PREPARED FOR:	BY:
Leidos, ASC Centennial, CO	Reed A. Lillie ENGINEER
	CHECKED: Peter S. Soles SENIOR MARINE CONSULTANT
Glosten 1201 WESTERN AVENUE, SUITE 200 SEATTLE, WASHINGTON 98101-2953 T 206.624.7850 GLOSTEN.COM	APPROVED: Timothy S. Leach, PE PRINCIPAL-IN-CHARGE

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Executive Summary

This study compares life cycle costs and benefits of various deck anti-icing and de-icing technologies for the Antarctic Research Vessel (ARV). Anti-icing refers to the prevention of ice accretion on exposed decks and superstructures, while de-icing refers to the removal of ice after it has already accumulated. Most thermal anti-/de-icing technologies in use today are capable of both anti-icing and de-icing. The primary difference to note is that de-icing of surfaces requires significantly more energy than anti-icing. To minimize energy demand, anti-icing methods should be employed proactively, whenever icing conditions are encountered or expected.

A literature search was conducted on the topic of ice accretion in high latitudes and on various methods and technologies to mitigate and remove ice accumulation on vessel superstructures. Owners, operators, and designers of polar class vessels were contacted to obtain insight into their practical experience with various de-icing and anti-icing systems, and cost and energy data were gathered from vendors. Regulatory rules and guidance documents were reviewed.

There are no prescriptive class or flag state rules requiring that anti/de-icing systems be installed on polar vessels. The ARV Concept Design (Reference 1) was used to estimate lifecycle costs of different options. Three technologies are recommended for deployment in various areas of the ship, based on capital expense (CapEx), operating expense (OpEx), and practical considerations. Table 1 summarizes these findings.

Table 1 Ice prevention & removal technologies and locations

Recommended Technology	Location
Steam lancing	• Focsle deck • Unmanned aerial vehicle (UAV) deck[1] • Port aft 01 deck in way of workboat and landing craft
Deck-mounted electric heat pads	• Exterior superstructure decks & stairways in way of emergency escape/evacuation routes • 02 port & starboard decks in way of life raft, rescue boat and lifeboats.
Under-deck waste heat glycol heating system	• Main deck aft

[1] If the UAV deck needs to be kept free of ice at all times, under-deck heat tracing may be the best solution.

Purpose

The purpose of this study was to develop recommendations for ice prevention (anti-icing) and/or ice removal (de-icing) systems to improve the ARV Performance Specifications.

Methodology

Methods and technologies for preventing and removing ice accumulation on vessels operating in high latitudes were researched. Applicable flag-state (United States Coast Guard [USCG]), class, and International Maritime Organization (IMO) rules related to anti-icing/de-icing systems were reviewed, and informal interviews were conducted with industry experts and owner/operators of vessels that routinely operate in polar waters. The exterior decks and spaces of the ARV Concept Design appropriate for anti-icing and/or de-icing measures were identified and separated into three categories. This was done so that capital expense (CapEx), operating expense (OpEx) costs, as well as other advantages and disadvantages of each technology could be compared fairly. This method also served as a means to substantiate, with data, what we anticipated might constitute an effective and cost-feasible "composite" solution – i.e., a selection of multiple system types, each to be used in different areas of the vessel.

Means of Ice Prevention and Removal

Literature

A literature search was conducted on the topic of ice accretion in high latitudes and on various methods and technologies to mitigate and remove ice accumulation on vessel superstructures. During this process, pertinent sources of key information were reviewed, including climatological data, peer reviewed papers and studies, marketing materials and technical documents on a range of de-icing system products, and relevant internal documents from current and past projects.

Input from Owner/Operators & Industry Experts

Detailed cost and energy data on a range of products was gathered from vendors. Owners, operators, and designers of polar class vessels provided insight on their practical experience with various de-icing and anti-icing systems, including the Director of Arctic Operations at Fednav, the Chief Engineer on the R/V *Nathaniel B. Palmer* (NBP), and the Vice President of Operations at Vard Marine.

The unanimous recommendation from subject matter experts was that the extent of mechanical de-icing systems should be minimized through prudent structural/architectural designs because of the high cost and/or electrical demand of such systems. For example, the foredeck could be covered with a whaleback focsle. A whaleback focsle is a structural cover over the foredeck area that protects the workspace and all foredeck machinery/gear from boarding seas, airborne spray, and precipitation. These bows are increasingly common on icebreaking government vessels and ice-strengthened platform supply vessels (PSVs) and anchor handling towing and supply (AHTS) vessels intended for operation in polar waters. A whaleback focsle can also be constructed to double as a flight deck or UAV deck, as was done on the RSS *Sir David Attenborough* (Figure 1).

Figure 1 Example of a whaleback focsle on the icebreaking vessel, RSS *Sir David Attenborough*

This approach is discussed further in the *Deck Area 2* section below.

Regulations and Guidelines

Deck de-icing regulations and guidelines were reviewed, including International Association of Classification Societies (IACS) Polar Class Rules (Reference 2), the American Bureau of Shipping (ABS) *Guide for Vessels Operating in Low Temperature Environments* (LTE Guide, Reference 3), and Det Norske Veritas Germanischer Lloyd (DNVGL) Offshore Standard, *Winterization for Cold Climate Operations* (Reference 4).

Installed de-icing systems for Polar Class vessels are not mandated by class or flag-state rules. Rather, there is extensive class guidance on the use of de-icing systems, which are non-binding standards (recommendations). However, under the IMO Polar Code (Reference 5), ships operating in the Arctic and Antarctic must carry a valid Polar Ship Certificate issued by class. This certificate constitutes class authorization for the vessel to perform the intended polar water operations and its issuance requires operators to outline measures and procedures to be used to mitigate hazards from sea ice, ice accretion, and low ambient air temperatures specific to their intended polar water operations. If the measures and procedures (including the use of de-icing systems) are deemed inadequate, class can deny issuance of the Polar Ship Certificate until their concerns and recommendations are addressed. In this sense, anti-icing/de-icing systems may be necessary for vessels exposed to superstructure icing risk although, again, there are not prescriptive rules. USCG regulations do require that ice accretion be accounted for in meeting stability requirements, however it is not permissible to consider the use of de-icing systems in order to satisfy the criteria.

Experts at the ABS Harsh Environment Technology Center (HETC), Fednav, and Vard Marine, confirmed that operators have considerable discretion as to the type(s), location, and extent of de-icing systems to be installed, provided a strong case is made that the selected measures are sufficient for the environmental hazards posed, or that other mitigation strategies will be employed to satisfactorily reduce superstructure icing risk.

In summary, it is incumbent on operators to adequately detail, in the body of the Polar Water Operations Manual, the means by which they plan to mitigate risks associated with superstructure icing. If these means are deemed inadequate, issuance of the Polar Ship Certificate may be stalled. Apart from this, there are no prescriptive class or flag-state rules that require a vessel to be outfitted with anti-icing/de-icing systems or technologies.

Methods & Technologies

Following the literature research effort, discussions with vendors, operators and peers, and review of the current regulatory framework, the following five technologies were identified as strong candidates for ice removal and prevention on the ARV:

1. **Manual steam lancing.** A steam lance is a handheld, manually operated nozzle that directly delivers steam to the deck. The nozzle is attached to a flex hose which is in turn attached to a fitting through which high pressure steam is delivered. The steam itself is generated from a boiler located either in the engine room, or other machinery space, or installed locally.
2. **Deck-mounted electric heat pads.** Deck-mounted electric heat pads are rectangular pads that bolt to the top surface of the deck and can be installed in whichever pattern the operator so chooses. They are heated electrically by resistive elements that are protected by a metallic shell. The pads range in size but are typically about one meter wide by one and a half meters long. The electrical energy used to heat the pads is provided by the ship's generators and requires burning additional fuel to meet power demands.
3. **Fixed under-deck waste heat glycol heating.** A waste heat glycol heating system uses a network of under-deck pipes through which a heated glycol solution is pumped. The heat from this solution radiates out from the pipes to heat the deck. The energy used to heat this glycol solution is recovered from exhaust gas heat and engine jacket-water heat.
4. **Under-deck electric heat tracing.** Under-deck electric heat tracing uses a network of high resistivity cables mounted directly to the underside of the deck plate. An electric current is passed through the cables, creating heat. Under-deck electric heat tracing was ruled out as being significantly less attractive than the similar alternative use of deck-

mounted electric heat pads. Such a system would require running an extensive amount of cabling throughout the vessel, which would interfere with other under-deck cabling and piping systems, resulting in a complex and costly installation. This would also present significant challenges for practical maintenance of the system over the life of the vessel. An under-deck electric system would also require considerably more fuel to effectively heat the decks than the other thermal anti-/de-icing systems under consideration in this study. Furthermore, this system would not be well suited to heating non-thermal conductive surfaces such as fiberglass grating which may be used on external inclined ladders. Lastly, configuring such a system to work in parallel with a network of ice sensors on deck (for automated monitoring and activation of heat zones) is believed to be untried to date and could present significant challenges for the shipyard during the detail design and construction phase. Considering there are commercial off-the-shelf (COTS) anti-/de-icing systems that feature this type of automated "intelligent" control system in a modular above-deck solution, it is difficult to make a case for pioneering a custom solution that works in a similar way.

5. **Oil fired boiler/steam piping.** An oil-fired boiler/steam piping system passes steam through a network of pipes mounted to the underside of the deck plate. As the pipes heat up from the steam, they radiate out heat which warms the deck above. This option was ruled out for similar reasons as under-deck electric heat tracing, in favor of a waste heat glycol heating system which uses only recycled energy.

Assumptions

The following assumptions were made for comparing various deck de-icing and anti-icing methods.

1. The ARV Concept Design (Reference 1) was used as the baseline vessel for comparison.
2. System percent active when in use: 100% active.
3. Worst case icing event: 0.50 in/hr. This value is from the NBP specifications and is the largest of three ice accretion rates that were compared. The other two, each less than 0.50 in/hr, were calculated using methods prescribed in the ABS *Guide for Vessels Operating In Low Temperature Environments* (Reference 3), and the article, "Vessel Icing," in NOAA's *Mariners Weather Log* (Reference 6).
4. Length of worst-case icing event: 24-hrs. This value is from the NBP specifications.
5. The only deck actively used in severe icing conditions will be the main deck aft.
6. The whole of the main deck aft will be heated.
7. The main deck aft will experience routine impact and friction/abrasion from various activities, including but not limited to the loading and discharging of vans and other cargoes and the recovery and stowage of jumbo piston cores.
8. The main deck aft will have a bolting pattern where equipment (winches, cranes, etc.) will be directly mounted to the deck.
9. The decks and stairways in way of emergency escape routes and lifesaving equipment are to be equipped with means of anti-icing.
10. Anti-icing of decks is not required for areas which will not be used in icing conditions except in way of emergency escape routes and lifesaving equipment.

11. Worst case icing will occur during transit in beam seas across Drake Passage in the shoulder and winter seasons, particularly the month of August when air and water temperatures are the coldest and wind speeds are high.
12. The UAV deck requires means of ice prevention or removal over its entire surface – i.e., completely cleared of ice before use. This includes the science foremast.
13. The capital cost of a waste heat glycol heating system for the main working deck is the same as that of the NBP per square meter and adjusted for deck area and inflation. The estimated cost, in 1990 dollars, of installing this system on the NBP was USD$219,570.

Comparing Methods & Technologies

Factors other than cost may preclude the selection of a certain anti-icing/de-icing technology for specific areas of the vessel, such as deck function (intended use) and location. For example, the aft main deck requires an underdeck solution because any above-deck solution would be damaged from the handling of cargo and other heavy equipment. This and other factors are discussed in more detail in the following sections. Because these factors drive which technology is best suited for a given deck, deck areas with similar functions and/or locations were categorized together such that they could be analyzed independently. This allowed for properly weighing these factors alongside cost for each anti-icing/de-icing system type.

Recognizing that there are operational differences between deck areas, the vessel was sub-divided into three primary groups or “categories” such that they could be evaluated independently: (1) external superstructure decks and stairways, (2) working and open decks above the main deck, and (3) the main deck aft. Because it is impractical to heat all external decks in their entirety, the extent of deck areas to be heated was determined based on cost and operational considerations. Cost and other relevant factors for each system type were then evaluated for each deck category. Final recommendations and conclusions are presented in the *Findings* section of this report.

Deck Area 1 - External Superstructure Decks & Stairways

This group of deck areas encompasses the 02 decks port and starboard in way of the life raft, rescue boat, and lifeboats aside from all external decks and stairways in the superstructure. Such areas are not required by regulation to be equipped with anti-icing or de-icing measures. However, per the ABS *LTE Guide*, any winterization plan that is submitted is to include, among other measures, the *proposed methodology for anti-icing or de-icing on escape routes deck surfaces, rails, doors, and stairs (must be ice accretion prevention)*. To limit the extent of the vessel’s anti-icing/de-icing system and thereby the total capital and operating cost, it is recommended that external stairways and decks only be heated in way of emergency escape routes and lifesaving equipment. This includes those areas of the 02-decks shown in Figure 2.

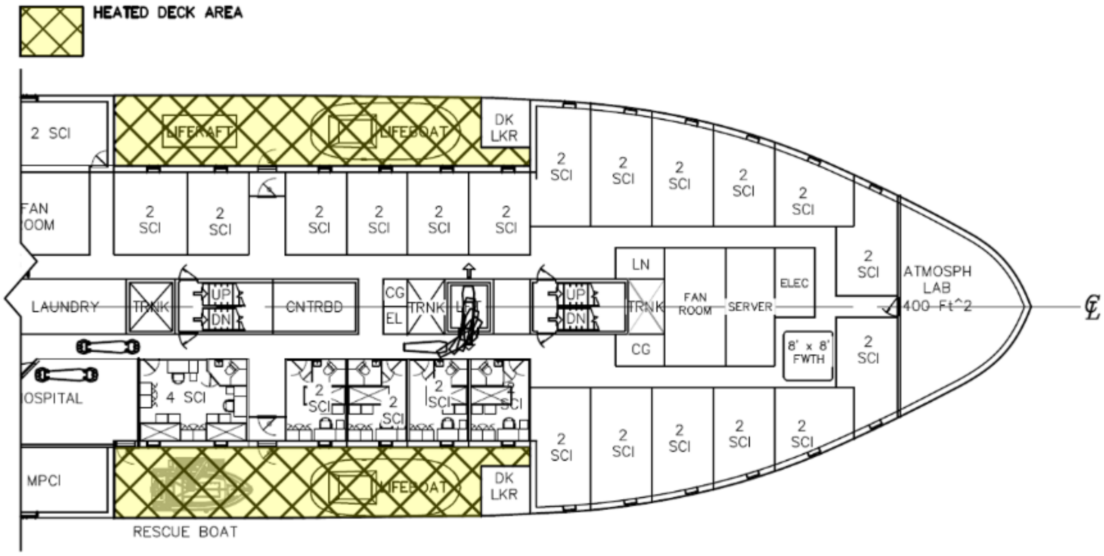

Figure 2 02 decks in way of lifeboats, life raft and rescue boat

The following is a discussion of the costs and other mitigating factors for each method of ice removal for Deck Area 1 (external superstructure decks and stairways).

Steam Lancing

Steam lancing is generally less costly and simpler than other methods of ice removal and requires little additional power to produce and pipe the steam. However, steam lances can only remove ice after it has accumulated – i.e., they cannot be used practically for preventing accumulation the way that installed mechanical systems can. For this reason, steam lances are not suitable for actively used decks, stairways, and other areas that need to remain ice free in case of emergency.

Steam lances also require manual labor and can leave moisture behind on the deck that can then rapidly re-freeze, exposing the crew to injury risks from slips and falls. Finally, because decks needing steam lancing may be far from one another, piping steam from a centralized source would be costly and impractical. Localized means of steam lancing would be a less complex and more economic approach and could be achieved with the use of small electric boilers. Figure 3 depicts a permanently installed local unit available in all popular voltages that can also be fueled with oil, natural gas, or L.P. gas.

Figure 3 Power Eagle ST Series hot pressure washer

Deck-mounted Electric Heat Pads

While more expensive and complicated than steam lances, deck-mounted electric heat pads are the better solution for Deck Area 1 given that external superstructure decks and stairways must be kept ice free in way of emergency escape routes and lifesaving equipment. They are also a more practical alternative to other methods of electric heating such as under-deck heat tracing. Heat tracing cables would cause interference with other under-deck systems and would be difficult to access for maintenance or repair.

One drawback of electric heat pads is that they can trap water/moisture between the pads and the deck, which can accelerate corrosion. For this reason, the pads should be removed during periods of the operating season when superstructure icing is unlikely to occur. Electric heat pads can also draw a considerable amount of power if installed and/or used too extensively. To better understand these cost and power ramifications, the capital cost to install deck-mounted electric heat pads on all external decks and stairways was estimated, as well as the operational cost of keeping these areas ice free in a worst-case icing event (0.50 in/hr).

Capital cost estimates were obtained from the Finnish company, *StarkIce*, an industry leading manufacturer of deck-mounted electric heat pads. *StarkIce* offers an "intelligent" anti-icing/de-icing system designed to improve the efficiency and cost feasibility of mechanical anti-icing/de-icing operations. The *StarkIce* system is composed of deck-mounted electric heat pads, or *Polarpads*, divided into discrete and independently controlled zones around the vessel, as appropriate. Aluminum top panels are recommended for industrial marine use and have been installed on over 20 vessels with an average replacement cycle of 8-10 years, depending on use and heating power. Figure 4 illustrates a typical *StarkIce Polarpad*.

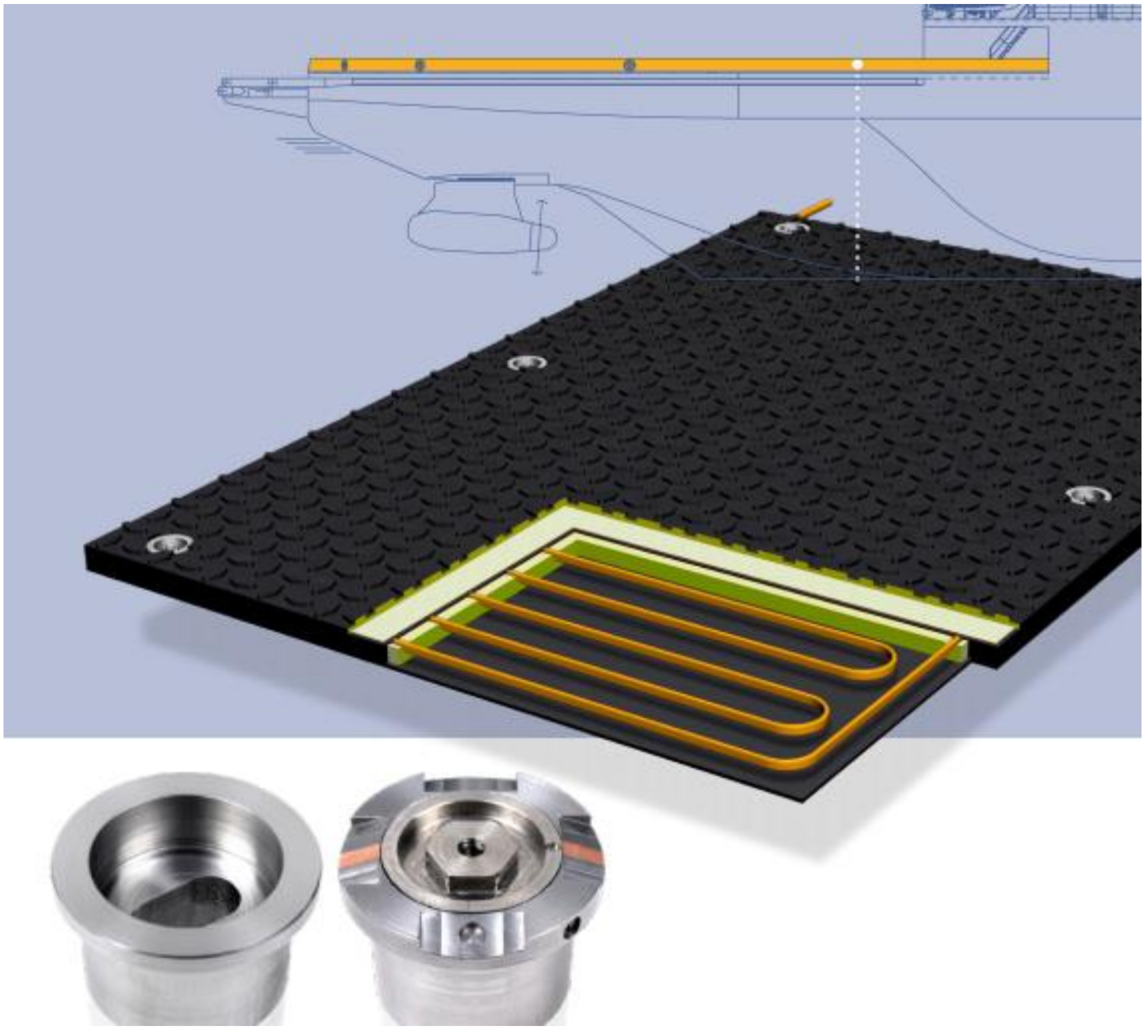

Figure 4 Typical *StarkIce Polarpad*

The *Polarpads* are installed in parallel with a network of ice detection sensors that relay information to a centralized control system. When ice is beginning to form in a particular area or "zone," a notification from the local sensor activates the heating elements in time to prevent the forming of ice. The *StarkIce* system delivers only as much power to a particular zone as needed to keep it ice free. This helps to minimize the total electrical demand during icing conditions and thus fuel consumption. Because of the obvious efficiency/cost advantages of the *StarkIce* system (and comparable capital outlay) relative to other commercially available de-icing systems, we used cost figures from *StarkIce* for our analysis. Despite this system's "intelligent" capability, the values summarized below were calculated assuming the system operates at 100% capacity. This was done to establish a worst-case baseline to allow a fair comparison to other de-icing technologies incapable of "intelligent" heating. The cost savings of using an "intelligent" heating system may be significant depending on metocean conditions.

The capital cost per square meter and total capital cost of the system was calculated based on the total area of all external superstructure decks and stairways on the ARV Concept Design. From Reference 7, it was determined that approximately 0.80kW of power is required to keep one square meter of deck area free of ice during the worst-case icing event of 0.5 in/hr. Knowing the total deck area to be heated, it was then possible to calculate the total power required. Table 2 presents a summary of the power load, fuel usage, and other values for a worst-case icing event.

Table 2 Summary of system costs and power demand for heating entirety of Deck Area 1

Parameter	Value
Capital cost of electric heat pads[1]:	USD$780/m^2
Total area of Deck Area 1:	1460 m^2
Total capital cost of electric heat pads[1]:	USD$1.14 million
Worst case ice accretion rate:	0.50 in/hr
Duration of worst-case icing event:	24-hrs
Power necessary to keep decks ice free:	0.80kW/m^2
Total power necessary to keep decks ice free:	1168kW
Specific fuel consumption:	180 gram/kWh
Density of marine diesel oil:	3225 gram/gal
Overall generator efficiency:	95.4%
Energy density of marine diesel oil:	17.08kWh/gal
Rate of fuel consumption:	68 gal/hr
Fuel consumption for duration of worst-case icing event:	1632 gal
Approximate price of marine diesel oil:	USD$1.50/gal
Daily OpEx costs in worst case icing event:	USD$2448/day

[1] Estimated service life of 8-10 years

For the same 24-hr period of time, two of the vessel's large engines, each operating at 80% capacity, will burn approximately 10,000 gallons of fuel. This illustrates that in a worst-case icing event it would be necessary to use 16-17% more fuel than a typical operating case to heat the entirety of Deck Area 1 with deck-mounted electric heat pads. This increase in fuel usage would necessitate carrying more fuel and the potential enlarging of fuel tanks to meet endurance requirements, underscoring that electric heat pads should be used very selectively – namely, only in way of emergency evacuation routes and lifesaving equipment.

Because they can be set to maintain a constant temperature, the top surface of deck-mounted electric heat pads can be kept ice free at all times. This makes them an attractive option for the areas in way of emergency escape routes and lifesaving equipment. Deck-mounted electric heat pads are also simpler and easier to install than an under-deck waste heat piping system which would interfere with other piping and cabling systems and be difficult to access and maintain. To illustrate the benefits of limiting electric heat pads to those external superstructure decks and areas in way of emergency escape routes and lifesaving equipment, the capital cost to install pads in just these areas was estimated, as well as the associated operating costs to keep them ice free. A representative sample of what this might look like on deck 4 of the ARV Concept Design is shown in Figure 5, a visual depiction between heating all of the exterior walkways on this deck (highlighted in white) and heating only the areas in way of emergency escape routes (highlighted in yellow).

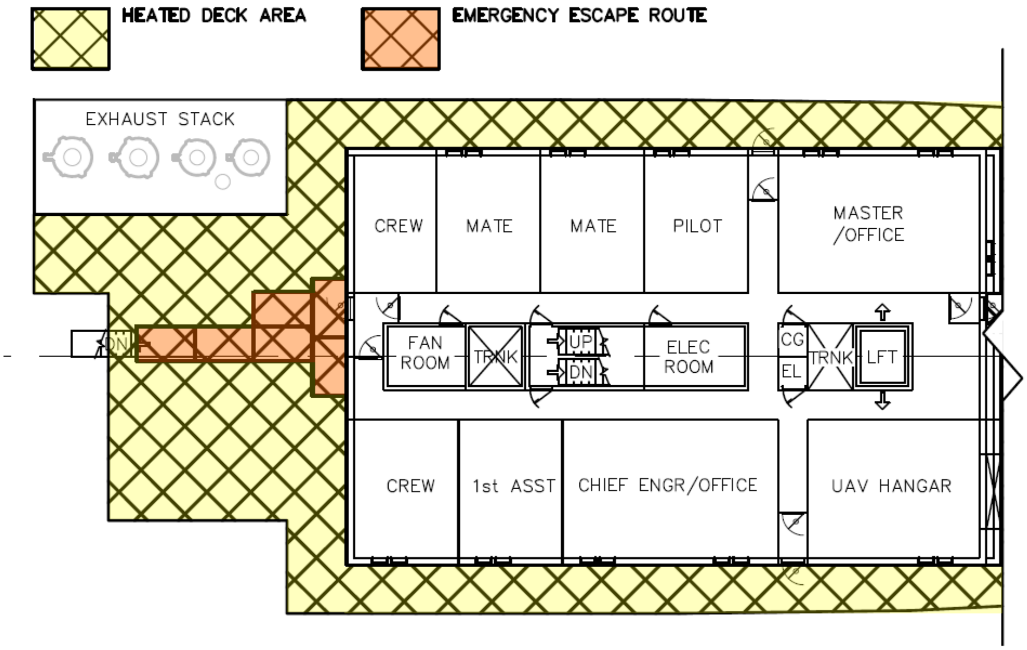

Figure 5 Comparison of emergency escape routes on deck 4 relative to the area of all external walkways on deck 4

Table 3 lists the costs and power demand to heat the external superstructure decks & stairways only in way of emergency escape routes and lifesaving equipment.

Table 3 Summary of system costs and power demand for heating only external emergency routes

Parameter	Value
Capital cost of electric heat pads:	USD$780/m^2
Deck area:	250 m^2
Total capital cost of electric heat pads:	USD$195,000
Worst case ice accretion rate:	0.50 in/hr
Duration of worst-case icing event:	24 hrs
Power necessary to keep decks ice free:	0.80kW/m^2
Total power necessary to keep decks ice free:	200kW
Specific fuel consumption:	180 gram/kWh
Density of marine diesel oil:	3225 gram/gal
Energy density of marine diesel oil:	17.08kWh/gal
Rate of fuel consumption:	12 gal/hr
Fuel consumption for duration of worst-case icing event:	288 gal
Approximate price of marine diesel oil:	USD$1.50/gal
Daily OpEx costs in worst case icing event:	USD$432/day

Using electric heat pads only in way of emergency escape routes and lifesaving equipment would reduce the fuel consumption during a worst-case icing event by over 1,300 gallons and save nearly USD$1M of CapEx costs.

Waste Heat Glycol Heating System

The greatest benefit to using a waste heat glycol heating system is that it uses waste (recycled) heat from the engines to warm the decks, meaning there are almost no additional operating costs. Like deck-mounted electric heat pads, a waste heat glycol system is also capable of preventing ice accumulation in the first place.

Waste heat glycol heating systems are more complicated than steam lancing or deck-mounted electric heat pads, as it requires the design, installation, and maintenance of a complex piping system mounted in the steel structure immediately below the deck. Within the vessel superstructure, where under-deck space is limited and/or permanently covered by a drop ceiling or other outfitting, access to these under-deck/overhead spaces can be difficult for purposes of routine system maintenance and repair. Additionally, these systems can interfere with other critical HVAC, pipe and cabling systems, complicating the design and installation process. Furthermore, because these pipes would be relatively far from the heat source (main engines), there may be a substantial amount of heat loss in the glycol solution, rendering the system less efficient and potentially requiring the use of additional heat sources, pumps, and the consumption of additional fuel.

Such complicating factors quickly drive up both CapEx and OpEx costs for a waste heat glycol system, making it an impractical solution, comparatively, for any deck above the main working deck.

Deck Area 2 - Working & Open Decks Above the Main Deck

Deck Area 2 includes the UAV deck (Figure 6), the focsle deck (Figure 7), and the port aft portion of the 01 deck in way of the work boat and landing craft (Figure 8).

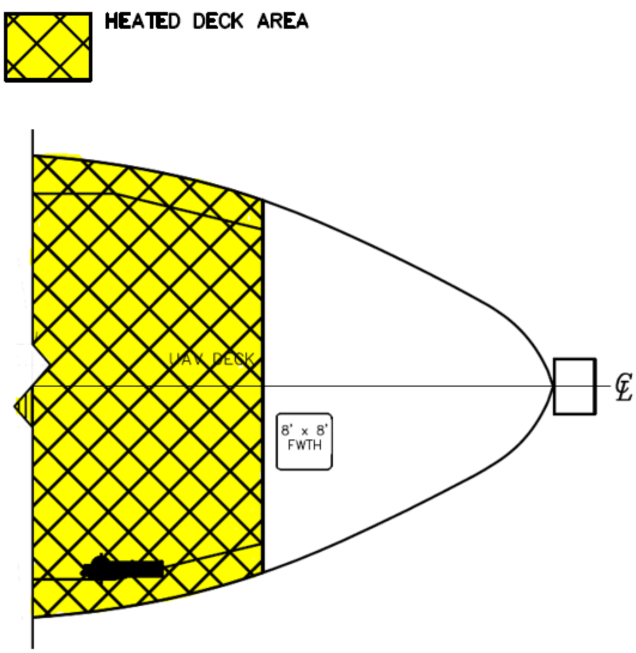

Figure 6 UAV deck

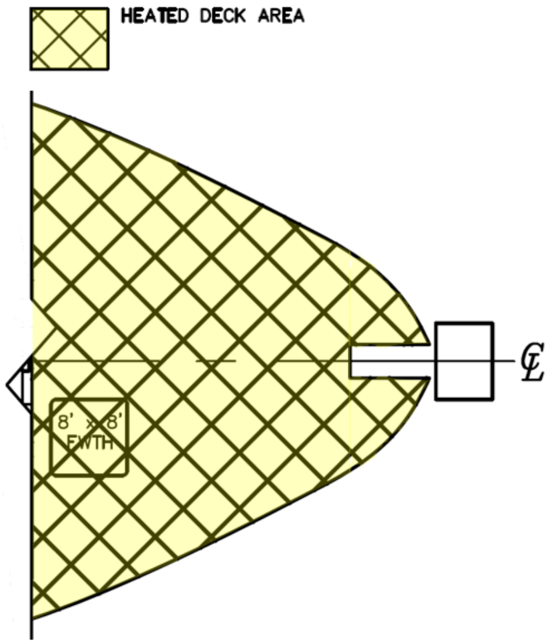

Figure 7 Focsle deck

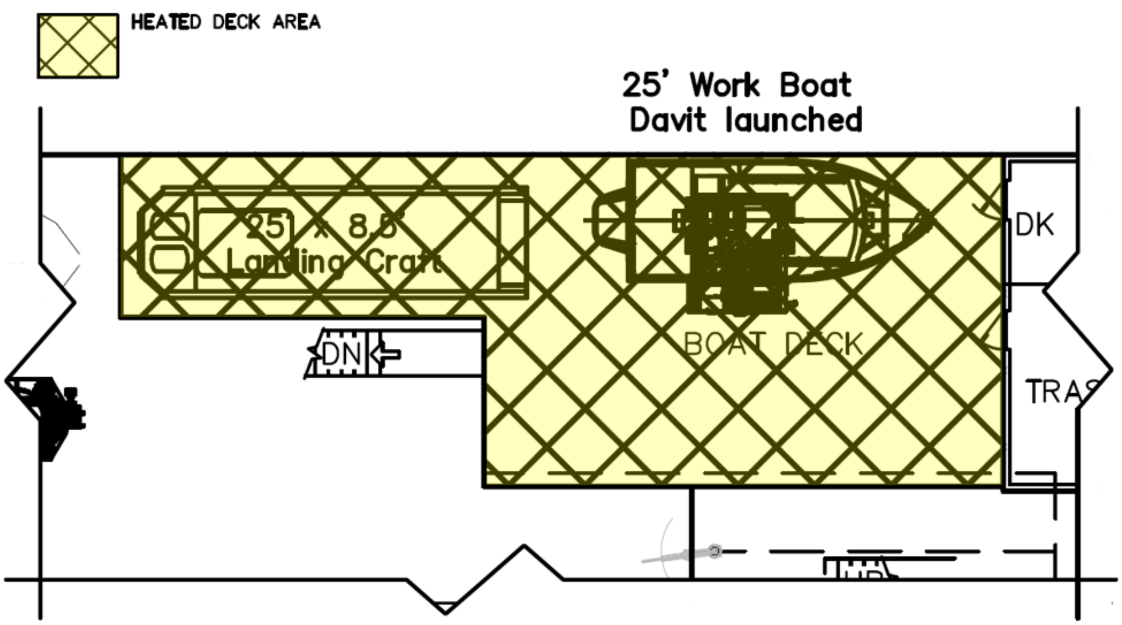

Figure 8 01 deck in way of work boat and landing craft

It is assumed that the entirety of these decks is to be provided with some means of ice prevention or removal. Based on conversations with vessel owner/operators, one of the most effective and practical solutions for keeping decks ice free is to prevent accumulation by way of structural/architectural means. This “design-in” approach to the prevention of ice accumulation is the best option for certain areas of the ARV, such as higher elevation decks where it would be impractical to run under-deck piping, and large deck areas where it would be too costly and draw too much power to heat electrically. For example, the incorporation of a whale-back focsle in the design would effectively enclose the foredeck and largely prevent spray from contacting and freezing on deck machinery and/or surfaces. Other examples of this approach are listed below:

- Positioning the house as far forward as possible to minimize weather decks forward.
- Making muster stations and walkways internal to the vessel or fully covered/enclosed to the extent possible.
- Eliminating exposed weather decks where they are not critical – e.g., 02 decks or higher.
- Extending overhead covering over external walkways where possible.
- Minimizing exposed exterior ladders and stairways.
- Designing high freeboard in exposed areas.

Although this approach would likely increase the total cost of construction, it adds virtually no cost to the operation and maintenance of the vessel and would likely be less costly than other anti-icing/de-icing solutions over the length of its service life. However, it is recognized that some of these items may conflict with science operations. For example, positioning the pilothouse as far forward as possible could make it harder to see science operations on the aft deck from the bridge.

For the other portions of Deck Area 2, where it may be less practical to design preventative measures into the superstructure, other means of ice prevention must be used. However, because the UAV deck and 01 deck in way of the work boat and landing craft are not expected to be in use during conditions when icing will occur, there is no need for them to be outfitted with a permanent mechanical anti-icing/de-icing system. If de-icing of these areas were to become necessary for any reason, a simpler and more economical means of ice removal may be the optimal solution.

Particular consideration must also be given to the anti-/de-icing of the science foremast. Because this mast uses fiber grating with low thermal conductivity it may be difficult to actively heat this area. There is also concern that heating the foremast may adversely affect the scientific instruments mounted to it. For example, it may be that using heat tracing positioned too closely to a sensor could interfere with its ability to function properly. This issue should be revisited during the contract design phase.

The discussion below compares different methods of anti-icing and de-icing for Deck Area 2 (excluding the science foremast) while considering cost ramifications and other factors.

Steam Lancing

Because Deck Area 2, including the equipment hatches located on the UAV and Focsle decks, does not necessarily need to be actively anti-iced, steam lancing may be the best solution when ice removal becomes necessary, based on its simplicity and low cost. However, steam lancing can leave moisture behind on the deck which can then rapidly re-freeze. If, on the UAV deck, this is deemed unacceptable from a safety or operational perspective, the next recommended heating solution would be the use of below-deck electric heat tracing. See *Deck-mounted Electric Heat Pads* (below) for discussion on why, for the UAV deck, an above-deck solution is a less desirable alternative than below-deck heat tracing.

As discussed in *Methods & Technologies*, it is also important to consider the CapEx and OpEx tradeoffs of below-deck electric heat tracing, especially as compared to steam lances. In particular, the UAV deck is relatively large, located far from the power plant, and completely exposed with no insulation afforded by adjacent structure. Thus, electrically heating this deck is expected to necessitate a comparatively high level of power. Finally, the installation of an under-deck heat tracing system so far from the power plant would require long cable runs. This reduces the efficiency of the system and complicates both installation and maintenance, increasing CapEx and OpEx costs.

Deck-mounted Electric Heat Pads

While electric heat pads are capable of keeping decks ice free, this functionality is not necessarily required for the UAV deck, focsle deck, or port aft portion of the 01 deck in way of the work boat and landing craft. It was also assumed that the entirety of these decks must be fitted with such means.

As discussed in the *Deck Area 1* section above, heating such a large deck area with electric heat pads would result in considerable electrical demand. It is for this reason that many vessel owner/operators refrain from outfitting large deck areas with deck-mounted electric heat pads. Furthermore, certain areas of the UAV deck will have a bolting pattern. Deck-mounted electric heat pads would interfere with this pattern, obstructing direct access to the deck fittings. Finally, it is assumed that the UAV deck will experience enough regular impact from operations to shorten the service life of any deck-mounted system.

If steam lancing is determined to be an un-workable solution for the UAV deck, the next recommended solution would be a below-deck electric heat tracing system. Should it be found that the UAV deck will not actually experience much damage from routine operations, and that steam lancing is not a viable option, then the recommended solution would be the use of deck-mounted electric heat pads. For those areas of this deck fitted with a bolting pattern (precluding the use of deck-mounted heat pads) it is recommended to use steam lances or below-deck electric heat tracing. It should again be noted that deck-mounted electric heat pads have many of the same drawbacks as below-deck electric heat tracing, namely high power demand.

Waste Heat Glycol Heating System

A waste heat glycol heating system is an impractical anti-icing/de-icing solution for any deck above the main deck (see sub-section *Waste Heat Glycol Heating System*, above). A waste heat system would be capable of keeping these decks free of ice, but that is not required for these deck areas because they will not be actively used in conditions when icing may occur. Though a waste heat system operates with energy already available (recycled heat), the operating cost benefits do not appear to outweigh the considerable increase in capital expenditure that would be required to install such a system.

Deck Area 3 - Main Deck Aft

Deck Area 3 encompasses the entirety of the main working deck aft, including the large equipment hatch used for loading and unloading 20 foot containers (Figure 9). Internal documentation for the NBP shows that the port and starboard aft corners of the main working deck of that vessel are not heated. Correspondence with the Chief Engineer on the NBP confirmed that their current system of waste heat under-deck heating for the main deck aft has proved adequate. Assuming similar operating requirements and conditions for the aft deck on the ARV, there may be no need to heat the full extent of the main working deck on this vessel. However, it was assumed that the entire deck, approximately 605 m^2, must be heated to allow the ARV to conduct missions more safely in harsher environments.

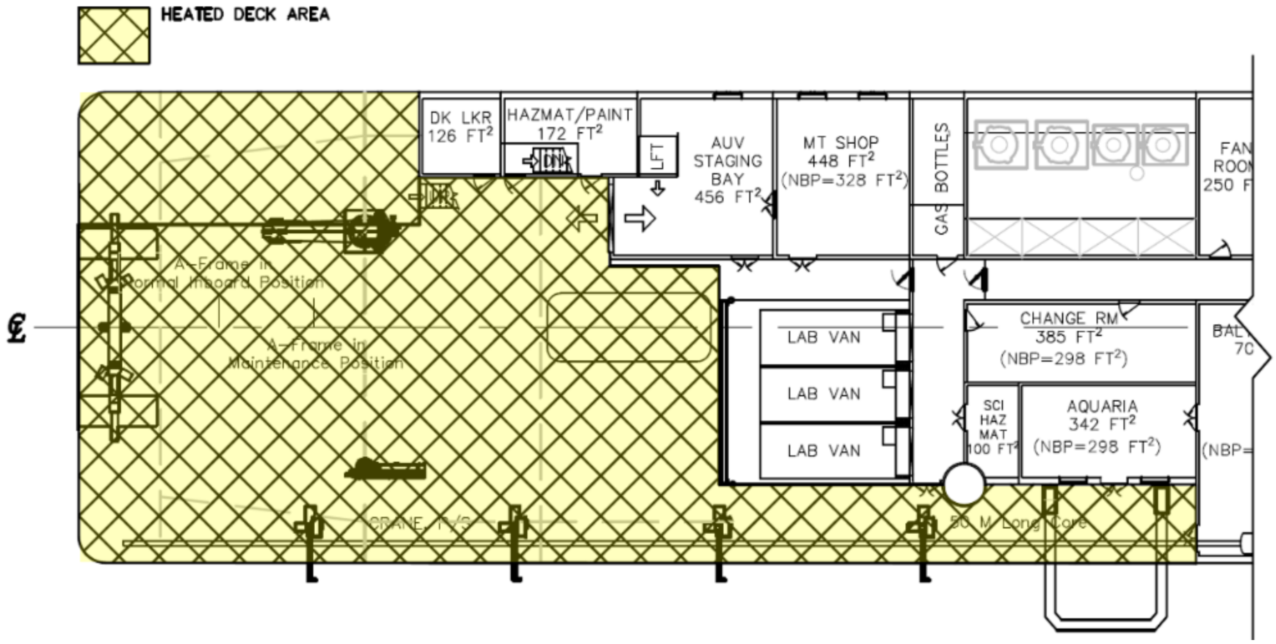

Figure 9 Main working deck

The main working deck is expected to see regular deck impact, abrasion, and pressure associated with deployment and recovery of science equipment, stowage and handling of cargoes, and other heavy-duty operations. For this reason, it was assumed that any above-deck heating system would become damaged during normal vessel operations. Thus, an under-deck heating solution for this area is highly preferred. Furthermore, because it is expected that this deck will be used in conditions where icing may occur, it is necessary that it remain ice free. This means that it requires a system capable of anti-icing. The discussion below compares different methods of ice prevention and removal for Deck Area 3.

Steam Lancing

The need for this deck to remain ice free at all times precludes the use of steam lancing, which cannot be used to prevent ice but only clear it once it has formed. If steam lancing were used on the main deck, its only advantage would be reduced cost and greater simplicity than deck-mounted electric heat pads or a waste heat glycol heating system. It would be impractical and inconvenient for such a large area, as well as laborious and potentially hazardous for the crew.

Deck-mounted Electric Heat Pads

Deck-mounted electric heat pads are an inappropriate anti-/de-icing solution for the main working deck. Although deck-mounted electric heat pads are capable of keeping this area ice free, and would constitute a less complex solution than the installation of an under-deck waste heat glycol heating system, they would be exposed to routine deck impact, abrasion, and pressure associated with normal operations. Given that they are designed primarily for foot traffic (not cargo/equipment operations), the pads would sustain damage and large areas of the deck would likely need to be replaced multiple times over the life of the vessel. Furthermore, the bolt pattern on the aft deck for securing cargoes and/or equipment will be a 2ft x 2ft grid. Deck-mounted electric heat pads would interfere with this pattern, obstructing direct access to the deck fittings.

Finally, as discussed in previous sections of this report, to heat such a large deck area with deck-mounted electric heat pads or under-deck electric heat tracing would require considerable electrical power and increase fuel consumption.

Despite costing an estimated USD$1.2 million to install, compared to the approximate USD$500,000 it would cost to install a comparable deck-mounted electric heat pad system, a waste heat glycol heating system is the apparent most practical solution for Deck Area 3. Countering the high capital cost, this system would result in almost no additional operating costs.

Because a waste heat glycol heating system would be under-deck, its components would be protected from damage, a necessity considering the nature of operations to be carried out on this deck. Furthermore, because Deck Area 3 is close/adjacent to the engine room, the pipe runs would be relatively short, helping to minimize cost, and there would be minimal heat loss in the glycol solution as it is circulated through the loop. There would also be much easier access to the pipe loop in this area (machinery space overhead) as compared to the superstructure, allowing for ease of maintenance. Most importantly, a waste heat glycol heating system in Deck Area 3 would be able to keep the aft deck ice free at all times, which is an operational necessity.

The large equipment hatch will also require an under-deck heating solution; however, means must be provided to disconnect this portion of the under-deck heating system when removal of the hatch is necessary. This can be achieved by the employment of an electric heat tracing system installed on the underside of the hatch cover. This arrangement allows electrical power to be easily connected and disconnected when the hatch is in use. If a waste heat glycol system were used for the underside of the hatch it would be susceptible to damage in handling, or (if the hatch is hinged) during load and discharge operations. For this reason, electric heat tracing appears to be the most practical solution for this limited area of the main working deck.

A waste heat glycol heating system is used on the main working deck of the NBP and has reportedly performed satisfactorily over many years of service. Because it is a proven technology on a similar vessel in a similar, if not identical application, the use of a waste heat glycol heating system is the apparent best option for Deck Area 3.

Determining Technical Feasibility of Waste Heat Glycol Heating System

The technical feasibility of a waste heat glycol heating system was examined to determine whether there would in fact be enough waste heat from the engines to heat the main working deck and meet the ship's other auxiliary heating requirements. These requirements include heat for the HVAC system, warming certain tanks, pre-heating fuel-oil (if necessary), and potable water heating.

Information was gathered on available waste heat and heating requirements from the R/V *Sikuliaq.* The *Sikuliaq* was chosen for comparison because it is a similar vessel that has been operating in a comparable environment with similar heating requirements. These heating requirements were parametrically scaled based on the assumed vessel characteristics of the ARV and known vessel characteristics of the *Sikuliaq*. This allowed for an estimation of the amount of waste heat that will be available on the ARV and the power required for all vessel systems in need of heating.

It was determined that even if all systems were running simultaneously at maximum load, there is sufficient waste heat power to meet the predicted loads and still heat the main working deck in a worst-case icing event. Thus, it is projected that a waste heat glycol heating system would in fact run completely on recycled energy, allowing for substantial operational cost savings. However, were a waste heat glycol heating system to be used more extensively throughout the superstructure areas of the vessel, there may not be sufficient waste heat power to meet all loads.

Findings

Under-deck electric heat tracing was ruled out as less attractive than deck-mounted electric heat pads due to the complexity of its design and installation. An oil-fired boiler/steam piping system was also ruled out because it uses fuel, whereas a waste heat glycol heating system uses recycled heat. Glosten recommends that a combination of the following three methods of ice removal and prevention be used on the ARV:

- Steam lancing.
- Deck-mounted electric heat pads.
- Under-deck waste heat glycol heating system.

Steam lancing has the lowest operating and capital costs of the three systems and is also the least complex. It does not, however, prevent the buildup of ice, necessitating its manual removal by the crew, exposing them to potential hazards. It is recommended that steam lancing be used on the areas of the vessel where anti-icing is not needed, and where it would be too costly or impractical to use other methods of ice prevention and removal. This includes the UAV deck, focsle deck, and the port aft portion of the 01 deck in way of the work boat and landing craft. It is assumed that these areas will not be used in conditions when icing would occur. Steam lancing these decks can be best accomplished with the use of localized electric boilers.

Deck-mounted electric heat pads are more costly to install than steam lances, but less costly to install than a waste heat glycol heating system. However, they have a high power demand. This makes them the costliest to operate and necessitates limiting their use to only those areas in way of emergency escape routes and lifesaving equipment, where it essential to keep decks free of ice. The use of a *StarkIce* “intelligent” system or similar would reduce fuel consumption and operating costs. Electric heat pads are also easier to install, access, and maintain than a complex waste heat system which would interfere with other under-deck piping and cabling, making them the preferred anti-icing solution for superstructure decks.

An under-deck waste heat glycol heating system is the most costly and complex solution and is practical only for the main working deck. It is assumed that this deck must be kept ice free at all times, excluding the use of steam lances. Furthermore, the nature of the work that will take place in this area of the vessel necessitates an under-deck solution, excluding the use of electric heat pads. Although the most costly, the system uses only waste heat from the main engines, meaning that some, or potentially all, of this additional CapEx cost might be recouped over the life of the vessel through savings on operating costs. However, it was not possible to calculate this payback period without a better understanding of the duration and conditions of icing the vessel will encounter. Because the main working deck is close to the engines, the extent of the system would be minimized compared to if it were installed in the superstructure. It would also be relatively easier to access and maintain. While long term repair and maintenance costs are a reality, they may be similar to or less than that for electric heat pads which would require periodic replacement if installed on the main working deck. Finally, waste heat glycol heating systems are a proven technology, having been used successfully on the NBP for many years.

A summary of these findings and recommendations can be found in Table 4.

Table 4 Summary of findings and recommendations

Technology	CapEx	OpEx	Anti-Icing Capable	Advantages	Disadvantages	Recommended Locations
Steam Lancing	Low	Low	No	• Simplest	• Requires manual effort to remove ice • Remaining moisture on deck can quickly re-freeze	Use in way of working & open decks above the main deck: • No need to keep these decks ice free • Use localized small electric boilers to simplify use and installation
Deck-mounted Electric Heat Pads	Intermediate	High	Yes	• No interference with under-deck systems • Easier to install, access, and maintain than waste heat piping system	• Requires use of additional fuel • More complex installation than steam lances • High power demand • Can trap water accelerating deck corrosion	Use in way of emergency escape routes & lifesaving equipment
Waste Heat Glycol Heating System	High	Low	Yes	• Uses recycled heat • Sheltered from hazardous above deck activities	• Interferes with under-deck systems • Complex & costly installation • Difficult to access & maintain • Heat is lost when piped too far from engines	Use on the main deck aft: • Close to engines • Easier under-deck access for maintenance • Protected from above deck activities

Specification Changes

Recommended Changes

Table 5 summarizes the changes recommended for the ARV Performance Specifications regarding deck anti- and de-icing technologies.

Table 5 Recommended changes

Specifications Section	Specifications Update
536.1 Deck Heating	Use steam lancing in way of working & open decks above the main deck, including the UAV deck.
	Use deck-mounted electric heat pads in way of emergency escape routes & lifesaving equipment.
	Use waste heat glycol heating system on the main deck aft.

Required Owner Decisions

Answers to two questions are required to inform selection of deck anti- and de-icing technologies to be specified for the ARV:

1. Should it be required that the UAV deck be kept clear of ice at all times?
2. Does the potential of remaining moisture to freeze to decks that were just steam lanced preclude the use of steam lances on the UAV deck?