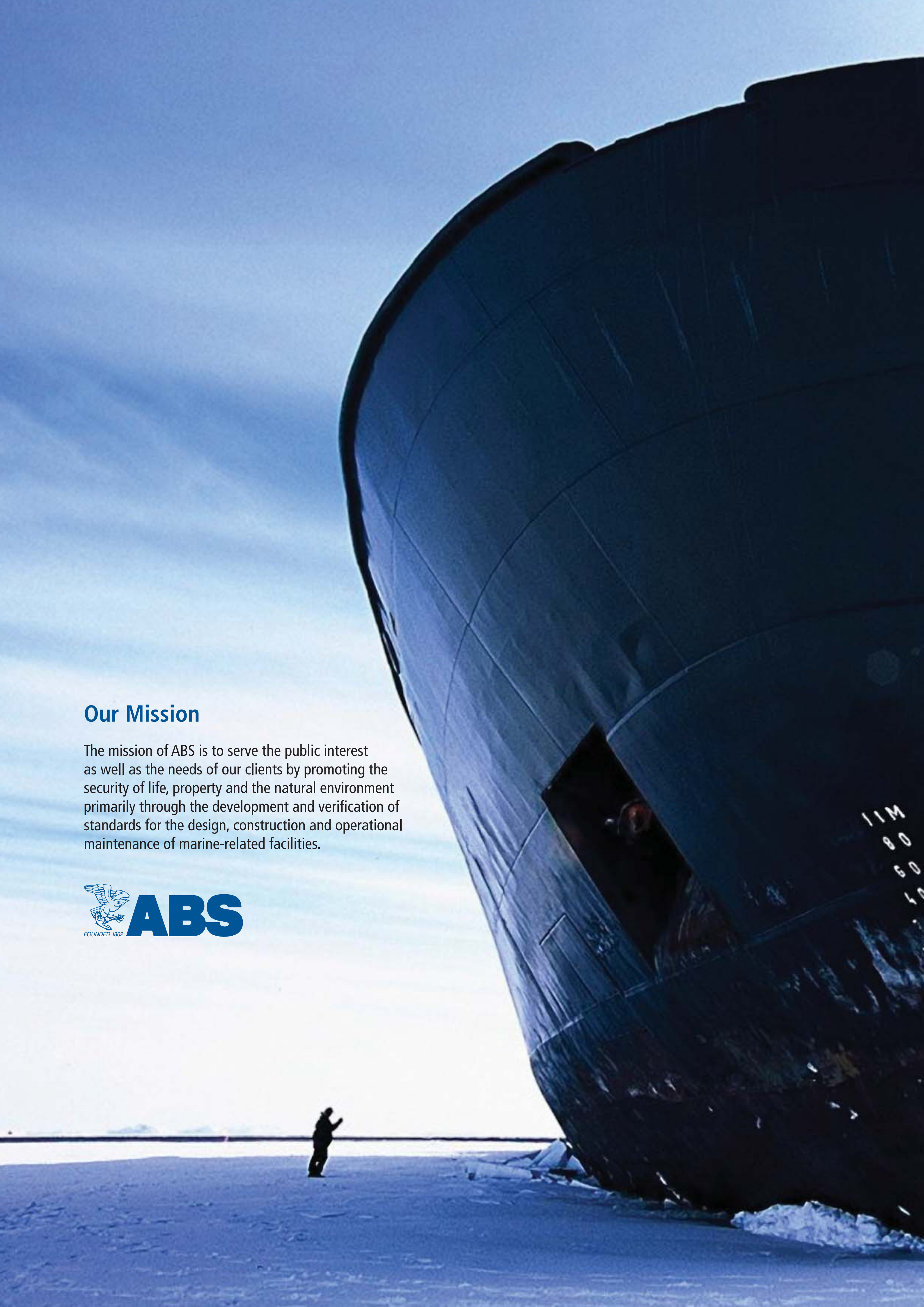
Low Temperature Operations

Guidance for Arctic Shipping

ABS
FOUNDED 1862



Our Mission

The mission of ABS is to serve the public interest as well as the needs of our clients by promoting the security of life, property and the natural environment primarily through the development and verification of standards for the design, construction and operational maintenance of marine-related facilities.

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Low Temperature Operations – Guidance for Arctic Shipping

The Arctic Prize

Shortcuts and Energy

There now appears to be almost unanimous scientific agreement that mankind is largely responsible for the increase in greenhouse gases that are contributing to global warming which, in turn, is causing a rapid retreat in the polar ice caps. Analysis indicates that more than 40 percent of the hard, multi-year, Arctic ice has melted away over the last quarter century. The pace at which the melt is occurring is constantly increasing with an estimated near 15 percent reduction in the perennial ice cover in just the last two years.

What continues to be debated is not if, but at what speed this retreat will continue. Some of the most aggressive models indicate that large sections of the Arctic could be ice-free during the summer months as early as 2013.

The implications for the international shipping and offshore industries are immense. The opportunities can be broadly considered as impacting two principal areas. The first is the potential for vastly increased exploration and production of energy resources within the Arctic, opening up opportunities for harsh environment compatible drilling units, production facilities and associated marine support and transportation activity. The second is the tantalizing prospect of new navigational routes, principally between Asia and Europe that, by significantly shortening the voyages, could fundamentally impact existing supply and demand shipping models.

While the navigational opportunities may still lay somewhat further in the future, the prospect of access to vast new fossil fuel energy resources has captured the world's attention. Norway's Snovhit field is already producing. Russian plans for the development of the vast Shtokman gas fields continue to advance. But these pioneering developments are minor when compared to analysts' projections of the potential energy riches that lie beneath Arctic waters.

Government and industry estimates vary but there appears to be agreement that the Arctic holds the largest untapped oil and gas deposits remaining in the world, aggregating in the hundreds of billions of potentially recoverable barrels of oil and hundreds of trillions of cubic feet of gas. The projections dwarf the predicted reserves of the world's current largest oil producer, Saudi Arabia. The deposits are thought to stretch from northern Russia to the Greenland Rift and across to the Beaufort Sea north of Alaska.

Regardless of the pace of the summer melt of the Arctic ice sheet, recovery of these reserves will still require highly specialized exploration and production units, capable of operating not only in winter ice but under the extremely harsh winter environment. Experience gained from offshore operations in Prudhoe Bay and off Sakhalin Island provides guidance but the challenges of Arctic resource development on such a broad projected scale have raised a host of technical and operational challenges that must be addressed by industry, including classification societies.

Among them will be development of a new fleet of harsh environment-capable offshore supply vessels (OSVs) to support the exploration and production (E&P) activity and significant numbers of Arctic shuttle tankers and LNG carriers capable of operating year round to move the oil and gas to market. The Vasily Dinkov series of new Arctic shuttle tankers, built to dual ABS and Russian Register class at Samsung Heavy Industries in Korea, is a precursor for what is likely to be a demand for many more such ships in the coming years.

Although the development of Arctic oil and gas resources will be of critical importance in meeting future global energy needs, their exploitation and recovery can be considered as the next logical step for an industry that has always sought out new fields in areas that have posed increased technical challenges. The prospect of new, shorter shipping routes between Asia and Europe, however, offers the prospect of a much more dramatic dislocation of accepted practices.

The Northern Sea Route from Shanghai to Rotterdam would slash the traditional voyage distance by almost 5,000 miles and represent around a 40 percent reduction in the transit distance. The challenge of designing and building a new fleet of large, ice class containerships, capable of making this passage during the summer months, pales in comparison to the impact that such a substantial reduction in the time of passage would have on the tonne mile productivity of the world's container fleet assuming conditions permit maintaining adequate service speeds. The economic attraction of such a route is overwhelming – cutting as much as 20 days off an Asia-Europe round trip would offer savings in bunkers alone of more than $2.5 million per voyage.

The lure of new energy resources and greater transportation efficiencies will induce a spate of new construction of offshore units, tankers, gas carriers and containerships. Of that there appears little doubt. But, as always with opportunities proffered to international maritime industries, timing will prove to be the critical element that will influence the success of these projects.

In the meantime, researchers, designers and classification societies are pushing ahead in their efforts to gain the knowledge, develop the standards and have the confidence that the new generation of marine facilities and vessels can be designed, built and operated safely in this challenging frontier. This booklet highlights some of the more recent developments being undertaken by class and, specifically by ABS, to assist industry to capitalize on these emerging opportunities.

Developing Rules for Polar Class Ships

For more than 50 years there have been requirements in ABS Rules for ships navigating in ice. ABS was the first classification society to approve a commercial oil tanker for ice navigation in the Arctic in the mid 1960s, the *Manhattan*. It was also the first society to class an LNG carrier for which an ice notation was issued, the *Methane Polar*, delivered in 1969.

The early requirements were prescriptive, based to a large extent upon the accepted Finnish-Swedish Ice Class Rules that resulted in the traditional ice class A, B and C ratings. The standards specified a percentage increase in scantlings above normal class requirements, together with structural reinforcement through intermediate framing of the critical areas particularly in the forward part of the hull.

In 1971, the Finnish-Swedish Ice Class Rules were completely revised, establishing design ice pressures for the corresponding ice ratings together with engineering equations for plating, framing, longitudinals, stringers, decks and bulkheads in the ice belt. Requirements for machinery, shafting, propellers, rudders and steering systems were more directly addressed. The ice ratings were expanded and redefined as IA Super, IA, IB and IC. These revised Finnish-Swedish Ice Class Rules were adopted by ABS with identical ice classes noted as IAA, IA, IB and IC.

In 1980 the ABS Rule Development department began the development of *General Ice Class Rules* to establish improved requirements for world-wide operation, ranging from those applicable to the highest class polar icebreaker to the more modest strengthening required for commercial vessels operating in first year ice.

This project involved a comprehensive review of the ship ice technology available at the time and reference to a database of 33 operating ice class vessels, including the highest class Arctic icebreakers. Reference was also made to the Canadian Arctic Shipping Pollution Prevention Act, the Russian Register Rules and the prevailing Finnish-Swedish Ice Class Rules.

The resulting ABS Rules were subject to wide-ranging review by industry and governments prior to their formal adoption in 1985. Those standards, subsequently updated and expanded to reflect improvements in technology and in-service experience, provided the bedrock of the ABS Rules for ships navigating in ice-infested waters until early 2008.

Methane Polar

At that time, ABS issued the *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters* that incorporates the results of a multi-year, joint research effort by the member societies of IACS into the demands that would be placed on a new generation of large commercial ships expected to be constructed to participate in the extraction and transportation of the vast energy resources thought to exist in the Arctic region. The IACS require-ments were issued as Unified Requirements concerning Polar class (URs I 1, 2 and 3) that address both structure and machinery, with a particular emphasis on propeller and shafting requirements. They apply to vessels contracted for construction on or after 1 March 2008.

The new ABS Guide (and IACS URs) include ice load definitions as well as specific strength requirements for plating, framing (including web frames and load-carrying stringers), plated structures (such as decks and bulk-heads), and the hull girder. The Guide also includes material requirements as well as corrosion and abrasion allowances. General strength requirements for hull appendages, stem and stern frames as well as provisions for local details. Direct calculations and welding are also contained in the new criteria.

Both open and nozzle propellers are addressed including design ice thickness and a strength index for calculating the propeller ice loads. Analytical tools are provided for calculating strength of the propeller blade. The Guide also defines accelerations imposed upon machinery due to ice impact/ramming so that the integrity of the arrangements for securing essential machinery is maintained.

The new IACS URs (and ABS Guide) are based upon the lowest Polar class having a general level of strengthening roughly comparable to the Baltic IA class, with the intention that a vessel conforming to the lowest Polar class should automatically have sufficient strength to meet the Baltic requirements.

The highest Polar class is intended to offer a level of capability for a ship to operate year-round in all polar waters, with due caution on the part of the operator with respect to limiting ship speed in severe conditions, avoiding aggressive maneuvers, impacts with glancing ice features and other operational risks.

Assuming the same ship configuration (identical hull form and frame spacing and span), experience shows that the highest Polar class (PC 1) should have approximately 250 percent greater shell plating thickness and a 700 percent greater frame strength requirement (shear and section modulus) compared to the lowest Polar class (PC 7). Based on this assumption, seven total ice classes are defined with plate thickness increasing by approximately 14 percent increments and the frame strength by approximately a 32 percent increment from one class to the next highest.

Each Polar class is defined in terms of its operational service limitation. The definitions are generic, because ships of any of the classes may operate safely in a wide range of actual conditions, depending on season and area.

In formulating ice class requirements, the IACS member society representatives examined design scenarios such as ramming, glancing, pressure and estimated ice loads from ship, ice and operational parameters. The service experience of existing ice-strengthened vessels built to previous Ice Class Rules suggests that glancing, ramming and pressure scenarios should be considered in developing strength requirements for Polar classes.

		IACS	
		PC 1	Year-Round Navigation in Arctic Waters
		PC 2	
		PC 3	
		PC 4	
		PC 5	
Winter Navigation in Sub-Arctic Waters	IA Super	PC 6	Summer Navigation in Arctic Waters
	IA	PC 7	
	IB		
	IC		
	FSICR		

Operational Service Limitations of Polar Class

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Two sets of equations were adopted in the applicable Polar UR to represent the structural requirement for the bow area to sustain ice loads due to glancing and ramming. The glancing scenario would set the local scantling requirement for the bow area, while the ramming case would be related to the longitudinal strength requirement. Since it is not practical to define the characteristics of design scenarios for all hull areas, most hull area strength requirements are defined as percentages of the bow area strength. The ice loads caused by a pressure scenario, which is quite difficult to define, are assumed to be encompassed by the defined Polar UR ice loads.

Ice loads for the ramming and glancing scenarios are determined by a set of ship parameters and a set of ice property parameters and an operational parameter – the speed at which the ship impacts the ice. The ship parameters include displacement, hull form at point of contact and effective added mass due to the impact. The ice parameters include crushing strength, flexural strength, ice thickness and local ice-edge geometry at the point of contact. The combinations of ice parameters and the ship speed are chosen to characterize the ice conditions for each Polar class.

All of the structural design requirements are based on the Polar UR load model. This model assumes a load patch of constant intensity in the vertical direction, peaked longitudinally. For use in plate, frame and grillage design, the load representation is simplified as a uniform rectangular patch. Within the ice-strengthened areas, it is assumed (and required) that stiffeners terminate in a manner that provides full fixity. Intersections with deep members, decks, bulkheads, etc. are designed to provide sufficient connectivity to offer the same restraint.

While most traditional ship design rule formulations are based on elastic criteria, the structure requirement for ships under ice loads uses a plastic design method. Requirements for both the shell plate thickness and frame strength in the Polar UR take into account plastic designs such that under the design ice load the shell plate and frame should be within acceptable limits.

For plating, the design loads governing the requirement should correspond to the load when the first plastic strain occurs in the structure. An ultimate strength margin factor was used to determine the limit state level. For framing, the energy method was used to formulate limits. To derive the plastic limit state, several possible energy-absorbing mechanisms were considered including a pure bending hinge, a combined shear/bending hinge, and a shear hinge. Additionally, unlike all other Ice Class Rules, the Polar UR gives a requirement for the ship's overall longitudinal strength to account for the global ice load due to ramming thick ice features.

The new IACS UR and ABS requirements, represent a significant step forward in adopting internationally harmonized requirements for Polar class ships. These Rules unify and clarify ice-strengthening requirements, regardless of the flag or operational area of the vessel, greatly simplifying the operational flexibility of these vessels to trade internationally.

New Polar Rules Address Machinery, Propeller Issues

New ice machinery rules for Baltic and polar ships have been developed by IACS (UR I 3) that have been adopted by ABS within the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters*. The standards are based on the *Finnish-Swedish Ice Class Rules (FSICR) for Propulsion Machinery* as amended for the harsher environment of the polar regions.

Unlike the previous Ice Rules, the new Rules are based on a more scientific approach to evaluate the ice load on propulsion machinery. Also, in order to maintain the lowest two polar ice classes (PC 6 and PC 7) equivalent to the two highest ice classes (IA Super and IA) in the Finnish-Swedish Rules, extensive calibration and validation for the ice load formulae were performed by the project team members drawn from the five class societies (ABS, Det Norske Veritas, Germanischer Lloyd, Lloyd's Register and Russian Maritime Register of Shipping), Canada Transport and Finland's Maritime Authority.

The new Machinery Rules are the result of a long period of research and development by circumpolar nations over the past 25 years. This has included analysis of the service history of propeller damage, propeller and shaft load measurements on full-scale trials, laboratory investigations and numerical simulations of propeller and ice interaction.

During the mid 1970s to late 1980s, it became increasingly evident that existing machinery regulations needed updating. For example, blade scantlings in the Baltic and Canadian Rules were dependent on a design ice torque, rather than a direct expression of the out-of-plane blade bending moment, which can cause major blade deformation and breakage.

At the end of the 1980s, both the Canadian and Baltic marine authorities had decided to update their respective machinery protection regulations. In order to share expertise and resources, a joint research project arrangement on blade design ice loads was entered into by Canada and Finland. Under the project, Finland developed a numerical simulation model of propeller and ice interaction during the ice milling operation, which incorporated a Finnish model for contact load components and a Canadian model for non-contact load components. A number of associated research programs provided additional information, such as ice properties at interaction velocities, and statistics of available full-scale data.

In developing the ice load formulae in UR I 3 for machinery, the joint project's results were used. To calibrate and validate the ice load formula, class societies performed extensive case studies based on their databases.

Polar Rules –
Areas Still To Be Addressed

Although the IACS Polar Unified Requirements (URs) that have been adopted in the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters* represent an important step towards enhancing and harmonizing the international standards for these vessels, there were a few unresolved issues when the new standards entered force. IACS has formed a hull panel to address these issues with the intent of amending the URs once appropriate criteria are agreed.

ABS has also targeted these issues and has included guidance for industry, where appropriate, in the revised 2008 edition of its *Guidance Notes on Ice Class*.

The main topics that are receiving further study include:

- Icebreaker: the highest Polar notation (PC1) is for year-round operation for a commercial vessel in all polar waters. However, the criteria do not explicitly address icebreakers.
- Stern requirements for Double Acting Vessels (DAVs): the IACS Polar Hull Panel considers that requisite scantling for the stern area of a DAV needs further study and clarification.
- The ice loads for hull forms other than icebreaking forms are to be defined.
- The grillage strength for structures under ice loads are to be further assessed.
- The additional inertial loads caused by ship/ice interactions for those structures not directly contacting ice are to be identified and studied. These structures include, as examples, the inner skin bulkhead and the containment system of LNG carriers.
- The requirements for the arrangement and for the scantling of the load-distributing stringers are to be addressed.
- The loads on appendages caused by ice are to be defined.

Table 1. Comparison of Baltic Ice Class to UR I 3

Requirements	Baltic Ice Class	UR I 3
Minimum power of propulsion machinery	X	
Rudder	X	X
Propeller	X	X
Shafting	X	X
CPP mechanism and blade attachment		X
Reduction gear	X	X
Sea inlet and cooling water system	X	X
Bearing and Stern seal		X
Cold engine starting arrangement	X	X
System design		X
Machinery fastening loading acceleration		X
Auxiliary systems		X
Ballast tank heating		X
Ventilation system heating		X
Steering systems	X	X

The IACS UR I 3 provides ice load and failure criteria for propulsion machinery and design guidance for the machinery system. In the current scope, the new requirement leaves the detailed scantling design for propulsion machinery to be done either using an advanced analysis method such as finite element (FE) for propeller blade strength or the engineering practices in industry, for example, the controllable pitch propeller (CPP) mechanism design. The coverage of URI 3 in comparison to that of Baltic Ice class FSICR is shown in Table 1.

Given the importance of propulsive power and propeller strength for vessels navigating in ice, ABS has developed procedures to assess the powering for ice navigation and propeller strength and related issues such as blade cavitation and vibration.

A systematic approach is proposed by ABS for an ice powering estimate by taking into consideration the ice resistance model test results, the propeller performance under a slow ship speed and the engine performance at a heavy load condition. A case study for a Polar class PC 7 aframax-sized tanker, for which the new Rules do not set specific powering requirements, shows that the

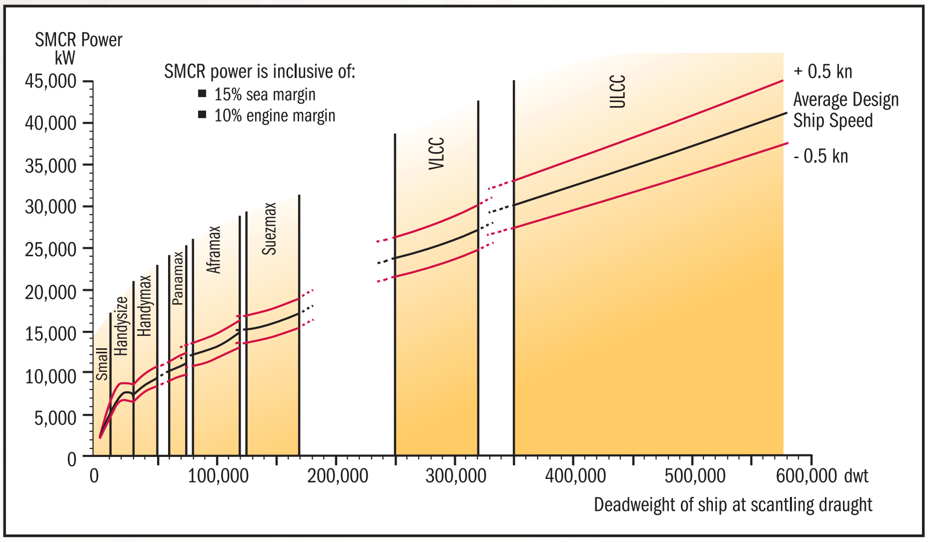
Table 2. Comparison of the power reductions for an aframax-sized tanker

	FSICR: Ice Resistance and Power	FSICR: Ice Resistance ABS Approach: Power	Model Test: Ice Resistance ABS Approach: Power
Engine Power	22,000 kW	18,632 kW	13,098 kW
Reduction compared to FSICR power		15.31 percent	40.5 percent

engine power needed to operate can be largely reduced compared to the power required by the Finnish-Swedish Rule formulae if the propeller is appropriately designed along with the use of a more accurate ice resistance value. Table 2 summarizes the comparison between the results for the combination of FSICR ice resistance value and power requirements; FSICR ice resistance value and the ABS approach for power requirement; and the model test value for ice resistance and the ABS approach for power.

When comparing these results with a typical engine power rating for non-ice tankers (shown in Figure 1), it is noted that instead of a typical VLCC tanker engine required by FSICR, a typical aframax tanker engine can be used for this IA class aframax tanker.

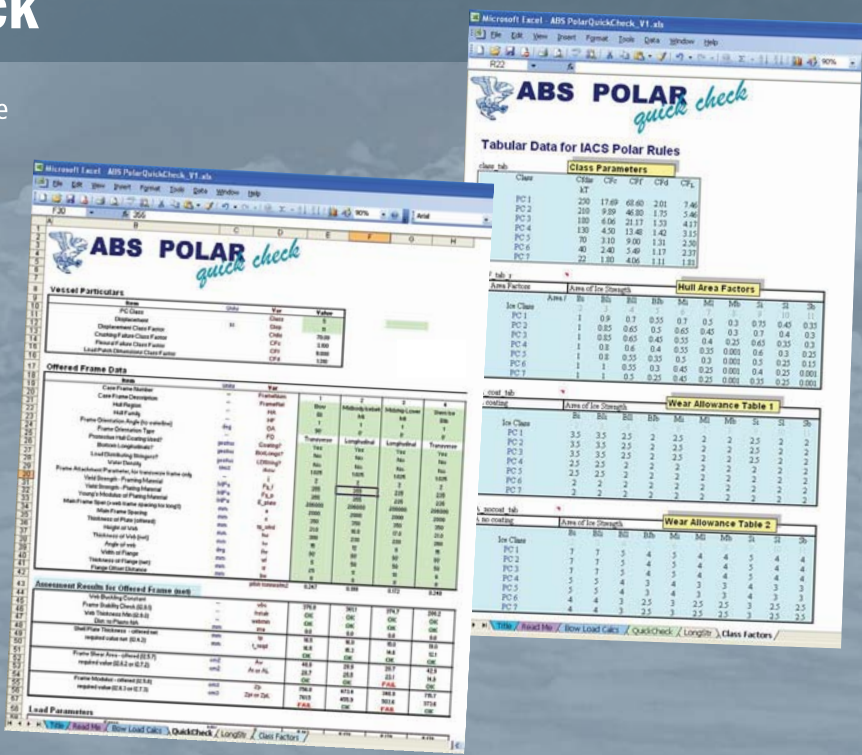
Figure 1. Engine power for non-ice tankers



ABS Polar Rule Check

To help clients to evaluate the hull structure of polar class ships against the applicable Polar Rules (and IACS UR I 2), ABS has developed a spreadsheet program, ABS Polar Quick Check, that provides users with a tool to check the Rules for ice loads, and the requirements for shell plating and frame strength. The program can also be used by ship designers to optimize the design of the hull structure, while maintaining compliance with Rule requirements.

The ship size, the intended polar class and the hull form angles are required as input so that the ice loads on the hull at the different locations can be calculated. The pre-designed shell plate and frames are checked against the rule scantling requirements. The results will show clearly as OK or FAIL.



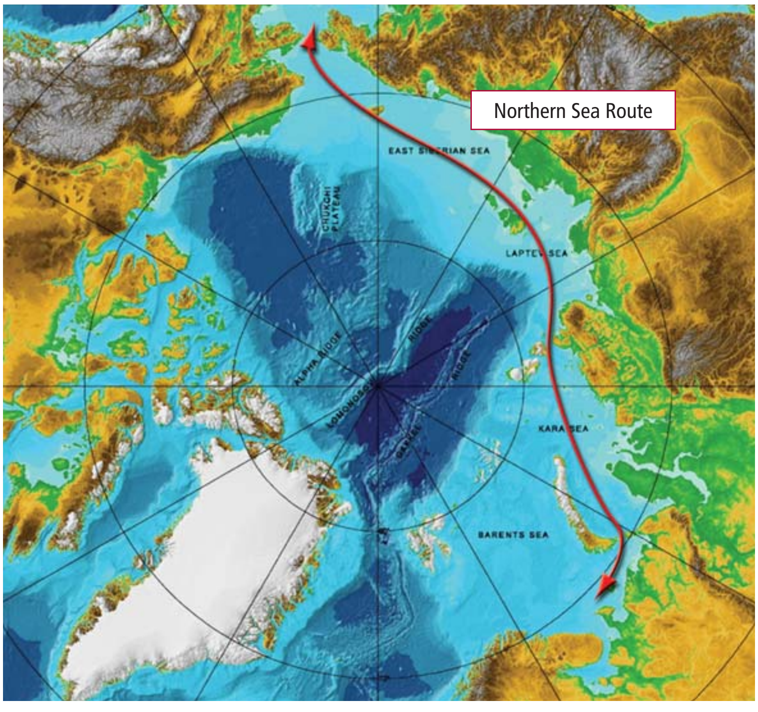
A REGULATORY FRAMEWORK FOR ARCTIC NAVIGATION

Vessels navigating the Northern Sea Route (NSR) in the Arctic region above Russia fall under two principal regulatory control mechanisms – the applicable international regulations formulated by the IMO, and the specific regional regulations issued by the Russian authorities.

International Regulatory Requirements

To promote the safety of navigation and to prevent pollution from ship operations in Arctic ice-covered waters, the Marine Safety Committee (MSC) and Marine Environment Protection Committee (MEPC) of IMO approved the *Guidelines for Ships Operating in Arctic Ice-Covered Waters*, as an addition to the mandatory and recommendatory provisions contained in existing IMO instruments.

IMO Guidelines define special measures for safety of life and protection of the environment in the Arctic region. The Guidelines harmonize different national requirements relating to hull structure, equipment, navigation and operation for different types and sizes of ships that may travel in the Arctic ice-covered waters. The standards expressed in these Guidelines have been developed to deal with additional risks imposed on ships due to harsh environmental and climatic conditions existing in Arctic ice-covered waters. These standards are additional to the basic requirements from relevant conventions.



IMO Guidelines cover a wide range of issues related to safety of vessels operating in the Arctic region. They are recommendatory rather than mandatory for vessels traveling in the Arctic ice-covered waters and are divided into three principal parts: the design and construction of hull structure and machinery; specific equipment requirements for a low temperature environment, including fire safety equipment, life saving appliances and navigational equipment; and operational guidelines, such as operational control, operating manual, training manual, crewing and emergency equipment.

IMO Guidelines refer to the IACS Unified Requirements (URs) for Polar Class for structural design and construction. These have been adopted by ABS and are available as the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters*. The IACS Polar Class UR was developed to harmonize the ice class requirements of various classification societies and Maritime Administrations.

Regional Regulatory Requirements

The Russian Government has adopted a two-tier approach to regulation of navigation within the NSR which reflects the needs and roles of the federal government on the one hand and regional governments on the other.

The Northern Sea Route Administration (NSRA), an agency of the Russian Ministry of Transportation, manages the entire stretch of the route from west to east. The responsibility of NSRA includes the "implementation of state supervision over the rational use of the NSR; organization of Arctic navigation, taking measures to ensure the safety of navigation on the lanes of the NSR and on the lanes of adjacent areas; taking measures to prevent and eliminate consequences of pollution to the marine environment and the northern coast of Russia, and supervision of vessels and offshore installations for this purpose which might be a potential source of pollution."

The regional governments are responsible for improving the transportation and economic infrastructure in their regions for effective support of the commercial feasibility of the route.

To secure safety of navigation through the NSR and to prevent pollution of the marine environment from ships, NSRA has developed the *Guide for Navigation through Northern Sea Route* to regulate the traffic in the NSR covered by ice. The Guide outlines the navigational-geographical and hydro-meteorological description of the NSR, including the natural environment such as sea ice distribution, geographical setting and regional climate, and ice navigation such as charts, routes, aids to navigation, communications and convoying. It references *Regulations for Navigation on the Seaways of the NSR* and *Regulations for Ice-breaker-Assisted Pilotage of Vessels on the NSR* which include navigation, operation and icebreaker-assisted pilotage requirements and other safety regulations. The Guide also provides nautical charts and sailing instructions for all Arctic areas.

As to the structural design and construction, equipment and supply requirements, the Guide refers to the *Requirements for Design, Equipment, and Supply of Vessels Navigating the NSR* to address these issues. As reported by Central Marine Research and Design Institute (CNIIMF), the requirements for design and equipment in the Guide are identical to those of the *Rules for Classification and Construction of Sea-Going Ships* of the Russian Maritime Register of Shipping (RS). ABS has a bilateral technical pact and dual class agreement with RS.

All ships planning to travel to frozen Russian ports during wintertime with an ice class lower than admissible by the port authority need an Ice Certificate to enter the ice-covered ports. The Ministry of Transportation of the Russian Federation authorizes CNIIMF to issue an Ice Certificate for vessels that describes their ability to operate in ice.

Regulatory development in this area is ongoing. The Northern Sea Route Administration regularly updates its *Guide for Navigation through the Northern Sea Route* and the referenced regulations for navigation, design, equipment and other issues to address new technical and legal developments and operators are recommended to verify that they have the latest information to hand prior to the commencement of the voyage.

An Ecologically-Sensitive Approach to Arctic Transportation

Vessels operating in the Arctic region are exposed to a number of unique demands. The presence of first-year and multi-year ice imposes additional loads on the hull, propulsion system and appendages. Low temperatures impact the ship and the cold, the lack of light and visibility affect the crew. In addition, the protection of the unique Arctic environment is of particular concern as the resources in this new frontier are exploited.

There is a need for large tankers and LNG carriers to transport the gas and oil that will be produced from these far northern locations. However, current operational experience in the Arctic is limited to much smaller vessels than those that are envisaged. All this, in addition to the probability that new owners and operators without operational experience in these harsh conditions will enter the market, impose a need for safety requirements that are in addition to those required for open-water operations that are applicable to ships operating in this area.

Safety and environmental standards for ships operating in cold climates and ice covered waters include international regulations, regional regulations as well as classification requirements. As it prepares for this new frontier, the industry is looking for broader guidance and is requesting more unified requirements governing the design and operation of ships for service in the Arctic. Additionally, concern for the environment can be expected to promote regulations that address emissions, contamination from water ballast and other ship-sourced pollution.

These new energy-related developments are largely concentrated in the Russian Arctic including the Barents Sea, the Pechora Sea and the Kara Sea. There are also new gas fields being developed on the Yamal Peninsula. Many environmental and indigenous rights concerns have been raised related to the development of these oil/gas fields and the transport of oil and gas from these fields.

The major energy transportation route, other than localized shuttle services, is expected to be from the western Russian Arctic to North America. However, shipping activity is likely to extend from the Barents Sea to the Bering Strait through the Northern Sea Route (NSR), stretching from the archipelago of Novaya Zemlya in the west to the Bering Strait in the east. The NSR also offers a substantial reduction in the shipping distance between north Asia and Europe.

Although some limited experience exists based on operations in the western end of the Russian Arctic, there is little experience or knowledge of the likely impact of shipping activity on the ecology of this undeveloped region. Given the short summer and low temperatures throughout most of the year, the level of bio-metabolism is expected to be extremely low, so that any ecological disturbance may require a much longer period to recover to its normal state compared to warmer regions of the world.

It is known, for example, that there are already numerous cases of the invasion of foreign marine species in the Pechora Sea as a result of the increased development activity. It is possible that more stringent regional requirements may become effective beyond the international requirements of the International Maritime Organization (IMO).

Emission Controls

The principal means of regulating emissions to the atmosphere from ships is the IMO's MARPOL Annex VI. This covers nitrogen oxide (NOx) and sulfur oxide (SOx) emissions and certain fuel oil quality matters, together with restrictions on the use and release of ozone depleting substances, the specification of vapor emission control systems where mandated and onboard incineration.

Both NOx and SOx have human health implications and are contributors to acid deposition which can have severe impacts in sensitive environmental areas such as the northern latitudes and the Polar regions. Additionally NOx, in combination with certain hydrocarbon emissions, will result in the formation of photochemical pollutants including smog in the lower atmosphere, which can have further detrimental effects on both health and the environment.

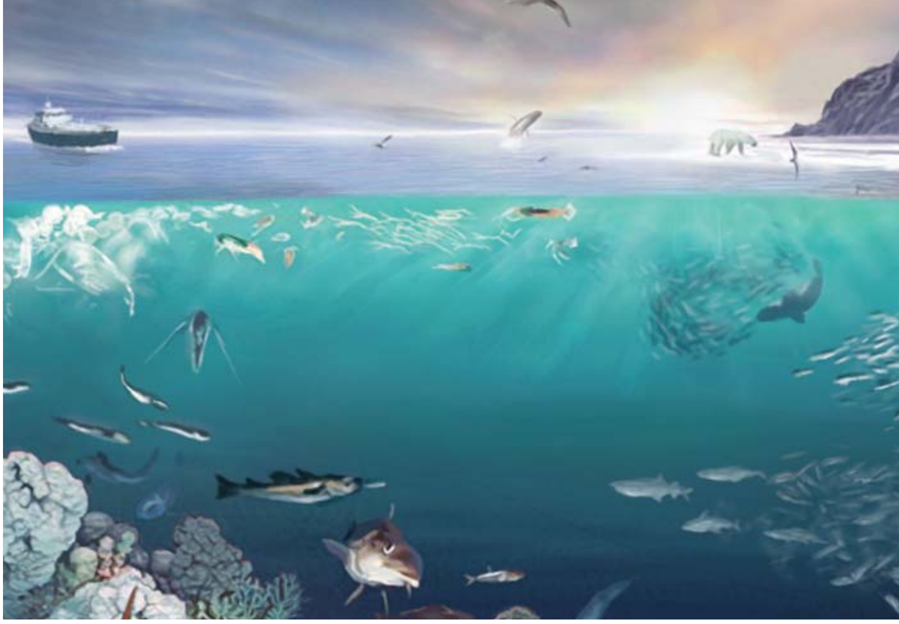
The Annex VI controls are international in their application, albeit with regional variations such as the small number of Emission Control Areas (ECAs). In considering the atmosphere emission controls potentially applicable to the polar areas, it is highly likely that regional, national or even local controls will be of greater significance. Pressure for such controls may stem from environmental, public or political pressures.

Whereas SOx can be controlled by limiting the fuel oil's sulfur content, controls on NOx emissions, together with aspects such as hydrocarbon particulate emissions, are directly related to the actual combustion machinery itself. Typically, this will involve the requirement for low emission engines together with the addition of primary (fuel oil emulsification/charge air humidification) and/or secondary (selective catalytic reduction) emission control systems. These elements would need to be addressed at the design stage for vessels intended to operate in polar regions.

Additionally a proposal was recently raised at IMO, that the carriage and use of residual blend fuel oils should be banned in the Antarctic Sea area. This proposal was initiated due to concerns related to the implications of an oil spill. However, if implemented, it would clearly have an effect on emissions, the alternative distillate grade fuel oils having inherently lower sulfur content which in turn would make the use of selective catalytic reduction units to substantially reduce NOx emissions that much more feasible.

In terms of area controls as applied to emissions, the MARPOL Annex I type approach to prohibiting all discharges of oil or oily mixtures within special areas could be particularly applicable to the prohibition on the incineration of shipboard-generated waste within defined areas such as the Polar regions. This could result in the carriage of increased quantities of waste machinery oils (derived from both fuel oil and lubricant treatment) being held onboard awaiting discharge by the ship to a suitable, and available, reception facility.

In addition to exhaust emissions from various forms of combustion machinery, the other potentially significant source of ship emissions to atmosphere would be the venting of cargo tank vapors during tanker operations. These vapors, laden with hydrocarbons, can have a detrimental effect both in themselves, and in combination with other emissions such as NOx. Therefore, closed vapor emission control systems could be seen as another prerequisite for polar operations with a consequent requirement for loading facilities to be equally equipped and able to handle the returned vapors in an environmentally responsible manner.



Invasion of foreign marine species in Arctic waters.

Ballast Water Management

Tankers or LNG carriers exporting cargoes from cold regions will enter the area in ballast. Ice-classed vessels are likely to have significant ballast capacity to reduce the range of waterlines which need to be reinforced for ice. On the other hand freezing temp-eratures can cause problems to the ballast water system. Therefore, ballast water systems need both design and operational consideration when operating in the Arctic or other cold weather areas.

It is not envisioned that there will be unique contamination issues with respect to operations in these regions, provided measures are taken to guard against large amounts of ice forming that could be carried into the inland areas where they would deposit non-indigenous marine life.

Further considerations for ballast water exchange in the period until the Ballast Water Management Convention enters into force in 2014 include the effect of icing on deck, which should be taken into consideration from both the stability and operational perspectives if the dilution method is permitted for ballast water exchange.

Unilateralism Drives Contingency Planning in the Arctic

The Arctic region is shared by eight nations – Canada, Denmark (Greenland), Norway, Russia, Finland, Iceland, Sweden and the United States – each committed individually and as a group to the goal of conservation under the Arctic Environmental Protection Strategy (AEPS) and the Arctic Council. However, the Council has no actual mandate under international law. Five of these nations also recently reached agreement through the Ilulissat Declaration to work cooperatively on a range of issues relating to the Arctic including safe navigation and sercha and rescue. Even so, there is concern that national interests will promote unilateral agendas.

Examples of some of the unresolved or developing political issues include:

- Boundary disputes such as those between Canada and the United States in the Beaufort Sea and between Canada and Denmark in the Nares Strait off northwest Greenland
- Contention over according the Northwest Passage status as an international waterway
- Russian claims to an extension of the Lomonosov Ridge giving it territorial rights as far as the North Pole

The negative of such nationalistic approaches is that each region may end up with a different set of regulatory requirements that offshore and vessel operators will need to follow.

It should also be noted that each area has a different environmental profile so not only should a vessel or structure be designed with its operating parameter in mind, the operator's oil discharge contingency plan

Russia's Arctic Claim

1) **North Pole:** Russia leaves its flag on the seabed, 4,000 m (13,100 ft) beneath the surface, as part of its claims for oil and gas reserves.

2) **Lomonosov Ridge:** Russia argues that this underwater feature is an extension of its continental territory and is looking for evidence.

3) **200-nautical mile (370 km) line:** Shows how far the country's agreed economic area extends beyond its coastline. Often set from outlying islands.

4) **Russian-claimed territory:** The bid to claim a vast area is being closely watched by other countries. Some could follow suit.

(ODCP) should take into account the specific area of intended operation.

It will be a challenge for the operators of offshore units and tankers trading in the polar waters to develop credible ODCPs because the differing biological issues in the various regions have many regulators and local residents lacking confidence that the industry can deal effectively with a significant spill.

To address these concerns, it will be necessary to develop and prove new technologies and strategies. For example, research results have identified a major response gap involving a worst-case discharge in close or very close pack ice. The result is often a thin inaccessible oil film on or under the ice. New technologies as well as operational strategies will be needed to find and map the oil, release trapped oil and to either concentrate thin oil layers for burning or introduce mixing energy for dispersion in mechanically-broken ice.

A less significant response gap is for batch releases into close pack ice, such as would result from a tanker spill or pipe rupture. This type of spill can result in a thick oil film for which burning is a potential option.

The spill response situation is even more positive in areas with stable fast ice where the ice remains static. This allows a thick film of oil to build-up over time and makes the oil more readily accessible by mechanical means with proven strategies available to achieve acceptable recovery/removal effectiveness. This normally occurs in near-shore areas.

Consideration should also be given to net environmental benefit analyses to defend, when necessary, a response strategy that may end up relying on natural dispersion and degradation processes within the ice cover when dealing with a spill that cannot be recovered mechanically or with burning.

ABS Provides Guidance for Ice Load Monitoring Systems

ABS has drafted a *Guide for Ice Load Monitoring Systems* for the development, installation and use of ice load monitoring systems aboard vessels either being built or retrofitted for service in heavy ice conditions. The systems are intended as an aid to the Master and navigating officers.

The systems covered in the new Guide extend from basic monitoring arrangements to highly sophisticated, fully integrated systems covering multiple parameters. It provides specifications for various types of hull monitoring systems to assist a shipowner in selecting an appropriate system dependent upon the type, size and expected trading patterns of a vessel.

The Guide defines the overall ice loads monitoring process, together with the procedures for data recording, collection, processing and evaluation of measured vessel performance. The collected data can assist the Master in identifying potentially harmful operational conditions and warn operating personnel when the performance parameters related to vessel strength are approaching pre-set allowable levels.

Vessels fitted with a system that complies with the requirements of the ABS Guide will be assigned an appropriate notation for entry in the ABS *Record*.

ABS Provides Guidance for Vessels Operating in Low Temperature Environments

The number of ice-classed vessels has dramatically increased in recent years because of the increased transport of oil from the eastern Baltic. Transportation routes from new northern oil and gas developments such as Sakhalin and Snovhit are mostly ice free but the harsh environment places operational challenges on the vessels and their crews. There is also the probability that new owners and operators without operational experience in these harsh conditions will enter the market in the future, imposing a need for guidance for these owners and operators as well as for shipyards building vessels for cold weather service.


Photo Courtesy of Primorsk Shipping Corp.

To help address these challenges, ABS produced the *Guide for Vessels Operating in Low Temperature Environments*. Guidance is provided for the preparation of vessels and other marine structures and their crew for operation in harsh environments. This Guide does not include requirements related to hull strengthening and machinery requirements which are covered by the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters* or the applicable Ice Class Rules for vessels operating in seasonal ice.

The low temperature Guide addresses various vessel design characteristics and equipment affected by cold temperature extremes. It has been organized in a format similar to the ABS *Steel Vessel Rules* and it provides supplemental requirements that are not addressed by existing Ice Class Rules. Vessels designed and equipped in accordance with the requirements of this Guide are eligible for a special class notation, but the application of the requirements is optional.

Each section of the Guide has a corresponding Appendix providing additional resource material to aid the designer/owner in understanding and meeting the Guide's requirements. Issues related to personnel safety and training are also covered. Supplementary information related to special weather conditions and vessel operating considerations are included.

Materials, Welds and Coatings

Suitable materials for low temperatures are mandatory for proper functioning of the hull structure and equipment. This section provides requirements for material classes to be used in the hull's structural members, material grades for the design service temperature, material testing temperatures and alternative requirements for higher strength steels. Coatings requirements, together with additional guidance on coating selections for various parts of the vessel, are listed.

Hull Construction and Equipment

Fresh water, ballast and fuel oil tanks should be carefully placed or fitted with heating equipment to avoid the chance of the tank's contents from freezing or leaking into the environment. The vessel's bow should be designed to reduce the effects of spray from freezing and collecting on the bow area. Bridge wings and deck houses should be specially designed or enclosed to protect equipment and crew. Vessel stability should take into account the effects of ice build-up on the hull.

Vessel Systems and Machinery

The effects of cold air can have unintended effects on systems and machinery. Accordingly, the combustion air system is required to be routed directly to the prime movers to avoid exposing machinery and the crew to the ambient temperature. Additional heating of lube oil may be needed for equipment located in the machinery space.

Deck equipment should be provided with heaters for reliable operation. Piping systems need to be provided with gaskets and hoses suitable for low temperatures along with arrangements to drain piping to prevent freezing damage. The heating system should be supplemented with additional heating units and insulation for crew comfort.

Firefighting and protection systems components are to be specially located to prevent freezing or provided with heating. In the event of an emergency, the emergency source of power is to be increased to provide heating for selected spaces for crew protection.

Safety Systems

Operations in cold climates require additional equipment to receive weather reports, special radar to make contact with ice and lights suitable for the cold. Life boats should be enclosed and specially designed to operate in the cold. Additional features should be included such as heating and communications equipment. Launching equipment should be designed to avoid the effects of freezing ice. Immersion suits are necessary for crew survival.

Specific Vessel Requirements

Some vessel types require additional consideration for low temperature operation because of special design or operational features. Requirements are included for LNG carriers, ore carriers, tankers and support vessels.

Crew Considerations

Working in cold weather can impact the crew unless proper preparations are made to equip the vessel and the crew for operation in the cold, dark and icy conditions. Clothing and work station design requirements are listed in the Guide. The Appendix lists supplemental information addressing human physiological responses to cold, maximum allowable work times, and clothing and personal protective equipment recommendations.

Training and Related Documentation

Training and manning are both important considerations for vessels operating in cold climates as special skills are necessary if they are to be accomplished safely and efficiently. The Guide provides information on the type of training needed as well as the documentation required onboard.

Weather Conditions

Extremely low temperatures, and the associated formation of ice, dominate operations in polar and sub-polar regions. In low temperatures, any precipitation will be in the form of snow, freezing rain, sleet or ice pellets. Visibility in any of these conditions can be very limited and ice build-up can produce a range of hazards. Ice accumulation due to spray is most likely in air temperatures below 2°C, and wind speeds of above 20 knots (10 m/s). It will worsen as wind speeds increase beyond this, and in higher sea states.

In very low temperatures, sea ice can form quite rapidly once the water temperature itself falls below 0°C. Ships with little or no ice capability can find themselves at risk if caught in these conditions, which are most likely to occur towards the onset of winter.

Most ships can be put at risk by ice movement, which can occur rapidly under high wind or currents. Conditions reported on ice charts or by remote imagery can change quickly, particularly the reported positions of the ice edge and the location of leads through the pack. It is important for mariners to be able to recognize the conditions in which such changes can occur and signs of the proximity of ice. Additional information is provided in the Guide describing the weather conditions likely to be encountered in the cold regions.

Vessel Operations

Low temperatures require additional tasks to permit equipment to function or to conduct vessel operations. Owners/operators are responsible for operational guidelines and keeping these guidelines updated. The Guide provides guidance on vessel operations related to each section of the Guide addressing design considerations including deck machinery and safety equipment.

Flag Administrations Contact List

Administrations have additional requirements when operating in their waters. A list of administration contacts is provided as an aid.

ABS Notations

A vessel designed, equipped, built, surveyed and crewed in accordance with the requirements of the *Guide for Vessels Operating in Low Temperature Environments* will be eligible for the notation **CCO+(TEMP)**. The ambient temperature for which the vessel is designed will be listed in the parentheses (e.g. **(-30°C)**). The notation will be listed in the ABS *Record*.

If vessel operation in a cold climate will be delayed, the Guide offers flexibility and cost savings to the owner in that crew training and installation of certain loose equipment for use only in cold climates can be deferred. For these cases a notation **CCO(TEMP)** will be listed in the ABS *Record*. This notation signifies the major equipment necessary for cold climate operation is installed and surveyed. When cold climate operation is planned, the additional Guide requirements can be complied with, a surveyor notified and the notation can be changed to **CCO+(TEMP)**.

Addressing the Human Element

Safety in Low Temperature Environments

Vessels operating in low temperature environments are exposed to a number of unique conditions, most stemming in one way or another from the prevailing harsh weather conditions. These additional challenges make it imperative that additional crew training be undertaken and that comprehensive operations manuals are provided.

Prior to entering Arctic waters, every member of the crew should be given a clear understanding of the risks of operating in extreme cold and the protective and preventative measures necessary for safety. Every crew member should be fully cognizant of the relevant procedures that govern their activities. They should be not only aware of the special equipment that is onboard the vessel but be fully trained in its use. An untrained or poorly trained crew can quickly endanger themselves and the ship.

It is essential that the operation of the various emergency safety systems in extreme conditions are fully understood and practiced with effective drills. It does not matter how experienced a mariner is, lifeboats and firefighting equipment require different operation in extreme cold. These drills should be conducted with the crew wearing the full complement of cold weather survival gear so they can become familiar with how this protective clothing can affect their mobility and dexterity.

It must be remembered that, once operating in extreme temperatures, many systems and components will be operating at or near their design limits. This is also true for crew members who may also quickly near their physical limits. Performance may degrade rapidly with a comparably rapid increase in the risks to personnel, equipment and the ship itself.

And while the crew should be trained in cold weather protection and operations, the Master and officers on board the ship should undertake a great deal more specific training before embarking on a voyage into Arctic waters. They should be fully conversant with the operation of all the special equipment that may be either fitted or have been placed aboard for the voyage, including the manufacturer's recommendations for

Photo Courtesy of Primorsk Shipping Corp.

use, operational limitations, maintenance and testing procedures as applicable.

The Master and officers should know the physical characteristics and limitations of the vessel, its hull structure, its machinery and equipment. It is essential that the Master is able to relate the ice conditions to the capabilities of the vessel, based on its ice class, powering and other features. The Master should be trained to interpret the various types of information that are available with regard to ice conditions. The Master should also be trained to identify the different types of ice formations by direct visual observation.

Crew welfare should be one of the highest priorities of the Master when operating in an extreme low temperature environment. Crew members are usually unable to recognize their own signs and symptoms of hypothermia. Impaired cognitive performance will lead to poor decision making and increased risk of accident, so decision verification procedures should be followed.

Allowable times for work outside, based on prevailing conditions, should be strictly enforced. Crew members should be drilled on how to recognize the early onset of cold-related injuries, such as freezing tissue, and be aware of the locations of nearby warming areas. And crew members should be assigned reasonable tasks by their officers. These should take into account the fact that activities which require tactile senses, hand dexterity, strength and coordination will be adversely affected either directly by the cold or by the need to wear cumbersome protective gear.

IMO Guidelines state that "all ships operating in Arctic ice-covered waters should carry onboard at all times an operating and training manual for all ice navigators onboard the ship." This is known as the IMO Contingency Planning for Shipboard Emergencies.

The IMO Contingency Planning for Shipboard Emergencies operating manual should address, and preferably provide, check sheets for actions that should be taken prior to entering the ice-infested region. These procedures should identify all the steps that are to be taken to prepare the vessel and prevent freezing damage.

These are just some of the issues that should be addressed by a comprehensive training and education program. They should be reinforced by extensive drills before entering the Arctic region and close monitoring of actual performance once the vessel is operating in the extreme temperatures.

The one essential element of any Arctic training program is survival – not just how to put on a survival suit but what to do in extremes when emergency and survival procedures have left the mariners effectively marooned in the most hostile of environments.

More specific information on safe operations in polar waters is contained in the ABS *Guide for Vessels Operating in Low Temperature Environments*.

Risks Related to Hypothermia

Mild Hypothermia	Moderate Hypothermia	Severe Hypothermia
Increased heart rate	Impaired respiration	Limited cognitive ability
Shivering	Decreased heart rate, blood pressure	Twitching of the heart muscles
Excessive discharge of urine	Blue-grey lips, nail beds or skin color	Possible cardiac arrest
Increased muscular tone	Muscle spasms	Unconsciousness
Decreased nerve conduction	Loss of feeling in or use of arms and legs	Death
Freezing tissue injury	Loss of muscle function	
	Slurred speech	
	Blurred vision	
	Impaired cognition	
	Shivering stops	


Photo Courtesy of Primorsk Shipping Corp.

Special Attention Needed for LSE in Polar Waters

There are many issues relating to safety systems and the functionality and suitability of such systems during operations in low temperature environments. Current classification Rules and statutory requirements stipulate specific fire detection and fire extinguishing systems to be installed in areas exposed to the weather. Yet the extremely harsh Arctic environmental conditions pose special risks related to this equipment. These may include:

Life Saving Equipment

- The presence of ice on the sea surface may inhibit deployment of life rafts and rescue boats, and also in making distance from a ship in distress
- The presence of ice on deployment mechanisms such as davits may interfere with lowering of boats and rafts
- Entrance to boat stations can be obstructed by snow and ice
- De-icing equipment (steam hoses) may freeze
- Hinges, lashes, gaskets, brake guide wires and sheaves may be frozen
- Snow and ice on winches may interfere with their use
- Ice on hooks, latches and hydrostatic release couplings may interfere with their use
- Winches may freeze
- Crew survival/rescue time in lifeboats and rafts in Arctic temperatures is limited
- The thermal insulating qualities of immersion suits must be adequate for the conditions
- Operability of escape chutes, hatches and doors in conditions of ice and snow may be limited

Firefighting Equipment

Significant risks are associated with the use of firefighting equipment in extreme low temperatures, the most significant being the potential freezing of fluids in lines. Specific risks include:

- Freezing of fire water hoses, piping, nozzles, etc. Fire mains are normally charged and pressure is maintained with a topping-off pump. At -30°C degrees, this may have to be changed and the fire mains drained until needed.
- Portable fire extinguisher storage may be obstructed or frozen
- Fire dampers may freeze in the stowage position

Controlling Ballasting Operations in Icy Conditions

For vessels operating in the Arctic, ballast water in side or hopper tanks above the waterline may freeze, starting at the top of the tank and at the side walls. When developing new designs, it is advisable to minimize the amount of ballast carried high in the vessel, especially in standalone tanks. Even in cases where the tank itself does not freeze completely, valve and suction line freezing can occur.

In extremely cold regions, thick ice formation or complete blockage within air and vent pipes has been noted. The extent of freezing depends on the temperatures encountered, on the duration of the voyage, and the salinity of the ballast water. Fresh or brackish water will freeze more easily, so higher salinity sea water should be used where voyage routing and local or regional environmental regulations allow.

It is highly unlikely that any sizeable tank will freeze solid, as the ice itself acts as an insulating layer, reducing the rate of heat transfer. However, ice represents a weight that may not be dischargeable when the vessel is loading, reducing deadweight capacity.

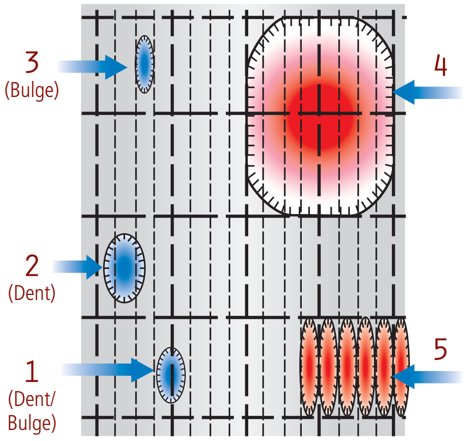
If ice chunks fall from the tank sides after the discharge of the liquid ballast, they may damage coatings or components. The ABS *Guide for Vessels Operating in Low Temperature Environments* requires ballast tanks arranged with the top of the tank located above the lightest operating draft to be provided with arrangements to prevent freezing of the ballast water. For example, bubble systems have been used satisfactorily to temperatures as low as -30ºC. Below this temperature, heating coils are required to be fitted in accordance with the Guide.

Seawater systems draw their supply from the sea around the vessel and must be designed to reduce the risk that inlets will become blocked by ice being ingested by the systems or forming within them. This can be accomplished by:

- **Location:** placing sea chest and sea bays low in the vessel, and away from ice flow lines
- **Configuration:** using weirs, strainers and other means to separate ice from the water
- **Heating:** normally by re-circulating hot water from cooling systems into the inlet areas

The most cost-effective solution will depend on the type of vessel and the nature of the service. Specific guidance for the design of sea box/bays, including special considerations for piping and valves, is provided. However, ice may still accumulate during periods alongside in cold conditions and so it will still be advisable to provide heating/water recirculation to deal with possible freeze-up and associated problems during start up. Therefore, several examples of heating and cooling arrangements are included in the ABS Guide.

Plastic Analysis of Grillages



1, 2, 3 Permissible local deformation
4 Large and impermissible deformation
5 Massive and impermissible damage

Krylov Ship Research Institute (KSRI), Russia

Grillage Analysis – Software for Evaluating Ice Belt Side Structures

The new IACS Unified Requirements (UR I 2) for structural requirements for polar class ships specifies that: "Web frames and load carrying stringers are to be dimensioned so that the combined stresses of shear and bending are to be maintained within the acceptable limit. Where these members form part of a structural grillage system, appropriate methods of analysis are to be used."

To assist designers in meeting this requirement, the newly expanded ABS *Guidance Notes on Ice Class* includes a methodology for meeting this requirement. Accompanying simplified spreadsheet software is also available to assist the designer in conducting the required analysis. The Guidance Notes provide a strength criterion, a method, an algorithm, and the software for the limit load assessment of complex longitudinally and transversely-framed ice belt grillages.

The need for this additional guidance stems from the fact that the IACS requirements consider only the plastic failure of transverse and longitudinal local frames. The ABS approach takes into account the possibility of the plastic collapse of either the entire section or a portion of a grillage in addition to the failure of individual beams. It addresses the scantlings of the supporting structures of an ice belt grillage, such as web frames and stringers, to avoid the collapse of the side grillage as a whole. The plastic strength of the structural members subjected to ice loads can be examined using the Guidance Notes and associated software.

The limit load in the Guidance Notes is obtained from the theory of limit analysis. Extensive nonlinear finite element (FE) analysis of isolated beams, stiffened panels and grillages has shown that the limit load of beam structures and complex grillages identifies the threshold for the external load. If the external load is higher than the limit load, the permanent plastic deflections approach the deflections which could require repair or replacement. If the external load is lower, the permanent deflections are small and do not exceed new construction allowances.

A major advantage of the ABS approach is that the proposed method for the limit load assessment is in agreement with nonlinear finite element analyses of numerous beam structures, including complex side grillages, of polar ships. The detail verification of the method was also performed by a comparison of proposed solutions with the results of physical model tests of Arctic ships' side grillages performed in Canada by MIL Systems and Carleton University.

The performed verification has shown that the proposed approach is a reliable method for the evaluation of the real carrying capacity of side structures subjected to local lateral loads. Designers can use the ABS Guidance Notes to find the structural elements of a grillage which need to be reinforced in order to prevent the loss of structural stiffness and development of unacceptable permanent deflections.

The algorithm and user-friendly software were developed based on the proposed method and strength criterion. The program is applicable to transversely and longitudinally-framed side structures subjected to ice loads. No special training is required for engineers to use the program.

The input information consists of common grillage parameters, dimensions of an ice load-patch, scantlings of grillage structural members and the material yield stress. The limit load, which a selected grillage can withstand without unacceptable permanent deflections, is considered as the output of the program.

A user can also obtain information on the type of the plastic deformation of each group of structural members and also receive information on the size of the deformed zone. This procedure, in combination with FE analysis, can be used to design equal-strength, side-structure elements and in many cases the proposed procedure also can be used as a substitute for the FE analysis and physical tests.

Operating in Low Temperatures

Propulsion and Auxiliary Machinery Issues

The machinery on vessels operating in very low ambient temperatures (such as -30ºC or less) may be subject to unusual operational events not occurring at higher temperatures. A failure mode effects analysis (FMEA) conducted early in the design evolution on various machinery and systems can help in identifying additional features or equipment/system design changes to prevent failures from occurring or to mitigate consequences, if failure occurs.

A vessel with diesel engines installed for propulsion and electricity generation, for example, may encounter situations in which the engines are unable to fire because of the low temperature of the combustion air – fuel mixture may fail to allow auto ignition when compressed in the engine cylinders. On the other hand, if auto ignition is able to occur in the engine cylinders, the engine cylinder design pressure limits may be exceeded because more air can enter the cylinder due to the cold air's higher specific density.

To prevent the failure mode of an engine being unable to fire, a special feature may be required such as incorporating a combustion air preheater. The preheating may be accomplished through the use of electric or steam heating or using the diesel's jacket water waste heat.

To prevent cylinder overpressure failure which leads to the engine producing too much power, overpressure protection can be achieved by installing a charge air bypass between the turbocharger compressor outlet to the turbocharger turbine inlet along with a charge air waste gate on the engine's air receiver and an exhaust waste gate from the turbocharger turbine inlet to the turbocharger turbine outlet. The arrangement can also be used to improve turbocharger performance and fuel efficiency at low engine loads when the vessel is operating in ice.

Machinery arrangements may be required to be modified as a result of low ambient temperatures. For example, in many cases, combustion air for diesel engines is taken directly from the machinery space. In very cold climates this arrangement will cause the machinery space's temperature to become too low, possibly affecting equipment function and personnel comfort and the ability to perform maintenance. The combustion air should be directly supplied to the diesel engines through duct work. The added advantage of this ducting arrangement is the combustion air temperature can be better controlled.

Photo Courtesy of DSME

Evaluating New Conceptual Designs for Arctic Operations

Design companies, when exploring the possibilities of a new technology for application in developing new Arctic offshore or marine transportation concepts, are looking for some confirmation that the design is feasible and will be capable of attaining classification. The granting of ABS Approval in Principle (AIP) is often a first step towards classification of such novel concepts.

The benefit of gaining AIP is that the client can obtain a document issued by an accepted, independent technical body as evidence of preliminary acceptability of the concept for classification to provide to regulatory bodies and project partners. It confirms that there are no significant impediments to further develop the concept.

The ABS *Guidance Notes on Review and Approval of Novel Concepts* divide the class approval process into the following stages:

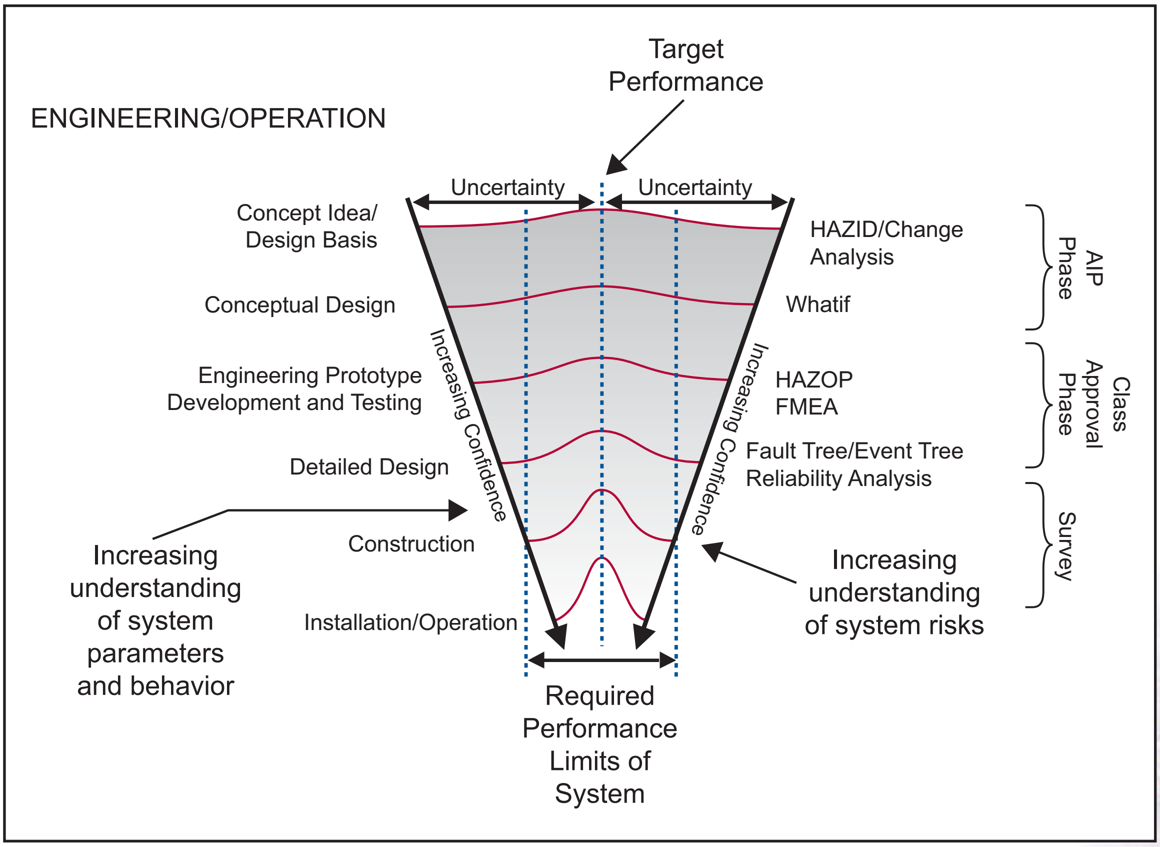
- Determine approval route
- Approval in Principle (concept development phase)
- Approval Road Map
- Final class approval (detailed design, construction, commissioning phase)
- Maintenance of class (implementation and operational phase)

This process involves ABS and the client working together to accomplish the following:

Determine Approval Route

As a first step, the approval route to achieve AIP needs to be determined. This will involve the client and ABS meeting to discuss the concept, its purpose, its novel features and, where it deviates from traditional approaches, the proposed operating envelope and the potential impact of the concept on other systems or components. Agreement will be

Novel Concept Review Process



reached as to the best methods to assess risk in the AIP phase as well as the appropriate level of engineering analysis.

AIP and Approval Road Map

As a minimum, the goal of achieving AIP should be the identification of hazards and failure modes applicable to the novel concept application along with suitable support information demonstrating the control of these hazards and failure modes is feasible. Throughout this phase, as the concept is being evaluated, an Approval Road Map will be defined which will lay out conditions to achieving final approval. The road map will define the approach needed from a risk assessment and engineering analysis standpoint to justify the novel aspects not covered by existing Rules, codes and standards.

Final Class Approval

This phase covers typical class approval submittals comprised of typical drawings, specifications, calculation packages and support documentation, along with submissions of those items outlined in the Approval Road Map. Upon completion of this stage, potential hazards and failure modes for the novel features will have been assessed versus agreed-upon acceptance criteria to a level of confidence necessary to grant full class approval to the design.

Maintenance of Class

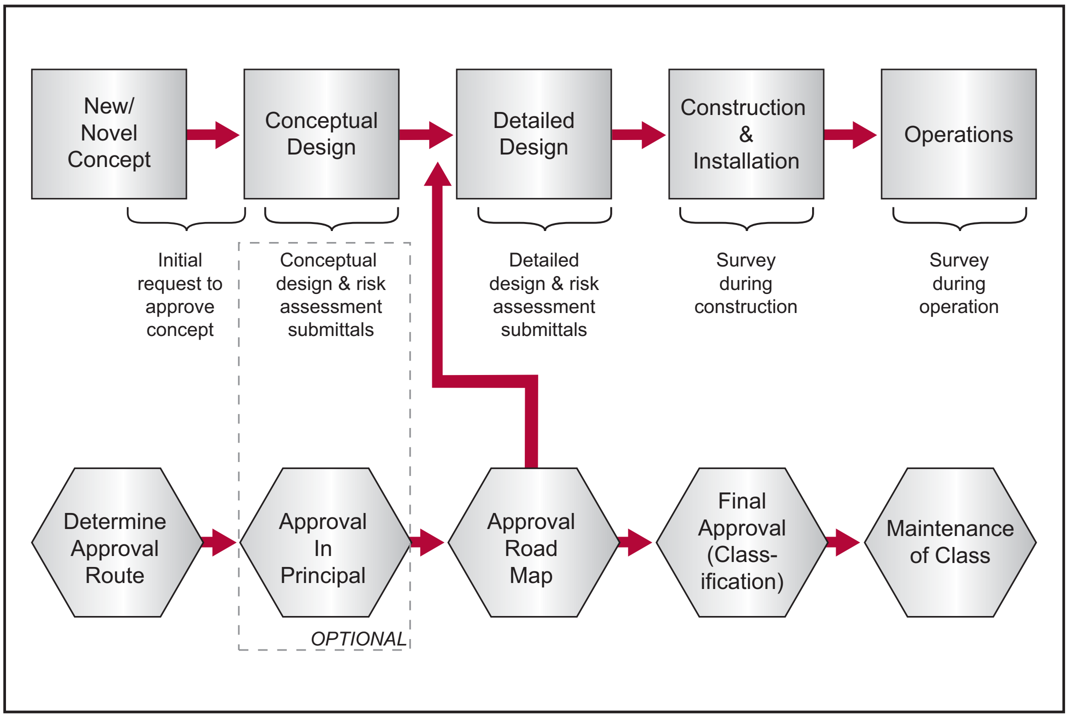
As a final condition of class approval, ABS will determine what conditions are necessary for the maintenance of class through additional survey scope or frequency of attendance, condition monitoring, required maintenance and inspection techniques to maintain levels of monitoring assumed in the design phase which may have been necessary to achieve various design parameters and, finally, as a means to verify assumptions and predictions made throughout the process.

Risk Assessments

Risk assessments at the conceptual stages of a novel concept are part of the requirement to obtain AIP. The specific requirements for risk assessments are based on the degree of novelty of the application. At a minimum, a qualitative risk assessment on the new concept will be required.

In general, for the concept development phase, a design basis, preliminary engineering and possibly testing results are used in the risk assessments. A qualitative risk assessment technique is generally the most suited method at this concept design phase. There are a number of qualitative risk techniques that can be applied, such as HAZID (hazard identification), What-if and HAZOP (hazard and operability analysis). However, the most

Novel Concept Approval Process



appropriate technique depends on the available concept design information and type of system being proposed.

Conducting a qualitative risk assessment involves a team brainstorming session that provides a unique forum for designers, operational and safety personnel, as well as ABS representatives, to discuss the concept in a structured manner. Prior to conducting a qualitative risk evaluation, the organization proposing the novel concept has to submit information on what method will be used, what subject matter experts will participate and what scope the assessment will have. Additionally, a risk ranking methodology or risk matrix must be submitted and approved by ABS.

After AIP has been assigned, there may be the need to perform more detailed, risk assessments to verify that the risks identified in earlier phases are properly managed. Such assessments may involve quantitative risk assessments, such as fault trees and event trees, in order to attain the necessary level of accuracy.

The systematic and detailed use of risk analysis techniques to compensate for the lack of industry experience can aid the project teams developing new designs for operation in the Arctic and similar harsh environments in identifying and addressing key design and operations issues.

ASSESSING THE RISKS OF FRONTIER PROJECTS

Marine transportation of oil and gas from the Arctic will pose new challenges for the design and operation of ships. Many technology innovations are being studied and implemented to respond to these challenges, and extensive research and development is needed for managing risk associated with operating oil and gas carriers in the harsh Arctic environment.

A risk-based decision making (RBDM) approach to assessing the risks associated with polar transportation activities may call for full-scale application of risk assessment methodologies, including quantitative frequency assessment, detailed consequence analysis and comprehensive risk evaluation.

The first step of an RBDM process is for the team to structure the decision that needs to be made. As with many sequential processes, this first step is critical to the success of the analysis.

Examples of these questions include:

- What aspects of this project pose significant risks?
- Of those risks, which of them can be addressed effectively by design measures?
- Do existing codes, standards and regulations apply that are important to controlling the significant risks?
- What aspects of the technology that are not addressed by current codes, standards, Rules and regulations will need to be verified?

These kinds of questions can be evaluated in a risk assessment, which forms the second step in the RBDM process, using techniques such as hazard identification, change analysis or any of several other techniques. Such risk assessments generally serve to document the pertinent existing risk mitigation and management measures.

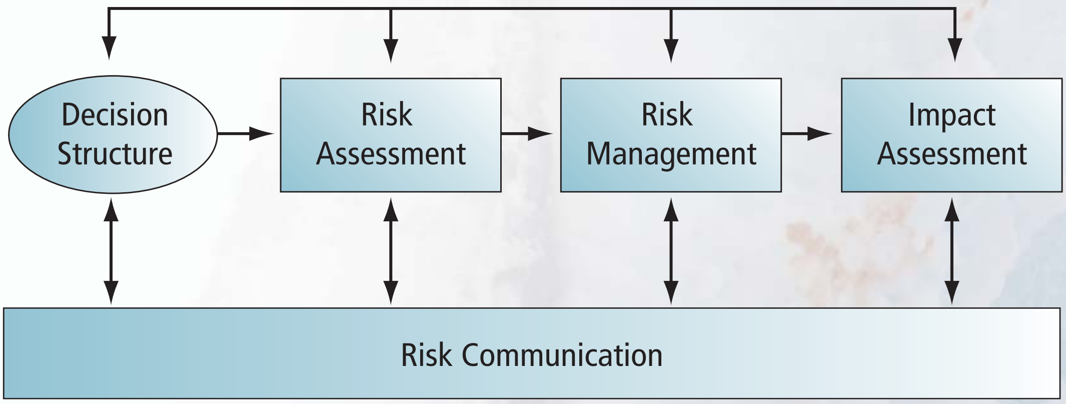
Impact assessment in a RBDM process can consist of re-analysis of the technology after new risk management measures are designed or can be an ongoing process that provides verification that the design intent of the risk management measures was achieved.

The basis for an effective RBDM application is to perform as little analysis as is necessary to provide the information needed by decision makers. This leads to very focused risk analysis efforts, including the use of approaches such as change analysis, relative ranking, and other qualitative techniques.

The performance limits may include required reliability, function, safety and strength among others. As more engineering and/or testing is conducted, a better understanding of the system parameters and behavior can be achieved.

A risk assessment of a frontier-expanding Arctic project should be conducted to verify that risks are being properly identified, managed during the development, and are within tolerable ranges by the completion of a detailed design.

Risk-Based Decision Making Process



R & D Focuses on Ice Loads for Arctic LNG Carriers

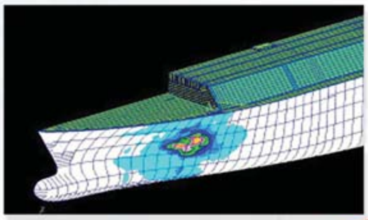
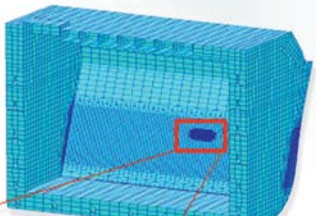
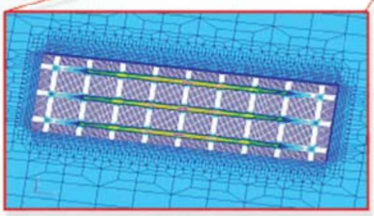
Unlike existing ice-capable oil tankers, no large Arctic-capable LNG carriers have been built, and sub-polar operating experience with these vessels remains limited. Yet the projected demand for Arctic LNG carriers presents unique design challenges particularly with respect to ice loading due to their greater size and higher operating speeds than most ice-going ships.

LNG containment structure is critical to the safety of the vessel, and the impact of ice operations on this system must be assessed. Prior to developing safe designs, research is needed into the quasi-static and dynamic loads to which the ships may be subjected. Appropriate load models and analysis tools should be developed.

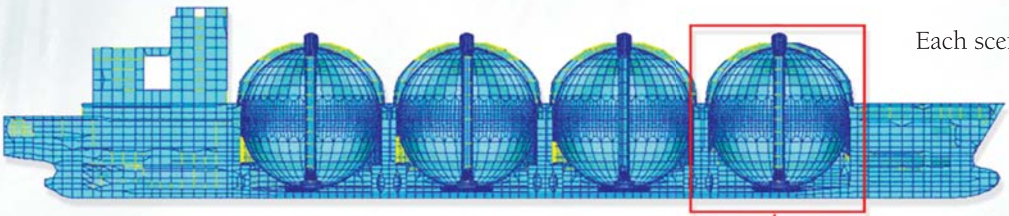
Specific regions in Russia, Canada and Alaska, of interest for their hydrocarbon reserves, present different ice conditions through which an ice-going LNG tanker would transit. Ice conditions encountered along the current and potential carrier routes can vary widely, including thin and thick first-year ice, thin and thick multi-year ice, small glacial ice masses, and grounded ridges. Additionally, wind and water currents can generate a range of ice pressure and ridging conditions.

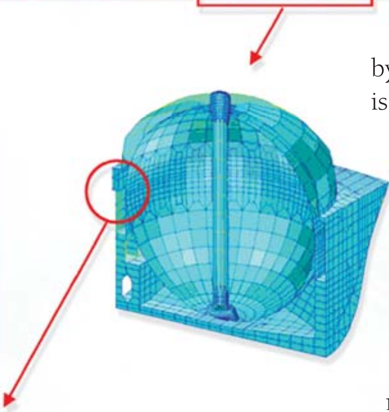
This means a variety of design scenarios must be considered to develop ice loads and appropriate contact models. These ship-ice interaction scenarios simulate impacts of various parts of the ship (stem, bow, shoulder, stern, appendage, propeller, turn of bilge), various ice conditions (previously mentioned) and different collision angles (head-on and oblique).

Each scenario involves an ice interaction which depends on the geometry of the ship-ice indentation as well as the ice strength and failure mechanism. Many of the cases can be approximated by the impact of two objects in which one is considered to be moving initially and the other at rest. The forces generated are found by equating the effective kinetic energy available with the energy expended in ice crushing and changes in potential energy, if any. It is assumed that ice force depends only on indentation via a pressure-area relationship, with the maximum force coinciding with the time of maximum penetration. From the penetration, the nominal contact area can be computed to give an initial load patch that can be used for structural analysis.

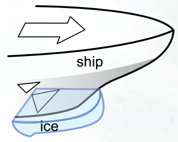
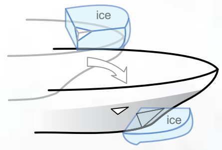
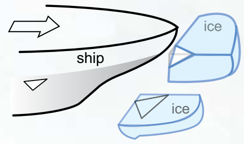
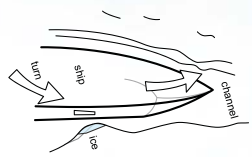
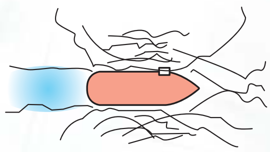
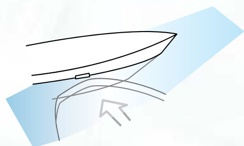




Finite element model of an LNG cargo containment system for membrane-type and spherical-type LNG carriers under ice loads.





Summary of Selected Ice Loading Scenarios

Position	Loading Scenario	Case	Picture
Shoulder	Glancing impact on shoulder: This is an oblique shoulder collision with an ice edge.	Case 7	
	Reflected on shoulder: This is a second oblique shoulder collision with an ice edge.	Case 9	
	Wedging on shoulder: This is a symmetrical shoulder collision with two ice edges.	Case 10	
Mid-ship	Glancing impact on mid-ship: This is an oblique mid-body collision with an ice edge.	Case 11	
	Close pack pressure (pressured ice load): This is a mid-body static contact with an ice edge.	Case 13	
	Ice floe impact pressure.	Case 21	

Structural analysis requires approximations to simulate the mechanics of realistic, internally complex ice loads which contain very high local pressures on small portions of the nominal contact area. The nominal load is converted to a representative load for structural analysis purposes using a procedure developed for the new IACS Unified Requirements for Polar Ships. The resulting smaller rectangular load of appropriate pressure to maintain the calculated force can then be applied to a finite element model of the hull.

A joint development project conducted by ABS, BMT Fleet Technology and Hyundai Heavy Industries (HHI) has begun. The project primarily focused on the structural integrity of cargo containment systems under different ice impact scenarios and has recently been completed leading to recommendations and guidance for these containment systems operating in ice conditions.

The four-phase study identified and generated severe ice loads for structural analysis; performed finite element (FE) analysis on the local model of hull structure and containment system under ice loads as well as developed an ice load model taking into account interaction between hull and ice, quasi-static loads and time varying dynamic loads; and investigated failure modes with development of cargo containment acceptance criteria. A specific intent was to check the containment system and hull structure simultaneously responding to ice impact loads.

A hazard identification or HAZID study was conducted to define hull critical ice impact load cases for a 150,000 m^3 carrier, membrane-type tank. Six impact scenarios or critical cases were analyzed in the study for each tank type carrier. They were:

1) bow glancing
2) shoulder glancing
3) shoulder reflected
4) shoulder wedging
5) mid-body glancing
6) mid-body pressure

The study provided an improved understanding of the cargo containment system under ice loads which will provide more detailed guidance for designers of LNG carriers and other large ships operating in ice.

The analysis assessed hull integrity and the impact of ice loads on the cargo containment system (CCS) through a range of elastic, plastic and large deformation models. The evaluation of analysis results made use of the methods and philosophy of the new IACS Unified Requirements for Polar Ships. The scantling calculations used compared the two types of tank types and were performed by both the Ice IA (Baltic requirements) and PC 7 (Polar requirements).

According to the FE results, all stresses of the cargo containment system structure of the membrane type and the skirt and the hull structure in way of the spherical tanks are satisfied with the stress criteria. It can be concluded that the strength of the CCS of a membrane type LNG carrier and the strength of skirt and hull structure of a spherical type LNG carrier are sufficient under the design loads.

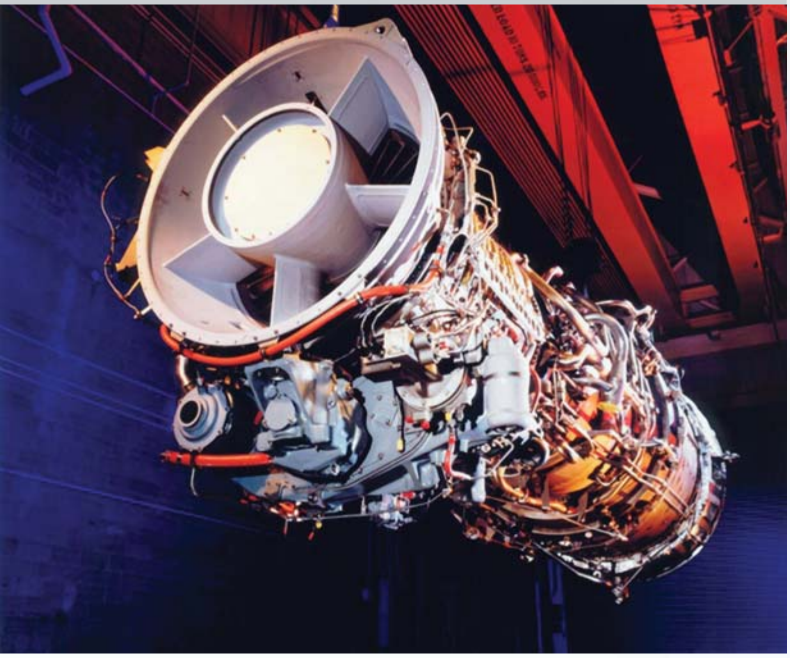
ABS AND RS JOINTLY DEVELOP RULES FOR ARCTIC GAS CARRIERS

ABS and the Russian Maritime Register of Shipping (RS) are to jointly develop classification *Rules for Arctic Liquefied Natural Gas (LNG) Carriers* under a wide ranging cooperative agreement between the two IACS members. This is the first pairing of societies to create Rules for the LNG market sector. It is the result of a strategic decision that it was in the best interest of industry to combine the shared experience and technical expertise of both societies to address the need for guidance with the design of the expected future fleet of these carriers.

Development of the joint Rules for Arctic LNG carriers allows ABS and RS to bring together the extensive experience of RS in technical safety standards for vessels operating in the severe polar environment and the experience of ABS with the design and construction of the latest generation of very large LNG carriers. Combined with the joint application of advanced technology using risk analysis, testing and computational methods, the approach is expected to result in the most comprehensive set of standards for these specialized vessels that will be available to industry.

Gas Turbines

An Option for Powering Arctic LNGs?



Manufacturers of gas turbines are looking to the proposed new fleet of Arctic LNG carriers as a potential area to further expand their presence in the marine and offshore markets.

The particular advantage of gas turbines in cold weather environments is the considerable amount of waste heat that is generated. Gas turbine generator sets can be used with individual waste heat recovery units that can provide steam for one or two steam turbine generators in combined gas turbine and steam electric (CoGES) propulsion systems. Supporters believe that, properly configured, the CoGES propulsion system offers optimum efficiency and availability across the range of power needs for vessels of this type.

A steam plant allows for redundancy of propulsion by separately-fired boilers. On larger installations, separately-fired superheaters and/or reheaters could enhance thermal efficiency. Since operators of Arctic LNGs will be looking for propulsion systems offering higher thermal efficiency, the mix of gas turbines with other load-sharing schemes could offer both increased flexibility and operational redundancy.

Currently the LNG fleet is powered by conventional steam turbines, slow speed diesels with onboard reliquefaction equipment or dual fuel diesel electric (DFDE) engines. Gas turbines are used aboard naval vessels and some commercial vessels, mainly cruise ships. Currently GE Energy is the leading supplier. They are also widely used for power generation aboard offshore vessels and platforms with ABS having certified a large number of units. Solar Turbines is another supplier that has identified Arctic LNG carriers as a natural extension of the generators it provides to floating offshore units in which electric propulsion or auxiliary generator sets are used.

Solar's gas turbine generator sets can be adapted to LNG carriers because of the broad range of kilowatt ratings from 5,000 kW per unit to nearly 18,000 kW per unit. This would allow for carrier operators to optimize their engine size for the vessel's power requirements. Various combinations of the turbines could be specified for maximum efficiency and fuel flexibility.

GE Energy has conducted HAZID studies with class societies and believes there are no significant concerns for using gas turbines with LNG carriers. Small compact designs, like those offered by GE with a wide range of power capability from 22,000 kW electrical in simple cycle to over 50,000 kW electrical in combined cycle, means that the gas turbine combined cycle equipment can be placed on the aft top deck of the ship, behind the accommodation section, reducing the size of the conventional large engine room thus providing space for more cargo.

Industry has a history of considering alternate ship power systems, with the new dual fuel gas-diesel units being specified for several recent LNG contracts as an example. Every system has its trade-offs. A gas turbine driving an electric generator for electric propulsion is seen as a convergence of technologies that can offer an attractive solution in some circumstances. Control system improvements also mean increased efficiencies and responsiveness for gas turbines, allowing for better control of emissions and seamless transfer of fuels.

While, the marine industry tends to be conservative, proponents of the technology say it is simply a matter of time before the gas turbine option is selected. Manufacturers such as Rolls Royce and Siemens are joining Solar and GE Energy in the competition to be selected for the projected fleet of new Arctic LNGs.

Design and Operational Issues for

LNG Carriers in Cold Environments

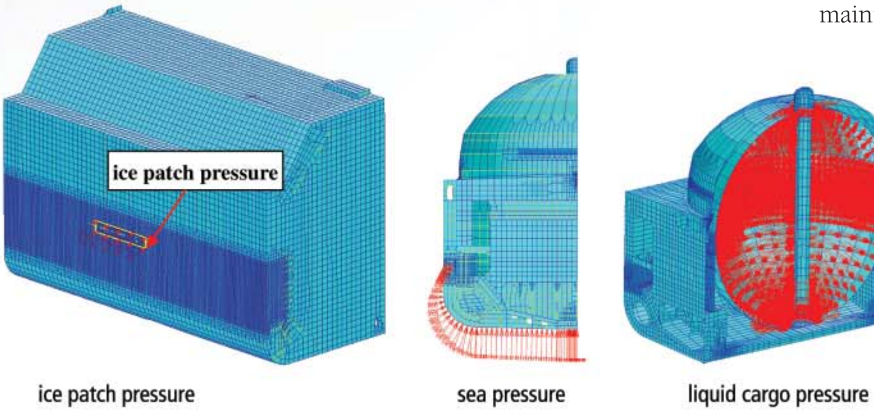
Gas transportation in an Arctic environment brings many hazards and operational issues that if not considered carefully, could potentially lead to undesired incidents. These are some of the issues that need special consideration during the development of the proposed new generation of Polar Class LNG carriers:

Suitability of Containment Systems

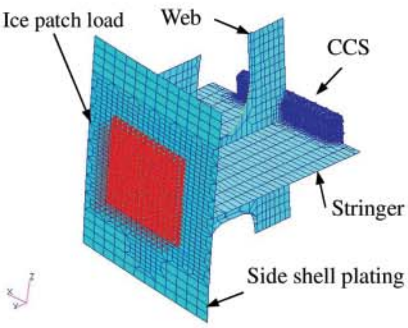
One of the major concerns for LNG carriers is whether existing LNG containment systems are suitable for Arctic operation. Existing Ice Class Rules have established design guidance for hull structures in an ice belt, design of external hull surfaces that will encounter ice and typically specify local ice loads for designing shell structures. Some Ice Class Rules specify additional hull girder bending loads for vessels that may be raised by an ice pack. In this regard, the consideration of the design adequacy and longevity of the various LNG containment systems as they are exposed to transmission of these loads through the hull structure needs to be considered.

Vibratory ice loads should also be considered for LNG containment system design. Though they do not directly encounter floating ice, the LNG containment systems may feel the vibratory excitations from ice that are transmitted through hull structures and their response to this type of loading is the subject of further study.

Global extreme ice loads may also need to be considered for LNG containment system design. During the Arctic winter, a vessel may ram into large ice ridges or floating ice, and the consequential deceleration of the vessel may pose new threats to the LNG containment systems. There are very limited studies on this scenario and data collection and further investigation is needed.



Configuration of applied loading for analysis



Ice patch load at critical loading location

LNG Cargo Tank Venting

Venting is one of the key issues essential to maintaining LNG cargo tank integrity due to the boil-off of gas evaporating from the tanks. Normally, there are elaborate measures to ensure boil-off gas utilization at all times in places like the boilers on conventional ships and more recently using it in diesel engines or gas turbines. The gas from the tanks is compressed and heated before being discharged to the machinery spaces. Therefore, the gas lines are not insulated. There may also be a need to consider the effect of the temperature drop of the gas being supplied to machinery spaces.

Ice Accretion/Formation

The adverse effects of ice loads on the relief valves and the PV valves in the vapor lines on deck require careful consideration during normal operation and cargo loading. These systems may possibly require the use of heat tracing to maintain functionality. Emergency shutdown valves at the manifold and at the tanks are critical in the safety chain on LNG

carriers. It is essential that they operate at all weather temperatures on deck.

Due to the layout typically used on LNG carriers, these designs have a large exposed deck area. The additional deck plating is either curved to cover the Moss-type spheres or as an integrated part of the containment system for both the MK III and No. 96 membrane tanks. This exposed deck plating should be designed in such a way as to withstand the additional load due to snow accumulation and ice build-up caused by spraying. Other exposed deck plating should be able to resist any dynamic loads due to sliding of the snow from the inclined decks or from dropped ice.

The snow accumulation and ice build-up is also an additional hazard for crew operations on the deck, particularly the passageway on each side of the vessel.

Heat Transfer

When heating the cargo-related valves and equipment to maintain functionality in the Arctic environment, there is always a chance of creating vapor traps which may impair the operation of these valves. Some means of temperature control should be provided to keep this equipment free of ice that does not create heat transfer into the LNG being transported.

In addition, the trade-off among the beneficial effects of a colder ambient temperature on the boil-off rate, the need for heating some equipment to maintain functionality and the heat gain into the system from same, and the increased sloshing, which may occur in harsh wave environments causing more boil-off, need to be carefully considered.

Loading Operations

LNG ships, because of the limitation of the design of the loading arms, are required to be ballasted or de-ballasted simultaneously when cargo is being transferred. Also, all cargo tanks are loaded simultaneously. This will require ballast water to be taken onboard, and may require heating of the ballast tanks sufficiently to prevent freezing while also considering that any excessive temperature rise in the ballast spaces can affect the cargo boil-off rate through the inner hull.

Further typical water spray operations used during offloading may necessitate heating of the water spray to prevent freezing of the hull structure in way of the cargo manifold. Heating equipment may need to be installed in the ballast space to prevent ice build-up as a result of water spray.

During cargo loading/unloading, piping needs to be hooked up to the ship's manifold. The manifold connection point should be monitored for the duration of the cargo transfer. This is typically a 12-hour operation. It is possible that the monitoring task can be achieved remotely using closed-circuit television.

Visibility

The summer fog, mainly in coastal regions and around islands in the western part of the Barents Sea, the winter snowstorms and the darkness are major contributors to reduced visibility in the Arctic region. The overall arrangement of an LNG carrier and the inability of bridge personnel to see directly in front of the vessel due to the containment system height above deck, may necessitate the use of special features such as cameras and other devices to assist in navigation.

ABS Notations for Ice Classifications

The following notations denote design parameters and restrictions.

Polar Ice Class

Ice Class PC 7 through PC 1

Vessels intended to operate in Polar waters are to fully comply with the requirements as specified in the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters* in addition to applicable requirements in ABS *Rules for Building and Classing Steel Vessels*.

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice includsions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Ice Breaker

Ice Class A2 through A5

This notation is assigned to a vessel designed and constructed for breaking ice to open navigable channels for other ships. Ice Breaker notation is to be assigned to vessels of ice class A2 through A5 built to the requirements of Section 6-1-1 of ABS *Rules for Building and Classing Steel Vessels*.

Ice Class

I AA through I C

The ice strengthening notations Ice Class I AA, I A, I B and I C indicate that the vessel is suitable for navigating the waters of the Northern Baltic in winter in accordance with applicable requirements of Section 6-1-2 of ABS *Rules for Building and Classing Steel Vessels*. The ice strengthening requirements of Section 6-1-2 of ABS *Rules for Building and Classing Steel Vessels* are in accordance with the Finnish-Swedish Ice Class Rules.

- AA Extreme Ice Conditions
- A Severe Ice Conditions
- B Semi-Severe Ice Conditions
- C Light-Severe Ice Conditions
- D Very Light Ice Conditions

Additional Ice Notation

CCO-HR (TEMP), CCO-HR (TEMP)+

These notations are assigned to vessels complying with the requirements specified in the ABS *Guide for Vessels Operating in Low Temperature Environments*.

CCO-HR(TEMP)

This notation is assigned to a vessel designed, built and surveyed in accordance with requirements in Sections 2-6 of the ABS *Guide for Vessels Operating in Low Temperature Environments* which address materials, welds and coatings, hull construction and equipment, vessel systems and machinery, safety systems and additional requirements for specific vessel types intended to operate in a low temperature environment. The emergency service hours (18 or 36) is listed as HR. The design service temperature for which the vessel is designed is listed in the parentheses.

CCO-HR (TEMP)+

The + notation indicates the placement of additional equipment onboard for the crew and specific low temperature environment training for the crew as per sections 8 and 9 of the ABS Guide.

Ice Class

A0 through C0 or D0

The ice strengthening notations Ice Class A0, B0, C0 and D0 indicate that the vessel is suitable for navigating independently in first year ice in accordance with applicable requirements of Section 6-1-1 of the ABS *Rules for Building and Classing Steel Vessels*.

Ice Class	Navigating independently or when escorted by an icebreaker of the following ice classes	Polar Waters with Multi-year Ice			Year around navigation in water with first-year ice with the ice conditions given in 6-1-1/Table 2
		Central Arctic basin(1)	Arctic offshore shelf(2)	Antarctic ice covered waters	
A5	Independently	Year around	Year around	Year around	Extreme
		Note 3	Note 3	Note 3	Extreme
A4	Independently	July through November	Year around	Year around	Extreme
		Note 3	Note 3	Note 3	Extreme
A3	Independently	Short term, short distance entries during July through September	July through December	February through May	Extreme
A2, A1	Escorted by Ice Breaker, Ice Class A3 or Higher Ice Breaker Ice Class Vessel	Note 3	Note 3	Note 3	Extreme
A2	Independently	—	August through October	March through April	Extreme
A1, A0	Escorted by A2 or Higher Ice Class Vessel	—	Note 3	Note 3	Extreme
A1	Independently	—	Note 3	—	Very Severe
B0	Escorted by A3 or Higher Ice Class Vessel	—	Note 3	Note 3	Extreme
A0, B0, C0	Escorted by A1 or Higher Ice Class Vessel	—	Note 3	—	Very Severe
A0	Independently	—	—	—	Severe
B0	Independently	—	—	—	Medium
C0	Independently	—	—	—	Light
D0	Independently	—	—	—	Very Light

Notes:

1. "Central Arctic Basin" means all of the multi-year ice covered waters of the Arctic Ocean and Arctic seas to the north from the boundary of the stable Arctic pack ice zone.
2. "Arctic Offshore Shelf" means Arctic waters within landfast and shear ice zones off the shores of continents, archipelagoes and Greenland.
3. Polar Ice classes, PC 7, PC 6, PC 5, PC 4, PC3, PC 2 and PC 1, whichever is applicable. See the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters*.
4. The shaded columns shaded are applicable for Ice Breakers.

Ice Class

A5 through A1

The ice strengthening notations Ice Class A5, A4, A3, A2 and A1 indicate that the vessel is suitable for navigating independently in multi-year ice in accordance with applicable requirements of Section 6-1-1 of the ABS *Rules for Building and Classing Steel Vessels*.

Thickness of First-Year Ice Cover in m (ft)	Concentration of Ice[1]			
	Very Close and Consolidated Ice, Fast Ice (from 10/10 to 9/10 or from 8/8 to 7/8)	Close Ice (from 9/10 to 6/10 or from 7/8 to 5/8)	Open Ice (from 6/10 to 3/10 or from 5/8 to 2/8) and Fresh Channel[2] in Fast Ice (more than 6/10 or 5/8)	Very Open Ice (less than 3/10 or 2/8), Fresh Channel[2] in Fast Ice (6/10 or 5/8 and less) and Brash Ice
1.0 (3.3) and above	Extreme	Extreme	Very severe	Severe
from 0.6 (2) to 1.0 (3.3)	Extreme	Very severe	Severe	Medium
from 0.3 (1) to 0.6 (2)	Very severe	Severe	Medium	Light
less than 0.3 (1)	Severe	Medium	Light	Very light

Notes:

1. These ratios of mean area density of ice in a given area are from the "World Meteorological Organization Sea Ice Nomenclature", Appendix B.7, and give the ratio of area of ice concentration to the total area of sea surface within some large geographic locales.
2. Provided the channel is wider than the ship.

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