electronics. Overall, the ice model tests demonstrated that the ARV can clear a channel in 3.3 ft of unbroken ice.

All results and findings from model testing are detailed within the Model Test Report, Reference (20).

3.4.2. Aloft Control Station (AloftCon)

An Aloft Control Station is a small, enclosed space located high above waterline and well above the bridge. Aloft Control Stations are typically fitted on the main mast trunk to increase range of view and ability to identify lead or weaknesses in the ice for more efficient passage. Similar stations are sometimes found on other types of ships (especially fishing vessels). Aloft Control Stations are fitted on nearly all icebreaking vessels. In a multi-national discussion with Captains of ice capable Antarctic research vessels, all operators preferred an elevated Aloft Control Station for ease of selecting ice leads, providing a 180-degree forward field of view, and an adequate view of the ship's wake.

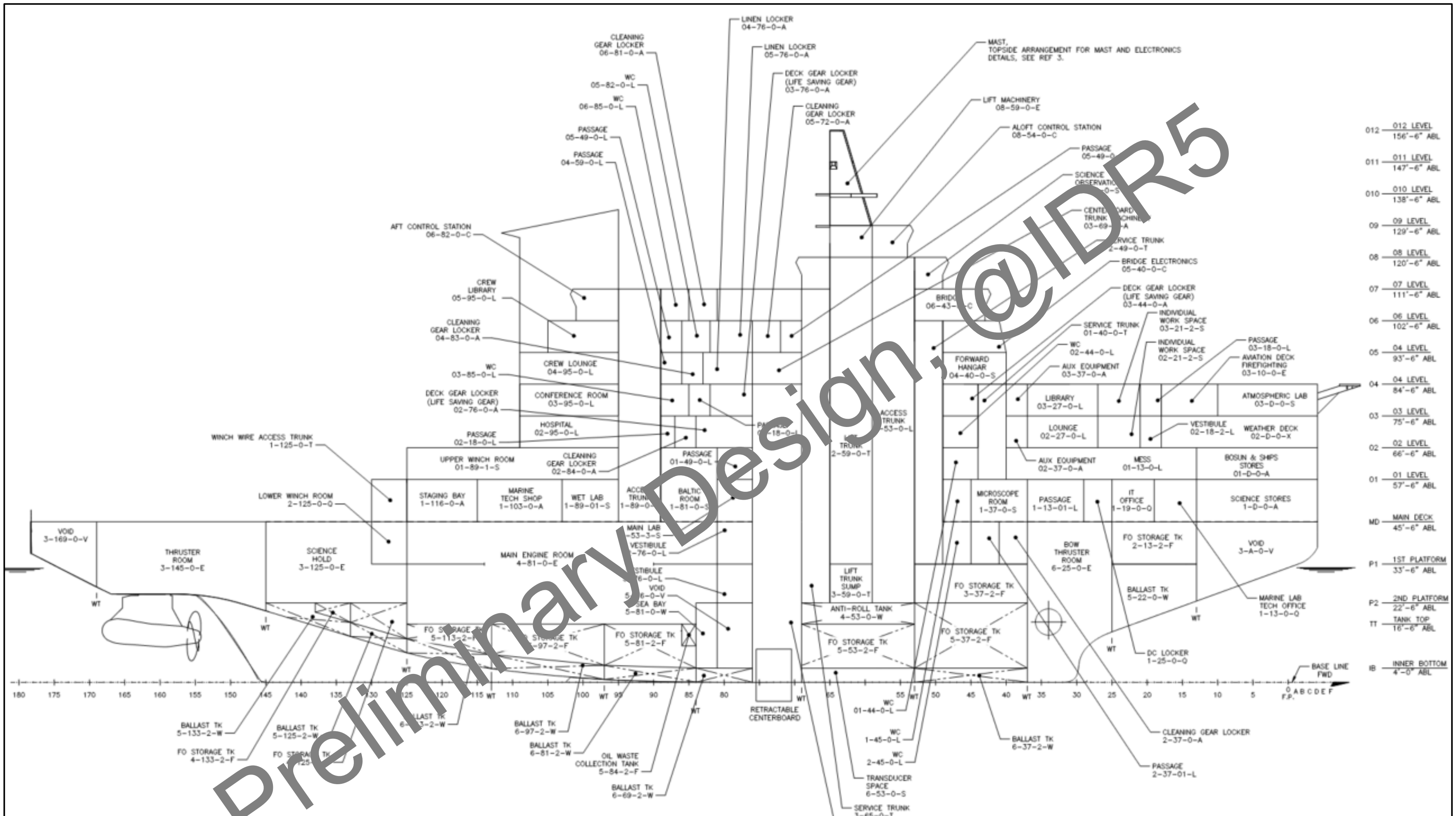
Stability concerns prevented initial design of an elevated Aloft Control Station. However, post-PDR, stability was reassessed, and an Aloft Control Station was incorporated into the ARV on the 08 Level.

3.5. General Arrangement

The ARV has an overall length of 365 feet. The ship is equipped with twin azimuthing propulsors located aft in the ship and a bow thruster located forward in the ship.

The ARV is designed with thirteen (13) decks: Tank Top, 2nd Platform, 1st Platform, Main Deck, and 01 through 09 Levels. Main science mission spaces are located on the Main Deck. Habitability spaces are located on the 01 through 04 Levels. The Main Engine Room and the Thruster Room span the 1st and 2nd Platform levels. The General Arrangement includes an atmospheric bow sprit design which has been shown effective by preliminary deck airflow analysis. The Bow Thruster Room is located on the Tank Top level. Figure 2 shows the inboard profile of the ARV. The General Arrangement drawing is Reference (21). The Topside Arrangement drawing, Reference (22), details the mast design, above-the-waterline electronics, small boats, lighting, outfitting, science and hull mechanical equipment. A 3D rending of the exterior of the ship has also been developed as Reference (23).

Figure 2: General Arrangement



3.6. Weight Summary

The displacement for the Full Load Delivery condition is shown in Table 10 and is estimated to be 13,004 LT with a VCG of 36.26 ft ABL. There are 1105 LT and 2.21 ft of weight and KG margin available. The design forecasts the Full Load at End of Service Life (EOSL) displacement to be 13,429 LT with a VCG of 36.63 ft. Table 10 summarizes the Full Load Delivery and EOSL conditions. Full details of the weight estimate, including KG margin and its associated risk assessment can be found in the Design Weight Estimate, Reference (24).

Table 10: Weight Summary

SWBS Group	Description	Weight (LT)	VCG (ft ABL)
1	Hull Structure	5,692	37.56
2	Propulsion	799	26.48
3	Electric Plant	528	39.29
4	Command & Surveillance	58	61.78
5	Auxiliary Systems	997	48.85
6	Outfit & Furnishings	563	53.72
7	Scientific	46	55.55
Light Ship		**8,684**	**39.25**
M	Margins	1,105	2.21
Light Ship with Margins		**9,790**	**41.46**
A	Full Loads with Science Loads *	3,214	20.44
Full Load Condition, BOSL		**13,004**	**36.26**
Weight Service Life Allowance (SLA)		425	-
KG SLA (Effective)		-	0.36
Full Load Condition, EOSL		**13,429**	**36.63**

D	Full Loads without Science Loads *	3,014	18.76
Full Load Condition without Science Loads, BOSL		**12,804**	**36.12**
Weight Service Life Allowance (SLA)		425	-
KG SLA (Effective)		-	0.37
Full Load Condition without Science Loads, EOSL		**13,229**	**36.49**

* Without liquid ballast

Growth margin and Service Life Allowance margin are detailed in the Design Margin Plan, Appendix B.

3.7. Green Ship Technologies

Green ship technologies that could be implemented on the ARV are continually being evaluated by the design team. While existing environmental regulations create a baseline for incorporation of green practices on the ARV, the technologies evaluated serve to build upon this baseline to align the design of the ARV with the mission of the NSF to promote the progress of science. A green ship design is based on the following principles:

- Minimize energy use.
- Minimize use of hazardous materials and environmental contaminants.
- Minimize air emissions.
- Minimize discharges to water.
- Minimize waste and scrap.
- Maximize use of recycled and recyclable material.
- Maximize use of rapidly renewable and regional materials.

This approach also allows the ARV design to be forward-looking in anticipation of future regulations. The proposed green ship technologies are detailed within the Green Ship Alternative Study Report, Reference (26).

Table 11 provides a summary of design decisions regarding green technologies that will be installed onboard the ARV.

Table 11: Implemented Technologies

Category	Technology
Hull Technologies	Hull Form balancing Icebreaking and Open Water Performance
Electric Plant	Integrated Electric Plant System
Electric Plant	Hybrid Battery
Electric Plant	Father-Son Generator Configuration
Electric Plant	Variable Frequency Drives
Electric Plant	LEDs
Propulsion Plant	Podded Electric Drive Propulsors
Auxiliary Systems	Decentralized HVAC
Auxiliary Systems	Waste Heat Recovery
Auxiliary Systems	NOVEC 1230
Auxiliary Systems	Water Mist
Pollution Control Systems	Oily Water Separator (5 ppm)
Pollution Control Systems	Ballast Water Management System (UV)
Pollution Control Systems	Sewage Treatment Plant (Biological Membrane)
Pollution Control Systems	Incinerator (Gasification System)
Pollution Control Systems	Exhaust Gas Recirculation
Pollution Control Systems	Ultra-Low Sulfur Fuel

3.8. Cyberinfrastructure

Cyberinfrastructure remained and continues to remain a pivotal platform during ARV preliminary design; not only to ensure development of a cyber-focused approach but also providing extended support to capture the potential technologies overlooked. ARV has evolved through each of the preliminary design iterations with cybersecurity and cyberinfrastructure developing parallel to the vessel and science mission design. Cyber maintained validity even as design evolved through constant collaboration, working groups, IPTs, and SME input. Cybersecurity/cyberinfrastructure efforts remained key in various design reviews, change request processes, and B-Spec development allowing cyber focus to reach well beyond cyber specific deliverables.

ARV cybersecurity requirements were developed following a moderate control baseline. This preliminary design deliverable provides the required security outline for all systems functioning on the ARV and sets future phases up for success in ensuring design and development continue to follow known cybersecurity requirements. Efforts during preliminary design provided points of inherited controls removing unneeded efforts by the following phases. The Final Design phase will continue to develop the design based on the control baseline while highlighting design support within the deliverable. Later phases will continue building on the deliverable utilizing it as support of the Authority to Operate (ATO) award.

Cyberinfrastructure was developed through the model and Shipwide Network Diagram, Reference (42). As iterations cycled through, ARV cyberinfrastructure started with systems called out in the P-Spec but quickly evolved into a logical diagram providing guidance and support for both science systems as well as vessel systems. The supporting team utilized the efforts to evaluate systems and capture overlooked capability requirements. The deliverable remains in a logical approach with the next step to support development of the physical network diagram followed by the wiring diagram. The cyberinfrastructure network diagram also leads into the hardware and software lists that will support meeting system functionality requirements in the phases following PD.

4. Hull Structure (Group 1)

4.1. Overview

The ARV structural design is required to meet the structural requirements of the P-Spec, ABS Marine Vessel Rules (MVR), as well as the additional Polar Class 3 notation. The ABS Polar Class 3 notation includes compliance with the International Maritime Organization (IMO) Polar Code for PC3.

4.2. Structure

The ARV structural configuration is described below. This configuration was selected to meet the structural requirements and ensure a producible and cost-effective design. The shipyard to build ARV has not yet been determined. Therefore, the ARV structural design is being developed without shipyard input on preferred materials, plating thicknesses, stiffener types, and sizes. However, the structural configuration used on ARV is intended to provide construction flexibility and align with typical practices across as much of the US commercial shipyard industrial base as possible.

Structural Configuration:

- Material: High Strength Steel (H36 grade steel)
- Framing System:
    - Shell and bottom plating are transversely framed
    - All other structure is longitudinally framed
- Stiffener Spacing: 2 ft
- Shell and Bottom Plating: 2 ft frame spacing
- All Other Structure: 8 ft frame spacing with 2 ft longitudinal spacing
- Typical Stiffeners: Angles
- Frames / Girders: Flange Plate or Built-Up Tee
- Ice Frames: Built-Up Tee

Further information on the ARV structural design is detailed within the Structural Design Report, Reference (27). Additional details of the ARV structure are shown in several drawings, including the Shell Expansion drawing, Reference (28), the Midship Section drawing, Reference (29), the Deck and Platforms drawing, Reference (30), and the Superstructure Structure drawing, Reference (31). Following PDR, additional structural drawings have been developed, including the Profiles drawing, Reference (74), the Typical Sections drawing, Reference (75), and the Miscellaneous Bulkheads drawing, Reference (76).

5. Propulsion Plant (Group 2)

The propulsion plant is a combination of twin azimuthing podded drive propulsors and one bow thruster. The propulsors and bow thrusters are equipped with electric motors powered from the vessel's hybrid diesel electric plant. The Propulsion System Report, Reference (32), details the design and characteristics of the propulsion plant. The Machinery Arrangement drawing, Reference (33), shows the layout of propulsion and machinery equipment with the machinery rooms. Additionally, the Fuel Oil System drawing and Lube Oil System drawings, References (34) and (35), detail fuel oil and lube oil for propulsion system support.

The High Voltage (HV) section of the electrical plant consists of two medium AC manufacturer supplied main switchboards that feed the main power to the HV switchboards of which there will be one per azimuthing pod. Each HV switchboard will receive power from one battery bank, two (2) 4053 eKW diesel generators, and one (1) 3040 eKW diesel generator. Power from the HV switchboards will power the azimuthing propellers and bow thruster motor.

The Wabtec 250 Series generator has been selected as the representative main diesel generators to complete preliminary design. A full listing of the representative equipment, manufacturers, and models are being tracked by the Master Equipment List (MEL), Reference (36). The MEL is a living document that is continually updated as the design matures, and equipment is selected. The shipyard will be responsible for actual down selection and contracting the approved manufacturer during DD&C.

6. Electric Plant (Group 3)

The Electric Plant is a hybrid diesel electric system that includes a Lithium Ion (Li-ion) battery system. This hybrid diesel electric plant with batteries has been sized to meet the unique missions of the ARV, including year-round science missions in Antarctic waters.

Electrical power for propulsion and ship service is provided by six main diesel generator sets working with two Li-ion battery packs. The supply power is distributed to the HV switchboards via power conversion equipment. The HV switchboards in turn feed the propulsion, Ship Service switchboards and battery systems.

The ARV features a seventh Emergency Diesel Generator (EDG) and its associated emergency switchboard as is required for emergency conditions on the ship.

The Li-ion battery system connected to this bus can be used to perform peak shaving operations and can replace the need for a spinning reserve on the vessel. These functions of the battery system increase genset efficiency, reduce fuel burn and reduce maintenance costs by reducing run time and allowing the gensets to run at an optimal constant speed. A secondary requirement for the battery system is for the system to be able to power the entire vessel strictly off battery power to produce a low Underwater Radiated Noise (URN), zero emission environment. This would require a more versatile battery system that can expand its capacity by installing 20-foot modular container battery systems onto the boat and wiring them into HV switchboards. A study was performed to size the batteries in the Battery Sizing White Paper, Reference (37).

The HV switchboards are designed to allow for interconnection between each other. In a low load condition where a single generator or battery bank is going to be the main supply of power for the ship, the two HV switchboards will use this interlock to supply power to the Ship Service (480V) switchboards. This allows for a split bus in higher demand operations and an interconnected HV switchboard configuration allowing for a single generator powering the ship in low demand conditions. The emergency switchboard will distribute power from the emergency generator to vital electrical loads when needed. Vital loads during an emergency are organized in such a way that they have dual power feeds supplying power. This ensures that in the event of a normal power feed loss emergency power is available within moments. Uninterrupted Power Supplies are being used to ensure operability of vital loads in the event of an emergency in addition to measured previously discussed and to ensure high quality power to sensitive equipment.

As discussed in the Electric Propulsion Architecture and Trade-Off Study, Reference (38), it is recommended to use the smallest main genset as the harbor generator. Additionally, in-port power can be provided for short periods of battery only power with the current design. Broader investigation to the battery system's behavior will be explored more in detailed design.

The lower voltage section of the electrical plant consists of power distribution for the Ship's Service loads on the vessel. Power converters and transformers connected to the HV switchboards supply power to the Ship's Service switchboards and are distributed to the Ship's Service loads. Two shore power connections, one starboard and one port, will be fed into the Ship Service switchboards. Electrical load centers will notably include the clean power distribution panels that provide power to laboratory areas and equipment where cleaner, consistent power is required. Additional detail can be found in the Electrical One Line Diagram, Reference (39) and the EPLA, Reference (40).

7. Command and Control (Group 4)

7.1. Command and Control Systems

Propulsion controls are provided and integrated through an ABS-approved Integrated Bridge System (IBS). An independent autopilot system will be provided as a backup to the autopilot function of the Dynamic Positioning System (DPS).

An Integrated Machinery Automation Control System (IMACS) will meet all requirements of ABS Automatic Centralized Control Unmanned (ACCU) notation and will interface with the machinery plant onboard the vessel. Machinery will also have manual controls and physical indicators and gauges, allowing operation independent of the IMACS.

7.1.1. Dynamic Positioning System (DPS)

The vessel will be equipped with controls to meet the ABS DPS-1 classification. The DPS will have the following control modes:

1. Autopilot mode
2. Joystick mode
3. "Green Control" mode
4. Fully automatic control mode

For sizing thrusters and equipment, a DP capability analysis was performed using the preferred DP system supplier, Kongsberg's calculations. Details of the analysis are shown in the ARV DP Performance Report, Reference (41). The DP analysis of the ARV thruster system has shown that the system can satisfy the DP requirements specified in Reference (1).

The system can hold station within 16.4 ft in both Sea State 4 and 5 in the best wind and wave heading of 0 degrees, in all current headings. Reference (1) requires that the ARV hold station at the best wind and wave heading combination. Therefore, based on analysis, when station-keeping is critical to operations, the vessel will maintain a heading within the acceptable range in Sea State 4 and 5.

7.2. Navigation Systems

The IBS provides integrated propulsion machinery controls, control and monitoring functions, and navigation instrumentation. Multifunction displays will be provided as the interface to the IBS.

7.2.1. Lighting

Navigation lights will be provided and arranged in compliance with USCG rules, Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), and UL 1104, *Standard for Marine Navigation Lights*.

A manually operating flashing red light will be installed to facilitate escort operations in ice, and a signal lantern in accordance with IMO International Convention for the Safety of Life at Sea (SOLAS) will be installed.

A minimum of two 1000-watt xenon searchlights will be provided. These portable searchlights can be installed in any combination to the two stands on each side of the Bridge top. At least two

LED floodlights, or “Ice Lights”, will be provided to illuminate the area in front of the bow of the vessel.

7.2.2. Radar Systems

The ARV is equipped with four complete radar systems: two 25 kW X-Band radar systems, one 30 kW S-Band radar system, and one stand-alone Polarimetric Ice Navigation Radar.

7.3. Communications

7.3.1. Interior Communications

The internal communications systems will include the following:

1. Voice Over Internet Protocol (VOIP) telephone system
2. Public address system
3. General Alarm System
4. Entertainment system
5. Ship alarm and monitoring system
6. Damage Control, including fire and gas detection system
7. Bridge equipment
8. CCTV
9. VHF Radio
    a. 2x Antenna on Mast for off-ship communications
    b. 3x Antenna Topside for on-ship communications (to limit blockage zones)
10. Sound powered telephone
11. Local Area Network (LAN)
    a. WiFi system, with coverage extending off the vessel (port and starboard amidships)

7.3.2. Exterior Communications

The ARV will be outfitted with an integrated suite of satellite communications equipment.

Primary high-speed Internet access will be provided by a Very Small Aperture Terminal (VSAT) system. Two VSAT antenna are provided to provide 360-degree coverage across the horizon, limiting blockage zones. Above 70 degrees latitude, internet connectivity will be provided by ganged systems via low earth orbit satellite systems. Because the operating area and schedule of the ARV may require it to be outside of VSAT footprints, an Iridium or Inmarsat™ antenna or FleetBroadband™ will also be included.

Exterior communications will include provision for obtaining weather satellite imagery and ice imaging. Specifically, exterior communications include:

1. 2x VSAT Antennas (for 360-degree coverage; limited blockage zones)

2. 1x FleetBroadband™ Antenna at top of Mast (for 360-degree coverage)
3. 1x GMDSS INMARSAT Antenna
4. 2x GMDSS HF Antenna
5. 2x GMDSS VHF Antenna
6. 2x GPS Antenna
7. 5x VHF Antenna
8. 1x UHF Antenna
9. 1x AIS Antenna
10. 2x Satellite Receivers (for NOAA / NASA HRPT, DMSP, MODIS, and Aqua data paths)
11. 1x Long Range Identification and Tracking
12. 4x Uncrewed Aerial System Antenna (90-degree coverage each; near Mast top)
13. 2x Global Xpress (GEO) Antenna
14. 1x VesselLINK (LEO) Antenna
15. 2x StarLink (LEO) Antenna
16. 1x Entertainment System Antenna
17. 2x WiFi Antenna (external on port and starboard sides)

7.4. Cyber Network Infrastructure

The shipwide network has developed via a collaborative approach support by the Cybersecurity IPT and Network Design WG. The effort has ensured consistent focus on vessel functionality, science mission needs, lessons learned from prior research vessel networks, along with meeting cybersecurity measures. The deliverable supplying network design is the ARV Shipwide Network Diagram, Reference (42), in addition to support through the B-Spec. The current Shipwide Network Diagram remains in a logical overview and highlights three security boundaries – Vessel, Science Mission, and Guest, providing opportunity to promote functionality while supporting security measures. The logical network diagram provides the foundation of moving into a physical network diagram in the following phases with all known systems containing an operating system and/or potential to connect to a network connected system depicted.

The backbone of the shipwide infrastructure is supported within a server room on the Main Deck. In addition to the server room on the Main Deck, a dedicated Heating, Ventilation, and Air Conditioning (HVAC) system has been designed in a neighboring space to the server room along with an Information Technology (IT) Office to support network and computer infrastructure. Well-defined interconnectivity requirements remain highlighted within the ARV Shipwide Network Diagram solidifying cross network boundary functionality needs such as Ultra-Short Baseline (USBL) interfacing with DPS.

8. Auxiliary Systems (Group 5)

8.1. Overview

The ARV includes multiple auxiliary systems:

Ballast System: The ballast system facilitates ballasting of the vessel to maintain draft, trim, and heel while underway. Details of the ballast system are located on the Ballast System Drawing, Reference (43).

Bilge System & Oily Waste System: The bilge and oily water systems collect, process, and transfer the bilge water and oily water generated onboard. Details of the bilge system and oily waste system are located on the Bilge and Oily Waste System Drawing, Reference (44).

Chilled Water System: Chilled water provides cooling for the vessel's air conditioning and refrigeration systems. The chilled water system consists of three chilled water plants that service the chilled water consumers. Details of the chilled water system are located on the Chilled Water System Drawing, Reference (45).

Control & Ship Service Compressed Air System: The compressed air system provides starting air for the main diesel generator engines, ship service air for tools and ship service demands, and air for control air and for laboratories air demands. Details of the compressed air system are located on the Control and Ship Service Compressed Air System Drawing, Reference (46), and the Starting Air System Drawing, Reference (47).

Deck De-icing: Deck heating is provided for all exterior working decks and the aviation deck to maintain the decks clear of ice and snow. The ARV is utilizing zonal deck de-icing to provide added flexibility in system operation, allowing for minimization of electrical loads associated with the deck de-icing system as specific deck may be de-iced only when the area is needed to be ice-free. Details of deck de-icing are located on the Deck De-icing Plan, Reference (48).

Firemain: The firemain system is a 'dry' type with all piping sloping back to the pump discharges, where drain valves are installed. Each fire pump that serves the firemain takes suction directly from the seabay through a strainer. The firemain also supplies emergency backup water to the fixed-based local fire-fighting system. Details of the firemain are located on the Firemain Drawing, Reference (49).

Fire Extinguishing System: Fixed fire extinguishing systems are installed to protect Category A machinery spaces, flammable or hazardous materials storage spaces, battery storage areas, enclosed UAV facilities, and other spaces in accordance with regulatory requirements. A water mist fire suppression system is provided to the Main Engine Room, Battery Room, and Auxiliary Machinery Space. Gaseous firefighting is provided to the Science Hazmat Locker, Pain Locker, Thruster Room, Main Engine Room, Bow Thruster Room, and Aviation Hangar. Details of the fire extinguishing system are located on the Fire Extinguishing System Drawing, Reference (50).

Freshwater Cooling System: Freshwater cooling system is provided for machinery cooling and is divided into separate systems for diesel engine jacket water cooling, propulsion machinery cooling, and auxiliary machinery cooling. Details of freshwater cooling are located on the Freshwater Cooling System Drawing, Reference (51).

Heating, Ventilation, and Air Conditioning (HVAC): HVAC is provided in the accommodation and public spaces, labs, working spaces, control spaces, electronics spaces, galley, dry stores, science stores, and passageways in air-conditioned areas. All other interior spaces that are not air-conditioned, excluding tanks and chain lockers, are mechanically ventilated and heated. Details of HVAC are located on the HVAC Drawing, Reference (52).

Mission Fuel System: Fuel oil may be carried on the ARV to allow the transport of fuel oil for scientific purposes. The Mission Fuel System will allow the carry and transfer of cargo fuel oil on and off the ship. Details of the cargo fuel system are located on the Mission Fuel System Drawing, Reference (53).

Potable Water Service System: The potable water system is designed to transfer, store, heat, and distribute fresh water to various ship systems. Details of the potable water system are located on the Potable Water Service Drawing, Reference (54).

Roll Tank System: The roll tank system features active controls on the air crossovers, a means for filling roll tanks with freshwater for operation, the option for using ballast to fill or empty the roll tanks, and connection to the emergency bus to protect against extended periods without roll migration if there is a loss of vessel power. Details of the roll tank system are located on the Roll Tank System Drawing, Reference (55).

Science Seawater System: The science seawater system provides ambient temperature seawater to science labs and to lab van sites on deck while the vessel is underway or stationary. The science seawater system consists of two seawater systems, one for science flow through needs and one for incubators. Details of the science seawater system are located on the Science Seawater System Drawing, Reference (56).

Seawater Service: The seawater service system is designed in accordance with ABS Ice Class PC3 notation. The seawater service system includes sea chests, a sea bay, pumps, and strainers. Details of the seawater service system can be found in the Seawater Service System Drawing, Reference (57).

Sewage System: The sewage system includes storage tanks, pumps, a marine sanitation device, and a vacuum collection system. The sewage treatment system consists of a sewage vacuum collection system that discharges to a sewage tank. Details of the sewage system are located on the Sewage System Drawing, Reference (58).

Waste Management: Pollution control and waste management is a key feature of the ARV. Details of pollution control and waste management are provided in the Pollution Control Systems and Waste Management Report, Reference (59).

8.2. Winterization Strategy

A Winterization Plan is required to be submitted to ABS for review detailing the methodology for de-icing, anti-freezing, and HVAC systems to obtain PC3 notation. The Polar Operations Design Features Report, Reference (73), has been developed to serve as a basis for the final Winterization Plan that will be submitted to ABS.

The ARV must be designed with means for anti-icing or de-icing on the following:

- External decks and bulkheads
- Radar antenna, communication antenna
- Navigational lights, search lights

- Lifesaving appliances
- Vents for tanks
- Escape route deck surfaces, rails, doors, and stairs
- Fueling stations
- Mooring equipment and controls

Additional means to prevent freezing are required on the following systems:

- Firefighting systems in tanks, cargo spaces, or on deck
- Fresh water lines in tanks, cargo spaces, or on deck
- Sanitary drains, black and grey water lines
- Ballast lines, in tanks, cargo spaces, or on deck
- Fuel and oil lines
- Ballast, fresh water, fuel, and oil tanks (and any tank and piping containing a fluid susceptible to low temperatures)
- Combustion air and ventilation air intakes

Means of heating and ventilation are required in the following areas:

- Crew and passenger cabins
- Public areas in accommodation
- Enclosed working spaces
- Combustion air
- Engine rooms
- Steering gear compartment
- Pump room

9. Outfitting and Furnishings (Group 6)

9.1. Overview

All outfitting materials and furnishings will be of commercial marine quality and suitable for the intended use.

Outfitting components, including ship fittings, rails, stanchions, and lifelines, joiner bulkheads, windows, preservatives and coatings, deck coverings, insulation, living spaces, service spaces, working and science spaces, storage spaces, and workshops will be provided per the ARV Performance Specification, Reference (1).

The Lifesaving drawing, Reference (60), details escape routes and locations of lifesaving appliances, such as ladders, lifejackets, and lifebuoys. Lifesaving equipment also includes the fast rescue boat with a dedicated davit, two (2) fully enclosed lifeboats, and six (6) life rafts in sheltered pockets.

The Insulation drawing, Reference (61), provides details of thermal insulation and acoustic insulation. The Anchoring drawing, Reference (77), has been developed to provide the anchor compartment layout and equipment details. The Mooring and Towing drawing, Reference (78), provides the mooring and towing equipment arrangements.

9.2. Habitability

Reference (1) requires the ABS notation HAB+(WB) as a threshold requirement and HAB++(WB) as an objective requirement, as well as specific Americans with Disabilities Act (ADA) requirements that can be applied to the ship. ABS guidelines segment the habitability requirements into two major components: accommodation areas and ambient environment. The Human Systems Interface (HSI) Report, Reference (62), details the requirements necessary to provide a safe, working interface between the crew of the ARV and the vessel itself.

9.2.1. Habitability Study

A Habitability Study, Reference (63), was conducted to evaluate the following areas of the vessel:

- General Habitability Considerations
- Access and Egress
- Crew and Scientist Staterooms
- Sanitary Spaces
- Food Service Spaces
- Recreation Areas
- Laundry Spaces
- Medical Spaces
- Scientific Mission Spaces

As a result of the assessments performed in Reference (63), most habitability requirements were found to be the same for both the threshold HAB+(WB) notation and the objective HAB++(WB) notation.

9.2.1.1. Ambient Environment

The ambient environment pertains to the environment that the crew is exposed to during any periods of work, leisure, and rest. ABS provides guidance in four general categories of ambient environment:

- Whole-body Vibration and Acceleration
- Noise
- Indoor Climate
- Lighting

9.2.1.2. ADA Compliance

The P-Spec, Reference (1), requires the vessel meet ADA guidelines where feasible. The ARV will be designed to be ADA compliant in the following locations:

- A minimum of one stateroom (to accommodate 2 persons)
- All scientist lounges and libraries
- Spa and Gym
- Mess
- Scientist Laundry
- Lab bench heights and reaches
- Elevators for wheelchair access to all science decks

Additionally, the following accommodations will be provided:

- Drinking fountains on ADA accessible decks to be ADA compliant
- A minimum of one ADA compliant public head on each ADA accessible deck

Other ADA considerations to be evaluated during the design of the ARV include design of elevators and provisions to accommodate transit of those with disabilities through the vessel during fire and emergency, as well as abandon ship events.

9.3. Noise Control

Noise has been mitigated throughout the ARV through rational placement of equipment and spaces to minimize noise transmission to functional areas of the ship. Noise Control Engineering, LLC (NCE) performed initial analyses for noise and vibration for the lengthened ship. This included compartment noise predictions for broad groups of compartments based on their location on the vessel. The initial results predicted several areas of concern using baseline outfitting. These areas include the Main Deck labs, spaces directly above the Engine Room, and the 02 Aft Deck. These exceedances can be mitigated using deck treatments and insulation.

The analysis for airborne noise is shown in the Airborne Noise Report, Reference (64). The analysis for vibration is shown in the Vibration Report, Reference (65). The analysis for underwater radiated noise and sonar self-noise is shown in Underwater Radiated Noise and Sonar Self-Noise Report, Reference (66).

10. Science Mission (Group 7)

10.1. Overview

Safely supporting NSF science operations are the primary objective of the ARV. The design and integration of science systems are divided into the following design areas:

- Overboard Handling Systems
- Science Laboratories
- Science Support Spaces (Holds, Lockers, Shops)
- Science and Cargo Vans
- Science Workboats and Handling Systems
- Science Network Infrastructure
- Science Acoustic Systems
- Centerboard Design
- Science Seawater Systems

The design and integration of science systems into the overall vessel design supports the successful science mission execution and performance as specified in the ARV Science Mission Requirements (SMR). The science systems integration is guided by the P-Spec, Reference (1). The ARV HM&E IPT employs an interdisciplinary and iterative design spiral methodology for science system design integration. Particular attention is given to design areas that impact multiple engineering disciplines and different areas of the vessel including workflow between science working decks and science laboratories, science underwater sensor integration with the hull form and hull structure, and inter-compartment systems such as the science seawater system, science wireways, and science network infrastructure. Full details of the science systems design and integration can be found in the Science Systems Report, Reference (67).

10.2. Overboard Handling Systems

The ARV science overboard handling systems integrate winches, A-frames, cranes, and a Launch and Recovery Systems (LARS) to comply with the Performance Specification, Reference (1). The science winches are located in two winch rooms: the Lower Winch Room and Upper Winch Rooms. The Lower Winch Room is located aft of the Main Engine Room below the Main Deck on the First Platform, starboard side, between Frames 114 and 123. The Upper Winch Room is located on the 01 Deck, starboard side, between Frames 83 and 112 aft of the Baltic Room and inboard of the Side A-Frame.

There are two types of winches on the ARV, direct drive and traction winches, designed to support a broad range of scientific sampling endeavors. All ARV winches are active heave compensated. Science over-boarding is supported by four specialized science winches in the Upper and Lower Winch Rooms. Primary controls for the science winches are in the 01 Winch Control Room (also referred to as the Deck Operations Station). The primary control for the conductivity-temperature-depth (CTD) winch is the Baltic Control Room located off the Baltic Room with a clear view of the ship. Secondary controls for the CTD winch and LARS are in the Deck Control Station. The four (4) science winches are: Hydrographic winch, Oceanographic winch, CTD winch, and a Coring winch. The CTD and Hydrographic winches are similar for commonality of parts and redundancy for uninterrupted operations. Additionally, the Main Deck features a 2’ x 2’ standard UNOLS bolt pattern for securing mission specific winches and over-boarding systems and removable bulwarks to facilitate over the side operations.

ARV is fitted with four (4) knuckle boom cranes. The two large knuckle boom cranes will match in type and will support cargo/container operations and over-boarding. The two smaller cranes will match in type, and one will be mounted to serve the forward aviation deck. The second smaller crane will be a portable crane capable of utilizing the ships bolt pattern to support equipment staging and utility needs on the Main Deck, as well as the over-boarding of light sampling gear. The three fixed mounted cranes will be personnel rated for lifting. The knuckle boom aspect improves both safety and control by minimizing the amount of exposed whip and potential for swinging.

There are two A-frames located on the Main Deck to serve the Aft Working Deck and Starboard Working Deck. The Stern A-Frame supports all over-boarding and towing operations astern and is primarily served by the Oceanographic Winch. The Stern A-Frame will support strength members up to 120,000 lb. break strength with 30 feet of vertical clearance and is rated to support the MeBo200 Seafloor Drill system. Support activities include operations such as net tows and bottom trawls, coring and dredging operations, and the deployment and recovery of seismic equipment, geo-technical drilling systems, large Remotely Operated Vehicles (ROV) and large Autonomous Underwater Vehicle (AUV) systems. It will also include a “servicing position” to facilitate block maintenance and change out, without the need to go aloft. The A-Frame will have integrated tugger/utility winches to support load trading, over-boarding, and deck operations.

The Starboard A-Frame supports general over-boarding and towing from the Starboard side deck, as well as serving as a backup load handling solution for the CTD rosette. The A-Frame will support a wide range of vertical casting and towing operations on the Starboard side, although sometimes side towing in ice conditions can be impractical. The Starboard A-Frame can be served by the Coring Winch, the Hydrographic Winch or the CTD Winch. The location and rating of the Starboard A-Frame is particularly driven by the need to support up to a 50-meter Piston Corer on the Starboard working deck using a large synthetic strength member. This strength member will be sized to minimize recoil and have a breaking strengthen of over 200,000 lbs.

The Piston Coring LARS consists of a truss system, to support the length of the core barrel, and a handling system to maneuver the truss between vertical and horizontal as well as in board and outboard. The Piston Coring LARS is located just aft of the Baltic Room on the Starboard working deck. The Piston Coring LARS features the ability to de-couple the head weight from the barrel and remove/handle liner sections from the top of the barrel directly into the Baltic Room in the shelter of the house rather than the Starboard quarter. The Baltic Room/CTD LARS is a positive capture articulating boom assembly located in the Baltic Room overhead and designed specifically for the CTD rosette. It is primarily served by the CTD Winch but can also be served by the Hydrographic Winch, both located in the Upper Winch Room.

The aft Working Deck handling system will all be served from a common hydraulic power unit (HPU), with the capability to run the two largest consumers (likely main crane and aft A-Frame) concurrently at 60% maximum speed. The forward crane and portable crane will each be served by their own independent HPU. Additional details of the Overboard Handling System can be found on the Handling Systems and Scientific Package Deployment drawing, Reference (68).

10.3. Science Laboratories

All laboratories, except for the Cold Storage Laboratories and the Atmospheric Lab, are located on the side-shell of the vessel, fitted with portholes for natural light. Flexibility is provided in laboratory outfitting and arrangement for the ARV to adapt for future technologies. Details of the ARV science laboratories outfitting, and arrangement are shown on the Science Space Arrangement Drawing, Reference (69).

Efforts were made to locate the main science working spaces on the Main Deck with a continuous and unobstructed passageway running from the forward science stores to the working deck. The passageway is wide enough to accommodate a standard pallet jack to facilitate movement of samples, equipment and supplies fore and aft. The wettest spaces aft and the driest spaces forward. Proximity was also considered to ensure an efficient and smooth movement of science samples from the working deck through the lab space. Double doors to facilitate equipment and stores loading/unloading are provided for all science spaces located on the Main Deck. Access to the working deck utilizes large watertight double doors.

The Aquarium Room is the wettest space accommodating large and small free flowing aquaria with large direct access to the starboard working deck and service from the science and incubator seawater systems. It will have a grated deck and sediment traps for efficient drainage during sampling and processing efforts.

The Wet Lab sits between the Aquarium Room and the Baltic Room with direct access to both as well as large direct access to the starboard working deck/A-frame area. It is a configurable, wash down capable wet workspace with extra sink capacity and sediment traps to support sample processing.

The Baltic Room is located between the Wet Lab and Main Labs with direct access to both as well as the main passageway. The Main Lab is large centrally located, highly configurable space between the Baltic Room and the Science Operations Center (SOC) and across the passageway from the Hydro and Biology/Chemical/Analytical Labs. Efforts were made to ensure the Main Lab could receive samples from the working deck through the Baltic Room with ample space to maneuver long piston core sections for subsampling or storage directly across the passageway in the Cold Storage Lab.

The Cold Storage Labs are located aft of the Hydro Lab and across from the Main Lab. The labs can be set up for cold work or sample storage and are co-located near the Liquid Nitrogen Plant next to the stack of the main passageway.

The Hydro Lab has proximity to the Baltic Room, Main Lab, and Biology/Chemical/Analytical Lab. The science seawater system serves the Water Wall with fixed flow through sampling instrumentation and contains a space for a salinometer room. Attention was spent to ensure that the space was large enough to accommodate both current and future flow through instrument needs as well as mission specific instruments while maintaining a configurable lab space.

The Biology/Chemical/Analytical Lab is between the Hydro Lab and the Computer/Electronics Lab. This lab supports a variety of disciplines in a configurable space, but it is also located furthest from the live animal/wet spaces to better isolate fixatives and other chemicals.

The Computer/Electronics Lab is a configurable dry space to support scientific electronics, instruments and sensor assembly, servicing and trouble shooting. It has bench space to support

CTD assembly, battery charging, acoustic release servicing, camera/video systems and other housed assemblies. It will also support photo/video editing, 3-D printing, and oversized plotters.

The SOC is located between the Main Lab and the science servers and across from the Computer/Electronics Lab. The SOC allows the Chief Scientist and Watch Leads to monitor and direct active science operations. It contains multi-monitor displays, the Watch Desk, a large Chart/Display table, Science System racks, a multi-beam workstation, and multiple smaller science workstations to support the team on watch at the time. Its central location near the Hydro and Biology/Chemical/Analytical Labs, Electronics Tech Shop, Computer/Electronics Lab, Server Room, Transceiver Room, and Science Stores make the SOC the focal point of the Science Mission operation.

Two (2) additional laboratories are provided but are not required to be located on the Main Deck:

- Atmospheric Laboratory (located on 03 Level and in proximity to the atmospheric sampling platform for air and aerosol sample)
- Meteorology Laboratory (located on 07 Level below the main science mast with access to the wire ways for sensors and instruments)

10.4. Science Support Spaces

Details of the ARV science support spaces outfitting and arrangement are shown on the drawing 5E1-601-D001 Science Space Arrangement Drawing, Reference (69).

The Science Main Deck is served by the Main Centerline Hallway which reaches from the aft working deck to the large door accessing the Science Stores Area. The hallway is designed to allow mobility of a pallet jack from bow to stern of the ship. The large Science Stores space is provided forward of the collision bulkhead. The entrance to the Science Stores is adjacent to the Science Office for the Lab technician with maintenance space and tools.

The Electronic Tech Shop is located on the Main Deck, forward of the Computer/Electronics Lab. It provides workstations and bench space for Electronics Techs to maintain and repair sensors and instruments for shipboard data collection and field electronics.

The Server Room is oversized for the current electronics complement, which provides storage for electrical and electronics supplies and provides space for anticipated future growth of the ship's server complement.

The Transceiver Room is situated above the Sonar Cable Trunk and Transducer Room. The space supports full sized racks and floor space for transceiver mounting with efficient cable routing to the Transducer Room below and network cabling to the SOC.

The Baltic Room provides a sheltered space amid ships to support water column sampling and profiling using the CTD rosette. The CTD LARS deploys the rosette from the overhead through a large pantograph door in the side shell. When the CTD is deployed, the lower pantograph door can be raised to protect against boarding seas. When the CTD rosette is recovered to deck, the pantograph door can be closed for complete weather protection for sampling, servicing, and storage.

The Staging Bay is aft of the Aquarium Room on the starboard side of the ship, it has large doors accessing the Starboard Working Deck and the Aft Working Deck. It provides a sheltered location for the staging, repair, and maintenance of deck sampling equipment between deployments. It also supports lockers for deck and rigging equipment and tools. The door to the Working Deck is sized such that either of the large Science workboats may be brought partially through the door for maintenance or equipment installation in inclement weather. The large door into the Staging Bay is supported by the Starboard Main Crane.

The Science Observation Deck (SOD) is located on the 07 Deck, above the Bridge and provides wide views for observation of marine mammals and sea birds and includes the Meteorological Lab within. From within the SOD, a 180-degree forward view of the ocean is provided.

The Aviation Hangar is a large multi-purpose space aft of the Aviation Deck for the storage, maintenance, and deployment of a wide range of unoccupied aerial systems for both science support and operational ice reconnaissance. This hangar also supports science sampling efforts on the fore deck in vans or instrument arrays.

10.5. Science and Cargo Vans

The ARV is required to accommodate at least 20 scientific and laboratory vans. The current van storage plan includes two (2) positions forward on the aviation deck, eight (8) vans double stacked in the hold, and a minimum of ten (10) positions on the main working deck. The sheltered Lab Van Garage is located forward on the main working deck and can accommodate three (3) lab vans with direct access into the ship. This can support mission specific laboratory or storage needs. No radiological sources are allowed within the skin of the ship. Use of radioactive isotopes or cesium source activities are limited to Rad Vans or Core Scanning Vans. These specially designed lab vans are located only on the main working deck and do not have direct access to the ship to prevent potential radiological contamination. Active Lab Vans would only be supported on deck, however vans stored in the hold will have access to end doors and electrical service is provided to support Refrigerator Vans.

The vans stored within the Science Cargo Hold are served through the Science Cargo Hold hatch. Once the vans are stacked two high and dogged together, they will be elevated on the van roller track, and tugged to the port or starboard side. Once in position, the roller track will be lowered locally, allowing the two high container stack to be captured by the hold's locks. This process will be repeated for storage of all eight Science Cargo Hold containers. The two (2) vans on the aviation deck will require a shore-based crane to load and unload.

Container load out is shown in the Handling Systems and Scientific Package Deployment drawing, Reference (68).

10.6. Science Workboats and Handling Systems

The ARV will have a total of four (4) dedicated science boats: two (2) 20-to-30 ft. Rigid Hull Inflatable Boats (RHIBs), one of which will be in a dedicated davit; one (1) Scientific Survey Workboat, with a dedicated davit; and one (1) Landing Craft Workboat.

The diverse makeup of the small boat complement on ARV is necessary to support a broad range of scientific activities and observations off ship. The small boats are the primary method of access to water, land, and sea ice for off-ship scientific endeavors. The smaller RHIBs need to be simple, open, multi-use platforms that maximize space available for science equipment and personnel. The Scientific Survey Workboat will be outfitted with sampling and survey equipment and sonars with a requirement for a 12-hr. endurance. The Landing Craft Workboat will need to be a robust and capable solution, as it is the only method of transporting bulky science cargo from ship to shore.

10.7. Science Network Infrastructure

The Science Mission Network Infrastructure design is shown on the ARV Network Diagram, Reference (42). The network diagram is the primary design artifact for the ARV network design with the Science Mission Network being one of three networks, in addition to the Vessel Network and the Guest Network.

The Science Mission Network electronics racks are co-located with the vessel electronics racks in the Server Room located on the Main Deck. Based on customer feedback, the electronics racks are located on the Main Deck in the vicinity of the Science Laboratories and Science Support Spaces to facilitate workflow and science wireway routing between the Science Mission Network electronics racks and science spaces. The Meteorology Lab and the Atmospheric Lab will also have electronic racks that can be used to support the Science Mission Network needs. The ARV will have dedicated Science Network cableways to ensure separation from power cables, to facilitate future network cabling changes, and to make it easy to run temporary data cable runs as needed to support science.

10.8. Science Acoustic Systems

The requirements for the Science Acoustic Systems that support the ARV marine science missions are provided in the ARV P-Spec, Reference (1). The arrangement of the underwater sensors is shown on the Scientific Electronic Arrangement Drawing, Reference (71). There are several spare sonar transducer wells on the hull bottom and there will be space reserved within the transducer cable trunk for the installation of additional sensors. Transducers on the sonar flat will be mounted behind ice windows for protection.

The location of the Transceiver Room is vertically aligned with the Transducer Room to minimize the cable run length and cable bends required for routing between the transducers and the transceivers; this arrangement is in accordance with the manufacturer recommendations. The science underwater sensors are listed in Table 12.

Table 12: Science Underwater Sensors

Description	Quantity	Model No.	Manufacturer	Notes
Deep Water Multi-Beam	1	EM 124	Kongsberg	Mounted on Sonar Flat, Transmitter
Deep Water Multi-Beam	1	EM 124	Kongsberg	Mounted on Sonar Flat, Receiver
Shallow Water Multi-Beam	1	EM 712	Kongsberg	Centerboard Mounted, Transmitter
Shallow Water Multi-Beam	1	EM 712	Kongsberg	Centerboard Mounted, Receiver
Acoustic Doppler Current Profiler (ADCP) 38 kHz	1	OS 38	Teledyne RD Instruments	Mounted on Sonar Flat
ADCP 75 kHz	1	OS 75	Teledyne RD Instruments	Mounted on Sonar Flat
ADCP 300 kHz	1	Workhorse Mariner	Teledyne RD Instruments	Mounted on Sonar Flat
Sub-Bottom Profiler 3.5 kHz	1	SBP 29	Kongsberg	Mounted on Sonar Flat

Marine Biology Echo Sounder/Sonar 18 kHz	1	EK80	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 38 kHz	1	EK80	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 70 kHz	1	EK80	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 120 kHz	1	EK80	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 200 kHz	1	EK80	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 333 kHz (Not required)	1	EK80	Kongsberg	Centerboard Mounted
Ultra-Short Baseline Transceiver	1	HiPAP 502P	Kongsberg	Mounted aft of Centerboard
Acoustic Release Transponder 12 kHz	1	cNode	Kongsberg	Centerboard Mounted
Hydrophone	5	TC4032	Teledyne RD Instruments	Sonar Flat and Centerboard Mounted
Forward Looking Camera	1	TBD	TBD	TBD Mounted
Forward Looking Sonar	1	TBD	TBD	Centerboard Mounted

10.9. Centerboard Design

The centerboard allows the scientific underwater sensors to be deployed below the vessel keel outside of the turbulent flow created by the vessel while underway to improve the functionality of the sensor readings. This arrangement also allows the underwater sensors to be raised above the vessel keel inside the centerboard trunk for protection from ice damage when the vessel is operating in ice-covered waters and during heavy ice breaking activities. The centerboard has three (3) deployed positions plus a full retracted servicing position with a hatch closure. The servicing position allows for access to the centerboard transducers without the need for dry-docking. The current arrangement features the EK sonars and shallow water multi-beam which do not function well behind ice windows and also includes two spares wells for mission specific or future use. The arrangement of the centerboard is shown on the Scientific Electronic Arrangement Drawing, Reference (71). Details of the centerboard trade-off study can be found in the Transducer/Centerboard Trade-Off Study, Reference (72). Details about movement and handling of the Centerboard design are part of a later design stage as further detailed development could add unnecessary cost and imply maturity when this is a design detail best left to the shipyards.

10.10. Science Seawater Systems

The Science Seawater System consists of two separate systems. Science Seawater supports pressure sensitive, ambient temperature seawater for flow-through and underway sensors and instruments in labs and lab van spaces. The Incubator Seawater System supports high flow ambient temperature seawater to Deck Incubator locations on the working decks as well as the Aquarium Room for live catch tanks. Each system will have two pumps for redundancy and include low-extractable CPVC piping for minimal interaction with the sample water. Diaphragm pump technology will be utilized for minimal impact to waterborne micro-organisms. Pumps will be able to draw from either a forward or aft science sea chest for better efficacy in different ice conditions and sea states. Cleaning and flushing ports are included in both systems for maintenance. The largest of the three (3) instrument manifolds supplied will support the Water Wall in the Hydro Lab. A second manifold will be located in the Wet Lab and a third manifold will be mounted as close as practical to the primary intake point for instruments requiring shorter runs. A secondary scientific seawater inlet will be provided in the centerboard and a tertiary scientific seawater sea chest will be provided just forward of Frame 69. The arrangement of the ARV Science Seawater System piping is shown on the Science Seawater Diagram, Reference (56).

11. Conclusions

Throughout the last year, the ARV has evolved from Concept Design to Preliminary Design and has gone through multiple design iterations. These design iterations resulted in a Preliminary Design that is compliant with the program's three primary KPPs and supports the Science Mission Requirements. PDR resulted in an agreement from the panel that the design is ready to advance to the Final Design phase. Technical issues that were open at PDR have been resolved during the post-PDR phase or will continue to be optimized via discussions with vendors throughout the Final Design phase.

12. References

1) ARV Performance Specifications, Rev. -, Change 02, 24 January 2023
2) ARV Report No. 5E1-070-R001, Systems Engineering Management Plan
3) ARV Report No. 5E1-000-R001, Builder Specification
4) ARV Report No. 5E1-076-P001, Reliability, Availability, and Maintainability (RAM) Plan
5) ARV CD Program Execution Plan - Appendix 1 - Science Mission Requirements (SMR), dated August 2021
6) ARV Report No. 5E1-070-P101, Requirements Verification Matrix (RVM)
7) ARV Report No. 5E1-020-R001, Design Reference Mission (DRM) Study
8) ARV Report No. 5E1-051-R001, Hull Form Trade Off Report
9) ARV Report No. 5E1-079-R001, Intact and Damage Stability Report
10) ARV Report No. 5E1-050-R201, Icebreaking Report
11) ARV Report No. 5E1-050-R021, Range and Endurance Calculations Report
12) ARV Report No. 5E1-000-R201, Regulatory Body Communications and Correspondence
13) ARV Report No. 5E1-052-R001, ARV Trade Off Studies
14) ARV Report No. 5E1-050-R101, Bubble Sweep-down CFD Report
15) ARV Drawing No. 5E1-100-D001, Hull Lines
16) ARV Report No. 5E1-079-R101, Seakeeping Performance Report
17) ARV Report No. 5E1-050-R001, Speed and Power Analysis Report
18) ARV Report No. 5E1-050-R011, Maneuvering Performance Report
19) ARV Report No. 5E1-098-P001, Model Test Program Plan
20) ARV Report No. 5E1-098-R101, Model Test Report
21) ARV Drawing No. 5E1-001-D001, General Arrangement Drawing
22) ARV Drawing No. 5E1-002-D101, Topside Arrangement
23) ARV Drawing No. 5E1-003-D101, 3D Rendering of Wholeship
24) ARV Report No. 5E1-096-R001, Design Weight Estimate
25) Society of Allied Weight Engineers. SAWE Recommended Practice Number 14 (RP 14) Weight Estimating and Margin Manual for Marine Vehicles, Issue No. (-). s.l.: SAWE, May 2001.
26) ARV Report No. 5E1-052-R101, Green Ship Alternatives Study Report
27) ARV Report No. 5E1-061-R001, Structural Design Report
28) ARV Drawing No. 5E1-110-D001, Hull Structure – Shell Expansion
29) ARV Drawing No. 5E1-117-D001, Hull Structure – Midship Section

30) ARV Drawing No. 5E1-130-D001, Hull Structure – Deck and Platforms
31) ARV Drawing No. 5E1-150-D001, Superstructure Structure
32) ARV Report No. 5E1-062-R001, Propulsion System Report
33) ARV Drawing No. 5E1-501-D001, Machinery Arrangement
34) ARV Drawing No. 5E1-261-D001, Fuel Oil System
35) ARV Drawing No. 5E1-262-D001, Lube Oil System
36) ARV Report No. 5E1-086-R001, Master Equipment List
37) ARV Report No. 5E1-313-P001, White Paper: Battery Sizing for Lithium-Ion Batteries
38) ARV Drawing No. 5E1-062-R101, ARV Electric Propulsion Architecture Trade-Off Study
39) ARV Drawing No. 5E1-301-D001, Electrical One-Line Diagram
40) ARV Drawing No. 5E1-300-D001, Electrical Plant Load Analysis
41) ARV Report No. 5E1-065-R001, Dynamic Positioning System Performance Report
42) ARV Report No. 5E1-415-D001, Shipwide Network Diagram
43) ARV Drawing No. 5E1-529-D101, Ballast System Drawing
44) ARV Drawing No. 5E1-529-D001, Bilge & Oily Waste System Drawing
45) ARV Drawing No. 5E1-532-D201, Chilled Water System Drawing
46) ARV Drawing No. 5E1-551-D101, Control & Ship Service Compressed Air System Drawing
47) ARV Drawing No. 5E1-551-D001, Starting Air System Drawing
48) ARV Drawing No. 5E1-5[illegible]7-D101, Deck De-Icing Plan Drawing
49) ARV Drawing No. 5E1-521-D001, Firemain Drawing
50) ARV Drawing No. 5E1-555-D001, Fire Extinguishing System Drawing
51) ARV Drawing No. 5E1-532-D001, Freshwater Cooling System Drawing
52) ARV Drawing No. 5E1-510-D001, HVAC Systems Drawing
53) ARV Drawing No. 5E1-544-D001, Mission Fuel System Drawing
54) ARV Drawing No. 5E1-533-D001, Potable Water Service System Drawing
55) ARV Drawing No. 5E1-529-D201, Roll Tank System Drawing
56) ARV Drawing No. 5E1-524-D001, Science Seawater System Drawing
57) ARV Drawing No. 5E1-520-D001, Seawater Service System Drawing
58) ARV Drawing No. 5E1-528-D001, Sewage System Drawing
59) ARV Report No. 5E1-593-R001, Pollution Control Systems and Waste Management Report
60) ARV Drawing No. 5E1-403-D001, Lifesaving Drawing

61) ARV Drawing No. 5E1-645-D001, Insulation
62) ARV Report No. 5E1-060-R001, Human Systems Interface Report
63) ARV Report No. 5E1-073-R001, Habitability Study
64) ARV Report No. 5E1-074-R101, Airborne Noise Report
65) ARV Report No. 5E1-073-R101, Vibration Report
66) ARV Report No. 5E1-073-R201, Underwater Radiated Noise and Sonar Self-Noise Report
67) ARV Report No. 5E1-020-R101, Science Systems Report
68) ARV Drawing No. 5E1-580-D001, Handling Systems and Scientific Package Deployment Drawing
69) ARV Drawing No. 5E1-601-D001, Science Space Arrangement Drawing
70) ARV Report No. 5E1-077-P101, Hazardous Materials Management Plan
71) ARV Drawing No. 5E1-301-D101, Scientific Electronic Arrangement Drawing
72) ARV Report No. 5E1-052-D201, Transducer/Centerboard Trade-Off Study
73) ARV Report No. 5E1-070-R401, Polar Operations Design Features Report
74) ARV Report No. 5E1-116-D101, Hull Structure – Profiles
75) ARV Report No. 5E1-117-D101, Hull Structure – Typical Sections
76) ARV Report No. 5E1-120-D001, Hull Structure – Miscellaneous Bulkheads
77) ARV Report No. 5E1-581-D001, Anchoring Drawing
78) ARV Report No. 5E1-582-D001, Mooring and Towing Drawing

13. Appendix 1: Preliminary Design Drawings and Reports

Document Control #	Contract / Non-Contract	Title	Current Rev	Current Rev Date
5E1-000-R001	C	Builder Specification	P2	11-Aug-23
5E1-000-R201	C	Regulatory Body Communications and Correspondence	P3	15-Aug-23
5E1-000-R401	C	Science Outfitting List	P0	31-Jan-23
5E1-001-D001	C	General Arrangement	P4	19-May-23
5E1-002-D101	C	Topside Arrangement	P3	28-Jun-23
5E1-003-R001	C	Design Summary Report	P3	24-Jun-23
5E1-003-D101	C	3D Rendering of Wholeship Exterior	P2	21-Jul-23
5E1-003-D201	C	3D Structural Producibility Model	P0	15-Aug-23
5E1-020-R101	C	Science Systems Report	P2	30-Dec-22
5E1-034-P001	C	Logistics Support Plan (LSP)	P1	2-Jan-23
5E1-050-R001	C	Speed and Power Analysis Report	P3	22-Jun-23
5E1-050-R011	C	Maneuvering Performance Report	P2	3-Jan-23
5E1-050-R021	C	Range and Endurance Calculations Report	P4	4-Aug-23
5E1-050-R101	C	Bubble Sweepdown Computational Fluid Dynamics Report	P3	2-Jun-23
5E1-050-R201	C	Icebreaking Performance Report	P2	9-Jun-23
5E1-051-R001	C	Hull Form Trade-Off Study	P3	28-Jul-23
5E1-052-R001	C	Trade-Off Studies Report	P1	30-Dec-22
5E1-052-R101	C	Green Ship Alternatives Study Report	P2	3-Jan-23
5E1-052-R201	C	Transducer and Centerboard Trade-Off Study	P1	17-Jan-23

Document Control #	Contract / Non-Contract	Title	Current Rev	Current Rev Date
5E1-052-R301	C	Novel or Emerging Technologies Report	P1	11-Jan-23
5E1-060-R101	C	Human Systems Interface (HSI) Report	P1	3-Jan-23
5E1-061-R001	C	Structural Design Report	P3	3-Aug-23
5E1-062-R001	C	Propulsion System Report	P2	4-Aug-23
5E1-062-R101	C	Electric Propulsion Architecture Trade-Off Study	P1	17-Jan-23
5E1-065-R001	C	Dynamic Positioning System Performance Report	P3	14-Jul-23
5E1-066-R001	C	Area Volume Report	P3	21-Jun-23
5E1-070-P001	C	Systems Engineering Management Plan (SEMP)	P0	11-Apr-22
5E1-070-P101	C	Requirement Verification Matrix (RVM)	P4	Aug-23
5E1-070-R102	C	ARV CAMEO Model Report	P1	27-Jan-23
5E1-070-R301	C	SMR Requirement Traceability Matrix (SMR RTM)	P2	Aug-23
5E1-070-R401	C	Polar Operations Design Features Report	P0	4-Aug-23
5E1-071-D001	C	Equipment Removal Drawing	P0	4-Aug-23
5E1-073-R001	C	Habitability Study	P2	22-Dec-22
5E1-073-R101	C	Airborne Noise Report	P3	Aug-23
5E1-073-R102	C	Vibration Report	P2	5-Jan-23
5E1-073-R201	C	Underwater Radiated Noise and Sonar Self-Noise Report	P3	15-Aug-23
5E1-073-P301	C	Noise Control Plan	P3	Aug-23
5E1-076-P001	C	Reliability, Availability, and Maintainability (RAM) Plan	P4	4-Aug-23
5E1-077-P001	C	System Safety Plan (SSP)	P4	4-Aug-23
5E1-077-P101	C	Hazardous Materials Management Plan (HMMP)	P3	4-Aug-22

Document Control #	Contract / Non-Contract	Title	Current Rev	Current Rev Date
5E1-079-R001	C	Intact and Damage Stability Report	P3	4-Aug-23
5E1-079-R101	C	Seakeeping Performance Report	P3	29-Jul-23
5E1-086-R001	C	Master Equipment List	P3	21-Jul-23
5E1-092-P001	C	Test and Evaluation Management Plan (TEMP) [formerly Vessel Test Plan]	P1	26-Sep-22
5E1-096-R001	C	Design Weight Estimate	P4	2-Aug-23
5E1-098-P001	C	Model Test Program Plan	P1	25-Nov-22
5E1-098-P002	C	Model Test Program Plan Statement of Work (SOW)	P0-2	25-Mar-22
5E1-098-R101	C	Model Test Report (Open Water and Ice)	P2	28-Jul-23
5E1-100-D001	C	Hull Lines	P3	7-Apr-23
5E1-100-D101	C	Blocking Plan	P0	3-Jul-23
5E1-110-D001	C	Hull Structure - Shell Expansion	P2	10-Jul-23
5E1-116-D101	C	Hull Structure - Profiles	P0	14-Jul-23
5E1-117-D001	C	Hull Structure - Midship Section [formerly Hull Structure (Midships) or Midship Section Drawing]	P3	14-Jul-23
5E1-117-D101	C	Hull Structure - Typical Sections	P0	28-Jul-23
5E1-120-D001	C	Hull Structure - Miscellaneous Bulkheads	P0	21-Jun-23
5E1-130-D001	C	Hull Structure - Decks and Platforms	P2	14-Jul-23
5E1-130-R101	C	Enhanced Aviation Deck Capabilities Assessment	P0	4-Aug-23
5E1-150-D001	C	Superstructure Structure	P2	21-Jul-23
5E1-170-R001	C	Mast Analysis Report	P0	19-Jul-23
5E1-259-R001	C	Stack Gas Flow Analysis Report	P0	28-Jul-23

Document Control #	**Contract / Non-Contract**	**Title**	**Current Rev**	**Current Rev Date**
5E1-261-D001	C	Fuel Oil System	P2	4-Jan-23
5E1-262-D001	C	Lube Oil System	P2	27-Dec-22
5E1-300-D001	C	Electrical Plant Load Analysis (EPLA)	P3	28-Jul-23
5E1-301-D001	C	Electrical System One-Line Diagram	P3	25-Jul-23
5E1-301-D101	C	Scientific Electronic Systems Arrangement	P3	2-Aug-23
5E1-310-R001	C	Alternate Engines with Aftertreatment Compatibility Study	P0	4-Aug-23
5E1-402-P001	C	Security Control Traceability Matrix (SCTM)	P4	6-Dec-22
5E1-403-D001	C	Lifesaving Drawing	P2	6-Dec-22
5E1-415-D001	C	Shipwide Network Diagram	P3	8-Aug-23
5E1-501-D001	C	Machinery Arrangement	P3	21-Jul-23
5E1-510-D001	C	HVAC Systems	P2	26-Sep-22
5E1-512-R101	C	Smart HVAC Power Demand Study	P0	4-Aug-23
5E1-513-D001	C	Machinery Space Ventilation Diagram	P0	14-Jul-23
5E1-517-D001	C	Waste Heat Recovery System & Hot Water Heating System	P2	30-Dec-22
5E1-517-D101	C	Deck De-Icing Plan [mechanical]	P2	29-Dec-22
5E1-520-D001	C	Seawater Service System	P2	29-Dec-22
5E1-521-D001	C	Firemain System	P2	23-Dec-22
5E1-524-D001	C	Science Seawater System	P2	27-Sep-22
5E1-528-D001	C	Sewage System	P2	29-Dec-22
5E1-529-D001	C	Bilge and Oily Waste System	P2	6-Jan-23
5E1-529-D101	C	Ballast System	P2	3-Jan-23

Document Control #	Contract / Non-Contract	Title	Current Rev	Current Rev Date
5E1-529-D201	C	Roll Tank System	P3	21-Jul-23
5E1-532-D001	C	Freshwater Cooling System	P2	30-Dec-22
5E1-532-D101	C	Jacket Water Cooling System	P2	30-Dec-22
5E1-532-D201	C	Chilled Water System	P2	23-Dec-22
5E1-533-D001	C	Potable Water Service System	P2	3-Jan-23
5E1-544-D001	C	Mission Fuel System [formerly Cargo Fuel System]	P2	27-Dec-22
5E1-551-D001	C	Starting Air System [formerly Ship's Compressed Air System]	P2	8-Dec-22
5E1-551-D101	C	Control and Ship Service Compressed Air System [formerly Scientific Compressed Air System]	P2	23-Dec-22
5E1-555-D001	C	Fire Extinguishing Systems	P2	29-Dec-22
5E1-580-D001	C	Handling Systems and Scientific Package Deployment	P3	28-Jul-23
5E1-581-D001	C	Anchoring Drawing	P0	29-Jun-23
5E1-582-D001	C	Mooring and Towing Drawing	P0	5-Jul-23
5E1-583-R001	C	Scientific Work Boat Builder Specification	P0	2-Aug-23
5E1-583-R002	C	Landing Craft Builder Specification	P0	2-Aug-23
5E1-583-R004	C	RHIB Builder Specification	P0	2-Aug-23
5E1-593-R001	C	Pollution Control Systems and Waste Management Report	P2	3-Jan-23
5E1-601-D001	C	Science Space Arrangement	P3	10-Jul-23
5E1-635-D001	C	Insulation Plan	P2	28-Dec-22

14. Appendix 2: Design Margin Plan

References

1) ARV Performance Specifications, Rev. -, Change 02, 24 January 2023.
2) Society of Allied Weight Engineers. SAWE Recommended Practice Number 14 (RP 14) Weight Estimating and Margin Manual for Marine Vehicles, Issue No. (-). s.l.: SAWE, May 2001.
3) ARV Report No. 5E1-096-R001, Design Weight Estimate.
4) NAVSEA Design Data Sheet (DDS) 051-1, Prediction of Smooth-Water Powering Performance for Surface-Displacement Ships, 15 May 1984.
5) American Bureau of Shipping Marine Vessel Rules, July 2021.
6) NAVSEA, "Electrical Systems Design Criteria and Practices (Surface Ships) for Preliminary and Contract Design," T9300-AF-PRO-020 Rev (1), June 2016

Introduction

The Design Margin Plan developed for the Antarctic Research Vessel (ARV) documents margins to apply throughout the acquisition cycle. Design margins ensure that, upon delivery, the ship meets predicted design values required by the Performance Specifications, Reference (1). Service Life Allowances (SLA) are also included to accommodate in-service growth throughout the ship's life or for mission upgrades after delivery.

Margins provide a method to set a robust design baseline to account for design risk and to allow changes and modifications as the design matures while still satisfying the specifications. In some cases, this plan identifies design margins as a range or individual values for each stage of the acquisition cycle. While in other cases a singular design margin is appropriate based on the system complexity and methodologies successfully used on previous designs.

Margins are included for the following design variables:

- weight
- vertical center of gravity
- speed and power
- singular design margins for propulsion plant, pumps & tankage
- electric loads
- heating, ventilation, and air conditioning (HVAC)
- structure

Service life allowances are included for the following categories:

- weight
- KG
- electric loads

Approach

The plan includes margins and allowances specifically implemented to address design risk inherent throughout the acquisition cycle and to account for expected growth due to added or modified systems during the ship's service life. Design margins are intended to account for design maturation and normal construction variances (e.g., preliminary and contract design, detail design and build, contract modification, government furnished material). Changes to specific design points, operational requirements, or major ship characteristics may result in a re-evaluation of the ship design and the margins allocated.

The margins outlined in this plan represent the values used in accordance with Reference (1) or based on industry best practices to allow for modifications as the design matures. Margins for all disciplines are intended to absorb unanticipated changes as the design develops and matures, final VFI is received, Government Furnished Information (GFI) is updated, and customer comments incorporated. Margins will be debited/credited as these changes are incorporated. GFI and Government Furnished Material (GFM) are the terms used by the Society of Weight Engineers to reflect government provided information on Navy Projects. For the purpose of this project, GFM margins will reflect customer furnished materials and information and will be referred to as Customer-Furnished Material (CFM) and Customer-Furnished Information (CFI) respectively.

Design Margins

Weight and KG

Weight and KG margins have been applied in accordance with SAWE RP 14, Reference (2). Two types of margins exist for weight and KG (vertical center of gravity above the keel) which are applied to the ARV design:

- Acquisition (Design) Margin – Margin to account for changes during design and construction.
- Service Life Allowance (SLA) – Allowance applied to absorb post-delivery modifications.

Acquisition Margin has been subdivided into two groups: Detail Design and Building (DD&B) margin and Contract Modification (ConMod) margin. DD&B margin is consumed during Detail Design & Construction (DD&C) to account for design changes due to drawing development, omissions, and errors in the Accepted Weight Estimate (AWE), outfitting details, variations between the actual ship and its curves of form, and similar differences. ConMod margins are consumed as customer driven contract modifications or changes to the P-Spec are issued.

Table B- 1 summarizes the acquisition margin. The total assigned Acquisition Margin for this revision (12.8% of Light Ship weight and 5.8% of Light Ship KG) exceeds the threshold Acquisition Margin chosen for DR5 (9.2% of Light Ship weight and 4.6% of Light Ship KG) indicating a low risk of exceeding the design weight and KG upon delivery.

In this revision, the DD&B margin for weight is set to produce an End of Service Life (EOSL) design draft of 32.50 ft. The DD&B margin for KG is assigned based on the assessed stability limit. While not required by the P-Spec, a portion of the DD&B margin has been allocated to ConMod margin for customer use.

Table B- 1: Acquisition Margin

Margin	Weight	KG
Threshold Margin for DR5	9.2%	4.6%
→ Detail Design and Building (DD&B)	8.8%	4.3%
→ Contract Modification (ConMod)	0.4%	0.3%

Total Assigned Margin for Rev P4	12.8%	5.8%
→ Detail Design and Building (DD&B)	12.4%	5.5%
→ Contract Modification (ConMod)	0.4%	0.3%

In addition to Acquisition Margin, a Service Life Allowance (SLA) for weight and KG has been applied to the BOSL (Beginning of Service Life) conditions in accordance with Reference (2) to produce EOSL conditions. SLA is calculated and applied as follows:

- A weight SLA of 425 LT, based on 3.2% of the cubic number [*(L x B x D)/100*], located at the center of gravity of the Light Ship weight.
- A KG SLA of 0.50 ft applied to the Light Ship VCG.

The SLA will be utilized to absorb customer directed changes if ConMod margin is insufficient to accommodate these modifications.

Speed-Power Margin

Power margins follow guidance set by NAVSEA DDS 051-1, Reference (4). Power margins are applied to Effective Horsepower (EHP) estimates to account for uncertainties in the resistance, hull-propeller interaction, and propeller efficiency estimates. Per Reference (4), power margins are applied to EHP over the entire speed range. The power margins to be used are based on the design stage and design maturity/risk:

- 8% during Preliminary and Contract Design, prior to conduct of self-propelled model tests.
- 6% during Preliminary and Contract Design, after self-propelled model tests with the stock propeller have been conducted. This margin is to be used with model test data which has been corrected for the difference between the anticipated performance of the final design propeller and the measured performance of the stock propeller.
- 4% during the final stage of Contract Design, after self-propelled model tests with the propeller have been conducted.

In predicting achievable speed, additional margins may be applied to the electrical generating plant. Per the ARV Performance Specification, Reference (1), Section 310, the cruise speed and required icebreaking performance with no more than 80% the selected generators maximum continuous ratings. The cruise speed and required icebreaking performance must also be achieved with any one generator offline. The Speed and Power Analysis Report will determine the required power for the specified icebreaking capability. Power margins to account for power losses from the generator to the propeller that are not already intrinsic to the calculation of required power will be evaluated with the propulsion and electric plant vendor(s).

Propulsion Plant

Propulsion margins will follow the guidance of the ARV Performance Spec, Reference (1). Per Reference (1) Section 200.1, the propulsion plant will be designed to minimize the size, weight and complexity allowed while maintaining reliable and economical operation and maintenance. The sizing of the propulsion plan will account for the vessel at its maximum displacement including service life margins.

Propellers

American Bureau of Shipping’s Marine Vessel Rules, Reference (5) provides guidance for design of propellers for propulsion machinery. The formulas for calculating propeller characteristics have inherent safety margins built in.

Bow Thrusters

Bow thruster capability will incorporate the requirements of ARV Performance Specification, Reference (1), Section 235.5, which states: “When the vessel is operating at a forward speed of 5 knots in calm seas and no wind, the net transverse thrust capability of the bow thruster(s) shall be at least 75% of the thrust capability when the vessel is operating at zero speed.”

Shafting

Marine Vessel Rules, Reference (5), provides guidance for design and construction of propulsion shafting. The formulas used to calculate shaft diameter have inherent safety margins built in to ensure sufficient strength to drive the specified load.

Pumps

Design margins shall be evaluated in the sizing of distributive system pumps dependent on the level of confidence in the status of the system arrangement and services provided.

Tankage

No tankage margins were specified by the AVR specification and requirement documents. Following general engineering practices, tankage shall assume a 2% volume loss for tank structure and 5% volume loss for tailpipe allowance. These values are in line with, but not set by, tankage margin values set out by American Bureau of Shipping in Reference (5).

Electric Loads

Electrical operating load margins under typical ship operating conditions shall also be in accordance with the NAVSEA Design Practice and Criteria Manual for Electrical Systems on Surface Ships, NAVSEA T9300-AF-PRO-020, Reference (6). Research Vessel is categorized as an auxiliary vessel resulting in the below margins. The majority of electrical loads are defined and set during the Detail Design phase.

Table B- 2: Electrical Load Margin

Margin Type	Margin Percentage
Contract Design	4.0%
Detail Design and Building	7.0%
Total Margin	**11%**

The above margins will be added to the total electrical power loads, on top of any system specific margins.

HVAC

Per ARV Performance Specification, Reference (1), Section 516.1, the chilled water plant should be designed so that 75% of the total plant cooling capacity can be provided with any single unit offline.

Design margins for HVAC equipment shall be evaluated during preliminary system sizing dependent on the level of confidence in the parameters used for system sizing.

Structure

Corrosion margin will be included in structural design as required by the American Bureau of Shipping in Reference (5). The margin will reflect the provided added shell thickness requirements for a vessel operating in ice.

Design Service Life Allowance

Weight and KG

Per Reference (1) Section 079.1.3, the service life allowance shall be 3.2% of the ship's cubic number. Cubic number is defined as Length x Beam x Draft /100. The weight service life allowance shall be located at the center of gravity of the light ship weight, while the lightship VCG shall be increased by 0.5 ft.

Electric Loads

Ship Service Electrical Growth Reserve

Per Reference (1), Section 300.2, a growth reserve of at least 15% shall be used for ship service electrical system design. Physical deck space should be reserved to allow for a minimum of 20% growth in space requirement for the electrical distribution system (ie. switchgears, power panels, motor control centers, etc.).

In-Port Shore Power

Per Reference (1), Section 315, shore power connection facilities shall be designed to provide power for normal in-port load conations plus a 20% growth allowance.

Switchboards

Per Reference (1), Section 324.1, “The ship service and emergency switchboard distribution sections shall be designed and sized for at least 20% future expansion in capacity.”

15. Appendix 3: List of Drawing Reservations

Document Number	Document Title	Reservation Number	Reservation Description
5E1-001-D001	**General Arrangement Rev. P4**	1	Anchor Handling System and location of Anchor Pocket reserved pending VFI and detail design.
		2	Mooring and towing reserved pending VFI and detail design.
		3	Mast, mast platforms and antennas reserved pending VFI and detail design.
		4	Access and egress reserved pending requirements.
		5	Roll tank reserved pending detail design.
		6	Vertical access to mast under design development.
		7	Cranes, handling and boats reserved pending VFI and handling systems and scientific package deployment drawing development.
5E1-002-D101	**Topside Arrangement Rev. P3**		
5E1-003-D101	**3D Rendering of Wholeship (Exterior Only) Rev. P2**		
5E1-071-D001	**Equipment Removal Drawing Rev. P0**	1	BERP and WERP sizes and locations reserved pending VFI and design development.
		2	Padeye capacities reserved pending equipment VFI weight data.
5E1-100-D001	**Hull Lines Rev. P3**		
5E1-100-D101	**Blocking Plan Rev. P0**	1	Seachest locations not shown and to be provided in a later design phase.
		2	Additional docking positions for paint access to be provided in a later design phase.
5E1-110-D001	**Hull Structure - Shell Expansion Rev. P2**	1	Callouts for atypical grades of steel are not shown and are reserved pending further design development.
		2	Local increases to scantlings in way of major equipment, sonars, and transducers are not shown and will be included in later phase of design.

Document Number	Document Title	Reservation Number	Reservation Description
		3	Headers on shell that provide end connections for tank bulkhead stiffeners are not shown and will be included in later phase of design.
		4	Non-typical structure, as well as details such as brackets, have not yet been developed and will be included in a later phase of design.
		5	Seachest, sonar and transducer openings in side shell are currently not shown but will be included during a later phase of design.
		6	Structural arrangement and scantlings in way of stern azimuthing thruster are preliminary and will be finalized during a later phase of design.
5E1-116-D101	**Hull Structure – Profiles Rev. P0**	1	Structural arrangement and scantlings in way of the bow thruster tunnel will be included in a later phase of design.
		2	Callouts for atypical grades of steel will be included in a later phase of design.
		3	Non-typical structure, as well as details such as brackets, have not yet been developed and will be included in a later phase of design.
		4	Breasthooks shown in the bow region are notional, and will be included in a later phase of design.
		5	Structural arrangement and scantlings in way of stern azimuthing thruster are preliminary and will be finalized during a later phase of design.
		6	Arrangement to be revised as needed for producibility during 3D modeling phase.
5E1-117-D001	**Hull Structure – Midship Section Rev. P3**	1	Size and location of openings are notional, coaming details, stiffener arrangement, and stiffener sizes in way of openings are reserved and will be included in a later phase of design.
		2	Collar and end connection details have not yet been developed and will be included in a later phase of design.
		3	Callouts for atypical grades of steel will be included in a later phase of design.

Document Number	Document Title	Reservation Number	Reservation Description
		4	Non-typical structure, as well as details such as brackets, have not yet been developed and will be included in a later phase of design.
5E1-117-D101	**Hull Structure - Typical Sections Rev. P0**	1	Size and location of openings are notional, coaming details, stiffener arrangement, and stiffener sizes in way of openings are reserved and will be included in a later phase of design.
		2	Collar and end connection details have not yet been developed and will be included in a later phase of design.
		3	Callouts for atypical grades of steel will be included in a later phase of design.
		4	Non-typical structure, as well as details such as brackets, have not yet been developed and will be included in a later phase of design.
		5	Arrangement to be revised as needed for producibility pending development of 3D producibility model.
		6	Margin plates forward of Frame 53 are reserved and sizes will be included in a later phase of design.
5E1-120-D001	**Hull Structure - Miscellaneous Bulkheads Rev. P0**	1	Size and location of openings are notional. Coaming details, stiffener arrangements, and stiffener sizes in way of openings are reserved and will be included in a later phase of design.
		2	Collar and end connection details have not yet been developed and will be included in a later phase of design.
		3	Callouts for atypical grades of steel will be included in a later phase of design.
		4	Non-typical structure, as well as details such as brackets, have not yet been developed and will be included in a later phase of design.
		5	This row serves as a placeholder for any future bulkhead arrangement changes.
5E1-130-D001	**Hull Structure - Decks and Platforms Rev. P2**	1	Stanchion sizes are reserved and will be included in a later phase of design.
		2	Local increases to scantlings in way of major equipment foundations are not shown and will be included in a later phase of design.

Document Number	Document Title	Reservation Number	Reservation Description
		3	Size and location of openings are notional, coaming details, stiffener arrangements, and stiffener sizes in way of openings are reserved and will be included in a later phase of design.
		4	Callouts for atypical grades of steel are not shown and will be included in a later phase of design.
		5	Headers in way of ISO container sockets are not shown and will be included in a later phase of design.
		6	Main deck HVAC trunks and vents are not shown and will be included in a later phase of design.
		7	Wing bulkhead knuckles on 2nd platform between Frames 138 and 145 deviate from the GA for structural continuity and constructability and will be converged in a later phase of design.
5E1-150-D001	**Superstructure Structure Rev. P2**	1	Stanchion sizes are reserved and will be included in a later phase of design.
		2	ISO and bolt sockets are not shown and will be included in a later phase of design.
		3	Structure around foundations (such as the heavy lift crane #2, ISO containers, etc.) is reserved and will be included in a later phase of design.
		4	Size and location of openings are notional, coaming details, stiffener arrangements, and stiffener sizes in way of openings are reserved and will be included in a later phase of design.
		5	Control room scantlings reserved pending further design development.
		6	Non-typical structure, as well as details such as brackets have not yet been developed and will be included in a later phase of design.
		7	Window details (such as locations, sizes, mullions, etc.) are shown as notional, and are reserved pending further design development.
		8	Details regarding external vestibules on the 05 Level are reserved pending further design development.

Document Number	Document Title	Reservation Number	Reservation Description
5E1-261-D001	**Fuel Oil System Rev. P2**	1	Final tank capacities are reserved pending development of the general arrangement.
		2	Pending heater and incinerator selection and location.
		3	Fuel oil heater pump is pending heater selection.
5E1-262-D001	**Lube Oil System Rev. P2**		
5E1-300-D001	**Electrical Plant Load Analysis (EPLA) Rev. P3**	1	Electrical equipment and characteristics are reserved pending analysis of finalized vendor selection, customer furnished information, and pending design maturation. Where data is not available, estimates are based on similar ships with best assumptions used to fit the hull and electric plan zonal architecture.
		2	Speed and power figures contained in this electric plant status summary sheets are reserved pending final hull form analysis.
		3	Future development of the electrical power system may require load shedding that would be added to this study.
		4	Other loads connected to the emergency power source as defined by 46 CFR 112.05-1(c) are reserved pending discussion with the USCG Marine Safety Center.
5E1-301-D001	**Electrical System One-Line Diagram Rev. P3**	1	Equipment, breaker, cable type and sizes are based upon preliminary information, actual sizes will be verified during design development.
		2	High voltage DC (HVDC) distribution system is not final and is shown to advance the design. The HVDC system does not reflect any specific vendor design.
		3	Low voltage DC system is notional as shown and reserved for future development.
		4	Generation system is preliminary pending final development of 5E1-501-D001 Machinery Arrangement Drawing.
		5	Propulsion system is preliminary pending development of 5E1-062-R001 Propulsion System Report.

Document Number	Document Title	Reservation Number	Reservation Description
		6	Design of the 480V & 208/120V AC system is reserved for future development.
		7	Missing load, breaker, and wire information to be added as information is made available.
		8	Reservations for power distribution panels pending as design matures.
		9	Lighting system is reserved for future development.
		10	Modular battery system is reserved for future development.
5E1-301-D101	**Scientific Electronic Systems Arrangement Rev. P3**	1	Exact dimensions of SES equipment reserved pending VFI. Footprints shown are approximate mounting plate dimensions and to be updated as VFI becomes available.
		2	Navigation equipment is reserved for future development.
		3	Temporary and permanent scientific wireways and conduits (including transducer dedicated conduits) are reserved pending future development of 5E1-001-D001 General Arrangement and 5E1-601-D001 Science Space Arrangement Drawings.
		4	SES transceiver arrangement equipment is reserved for future development of 5E1-601-D001 Science Space Arrangement Drawings.
		5	Scientific Meteorological System and wind measurement equipment is reserved for future development.
		6	Scientific instrumentation water sampling equipment is reserved pending future development of 5E1-524-D001 Science Seawater System.
		7	SES operation stations are reserved pending future development of 5E1-001-D001 General Arrangement and 5E1-601-D001 Science Space Arrangement Drawings.
		8	Sea chests and transducer protective provisions are pending future development and VFI.
		9	Models and manufacturers of all equipment are reserved pending final detailed design.

Document Number	Document Title	Reservation Number	Reservation Description
		10	Mast arrangement is reserved pending development of the Topside Arrangement drawing.
		11	Conduit and centerboard ventilation is reserved pending future development.
		12	Equipment within the Transceiver Room (2-59-1-Q) including processing equipment is reserved pending development.
		13	Ice door at centerboard trunk opening is reserved for future development.
5E1-403-D001	**Lifesaving Drawing Rev. P1**	1	A notional RHIB is shown pending selection of 20-to-30 ft RHIB required by Reference 5, PARA 583.1.2.
		2	Life rafts with a minimum total capacity of 84 on each side sufficient to accommodate the total number of persons on board as required by Reference 5, 199.261.b.2.ii is reserved pending equipment selection.
		3	A notional enclosed lifeboat with capacity to accommodate 125% of the total number of personnel on board on each side of the vessel as required by Reference 5, PARA 583.1.5 and REF 4 Regulation 31.1.1 is reserved pending equipment selection.
		4	A notional workboat is shown pending selection of ~30 ft boat required by Reference 5, PARA 583.1.3.
		5	Lifeboat embarkation and deployed positions, reserved pending design development and selection of the make and model of the davit and boat.
		6	Rescue boat embarkation and deployed positions, reserved pending design development and selection of the make and model of the davit and boat.
5E1-415-D001	**Shipwide Network Diagram Rev. P3**	1	Systems highlighted in current versioning are the full understanding of supportive needs at the time of release. Continued development of system inclusion will continue through Final Design.

Document Number	Document Title	Reservation Number	Reservation Description
		2	List of Material will be developed during Final Design as hardware is selected, to include the number of SANs required to support Vessel and Science Mission.
		3	Final List of Material will impact system breakouts overviewed on Sheets 6-9. Current control station breakouts are meant as initial requirement population with understanding certain system selection will potentially alter actual population of control stations.
5E1-501-D001	**Machinery Arrangement Rev. P3**	1	Size and location of emergency diesel generator start battery reserved pending receipt of VFI.
		2	Shore power cabinet and shore power receptacle cabinet reserved pending receipt of VFI.
		3	The location of all Novec 1230 fixed firefighting equipment (555-2) reserved pending changes to the GA drawing to facilitate storage in accordance with ABS Rules.
		4	Handling system HPUS reserved pending revision to the Handling Systems and Science Package Deployment drawing and receipt of VFI.
		5	Watermist tank located in 1-109-6-E reserved pending finalization of capacity.
		6	Arrangement of 4-81-0-E, Main Engine Room – Upper Level, high voltage equipment reserved pending analysis of vendor environmental requirements.
		7	Maintenance envelopes and location of propulsion converters (314-3) reserved pending verification of maintenance envelopes and interferences of stanchions.
		8	Fuel and ballast manifolds reserved.
5E1-510-D001	**HVAC Systems Rev. P2**	1	Lab snorkel system reserved pending vendor outreach and receipt of vendor furnished equipment.

Document Number	Document Title	Reservation Number	Reservation Description
		2	HVAC equipment sizes and airflows are reserved pending performance of detailed heating and cooling load calculations and HVAC system analyses.
		3	Notional duct sizing is reserved performance of preliminary pressure drop calculations.
		4	Airborne and structureborne noise levels are reserved pending detailed noise analyses and measurement.
		5	Fan room locations are shown per the General Arrangement, Rev P3. Future revisions of the General Arrangement will re-evaluate fan room locations per this drawing to relocate fan rooms for better usability.
5E1-513-D001	**Machinery Space Ventilation Diagram Rev. P0**	1	Diesel engines combustion air intake and exhaust piping heat dissipation calculations, preheating and reheating calculations, heaters and heating arrangement, and pressure drop calculations are reserved pending development.
		2	Expansion joints and resilient hangers are reserved pending development.
5E1-517-D001	**Waste Heat Recovery System & Hot Water Heating System Rev. P2**	1	Individual flow rates and piping sizes are reserved pending system development and vendor furnished information.
5E1-517-D101	**Deck De-Icing Plan [mechanical] Rev. P2**	1	Main working deck (Weather Deck 1-89-01-X) heating medium reserved pending resolution of requirement conflict with Reference 1, ARV Performance Specification, Section 517.2, Line 2047.
5E1-520-D001	**Seawater Service System Rev. P2**		
5E1-521-D001	**Firemain System Rev. P2**		
5E1-524-D001	**Science Seawater System Rev. P2**	1	Location of dedicated scientific seawater sea chests is pending finalization of hull form.
5E1-528-D001	**Sewage System Rev. P2**		
5E1-529-D001	**Bilge and Oily Waste System Rev. P2**		

Document Number	Document Title	Reservation Number	Reservation Description
5E1-529-D101	**Ballast System Rev. P2**		
5E1-529-D201	**Roll Tank System Rev. P3**	1	Air cross-duct drain is reserved pending next design stage.
		2	Tank’s vent/overflow detail is reserved pending next design phase.
5E1-532-D001	**Freshwater Cooling System Rev. P2**		
5E1-532-D101	**Jacket Water Cooling System Rev. P2**		
5E1-532-D201	**Chilled Water System Rev. P2**		
5E1-533-D001	**Potable Water Service System Rev. P2**		
5E1-544-D001	**Mission Fuel System Rev. P2 [formerly Cargo Fuel System]**	1	Mission fuel stripping system pending resolution of requirement conflict with ARV Performance Specification, Section 540.2, Line 2390.
5E1-551-D001	**Starting Air System Rev. P2 [formerly Ship's Compressed Air System]**		
5E1-551-D101	**Control and Ship Service Compressed Air System Rev. P2 [formerly Scientific Compressed Air System]**		
5E1-555-D001	**Fire Extinguishing Systems Rev. P2**		
5E1-580-D001	**Handling Systems and Scientific Package Deployment Rev. P3**	1	Crane & crane clearance areas reserved pending VFI.
		2	Sequence showing the handling of long cores is reserve pending VFI of the equipment.

Document Number	Document Title	Reservation Number	Reservation Description
		3	Space reservations for work boat, rescue boat, life boat, & landing craft and respective handling systems are pending VFI.
		4	Core weight & clearance reserved pending VFI.
		5	Maintenance envelopes of handling equipment is reserved pending VFI.
		6	Deck operations station line of sign reserved pending final arrangement of compartment.
		7	Portable winch depiction and specification is reserved 10' x 10' pending VFI.
		8	Typical details of turning sheeve and flag block is reserved pending VFI.
5E1-581-D001	**Anchoring Drawing Rev. P0**	1	Hawse pipe and anchor pocket details to be included in a later design phase, when shipyard preference and capability is provided.
5E1-582-D001	**Mooring and Towing Drawing Rev. P0**	1	Load ratings of Palmer Pier bollards were taken from NSF Palmer Pier drawing, load testing each bollard is required prior to finalization of this ARV Palmer Station Mooring Arrangement, and allowable weather conditions defined in General Note 12.
5E1-601-D001	**Science Space Arrangement Rev. P3**	1	Multi-part, watertight, pantograph shell door operational area reserved pending final VFI.
		2	BOM (40) uni-strut bolt down locations are reserved pending final VFI.
		3	Bulkhead pass-throughs to adjacent labs and spaces in all labs with approved watertight and fire boundary ratings.
5E1-635-D001	**Insulation Plan Rev. P1**	1	Compartments labeled as "unassigned" have been given a category of 3. As the design develops and these compartments are updated, the insulation information will be updated as well.
		2	Fire integrity of bulkheads and decks are to be updated pending the details regarding penetrations for passage of electric cables, pipes, and vent ducts which will be available as the design matures.

Document Number	Document Title	Reservation Number	Reservation Description
		3	Labs and science spaces have been given a category of 9 due to being most closely related to workshops. As the design develops, the insulation information will be updated if it is determined that category 3 is suitable for specific spaces.
		4	Insulation details to be added in future revisions of this drawing and installed in accordance with Reference 2 Part C Reg 9 PARA 2.3.3.
		5	Locations where localized acoustic treatments are required in addition to structural fire protection and thermal insulation will be identified pending design development.
		6	Thermal Insulation detail drawings to be added in figure revisions of this drawing in accordance with details from general note #10.

16. Appendix 4: Documents That Require Convergence

Document Control #	Title	Current Rev	Current Rev Date	Convergence Details
5E1-000-R401	Science Outfitting List	P0	31-Jan-23	Update to suit latest General Arrangement compartmentation (administrative changes)
5E1-020-R101	Science Systems Report	P2	30-Dec-22	Update to suit current status of Handling Systems, Scientific Electronics System Arrangement, General Arrangement as it pertains to Science Labs and Support Spaces
5E1-050-R011	Maneuvering Performance Report	P2	3-Jan-23	Update to suit latest VCG, sail area, and Hull Variant 11 characteristics
5E1-052-R001	Trade-Off Studies Report	P1	30-Dec-22	Update Aloft Control Station section to suit addition of AloftCon and reflect latest AloftCon P-SPEC requirements
5E1-052-R101	Green Ship Alternatives Study Report	P2	3-Jan-23	Update Hull Form section to suit HV11 Update Electrical Systems and Air Emissions Reduction section to suit Alternative Engines Aftertreatment Study Update HVAC section to suit HVAC Power Demand Study
5E1-052-R201	Transducer and Centerboard Trade-Off Study	P1	17-Jan-23	Update to reflect removal of box keel and updates to Scientific Electronics System Arrangement drawing
5E1-052-R301	Novel or Emerging Technologies Report	P1	11-Jan-23	Update Battery Storage section to suit latest battery incorporation
5E1-060-R101	Human Systems Interface (HSI) Report	P1	3-Jan-23	Update to suit latest General Arrangement
5E1-062-R101	Electric Propulsion Architecture Trade-Off Study	P1	17-Jan-23	Update Hybrid Diesel Electric with Batteries section to suit latest battery incorporation
5E1-073-R001	Habitability Study	P2	22-Dec-22	Update to suit latest General Arrangement
5E1-073-R102	Vibration Report	P2	5-Jan-23	Update vibration analysis to suit latest hullform and structural drawings

Document Control #	Title	Current Rev	Current Rev Date	Convergence Details
5E1-261-D001	Fuel Oil System	P2	4-Jan-23	Update system routing to suit latest General Arrangement compartmentation
5E1-262-D001	Lube Oil System	P2	27-Dec-22	Update system routing to suit latest General Arrangement compartmentation
5E1-403-D001	Lifesaving Drawing	P2	6-Dec-22	Update to suit latest General Arrangement
5E1-510-D001	HVAC Systems	P2	26-Sep-22	Update system sizing, routing, and service locations to suit latest General Arrangement compartmentation Update MER system arrangement to reflect Machinery Space Ventilation Diagram deliverable
5E1-517-D001	Waste Heat Recovery System & Hot Water Heating System	P2	30-Dec-22	Update system sizing, routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation and tank volumes
5E1-517-D101	Deck De-Icing Plan [mechanical]	P2	29-Dec-22	Update system sizing and coverage to suit latest General Arrangement deck and exterior stair locations
5E1-520-D001	Seawater Service System	P2	29-Dec-22	Update equipment and service locations, system routing, and pipe sizing based on latest Machinery Arrangement and General Arrangement compartmentation
5E1-521-D001	Firemain System	P2	23-Dec-22	Update system routing and service locations to suit latest General Arrangement compartmentation
5E1-524-D001	Science Seawater System	P2	27-Sep-22	Update system routing and service locations to suit latest General Arrangement compartmentation, including potential locations for deck-side incubators
5E1-528-D001	Sewage System	P2	29-Dec-22	Update system routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation
5E1-529-D001	Bilge and Oily Waste System	P2	6-Jan-23	Update system routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation

Document Control #	Title	Current Rev	Current Rev Date	Convergence Details
5E1-529-D101	Ballast System	P2	3-Jan-23	Update system sizing, routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation and ballast tank locations and volumes
5E1-532-D001	Freshwater Cooling System	P2	30-Dec-22	Update equipment and service locations, system routing, and pipe sizing based on latest Machinery Arrangement and General Arrangement compartmentation
5E1-532-D101	Jacket Water Cooling System	P2	30-Dec-22	Update equipment locations based on latest Machinery Arrangement. Update system routing to suit.
5E1-532-D201	Chilled Water System	P2	23-Dec-22	Update system sizing, routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation
5E1-533-D001	Potable Water Service System	P2	3-Jan-23	Update system routing, pipe sizing, and service locations to suit latest General Arrangement compartmentation Add de-ionized water connections per latest Science Space Arrangement
5E1-544-D001	Mission Fuel System	P2	27-Dec-22	Update system routing and service locations to suit latest General Arrangement compartmentation Update location of equipment per latest Machinery Arrangement
5E1-551-D001	Starting Air System	P2	8-Dec-22	Update system routing to suit latest General Arrangement compartmentation Update location of equipment per latest Machinery Arrangement
5E1-551-D101	Control and Ship Service Compressed Air System	P2	23-Dec-22	Update system routing and service locations to suit latest General Arrangement compartmentation Update location of equipment per latest Machinery Arrangement

Document Control #	Title	Current Rev	Current Rev Date	Convergence Details
5E1-555-D001	Fire Extinguishing Systems	P2	29-Dec-22	Update system sizing, routing, and service locations to suit latest General Arrangement compartmentation Update location of equipment per latest Machinery Arrangement
5E1-593-R001	Pollution Control Systems and Waste Management Report	P2	3-Jan-23	Update to reflect addition of Garbage Stowage space and any changes to Pollution control System sizing and routing as a result of the needed convergence changes to those system described in this table
5E1-635-D001	Insulation Plan	P2	28-Dec-22	Update to suit latest General Arrangement