

Winterization Guidelines for LNG/CNG Carriers in Arctic Environments

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ABSTRACT

Vast reserves of gas and oil are expected to be developed in the offshore areas of the Russian Arctic. Atlantic states in North America and Europe are expected to be the chief consumers of this energy. Difficulties in piping gas and oil across vast stretches of arctic land mass, and the difficulty and time required to build such pipelines, suggest that significant quantities of this gas and oil will be transported by ship from both the Russian Arctic region and the Baltic Sea. Year-round carriage by sea will place extreme challenges on the ships and their crews. This paper discusses those ship design and operation challenges for this trade. There are two related perspectives of this paper:

- Winterization of vessels operating in the arctic environment
- Implications for design, winterization, and operations due to the needs of humans operating under arctic conditions.

From the first perspective, traditional consideration is given to winterization issues such as: de-icing, ice effects mitigation (such as sea chest designs), interaction between ice breakers and their escorted ships, piping arrangements, fire fighting arrangements and main/auxiliary machinery.

The second considers the implications on ship design, winterization, and operation to meet the requirements and needs of the crew. These include concerns related to: environmental controls, cold weather clothing, crew support and habitability, human performance in cold weather, safety and medical issues, personnel characteristics, and machinery operation and maintenance.

The paper presents and summarizes the *ABS Guide for Vessels Operating in Low Temperature Environments* providing standards for the winterization and human support and operation of vessels operating in arctic conditions.

INTRODUCTION

The North-East Passage or Northern Sea Route has been seen as a shortcut for shipping between Europe and the Far East beginning with exploratory voyages in the 16th Century.

Since the end of the 19th Century, Russia has put considerable effort into developing the infrastructure of its Arctic Regions by developing marine transport systems. A significant experience in organizing Arctic navigation has been accumulated, however, the difficult ice conditions and the geo-political difficulties of the region have prevented the use of the Northern Sea Route by international shipping (Fridthof Nansen Institute, 1999). Still, Russian commercial shipping has been navigating Arctic waters for decades. Nickel has been shipped from northwest Russia year-round since the 1970's - with the help of a fleet of powerful ice-breakers (Mahmood and Revenga, 2006).



In the last few years, new attention has been drawn to the Arctic Regions. Huge oil and gas reserves, both onshore and offshore, are being made available to the international market. New gas fields are being developed in Norway (Snøhvit) and Russia (Shtokman). The LNG liquefaction plants under construction will supply the gas markets in Europe and North America within the next five years, however, this development may merely be the tip of the iceberg: potential gas reserves in the Barents and Kara Seas may dwarf the current proven reserves. It has been estimated that up to 25 percent of the world's undiscovered gas reserves may be located in the Arctic Regions.

New LNG liquefaction plants are being considered or are under construction in areas with harsh winter conditions. A plant for the Sakhalin II project in Eastern Siberia may be delivering LNG to the Far East markets by 2008, while another plant at Ust-Luga near St. Petersburg may be completed by 2009 to supply the North American market.

It is envisaged that the Arctic gas fields will be developed by using a combination of pipeline network and LNG marine transport system. Currently there is an existing pipeline network supplying Europe from Northern Russia and more pipelines are intended for the near future. As many of Arctic development projects are intended to supply markets in North America, LNG carriers are a necessary part of the Arctic energy chain.

Despite the use of gas pipelines, it is anticipated that a considerable number of LNG carriers will be needed for the Arctic gas trade. These ships will be required to operate in severe weather conditions with very low air temperatures, and in some routes, to navigate in ice-covered waters either during the winter months or all year-round. Additionally, the Arctic natural environment is highly sensitive to any kind of pollution and, due to the remoteness of the region, clean-up operations would be very difficult and costly.

LNG carriers operating in the Arctic Regions are exposed to unique risks for which classification societies are establishing new guidance to meet the challenge of maintaining the necessary levels of safety and environmental protection for the operation of these ships (Mahmood and Revenga, 2006).

WINTERIZATION OF LNG CARRIERS

For the purpose of this paper, winterization is defined as the preparation of a ship for safe operation in extreme cold weather conditions by adapting the design and operation procedures to the requirements imposed by the intended service. Mean daily temperatures below 0°C are expected to be encountered by the ship during the voyage or in port. The American Bureau of Shipping recently published the *Guide for Vessels Operating in Low Temperature Environments (LTE Guide)* to address various design, operation and crew requirements related to extreme cold weather conditions.

Although many of the design and operational aspects being considered for winterized LNG carriers can be applied to any type of ship operating under the same conditions, there are particularities specific to LNG carriers which need to be specially considered. The *LTE Guide* has requirements addressing:

- Materials and coatings;
- Hull construction/arrangement and equipment;
- Vessel systems and machinery;
- Safety systems for personnel;
- Specific vessel requirements for four vessel types;
- Crew considerations; and
- Crew training



From the classification perspective the *LTE Guide* addresses a number of issues not covered by the Rules or vessels receiving ice class notations. A brief description of the major issues affecting LNG carriers and the reasoning for the requirements follows (Mahmood and Revenga, 2006).

CLASS NOTATION

The *LTE Guide* is applicable for vessels operating in cold climates where design service temperatures of -10°C or less are anticipated. Vessels designed, built and surveyed in accordance with the requirements of the *LTE Guide* will be assigned either of the two class notations: **CCO-HR(TEMP)** or **CCO-HR(TEMP)+**. The notation symbols signify the following:

- **CCO:** Cold Climate Operation
- **HR:** The number of hours of emergency services time, either 18 hours based on the SOLAS regulations or 36 hours for vessels operating in remote areas where rescue efforts may be delayed.
- **TEMP:** The Design Service Temperature (DST) for the vessel is listed. DST is defined as the lowest mean daily average temperature in the area of operation for data taken over at least a 20 year period. This definition is from International Association of Classification Societies, Unified Requirement S6, Use of steel grades for various hull members-ships of 90 m in length and above, section 6.3.
- **+**: This symbol indicates the vessel's crew has been trained, and loose gear necessary for operation in low temperatures is onboard. It is recognized that in some cases a vessel may not trade in cold climates at the time of delivery. Therefore, an owner may delay crew training and installation of loose gear until such time.

Engineering plans must be sent to an engineering technical office for approval. A Surveyor will confirm the required systems are installed and are functional at the initial survey. Verification of continued functionality of the systems will occur at subsequent annual surveys. Owners who delay crew training and provision of loose gear may contact the Survey Department at any time to arrange a survey to change the class notation to indicate "+".

Additional resources and elaboration have been provided in the Appendices to provide users of the *LTE Guide* guidance for meeting the requirements. Contacts for national administrations that have additional requirements for vessels operating in their territorial waters are provided. Guidance in the form of temperature charts in the Arctic region along with a listing of meteorological organizations is also provided.

MATERIALS AND COATINGS

Vessels seeking a low temperature environment certification are required to have their hull structural materials selected based on the DST and appropriate material class in accordance with 6-1-1/35, Hull Structural Materials of the ABS Rules for Building and Classing Steel Vessels (*ABS, Steel Vessel Rules, 2006*).

Any area of the vessel exposed to low air temperatures must be constructed with ductile materials suitable for operation in this environment. For design purposes, the vessel must be assigned a DST.

Structural steel class and grades for weather exposed plating and for inboard framing members attached to this plating may need to be upgraded if the design service temperature for the vessel is below the calculated design temperature of the material in the specific location.

Materials used for essential equipment exposed to the weather must be of steel or other suitable material with ductility properties at the minimum anticipated temperature for which the equipment is to operate. This is approximately 20°C below the DST. Exposed machinery include anchoring and mooring equipment, lifting appliances such as cranes, etc. Obviously, materials intended for cryogenic service which are exposed to the weather will remain suitable for the service.

Appendix 2 of the Guide includes some additional information for coatings including a chart for the coefficient of friction for various coatings and ice.

HULL CONSTRUCTION/ARRANGEMENT AND EQUIPMENT

The *LTE Guide* requirements consider LNG carriers operating in waters without any significant ice cover. Several hull construction issues affecting LNG carriers are discussed in the following paragraphs.

Ice Loads on Deck

One of the potentially significant consequences for any ship in transit through cold weather waters is the concentration of ice on deck. While the amount of ice concentrated on deck will not normally exceed the design loads used in the analysis of the deck local strength, LNG carriers have deck features that can result in higher ice loads on deck.

LNG carriers with both spherical tanks and membrane containment systems have large deck surfaces with a pronounced angle of inclination. Ice accumulating in such surfaces may constitute a hazard to the deck structure if the ice layer becomes so heavy that it detaches and falls on the flat deck, and the impact, or the ice accumulation, may exceed the deck design loads. Although the deck may be strengthened to withstand these additional ice loads, a more economical solution may be fitting external obstacles in the inclined surfaces, such as horizontal flat bars, to prevent ice layer detachment.

Consideration may be given to provide accessibility by the crew to these inclined surfaces in order to remove the ice layer before they become a hazard.



Ballast Tanks

Means must be provided to prevent freezing of the ballast water in the fore peak, after peak and wing tanks. For DST of -30°C to -10°C , these arrangements may be in the form of heating systems or turbulence-inducing systems such as continuous circulation of the ballast water through the tanks. However, steam heating coils are required to be installed if the DST is less than -30°C .

Superstructure and Deckhouses

The LTE Guide recommends the bow area be fitted with a forecastle to deflect waves and spray away from the deck areas aft of the bow. Alternatively, the shell plating in the bow area is to be flared to produce a similar effect.

Bridge wings are to be enclosed or designed to protect navigational equipment and operating personnel. External access to the navigation bridge windows is to be provided to facilitate ease of cleaning. Alternating navigation bridge windows are required to be heated.

Personnel required to perform external duties such as being a lookout when underway, security at the gangway when in port, or being on deck during loading operations are to be provided with a heated deckhouse.

ARCTIC LNG CARRIERS

For the purpose of this paper, Arctic LNG carriers are those navigating in Arctic ice-covered waters as defined in the IMO Guidelines (IMO, 2002a). These ships will be assigned an Ice Class compatible with the intended trade. For all year-round operation in Arctic waters, Polar Class requirements have been developed by the International Association of Classification Societies (IACS) (IACS, 2006a, 2006b, and 2006c), applicable to any type of vessels constructed of steel, as mandated in the IMO Guidelines. These general requirements will be applicable to LNG carriers, but this paper will concentrate in the design and operational concerns characteristic to an LNG carrier.

The issues covered for the winterization of LNG carriers will be also applied to Arctic LNG carriers with the difference that the low temperatures encountered by these ships will be even more extreme. Therefore, different solutions may be required to safely operate in these conditions.

From the classification perspective, the following concerns should be addressed.

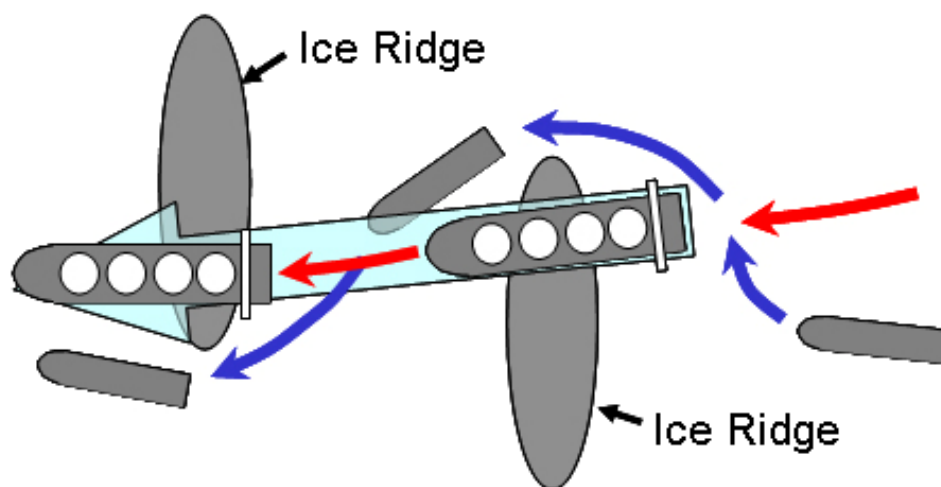
Ice-strengthened hull structure

Hull structure for LNG carriers can be strengthened for ice navigation following the same current Classification Rule requirements as that for other Ice Class vessels (ABS, 2006 – Part 6 Chapter 1) or the IACS requirements for Polar Class ships (IACS, 2006b). However, consideration may be given by the designers to new hull shapes that may reduce ice impact loads and induced vibrations in LNG carriers which may be

particularly sensitive to these types of loads. Guidance may be taken from the *ABS Guidance Notes on Ice Class* (ABS, 2005).

Effect of ice impact loads in the cargo containment system

The LNG containment systems currently available in the market may have a significant sensitivity to ice impact loads which must be assessed. The inertial loads from the cargo and/or the LNG tank mass resulting from the ship/ice interaction will be transmitted to the structure in different ways depending on the type of containment system considered. The accelerations to be considered in the design of these systems will also depend on the severity of the ice conditions and ship operation (speed, etc). Larger vessels are unable to manoeuvre as easily as smaller vessels and may contact ice more frequently. In addition, ice induced vibrations may have a detrimental effect on the containment system, reducing the fatigue life of its component materials. Careful consideration must be paid to the means to assess the adequacy of the containment system subjected to these loads and vibrations. The knowledge acquired with current ice class ships in operation in the Arctic Regions will be vital to provide accurate ice loading conditions to be applied in arctic LNG carrier design.



A greater hazard may be encountered if an LNG carrier needs to use the ramming mode to overcome obstacles such as ice ridges. The question raised is whether any LNG carrier will be able to safely withstand such high acceleration levels in its cargo containment system. A study to verify the suitability of the different containment designs to ramming operations may be needed.

Sloshing in cargo tanks

Directly related to the ice impact loads is the induced sloshing in partially loaded cargo tanks. Recently, extensive studies have been performed to verify the suitability of LNG carriers with membrane type containment systems to carry partial loads (Lee, Kim, and Hwang, 2004). Powerful sloshing simulation programs such as ABS SLOSH3D and ABS SLOSH2D have been used to analyse the effect of the partially-loaded membrane tanks, taking as a basis of analysing the North Atlantic operating environmental conditions. The sloshing hydrodynamic loads are also used for the structural analysis of the pump tower, together with ship motion accelerations and thermal stresses, by means of finite element analysis methods. The same tools may be used to determine the suitability of the membrane type containment system to sloshing induced by ice impact loads.

VESSEL SYSTEMS AND MACHINERY

Ice-Strengthened Propulsion Systems

Most LNG carriers currently in service use steam turbine propulsion. However, a significant number of vessels on order have other alternative propulsion systems, e.g. dual-fuel diesel-electric propulsion or directly driven slow speed diesel engines. For navigation in ice-covered waters, propulsion machinery, reduction gears, shaft lines, propellers and steering systems must be adequate to withstand the ice impact loads and their materials exposed to sea water temperature must be of steel or other ductile materials suitable for low temperature. Detailed requirements for the strengthening of the propeller and propulsion line as well as for propulsion machinery, reduction gears, related auxiliary systems and steering systems are available in the current

Classification Rules for Ice Class vessels (ABS, 2006 – Part 6 Chapter 1 and ABS, 2005). IACS requirements in this regard for Polar Class ships (IACS, 2005c) have been recently made available to the industry.

Alternative propulsion systems may be proposed for LNG carriers navigating in ice-covered waters. Azimuthing propulsors, normally known as pods, are used in Ice Class oil tankers in service and may be suitable candidates for LNG carriers. Non-conventional propulsion systems must be specially considered on the basis of their particular operational profile and loading cases.

Sea Water Supplies

During navigation and at port in ice-covered waters, attention must be paid to sea water supplies for essential operational systems and safety systems. Currently Classification Rules for Ice Class ships have requirements for sea inlet chests intended to prevent the clogging of sea water inlets by ingestion or accumulation of ice. Similarly the IACS requirements for Polar Class ships will cover these aspects. In LNG carriers, sea water supplies are needed for the ballast system, the cooling water system serving propulsion machinery, inert gas cooling, main and emergency fire pumps supplying the fire and wash deck system and the water spray system. The *LTE Guide* presents five sea water supply arrangements for guidance.



Protection of Deck Machinery and Systems

Generally, deck machinery and systems are not prepared for freezing temperatures. Essential equipment and systems must be available at all times and in any temperature conditions. The methods to adapt this equipment to the Arctic environment may vary and will depend on the type of equipment and systems, their criticality for the safety of the ship and its crew, and the protection of the environment.

Essential equipment and systems ideally should be located in spaces protected from the extreme cold weather, however, it is recognized that often exposure to extreme ambient weather will be unavoidable.

In addition to the standard deck equipment and systems onboard any type of vessels, LNG carriers will have equipment on deck specific to its operation. This equipment must be considered essential, and therefore adequately protected and heated for operation under anticipated weather conditions. Particular attention must be made to safety systems and components such as cargo tank pressure relief valves and deck water spray systems.

Steam or thermal oil tracing and heating may be used for essential deck machinery and piping and safety systems and components, provided that the adequate redundancy is built up in the heating system to prevent its unavailability after a single failure. The maximum temperature of the steam or the heating media within the

cargo area must take into consideration the temperature class (i.e., auto-ignition temperature) of the cargo being carried.

Combustion air for prime movers is to be pre-heated to permit proper functioning of the equipment. The Guide requires the combustion air to be led directly to the equipment so as to avoid the machinery space temperature from dropping.

Heating and ventilation in the accommodations are to be designed for satisfactory distribution of heating at the DST. Spaces bordering exterior bulkheads may be provided with supplementary heating. In any case, the accommodation spaces are to be able to be heated to 20°C at the DST.

Low temperature lubricating oil should be used in rotating machines exposed to the weather. The Guide assumes heated lube oil sumps are provided to accomplish this. Lube oils sumps are prohibited from being heated with steam in order to prevent contamination of the oil in the event of a steam coil leak. Heat tracing or alternative means to maintain the hydraulic oil temperature may be considered.

Cranes or other lifting equipment are to be designed for the lowest anticipated temperature instead of the DST. For the purposes of the Guide, the lowest anticipated temperature is 20°C less than the DST.

Spaces on deck such as the motors room and the compressors room should be maintained at a temperature above the minimum operating temperature of the equipment and systems contained inside those spaces. Continuous temperature monitoring with remote reading in the cargo control room would be expected.

SAFETY SYSTEMS

In this section there are requirements related to the protection and survival of the personnel onboard the vessel and the vessel itself. Vessels operating in the arctic may experience delays in rescue and medical services.

Heating for Survival

The Guide lists a dozen spaces that must be supplied with heating in the event of an emergency. The heating system must be able to maintain a minimum of 10°C at the DST. The SOLAS regulations and the ABS Rules require emergency services to be of 18 hours duration. For vessels operating in remote regions, this time can be increased to 36 hours and reflected in the classification notation.

Navigational Equipment

The Guide lists various equipment that must be installed onboard:

- Weather telefax receivers or similar,
- Radar systems capable of picking up ice targets,
- Adequate communications and signalling equipment,
- High powered search lights for navigating in darkness,
- Sound reception system for navigation bridge for exterior noises/signals.

Live-saving appliances and navigational equipment

This addresses requirements for various life saving appliances. They are based in part on the following International Maritime Organization (IMO) documents:

- MSC Circular 1056/MEPC Circular 399 (IMO, 2002a), Guidelines for Ships Operating in Arctic Ice-Covered Waters.
- IMO Life Saving Appliances Code (IMO, 2003) (from MSC.81(70) (1998) and MSC.48(66) (1996)).

The flag state administration and the administrations responsible for the coastal areas that the vessel will be operating in may have requirements in addition to those listed.

Life saving appliances are to be of a type that is rated to perform its functions at a minimum air temperature of -30°C or at a lower temperature if expected to be encountered. The same consideration should be taken for the means to access the ice surface from the ship when the ship should be evacuated while sailing in solid ice and the lifeboats cannot be lowered into ice-free water.

The types of appliances addressed include lifeboats, life rafts, rescue boats, launching stations, ice gangways, immersion suits, alarms, escape routes, and access routes.

ENVIRONMENTAL PROTECTION

In addition to the current Regulations in the IMO MARPOL Convention (IMO, 2002b), it is anticipated that the increase of maritime traffic in the Arctic Regions would bring in the future the declaration of part of or the whole Arctic Regions as Special Area under MARPOL Annex I and SOx Emission Control Area (SECA) under MARPOL Annex VI. LNG carriers intended to trade in the Arctic Regions should be designed to take into account all the current and foreseeable statutory Regulations for environmental protection in addition of coastal state requirements related to the same issue.

The IMO Guidelines (IMO, 2002a) make a strong statement in this regard by referring in a considerable number of its sections to the need for preventing pollution from ships navigating the Arctic Regions.

The LTE Guide references the optional classification notation, POT, Protection of Fuel and Lubricating Oil Tanks which is in 4-6-4/17 of the ABS *Steel Vessel Rules*. These requirements provide additional protection to these tanks in the event of vessel collision or grounding affecting tanks in the after area.

CREW CONSIDERATIONS

Working in cold weather environments has significant implications on human capabilities, and unless proper precautions are made, these can be hazardous to a person's health. In recognition of these implications on human health and performance due to working in cold climates, the LTE Guide also provides:

- Basic information on human performance and health hazards when working in Arctic conditions
- Guidance for design or selection of clothing
- Design of equipment to be operated in cold conditions
- Information that can be used to help generate cold weather operations safety and operating procedures
- Information that can be used to preserve the health of persons working in cold environments

The information is provided for those owners, designers, or operators that would like information of the sort provided as a reference to consider in the course of ship design, outfitting, and ship operation.



Human Response to Cold and Arctic Exposure

The core (trunk) of the human body should remain within a small temperature range for healthy function. Excessive cooling or excessive heating will result in abnormal cardiovascular and neurological function. The skin is the organ through which a person regulates body temperature. With an average skin temperature of 33°C (91.4°F), conductive heat loss occurs at temperatures below this value, therefore, it is easy to see how cold weather performance can significantly influence normal body function. As a person cools:

- Metabolism is increased to generate more body heat – as cooling continues a person will begin to “shiver” – a visible sign that body cooling has progressed beyond a comfortable level. Increased metabolism will reduce the amount of time a person can sustain work.
- Safe manual materials handling tasks require the use of sense of touch, hand dexterity, strength, and coordination. Decreases in the ability to produce force, exhibit fine control over objects, and sustain muscular work loads occur in cold working environment.
- Work in cold environments is related to an increased risk for musculoskeletal injury.
- Motor function impairments of the arms and hands will occur long before cognitive or hypothermic-related disabilities occur. Impaired cognitive performance will lead to poor decision-making and increased risk for accident.
- Persons suffering from arthritis or rheumatism will generally experience increased levels of pain during cold weather operations.

Decreases in Cognition/Reasoning Ability Due to Cold Exposure

Extremely cold conditions (below 10° C (50° F)) adversely influence mental skills and coordination. As operational temperatures decrease, the frequency of cognitive error will increase.

Tasks requiring vigilance may be hampered after prolonged exposure to cold. Decision verification procedures should be implemented.

Cold weather operations, coupled with other physical distracters, such as noise or motion environments, will influence the quality of perception, memory and reasoning and compound the risk of decision-making error.

Health Hazards Related to Cold Exposure

The list of potential injuries and issues for occupational work in cold environments is lengthy. Personnel should have adequate training to enhance preparation for work in cold environments. Proper planning and precaution can deter the potential risks of cold work.

Freezing tissue injury (frostbite). Frostbite occurs as a result of limbs and facial areas being exposed to low ambient temperatures and wind. Generally, frostbite is accompanied with discoloration of the skin, along with burning and/or tingling sensations, partial or complete numbness, and possibly intense pain. Hands, feet, noses, and ears are more commonly affected by frostbite. If the nerves and blood vessels have been severely damaged, gangrene may follow, and amputation may eventually be required. If left untreated, frostbitten skin gradually darkens after a few hours. Skin destroyed by frostbite is completely black and looks loose and flayed, as if burnt.

There are four levels of frostbite.

- First degree frostbite results in vesicles (blisters) that damage only the outer skin.
- Second degree frostbite is associated with full thickness skin loss.
- Third degree frostbite involves the skin and underlying tissue.
- Fourth degree frostbite is the worst and results in freezing to the bone. This level of frostbite typically results in amputation of the affected tissue.

Raynaud's Sign (White Finger). Raynaud's sign represents a disease and relates to the body's hypersensitivity to cold causing the arterial musculature to spasm and constricts peripheral blood flow at a much higher level than typical for a given ambient temperature. Less severe cases of Raynaud's sign, referred to as primary Raynaud's, are idiopathic (a medical condition of unknown origin), while secondary cases occur as a result of an underlying physiologic condition or environmental exposure.

Hypothermia. Hypothermia is a rapid, progressive mental and physical collapse due to the body's warming mechanisms failing to maintain normal body temperatures.

While hypothermia is often associated with immersion in cold water, it can also occur in air when suitable cold weather protection is not employed. Conditions of extremely low dry-ambient temperature or mildly cold ambient temperatures with wind and dampness can lead to a general cooling effect on the body. If metabolic heat production is less than the gradient of heat loss to the environment hypothermia becomes an issue. Table 1 presents the symptoms of hypothermia.

Cardiovascular Function and Cold Exposure. Sudden changes in cardiovascular function occur every day when individuals are exposed to cold weather after previous exposure to a thermo-neutral climate. These changes cause a sudden increase in the workload placed on the heart and may cause subsequent cardiovascular problems.

TABLE 1
Symptoms of Hypothermia

Mild Hypothermia	Moderate Hypothermia	Severe Hypothermia
Increased heart rate, resulting from venous return increase	Impaired respiration	Limited or no cognitive ability
Shivering	Decreased heart rate, blood pressure	Twitching of the heart muscles (atrial and ventricular fibrillation)
Excessive discharge of urine - resulting from central pooling of blood flow and resulting in rapid delivery to the kidneys	Blue-gray 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
Shivering	Loss of muscle function	
	Slurred speech	
	Blurred vision	
	Impaired cognition	
	Confusion	
	Shivering stops (resulting of used energy in prior stages)	

Respiratory Function and Cold Exposure. Cold air has an influence on airway resistance and pulmonary function. This response can cause significant problems for individuals with asthma. There is evidence of long term occupational exposure to cold causing chronic obstructive pulmonary disorders. The increased constriction of the bronchial air passages causes an increase in airway resistance and thus greater effort in breathing.

Monitoring Environmental Conditions

Working in cold environments requires an understanding of the interaction between ambient temperature, wind speed, relative humidity, personnel protective equipment and task being performed. In order to limit the risk during operational activities due to cold stress and further prevent local cold injuries and general freezing, specific preventative measures should be evaluated and introduced during the planning and execution of the daily work activities. The information in Tables 2 and 3 can assist in estimating cold risks and guide preventative measures.

Climatic metrics such as temperature, wind speed, and humidity should be regularly monitored in the locations where outside work is to be performed. Of primary importance is a regular reporting of the wind chill or equivalent temperature.

Regular communications should be maintained regarding allowable time to work outside. Indoor personnel should regularly monitor outside workers so best work-to-rest/warming schedules are maintained.

TABLE 2
Relationship between Wind Chill and Exposure Danger

WIND CHILL CHART										
		Ambient Temperature (°C)								
		4	-1	-7	-12	-18	-23	-29	-34	-40
Wind km/h	Velocity mph	Equivalent Chill Temperature (°C)								
Calm										
0	0	4	-1	-7	-12	-18	-23	-29	-34	-40
8	5	3	-3	-9	-14	-21	-26	-32	-38	-44
16	10	-2	-9	-16	-23	-30	-35	-43	-50	-57
24	15	-6	-13	-20	-28	-36	-43	-50	-58	-65
32	20	-8	-16	-23	-32	-39	-47	-55	-63	-71
40	25	-9	-18	-26	-34	-42	-51	-59	-67	-76
48	30	-16	-19	-22	-36	-44	-53	-62	-70	-78
56	35	-11	-20	-29	-37	-46	-55	-63	-72	-81
64	40	-12	-21	-29	-38	-47	-56	-65	-73	-82

Source: Threshold Limit Values (TLV™) and Biological Exposure Indices (BEI™) booklet; published by ACGIH, Cincinnati, Ohio

Little danger in less than one hour exposure of dry skin	DANGER – Exposed flesh freezes within one minute	GREAT DANGER – Flesh may freeze within 30 seconds
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Source: Canadian Center for Occupational Health and Safety, 1999

TABLE 3
Suggested Maximal Allowable Work Times

Equivalent Temperature	Consequence - Action
Below -30°C	No outdoor work performed unless deemed critical from a safety or operational perspective
Below -21°C	Available outdoor working time is below 50% of working hour.
Below -12°C	Available outdoor working time is below 75% of working hour.
Below -6 °C	Available outdoor working time is below 90% of working hour.
Above -6 °C	Normally 100 % Available working time

Clothing and Personal Protective Equipment

For appropriate protection/isolation against cold climate conditions, adequate clothing should be selected and used onboard during cold periods. Such optimal clothing should be able to mitigate water and humidity during work and at the same time insulate sufficiently to maintain thermal comfort during rest. The insulating effect of the clothing is influenced by different factors including temperature, wind and humidity. Specific guidance is provided covering:

- Hand Protection
- Head and Eye Protection
- Foot Protection
- Maintenance of Personnel Protective Equipment
- Immersion Suit Protection

Nutrition Considerations in Cold Climates

The added weight of protective clothing and the limitations in mobility created by protective equipment will increase the mobility demands of the operator, thus increasing the metabolic needs for a given task.

Workstation Design and Operational Considerations

The analysis of outdoor work situations should be performed early in design/layout development, and should be updated when design changes are made that will influence personnel's exposure to cold stress.

Outdoor operations analyses (an examination of the tasks to be carried out in cold conditions) should be carried out for open work areas and semi-open work areas. The objective of these analyses is to identify and remedy task performance issues due to overall exposure to temperature, wind, icing and precipitation, including investigation of the weather protection necessary to comply with exposure limits.

Accommodations and Environmental Control

All personnel accommodations should be designed and arranged to protect the occupants from unfavorable environmental conditions and to minimize risk of injury during normal (including ice transiting or icebreaking) operations and emergency conditions.

CONCLUSIONS

The thriving LNG market is riding the wave of the increasing energy demand. The development of new gas fields in the most inhospitable regions of the Earth brings extraordinary challenges to the industry and the Arctic Regions are most likely the next target of the gas industry to supply North America, Europe and the Far East.

Classification societies are teaming with the industry to ensure that the excellent record of safety in the LNG maritime transportation for more than 40 years is maintained even in the harshest conditions. Classification Societies have been participating actively in Joint Industry Projects and Joint Development Projects with designers, ship owners, operators, energy majors, shipyards and Regulatory Bodies to provide practical solutions to the challenges of ice navigation. In the near future, new Rules and Guides will be published by individual Classification Societies and IACS to provide the industry with the basis for the construction of Ice Class and Polar Class LNG carriers that can operate in Arctic waters safely while respecting the pristine natural environment.

The LTE Guide and soon to be published Polar Ice Class Rules provide LNG carrier operators the vessel requirements to successfully operate in the Arctic along with additional requirements for personnel to work in this harsh environment.

REFERENCES

- ABS, 2001, Guide for Crew Habitability on Ships.
- ABS, 2003, Guidance Notes on Review and Approval of Novel Concepts.
- ABS, 2005, Guidance Notes on Ice Class.
- ABS, 2006, Rules for Building and Classing Steel Vessels.
- Appolonov, Evgeny M. Scientific Aspects of LNG Arctic Carriers' Design. 2nd Annual Conference Arctic Shipping 2006, St. Petersburg, Russia April 25-26
- IACS, 2006a. Unified Requirement UR I1 - Polar Class Descriptions and Application. *International Association of Classification Societies*.
- IACS, 2006b. Unified Requirement UR I2 - Structural Requirements for Polar Class Ships. *International Association of Classification Societies*.
- IACS, 2006c. Unified Requirement UR I3 - Machinery Requirements for Polar Class Ships. *International Association of Classification Societies*.
- IMO, 2002a, Guidelines for Ships Operating in Arctic Ice-Covered Waters, MSC/Circ. 1056, MEPC/Circ. 399. *International Maritime Organization*.
- IMO, 2002b. MARPOL 73/78 Consolidated Edition, IMO-520E. *International Maritime Organization*.
- INSROP, The Northern Route User Conference Secretariat, 1999: The 21st Century: Turning Point for the Northern Sea Route? The Fridthof Nansen Institute.
- Lee H., Kim J.W., Hwang C., 2004, Dynamic Strength Analysis for Membrane Type LNG Containment System Due to Sloshing Impact Load, The Royal Institution of Naval Architects, International Conference on Design and Operation of Gas Carriers, London Sept. 22-23.
- Mahmood, Mumtaz, and Revenga, Arturo (2006). Design Aspects of Winterized and Arctic LNG Carriers – A Classification Perspective. Offshore Mechanics and Arctic Engineering (OMAE) conference. Hamburg.