Guidelines For Classification And Construction

Part 1 Seagoing Ship

Volume 10

GUIDELINES FOR SHIPS INTENDED TO CARRY COMPRESSED NATURAL GASES IN BULK

2017

Biro Klasifikasi Indonesia

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The following Rules come into force on 1ST January 2018.

Foreword

The “Guidelines for Ships Intended to Carry Compressed Natural Gases in Bulk” has been developed to classify the ships transporting Compressed Natural Gas (CNG). This Guidelines provides requirements for design, construction and periodical surveys required for maintenance of classification that would be applicable to CNG carriers. This Guidelines is to be considered as supplementary requirements to those given for the assignment of the related rules for Seagoing Ships. This Guidelines is divided into fifteen sections as follows:

Section 1. General
Section 2. Materials
Section 3. Ship Arrangements and Location of Cargo Tanks
Section 4. Arrangements and Environmental Control in Hold Spaces
Section 5. Scantling and Testing of Cargo Tanks
Section 6. Piping Systems in Cargo Area
Section 7. Overpressure Protection of Cargo Tanks and Cargo Piping Systems
Section 8. Gas Freeing of Cargo Containment system and piping system
Section 9. Mechanical Ventilation in Cargo Area
Section 10. Fire Protection and Extinction
Section 11. Electrical Installations
Section 12. Control and Monitoring
Section 13. Test After Installations
Section 14. Filling Limits for Cargo Tanks
Section 15. Survey

Any quires or comments concerning this Guidelines are welcomed through communication (either by phone call or email) with BKI Headquarters. Users are advised to check periodically with BKI to ensure that this version of this Guidelines is latest publication.

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Section 1 General

A. General

1. Introduction

This Guidelines contains provision for the classification of ships engaged in the transportation of compressed natural gases (CNG).

2. Scope

The Guidelines provides requirements to cargo tank strength and materials, systems and equipment, safety and availability, and the relevant procedural requirements applicable to ships engaged in the transportation of CNG.

3. Application

3.1 The requirements in this Guidelines shall be regarded as supplementary to those given for the assignment of the Rules for Hull (Pt.1, Vol.II), Rules for Machinery Installations (Pt.1, Vol.III), Rules for Electrical Installation (Pt.1, Vol.IV), Rules for Materials (Pt.1, Vol.V) and Rules for Welding (Pt.1, Vol.VI).

3.2 The minimum and/or maximum operating temperature (°C), maximum acceptable cargo density (kg/m^3) and the design pressure (MPa), shall be stated in the BKI Registers.

In the case of carriage of the gas in the chilled condition the carriage temperature shall be stated. If no chilling is provided ambient temperature will be stated.

3.3 Ships having offshore loading arrangements shall comply with the requirements in Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol.IX) Section 11.

3.4 The process plant and relief system shall be designed according to a standard recognised by BKI.

4. Fundamental safety requirements

4.1 The overall safety with respect to life, property and environment shall be equivalent to or higher than comparable LNG vessels built and operated according to typical ship rules and industry practices.

4.2 For new concepts a quantitative risk assessment (QRA) shall be submitted as a part of the classification documentation. The QRA shall comply with the principles for safety assessment outlined in e.g. IMO Report MSC 72/16 and Reference Notes on Risk Assessment for the Marine and Offshore Oil and Gas Industries. For new concepts or modifications to existing systems a hazard identification (HAZID)/hazard operability study (HAZOP) of the cargo tank, cargo piping, process system, operational procedures etc. shall be submitted for information.

4.3 The fundamental safety requirements shall take into consideration safety targets for:

- Life, with respect to crew and third-party personnel.

- property, e.g. damage to ship and off-hire
- environment, e.g. gas release to the atmosphere.

B. Class Notations

Ships complying with the requirements of this Guidelines are eligible for the assignment of the service notation **"COMPRESSED NATURAL GAS CARRIER"**, as defined in Guidance for Class Notations (Part 0, Vol.B), Sec. 2.

C. Definition

1. Terms

Table 1.1 Definition

Terms	Definition
blow down	depressurising or disposal of an inventory of pressurised gas
cargo area	that part of the ship which contains the cargo tanks, hold spaces, process area, turret space and cofferdams and includes deck areas over the full length and breadth of the part of the ship over the above-mentioned spaces
cargo hold vent pipes	low pressure pipes for venting of cargo hold spaces to vent mast
cargo load/unload valve	the valve isolating the cargo piping from external piping
cargo piping	the piping between the cargo tank valve and the cargo load and or unload valve
cargo tank	consists of the storage system for the compressed gas, i.e. all pressurised equipment up to the cargo tank valve
cargo tank valve	isolates the cargo tank from the cargo piping
cargo vent piping	the piping from the cargo relief valve to the vent mast
class H fire division	divisions formed by bulkheads and decks. See Section 10.B.8
coiled type cargo tank	a cargo tank consisting of long lengths of small diameter coiled piping
cylinder type cargo tank	a cargo tank consisting of an array of cylinder type pressure vessels connected by cargo tank piping. The following definitions are relevant for the cylinder type tank: – cargo tank cylinder is a large diameter cylinder, i.e. standard offshore pipe, composite wrapped pipe of composite tank, with end-caps constituting the main tank volume – cargo tank piping is the piping connecting the cargo tank cylinders up to the cargo tank valve
pressure	the following pressure definitions are used: – design pressure is the maximum gauge gas pressure which has been used in the calculation of the scantlings of the cargo tank and cargo piping. – maximum allowable operating pressure is 95% of the design pressure – set pressure of pressure relief system, the design pressure less the tolerance of the pressure relief system
design temperature	design temperature for the selection of materials in cargo tanks, piping, supporting structure and inner hull structure is the lowest or highest temperature which can occur in the respective components. Reference is made to Section 2.A.2 of this Guidelines.
gas dangerous area and zones	regarding the definitions of gas dangerous area and zones the principles of Rules for Ships Carrying Liquefied Gases In Bulk (Pt.1, Vol.IX), Sec.1 and Sec.10 applies. The extension of the gas dangerous zones shall be re-evaluated taking into account high pressure relief sources and new equipment. IEC-92 may be used for guidance in evaluating the extent of the zones.
hold space	the space enclosed by the ship's structure in which a cargo tank is situated
hold space cover	the enclosure of hold space above main deck ensuring controlled environmental conditions within the hold space

D. Documentation

1. Documentation requirements

1.1 General

The following plans, calculation and information, as appropriate, are to be submitted in addition to those required by Rules for Classification and Surveys (Pt.1, Vol.I) Sec.2. D, E, F.

Table 1.2 Documentation requirements

Object	Documentation type	Additional description	A/R
Gas specification	Characteristics of natural gas to be carried		A
Bilge water control and monitoring system	Arrangement plan	Sensors in hold spaces.	A
Hazardous area classification	Hazardous area classification drawing		A
Explosion (Ex) protection	Electrical schematic drawing	Single line diagrams for all intrinsically safe circuits, for each circuit including data for verification of the compatibility between the barrier and the field components.	A
Explosion (Ex) protection	Arrangement plan	Electrical equipment in hazardous areas. Where relevant, based on an approved 'hazardous area classification drawing' where location of electric equipment in hazardous area is added (except battery room, paint stores and gas bottle store).	A
	Explosion protected equipment maintenance plan	IEC 66079-17	A
Inert gas system	Control and monitoring system documentation		A
	Piping diagram (PD)	– Including drying and backflow prevention arrangements. – Inerting, purging and gas freeing of cargo tanks and hold spaces.	A
	Arrangement plan	– To show all details including – inert gas plant – cooling and cleaning devices – non-return devices – pressure vacuum devices – inert gas distribution piping.	A
	Operational manual		R
Emergency shut down (ESD) system	Cause and effect diagram	Including all items that gives alarm and automatic shutdown.	A
	Control and monitoring system documentation		A
Hydrocarbon gas detection and alarm system, fixed	Control and monitoring system documentation		A
	Arrangement plan	Detectors, call points and alarm devices.	A

Table 1.2 Documentation requirements (Continued)

Object	Documentation type	Additional description	A/R
Fire Water System	Piping diagram (PD)		A
	Capacity analysis		A
	Arrangement plan		A
Cargo tank deck fire extinguishing system	Fixed fire extinguishing system documentation		A
Cargo handling spaces fire extinguishing system	Fixed fire extinguishing system documentation		A
External surface protection water-spray system	Fixed fire extinguishing system documentation		A
Ventilation systems for cargo handling	Arrangement plan	Including gas safe spaces and air locks in cargo area.	A
	Specification	Fans.	R
Cargo handling arrangements	Risk analysis	For new concepts, a quantitative risk assessment (QRA) shall be submitted as a part of the classification documentation. The QRA shall comply with the principles for formal safety assessment outlined in IMO Report MSC 72/16 and 74/19. For new concepts or modifications to existing systems a hazard identification (HAZID)/ hazard and operability study (HAZOP) of the cargo system, process system (if applicable), operational procedures etc. For new concepts documentation of fire loads based on risk analysis and fire and explosion analysis.	R
	Dispersion study	In case of cold venting. Purpose to evaluate the extent of the gas dangerous area.	R
	Escape route drawing		R
	Safety philosophy		R
	Flare heat radiation study	Heat radiation towards cargo holds and other important areas and equipment.	R
	Flare and blow down system report	Blow down calculations also including cooling effect of depressurizing.	R
	Arrangement plan	Locations of: machinery spaces, accommodation, service and control station spaces, chain lockers, cofferdams, fuel oil tanks, drinking and domestic water tanks and stores cargo tanks and cargo piping systems cargo control rooms cargo piping with shore or offshore connections including loading and discharge arrangements and emergency cargo dumping arrangement (if fitted	A
	Specification	Insulation including arrangement, if fitted.	R
	Operational manual	Information related to all cargo operations.	A
	Cargo list	Information on gas specification to be carried on the ship.	R
	Commissioning procedure	Gas trial program for complete cargo system including tanks.	A

Table 1.2 Documentation requirements (Continued)

Object	Documentation type	Additional description	A/R
Cargo piping system	Piping diagram (PD)	– Cargo and process piping including vapour piping and vent lines of safety relief valves or similar piping, and relief valves discharging cargo from the cargo piping system. – Auxiliary systems like glycol, steam, lubrication oil, etc., if fitted.	A
	Pipe stress analysis	Complete stress analysis for each branch of the cargo piping system according to ANSI/ASME B31.3.	R
	Specification of pipes, valve, flanges and fittings	Including non-destructive testing specification.	A
Cargo valves control and monitoring systems	Control and monitoring system documentation		A
Compressed gas cargo tank arrangements	Design analyses	– Stress analysis including interaction between hull and tank system. – Ultimate (burst) strength of the cargo tanks. – Fatigue analysis for cargo tanks. – Relevant fatigue crack propagation calculations for cargo tanks. – Fatigue crack propagation calculations for the cargo tank piping using leak-before-failure principle.	R
	Non-destructive testing (NDT) plan	Welds.	A
	Material specification, metals	Including internal structures and piping.	A
	Material specification, non-metallic material		A
	Welding procedures (WPS)		A
	Temperature calculation	Calculation of maximum and minimum design temperature for materials in the cargo tank, supporting structure and inner hull due to loading/ unloading and depressurising.	R
Compressed gas cargo tank arrangements	Arrangement plan	All tank details including – complete tank – access for inspection – support arrangement with anti-float/anti-roll supports – tank and hold space insulation, if fitted – tank connections – hold space temperature keeping arrangement, if fitted.	A

Table 1.2 Documentation requirements (Continued)

Object	Documentation type	Additional description	A/R
Compressed gas cargo tank arrangements	Arrangement plan	Protection of cargo tank system with double hull and minimum distance to ship bottom.	A
	Test procedure at manufacturer	Prototype testing with full scale fatigue and burst tests for cargo tanks.	A
	Design basis	The cooling effect from gas released as a result of a leakage or rupture of piping and cargo tank.	A
	Calculation report	– Raking damage calculations, showing that the maximum ship speed, at which the extent of raking damage will not penetrate into the forward cargo hold space, is sufficient for safe manoeuvring of the ship at not less than 5 knots. – Collision damage analysis which demonstrates that the energy absorption capability of the ship side is sufficient to prevent the bow of the striking vessel(s) to damage the cargo tanks.	R
	Calculation report	– Hull steel temperature when cargo temperature is below -10°C. – Vibration analysis if considered relevant.	R
Cargo compartments over- and under-pressure prevention arrangements	Specification	Relief valves.	R
	Calculation report	Required cargo hold relief hatch capacity.	A
Cargo compartment control and monitoring systems	Control and monitoring system	– Gas leak monitoring. – Temperature in cargo tanks. – Temperature and oxygen in hold spaces. – Moisture and H_2S at load/unload or shore connection.	R
	Plan for periodic test of field instruments	Including intervals between recalibration.	A
Cargo pressure control and monitoring system	Control and monitoring system	Pressure in – each hold space – each cargo tank – cargo piping at load/unload connection.	A
	Plan for periodic test of field instruments	Including intervals between recalibration	R
For machinery using of cargo as fuel	Gas fuel arrangement	See the Guidelines for the Use of Gas as Fuel for Ships (Pt.1, Vol.1)	

Note:
A = for approval
B = for reference

1.2 Other plans, specifications or information may be required depending on the arrangement and the equipment used in each separate case.

1.3 Reference documents are:

- Rules for Classification and Surveys (Pt.1, Vol.I)
- Rules for Hull (Pt.1, Vol.II)

- Rules for Machinery Installations (Pt.1, Vol.III)
- Rules for Electrical Installation (Pt.1, Vol.IV)
- Rules for Materials (Pt.1, Vol.V)
- Rules for Welding (Pt.1, Vol.VI)
- Rules for Ships Carrying Liquefied Gases in Bulk. (Pt.1, Vo.IX)
- International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, IGC Code, Res. MSC. 370(93)
- ASME VIII Div.1 - ASME Boiler and Pressure Vessel Code
- ASME VIII Div.2 - ASME Boiler and Pressure Vessel Code - Alternative Rules for Pressure Vessels
- ASME VIII Div.3 - ASME Boiler and Pressure Vessel Code - Alternative Rules for Construction of High Pressure Vessels
- ASME X – ASME Boiler and Pressure Vessel Code – Fiber-Reinforced Plastic Pressure Vessel.
- ASME B31.3 - Process Piping
- API RP521 - Guide for Pressure Relieving and Depressurizing Systems

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Section 2 Material

A. General

1. Material

1.1 The materials used in the hull structure shall comply with the requirements for manufacture, survey and certification given in Rules for Material (Pt.1, Vol. V), Rules for Welding (Pt. 1, Vol. VI), and Rules for Hull (Pt. 1, Vol. II).

1.2 For the cylinder type cargo tank the materials used in the cylinder and end-caps shall comply with the requirements for manufacture, survey and certification given in ASME Section VIII. See also 1.7. Due regard shall be given to corrosion protection.

Note:

The use of suitable protective coating or liners can be an acceptable means of corrosion protection

1.3. For the coiled type cargo tank the materials used shall comply with the requirements for manufacture, survey and certification given in the ASME Section VIII. or a recognised standard accepted by BKI. See also 1.7.

1.4 The materials used in the cargo tank piping, cargo piping and all valves and fittings shall be of quality AISI 316 L or equivalent with respect to ductility, fatigue and corrosion resistance, and shall comply with the requirements for manufacture survey and certification given in the Rules for Material (Pt. 1, Vol. V), Rules for Welding (Pt.1, Vol. VI) and Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX).

Note:

Unprotected piping on open deck is recommended to be painted.

1.5 Cargo hold vent pipes shall be of a fire-resistant material capable of withstanding the calculated pressure.

1.6 CNG cargo tanks designed and built using composite materials will be specially considered and are to be designed and constructed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Sections X, or equivalent. BKI will review the composite materials proposed to be used in the construction of the cargo tank for any additional requirements as may be deemed necessary considering the specific application. The additional requirements needed, if any, will be communicated to the manufacturer by BKI, See also section 5.D.

1.7 All material used in the cargo tank and cargo piping shall be made at an approved manufacturer and provided with material certificate issued by BKI.

2. Design Temperature

2.1 The maximum design temperature for selection of materials is the highest temperature which can occur in the cargo tanks or cargo piping due to:

– loading/transport/unloading.

2.2 The minimum design temperature for the selection of materials is the lowest temperature which can occur in the cargo tanks, cargo piping, supporting structure or inner hull due to:

- loading/transport/unloading.
- the cooling effect from accidental release of cargo gas.

When determining the minimum design temperature the cooling effects from an accidental release inside the cargo holds shall be documented. The documentation shall address:

- a leakage or complete rupture of the cargo tank piping at one location for the cylinder type system
- the cooling effect from the complete rupture of one pipe in the coil for the coiled system.

Partial protective boundaries shall be provided to prevent direct cooling down of tank units or of ship's structure. Ambient temperatures for calculating the above steel temperatures shall be 5°C for air and 0°C for sea water unless other values are specified for special areas.

Section 3 Ship Arrangement and Location of Cargo Tanks

A. General

1. Application

1.1 The ship shall meet the requirements to survival capability and ship arrangement as given in Rules for Ships Carrying Liquefied Gases in Bulk (Pt. 1, Vol. IX) Sec. 2 and Sec. 3. In addition, the below requirements apply.

1.2 A tanker for compressed natural gas is to be of a double hull construction with double sides and double bottom.

Equivalent bottom solutions may be used if they can be shown by calculations or tests to offer the same protection to the cargo tanks against indentations and have the same energy absorption capabilities as conventional double bottom designs, see raking damage described in 3.1.

2. Divisions

The cargo holds shall be segregated from engine rooms and accommodation spaces and similar spaces, by cofferdams, see Rules for Ships Carrying Liquefied Gases in Bulk (Pt. 1, Vol. IX) Sec.3.

3. Collision and grounding

3.1 For conventional double bottom designs the double bottom height shall at least be **B**/15 or 2 m whichever is less, but not less than 1.0 m.

A safe maximum navigating speed whereby the cargo tank or its supports are not damaged by grounding on a rocky seabed, shall be determined by grounding raking damage calculations. The maximum navigating speed shall be equal to or larger than the minimum safe manoeuvring speed of the vessel. For the purpose of these calculations this speed shall not be taken to be less than 5 knots.

> ***Note:***
>
> *For grounding raking damage calculations, a triangular shaped rock with a width of twice the penetrating height may be used.*

3.2 A collision frequency analysis shall, for new projects, be conducted for a characteristic vessel trade. The analysis shall determine the annual collision frequency and associated collision energies of striking vessels, based on vessel sizes, types and speeds determined from traffic data for the selected trade. If applicable traffic data for the actual trade is not available, or no specific trade rather than world-wide trading is planned, relevant traffic data for North Sea trading acceptable to BKI may be used.

3.3 Collision damage analysis shall be conducted to demonstrate that:

For the ship sizes and energies determined in 3.2 the energy absorption capability of the ship side shall be sufficient to prevent the bow of the striking vessel(s) from penetrating the double side into the position of the cargo tanks, thus not damaging the cargo tanks.

Alternatively:

For the purpose of the calculations it may conservatively be assumed that all the collision energy will be absorbed by the struck ship side. Hence, the following simplifications will be accepted:

- the use of an infinitely stiff striking bow
- hit perpendicular to the ship side and no rotation of struck ship
- no common velocity of the two ships after collision

In lieu of more specific information a raking bow with a stem angle of 65°, i.e. a typical bow for a 5000 tonnes standard supply vessel, may be used. It shall be demonstrated by calculations that the side of the CNG carrier has an energy absorption capability according to 3.2, but not less than given by the formula in 3.4 without the bow penetrating into the position of the cargo tanks.

3.4 The minimum collision energy in MJ to be absorbed in the collision shall be taken as:

$$E_{min} = \max\left\{13 \cdot \left(\frac{L_{PP}}{100}\right)^2 \frac{1}{\left(1 + 0.8\,\dfrac{\Delta_1}{\Delta_{CNG}}\right)};\ 1,0\right\}$$

where:

L_{pp} = length between perpendiculars of the CNG vessel in m

$\Delta 1$ = the displacement of the average size of the population of striking vessels which can be taken as 10000 tons

Δ_{CNG} = the displacement of the struck CNG vessel, in tons.

3.5 For conventional double side designs the width of the double side shall at least be minimum **B**/15 or 2 m whichever is the greater.

Equivalent side solutions may be used if they can be shown by tests or calculations to offer the same protection to the cargo tank against indentations, i.e. the same energy absorption capabilities as conventional double side designs, and complies with the energy absorption requirements in 3.2, 3.3 and 3.4 whichever is the more conservative. The minimum horizontal distance from the outer hull to the cargo containment system shall not be less than as stated in the beginning of this paragraph.

3.6 Due to changing ship lines at the ends of the cargo area it will be acceptable to apply the minimum double bottom height in 3.1 and the minimum double side width in 3.5 at the forward cross-section and aft cross-section of the of the cargo area.

When the side width, w, and the double bottom height, h, are different, the distance w shall have preference at levels exceeding 1.5 · h above the base line as shown in Fig. 3.1.

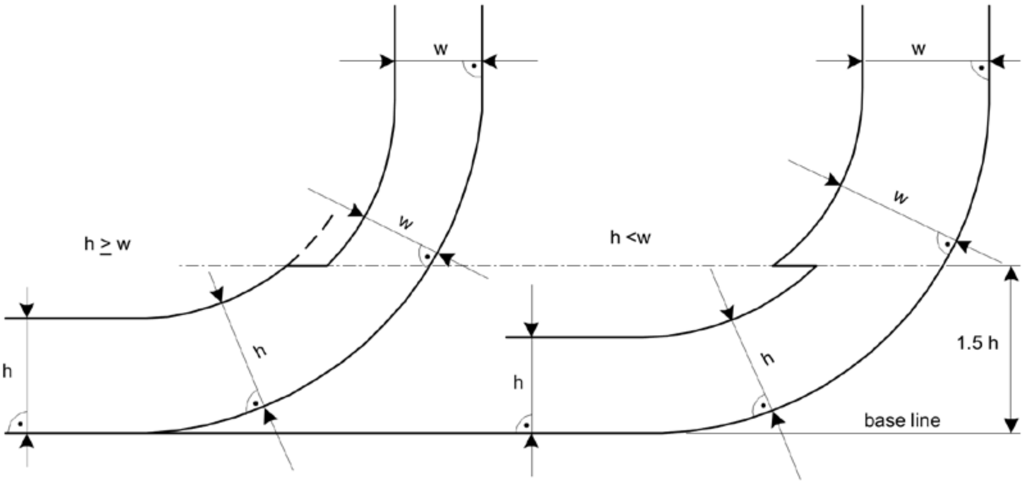

Fig. 3.1 Minimum double bottom height and double side width

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Section 4 Arrangements and Environmental Control in Hold Spaces

A. General

1. Application

1.1 The principles for access for inspection given in Rules for Ships Carrying Liquefied Gases in Bulk (Pt. 1, Vol. IX) Sec. 3.5 shall be used where visual inspection is required. For the cylinder type cargo tank access for inspection of cargo tank cylinders, supports, foundations and cargo tank piping shall be arranged from outside the cylinders. For the coiled type cargo tank a method for inspection from inside by use of special inspection tools shall be predetermined.

1.2 An inspection plan shall be developed and submitted for approval. The plan shall include a detailed description on how safe access for inspection is provided.

1.3. The cargo tank valve shall be mounted outside the hold space. For enclosed hold spaces, the provisions in 2 and 3 apply.

Note:

Cargo tanks may be located in enclosed or open hold spaces.

1.4 For open hold spaces special attention shall be given to corrosion protection and fire protection of the cargo tanks and the possibility for detecting a leak within the cargo area.

2. Inerting of hold spaces

2.1 The hold space shall be inerted with nitrogen or inerted with other suitable non-corrosive medium. The nitrogen supply system shall be arranged to prevent back flow in the case of overpressure in the hold space. The nitrogen system shall be designed with redundancy to the extent necessary for maintaining safe operation of the vessel.

2.2 For composite cargo tanks the hold space is to be enclosed and inerted.

The atmosphere in the hold space is to be purged with nitrogen or other suitable inert gas and the concentration is to be kept under 30% of LEL (lower explosion limit).

3 Overpressure protection of hold spaces

3.1 Hold spaces shall be fitted with an overpressure protection system. The following functional requirements apply:

1) Pressure control of inerted atmosphere with positive pressure automatically adjusted between 0.005 and 0.015 MPa above atmospheric pressure shall be provided.
2) Pressure relief device, normally set to open at 0.025 MPa, shall be provided. The relief device shall have sufficient capacity to handle a rupture of the largest cargo tank piping in the hold space for the cylinder type cargo tank and a rupture of one pipe in the coil for the coiled type cargo tank. This applies to the largest cargo tank in the relevant hold space.
3) The discharge from the hold spaces shall be routed to a safe location.

4) In addition to the relief system required by 2) relief hatches, normally set to open at 0.04 MPa shall be provided in each hold space cover.

5) It shall be demonstrated that the pressure protection devices and their surrounding structures are capable of handling the lowest temperature achieved during pressure relieving at maximum capacity.

4. Drainage

4.1 Hold spaces shall be provided with a suitable drainage arrangement not connected with machinery spaces. Means for detecting leakage of water into the hold space shall be provided.

5 Area classification

5.1 The extent of gas dangerous zones and gas dangerous spaces shall follow the principles in Rules for Ships Carrying Liquefied Gases in Bulk (Pt. 1, Vol. IX).

5.2 If cold venting is used for the gas relief system a gas dispersion analysis shall be conducted in order to evaluate the extent of the gas dangerous zone. The analyses shall be carried out according to a recognised standard/software and the boundaries of the gas dangerous zone shall be based on 50% LEL (lower explosion limit) concentration.

Section 5 Scantling and Testing of Cargo Tanks

A. General

1. General

1.1 The cargo tank shall be designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Changes to material properties with time due to long term static loads and the environment shall also be considered for composites.

1.2 The cargo tank together with supports and other fixtures shall be designed taking into account all relevant loads listed in Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec. 4.

1.3 The dynamic loads due to ship motions shall be taken as the most probable largest loads the ship will encounter during its operating life, normally taken to correspond to a probability level of 10^{-8} in the North Atlantic environment.

Loading rates shall be considered for composites, since these materials have rate dependent properties.

1.4 The dynamic effect of pressure variations due to loading and unloading shall represent the extreme service conditions the containment system will be exposed to during the lifetime of the ship. As a minimum, the design number of pressure cycles from maximum pressure to minimum pressure shall not be less than 50 per year.

1.5 Vibration analysis shall be carried out as outlined in Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec. 4.

1.6 Transient thermal loads during loading and unloading shall be considered.

1.7 The effects of all dynamic and static loads shall be used to determine the strength of the structure with respect to:

- maximum allowable stresses.
- buckling
- cyclic and static fatigue failure.
- crack propagation.

1.8 For cargo tank types other than coiled type and cylinder type, the requirements for cylinder type tanks given in C applies, as relevant.

1.9 Process prototype testing shall be carried out to document that the system functions as specified with respect to accumulation and disposal of liquids. It shall be verified that liquid hammering does not occur in the piping system during any operation.

Where it is impractical to perform full scale testing, successful operation can be simulated computationally and in small scale testing to provide adequate assurance of functionality. Commissioning and start-up testing shall be witnessed by a surveyor and is considered complete when all systems, equipment and instrumentation are operating satisfactorily.

B. Coiled type cargo tank

1. General

Requirements for the coiled type cargo tank shall be specially considered. The requirements applicable for the cylinder type cargo tank shall be complied with, as found relevant.

C. Cylinder type cargo tank.

1. Cargo tank cylinder

1.1 The stresses in the cargo cylinder and the hemispherical end caps shall fulfil the burst requirements given in ASME Section VIII. As a rule, the spherical ends are to be use. The stress in the spherical ends are to comply with the Rules Ship Carrying Liquefied Gas in Bulk (Pt.1, Vol.IX) Sec.4. The pressure used for calculating the wall thicknesses is the design pressure defined in Section 1 Table 1.1. The maximum operating pressure shall not be higher than 95% of the design pressure. Hemispherical ends shall have a cylindrical extension (skirt) so that the distance to the circumferential weld to the cylinder is not less than:

$$l_{cyl} = \sqrt{R \,.\, t}$$

where:

R = Radius in mm of hemispherical end.

t = Thickness in mm of hemispherical end.

For elliptical or toro-spherical end-caps additional requirements may apply subject to agreement with BKI.

The local equivalent surface stress (primary bending + membrane stress) in the cargo tank cylinders according to Von Mises shall not exceed 0.8 R_{eH}.

The cargo tank cylinder shall be subject to fatigue analysis by both S-N curves and fracture mechanics crack propagation analysis as described in C.1.2 and C.1.3.

The number of load cycles to be used for design is the number of cycles expected during design life multiplied by a design fatigue factor (DFF) in order to achieve an appropriate safety level.

The minimum calculated fatigue life for all analysis options is not to be less than 25 × DFF years.

1.2 S-N curves shall be applicable for the material, the construction detail and the state of stress in question. Model testing of cargo tank details as fabricated is required to establish the curve. Testing shall be carried out for longitudinal welds and circumferential girth welds of the cargo cylinders. Testing may also be required for special details as deemed necessary by BKI.

> ***Note***
>
> *The test specimens can be either coupon tests or full ring test specimens cut from fabricated cylinders at the actual pipe production line. Normally, ring tests will provide more realistic results for longitudinal welds.*
>
> *For circumferential girth welds coupon tests should be carried out.*

Two alternative formulations are given based on the following definitions of characteristic value for $\log_{10} N$ for the system of ns cylinders:

1) Mean value minus 3 standard deviations (μ-3σ) and no further adjustment
2) Mean value minus 2 standard deviations (μ-2σ), supplemented with a system effect term.

The two formulations for the estimate of the characteristic value of $\log_{10}N$ for the system of ns cylinders are correspondingly denoted as Alternative 1 and Alternative 2:

Alternative 1

The characteristic S-N curve for use in design is defined as the "mean-minus-three-standard-deviations" curve as obtained from a $\log_{10}\Delta\sigma$ - $\log_{10}N$ plot of experimental data. With a Gaussian assumption for the residuals in $\log_{10}N$ with respect to the mean curve through the data, this corresponds to a curve with 99.865% survival probability. The uncertainty in this curve when its derivation is based on a limited number of test data shall be accounted for. It is required that the characteristic curve be estimated with at least 95% confidence. When a total of n observations of the number of cycles to failure N are available from n fatigue tests carried out at the same representative stress range $\Delta\sigma$, then the characteristic value of $\log_{10}N$ at this stress level is to be taken as:

$$\log_{10} N_c = \overline{\log_{10} N} - c_3(n) \cdot \sigma \log N$$

where:

$\overline{\log_{10} N}$ = Mean value of the n observed values of $\log_{10}N$

$c_3(n)$ = Factor whose value depends on number of tests n and is tabulated in Table 5.1.

$\sigma \log N$ = Standard deviation of the n observed values of $\log_{10}N$.

The combined Miner sum for fatigue loads due to loading/unloading and dynamic ship loads is not to be higher than 0.1 (DFF = 10) for cylinders with design S-N curve established as mean minus 3 standard deviations and with enhanced control in fabrication with respect to production tolerances. Out-of-roundness has not been specifically considered for the longitudinal welds, and the weld length is not explicitly accounted for in the design analyses. The safety level is calibrated for a long weld.

Alternative 2

Here the system information is taken into account providing an estimate of the characteristic value of $\log_{10}N$ for the system based on "mean value minus two standard deviations" of the test data.

$$\log_{10} N_c = \overline{\log_{10} N} - \left[c_2(n) + 0.5 \log_{10} \cdot \left(\frac{\ell_{weld}}{\ell_{ref}} n_s\right)\right] \cdot \hat{\sigma} \log N$$

where:

$c_2(n)$ = A factor whose value depends on number of tests n and is tabulated in Table 5.1 corresponding to a 97.725% probability of survival.

For $\hat{\sigma} \log N$ = 0.20, the expression for the characteristic value of $\log_{10}N$ for the system is identical to the expression for the S-N curve for traditional offshore applications

ℓ_{weld} = Length of weld subjected to the same stress range, typical length of one cylinder.

ℓ_{ref} = Reference weld length with similar weld quality and fatigue strength as the tested specimen. 120 mm may be used if not otherwise documented by fatigue testing.

n_s = Number of similar connections subjected to the same stress range, typical number of cylinders.

The combined Miner sum for fatigue loads due to loading/unloading and dynamic ship loads is not to be higher than

1) 0.2 (DFF = 5) with length effect and design S-N curve established as mean minus 2 standard deviations. The cylinders are assumed to be fabricated with enhanced control with respect to production tolerances. Out-of-roundness has not been specifically considered for the longitudinal welds.
2) 0.33 (DFF = 3) with length effect and standard design S-N curves. Out-of- roundness and local stress concentrations are to be specifically considered in design, i.e. all local stresses are to be included in the fatigue stress range. This does not necessarily require enhanced control in fabrication of the cylinders.

The critical level of a sum of cumulative fatigue damages (both due to dynamic load and due to loads caused by the cargo handling operation) is to be not more than 0.1 (i.e. the minimal life time obtained by means of the fatigue curve is to be not less than 200 years with the design service life of the ship being 20 years).

Table 5.1 Coefficient $c(n)$ for estimation of characteristic values with confidence 95%

Number of tests, n	$c_2(n)$ survival prob. 97.725%	$c_3(n)$ survival prob. 99.865%
2	32.2	46.0
3	9.24	13.7
5	5.01	7.29
7	4.09	5.96
10	3.45	5.05
12	3.26	4.72
15	3.07	4.45
20	2.88	4.19
25	2.75	4.00
30	2.65	3.91
50	2.48	3.66
100	2.32	3.44
∞	2.00	3.00

1.3 Additional fatigue analyses using fracture mechanics crack growth calculations shall be carried out for the cargo tank cylinders using mean plus 2 standard deviation values for the crack growth data ($\mu+2\sigma$). The analysis shall be carried out for planar defects assumed located in both the longitudinal and circumferential welds of the cylinders. The calculated fatigue life for a crack to grow through the cylinder wall thickness shall be 3 times the design life, but not less than 75 years (i.e. using DFF = 3 and no system length effect). A realistic stress concentration factor relevant for the weld toe shall be applied. The assumed initial planar defect shall reflect the largest non-detected defect during the non-destructive inspection carried out. The applied crack growth parameters shall be documented for the cylinder base material and its welds.

The fracture mechanics assessments may be carried out according to e.g. BS 7910 Guide to methods for assessing the acceptability of flaws in metallic structures or equivalent standard.

1.4 If the necessary number of load cycles for the crack to propagate through the wall thickness required in C.1.3 cannot be shown, or if Leak-Before-Failure is to be used, it shall be documented that unstable fracture will not occur in the cylinder from a fatigue crack before a possible leak from the calculated through thickness crack can be detected and the tank pressure relieved (blown-down). Applied fracture toughness values shall be documented for the base material, heat affected zone and weld metal for the relevant operation temperature.

1.5 The supported areas of the cargo containment cylinders shall be included in the fatigue calculation required by C.1.2, C.1.3 and C.1.4.

2. Cargo tank piping

2.1 The stresses in the cargo tank piping shall fulfil the requirements given in the Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec. 5. 5.11. The stress calculation shall include all relevant loads given above including vibrations. The calculation of maximum stresses and stress range may be carried out according to ASME B31.3. The design principles given in Section 6. A.4 applies also for the cargo tank piping.

2.2 The cargo tank piping shall be subject to fatigue analysis. The S-N curve shall be applicable for the material, construction detail and state of stress considered. Model testing of details of piping as fabricated may be required. The S-N curve shall be based on the mean curve of $\log_{10}N$ with the subtraction of 2 standard deviations from $\log_{10}N$. The Miner sum from combined dynamic loads and fatigue loads due to loading and unloading shall not be higher than 0.1.

2.3 Fatigue crack propagation calculations shall be carried out for the cargo tank piping. The analysis shall be carried out for defects assumed located in circumferential welds only as the piping shall be of a seamless type or equivalent. The leak-before-failure principle shall be used, i.e. a crack shall propagate through the thickness allowing gas detection and safe blow-down or venting of the affected cargo tank before a complete rupture takes place. Design criteria as for C.1.3 apply.

2.4 The cargo tank piping shall be adequately supported so that the reaction force from a complete rupture of a pipe will not lead to rupture of other pipes by the damaged pipe hitting other pipes. At the same time sufficient flexibility shall be provided in order to allow the cylinders to expand due to pressure and horizontally movement of the cylinder nozzle due to accelerations and vibrations without causing excessive stresses in the piping system which might lead to yielding or fatigue problems. Cargo tank piping up to the cargo tank valve shall be of all welded construction.

2.5 All fittings in the cargo tank piping shall be of forged type. Alternative solutions may be considered by the Society.

3. Welding requirements

3.1 Welding procedure qualification

Pre-production weldability testing shall be carried out for qualification of the tank material and welding consumable according to a weldability testing programme including bead on plate, Y-groove and also fracture toughness tests of base material, HAZ and weld metal. Metallographic examination shall be conducted to establish the presence of local brittle zones. The maximum and minimum heat inputs giving acceptable properties in the weld zones with corresponding preheat temperature, working temperatures and post weld heat treatment temperatures (if post weld heat treatment required) shall be determined for both fabrication and installation welding. The testing programme for the cargo tank cylinder shall be in accordance with ASME Section VIII. Relevant documentation may be agreed in lieu of weldability testing. Fracture mechanics testing at the minimum design temperature shall, however, be performed for the base material, heat affected zone and weld metal after being subjected to any post weld heat treatment. Weld production testing shall be carried out according to ASME Section VIII.

4. Pressure testing and tolerances

Fabrication tolerances and hydraulic testing of the complete cargo tank shall be in accordance with the Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) or recognized standard as applicable.

5. Non-destructive testing (NDT)

All welds in cylinders and cargo tank piping shall be 100% NDT tested in accordance with an approved NDT program. Reference is made to C.1.3 regarding required detectable crack size.

6. Post weld heat treatment.

All longitudinal welds in the cylinders shall be post weld heat treated or stress relieved by an equivalent procedure acceptable to BKI.

7. Prototype testing.

7.1 A set of full scale (with respect to diameter, thickness, number of circumferential welds, including end-caps but not necessarily full length) fatigue and burst tests shall be performed. It shall be documented that the cylinder wall, end-caps and welding has sufficient reliability against fatigue and that the cylinder possesses sufficient burst resistance after twice the number of anticipated design lifetime pressure induced stress cycles. A minimum of 3 tests shall be performed.

One burst test shall be carried out after having been subjected to twice the anticipated number of stress cycles and 2 fatigue tests to document that the fatigue capacity during the design lifetime is:

- 15 × the number of stress cycles for fatigue design analysis without length effect, and
- 10 × the number of stress cycles for the cylinders when length effect has been explicitly included in the design analyses.

D. Composite type cargo tank

1. General

1.1 All general requirements from A.1 apply also to composite tanks.

1.2 The composite cargo tanks addressed here are made of fibre reinforced plastic. A typical simplified pressure vessel with a laminate and inner and outer liner is shown in Fig. 5.1.

The inner liner is the fluid barrier. It may also be designed to carry part of the loads. The composite laminate carries the pressure loads alone or in combination with the inner liner. The fibres are typically carbon, glass or aramid. The plastic matrix is typically an epoxy or polyester. Other fibres and matrices may be used. Whatever material system is chosen the material properties shall be sufficiently characterized. Requirements for the characterization of composite materials are given in ASME Section X or other recognized standard by BKI. The outer liner is a protective layer against external loads/environments. It does typically not carry any loads.

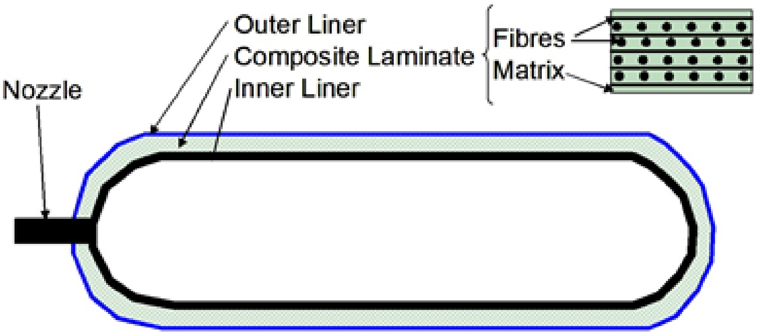

Fig. 5.1 Typical simplified composite pressure vessel

1.3 All metal parts shall be designed according to the requirements given in C. If the liner is made of polymeric materials, ASME Section X can be used. Additional requirements are also given in D.8 to D.9.

1.4 The dynamic short term loads due to ship motions shall be taken as the most probable largest loads the ship will encounter during its operating life (normally the characteristic load effect is defined as the 99% quantile in the distribution of the annual extreme value of the local response of the structure, or of the applied global load when relevant). Dynamic long-term loads may be taken as realistic load sequences.

1.5 The requirements given here are mainly related to cylindrical cargo tanks. Requirements for coiled type cargo tank shall be specially considered. The requirements applicable for the cylinder type cargo tank shall be complied with as found relevant.

2. Cargo tank cylinder – calculations

2.1 As a minimum requirement, the composite tanks shall be designed for (not limited to) the potential modes of failures as listed in Table 5.2 for all relevant conditions expected during the various phases of its life. All failure mechanisms that can be related to the limit states shall be identified and evaluated.

Table 5.2 Typical limit states for the tank system

Limit state category	Limit state or failure mode	Failure definition or comments
Ultimate limit state (ULS)	Bursting	Membrane rupture of the tank wall caused by internal overpressure, possibly in combination with axial tension or bending moments.
	Liquid tightness	Leakage in the tank system including pipe and components, caused by internal overpressure, possibly in combination with axial tension or bending moments.
	Buckling	Buckling of the tank cross section and/or local buckling of the pipe wall due to the combined effect of bending, axial loads and possible external overpressure (when flooding).
	Damage due to wear and tear	Damage to the inside or possibly to the outside of the tank during operation or installation, resulting into burst or leakage.
	Explosive decompression	Rapid expansion of fluid inside a material or interface leading to damage that may cause leakage or burst.
	Chemical decomposition Corrosion	Chemical decomposition or corrosion of materials with time that leads to a reduction in strength, resulting into burst or leakage.
Accidental limit state (ALS)	Same as ULS	Failure caused by accidental loads directly, or by normal loads after accidental events (damage conditions).
	Impact	Damage introduced by dropped objects
	Fire	Resistance to fire.
	Cooling down	Accidental quick release of the gas can cause cooling down of the damaged and possibly neighbouring tanks. Materials and structures should be able to operate under these conditions.
Fatigue limit state (FLS)	Fatigue failure	Excessive Miner fatigue damage or fatigue crack growth mainly due to cyclic loading, directly or indirectly.
	Resonance	The effect of vibrations and resonance frequencies may cause fatigue and shall be considered.

2.2 The pressure used for calculating the composite lay-up is the design pressure defined in Section 1 Table 5.3. The maximum operating pressure should be 5% or more below the design pressure. The ends and cylindrical part of the composite laminate shall be made in one piece. Special attention shall be given to all metal composite connections. These connections shall be designed and qualified according to ASME Section VIII Div.1.

2.3 The cargo tank cylinder and all composite metal joints shall be subject to fatigue analysis. The S-N curve shall be established as described in C.1.2. The Miner sum (for both dynamic loads and fatigue loads due to loading and unloading) shall not be higher than 0.02.

2.4 Fatigue calculations shall be carried out for the laminates in the fibre directions and for all relevant interface properties as described in ASME Section X.

2.5 The maximum and minimum temperatures of the cylinders shall be defined. Extreme and long-term temperatures should be defined if necessary. Temperature changes due to pressure changes during loading, off-loading and blow down shall be considered.

2.6 All material properties shall be established for the relevant operating and extreme environments.

2.7 The cargo tank cylinders shall be supported as described in C.1.5.

2.8 Stresses (static and dynamic) from all sources shall be included in the calculations, like primary bending, membrane stress, thermal stresses and vibrations. The cargo containment cylinders at supports shall be included in the fatigue calculation required by D.2.3.

2.9 Different expansion coefficients for steel, composite and other materials shall be considered.

2.10 The resonance frequencies shall be checked, see also A.1.5. Vibrations from machinery and wave loading should not coincide with the resonance frequencies of the pressure vessel (filled or unfilled).

2.11 The safety factors for all load bearing metal parts shall be the same as given in C. The safety factors for the composite laminate are given in ASME Section X and safety class high shall be chosen. The partial safety factors are given for the entire system. The effect of combining various components in a system is described by the system effect factor γ_S. If the components do not interact the system effect is not relevant and $\gamma_S = 1.0$. Otherwise a system factor shall be documented. A value of $\gamma_S = 1.10$ can be used as a first approach. In some cases, a system may consist of parallel components that support each other and provide redundancy, even if one component fails. In that case a system factor smaller than 1 may be used if it can be based on a thorough structural reliability analysis.

Note

1) In the case of a number of tanks connected in sequence, the failure of one section (i.e. plain pipe or end connector) is equivalent to the failure of the entire system. This is a chain effect in which any component of the sequence can contribute. As a consequence, the target safety of individual section should be higher than the target safety of the entire system, in order to achieve the overall target safety.

2) A continuous spoolable tank has only two end connectors (one at each end). Failure of an end connector is also a system failure. However, since there are only two connectors it is not a chain effect and $\gamma_S = 1.0$ *can be used.*

3. Cargo tank piping

3.1 It is assumed here that piping is made of metal and the same requirements as given in C.2 apply.

3.2 Composite piping may be considered on an individual basis.

4. Production requirements and testing after installation.

4.1 Fabrication tolerances and hydraulic testing of the complete cargo tank are to comply with applicable standards/codes used in the design of cargo tank.

Note

A test pressure equal to 1.3 times the design pressure is considered appropriate.

4.2 The cargo tanks shall be tested on the ship after installation as a final acceptance test. The test pressure shall be 1.3 times the design pressure.

5. Full scale prototype pressure testing and tolerances.

5.1 A set of full scale (with respect to diameter, thickness, number of circumferential welds, including end-caps but not necessarily full length) fatigue and burst tests shall be performed and it shall be documented that the cylinder wall, end-caps and welding have sufficient reliability against fatigue and that the cylinder possesses sufficient burst resistance. Possible damage during installation or operation shall be included in the design tests, see also D.5.4. The sequence of the failure modes in the test shall be the same as predicted in the design. If the sequence is different or if other failure modes are observed, the design shall be carefully re-evaluated. Minimum test requirements are given in Table 5.3.

5.2 Additional testing should be done whenever uncertainties in the analysis cannot be resolved. These uncertainties may be related to the structural analysis, boundary conditions, modelling of local geometry, material properties, failure modes, properties of interfaces, etc.

5.3 Testing may be done at room temperature and with water as a pressure medium if the effect of temperature changes and fluid changes can be well described. If the effect of changing the environmental conditions is uncertain, testing should be carried out in the worst conditions and possibly with gas.

> ***Note***
>
> *Testing with gas requires special safety precautions during testing and it may not be possible to carry out the tests on board the vessel.*

5.4 The tank shall be exposed to typical impact damage, like damage from a dropped hammer etc. Subsequently a pressure test and a fatigue test shall be carried out. The testing may be combined with the tests specified in Table 5.3.

5.5 The specimen geometry for testing may be chosen to be different from the actual under certain conditions. Specimens may be shorter than in reality. If shorter specimens are chosen, the free length of the tank pipe between end-fittings should be at least 6 × diameter. Scaled specimens may be used if analytical calculations can demonstrate that:

- all critical stress states and local stress concentrations in the joint of the scaled specimen and the actual tank are similar, i.e. all stresses are scaled by the same factor between actual tank and test specimen.
- the behaviour and failure of the specimen and the actual tank can be calculated based on independently obtained material parameters. This means no parameters in the analysis should be based on adjustments to make large scale data fit.
- the sequence of predicted failure modes is the same for the scaled specimen and the actual tank over the entire lifetime of the tank
- an analysis method that predicts the test results properly but not entirely based on independently obtained materials data, may be used for other joint geometry. In that case it should be demonstrated that the material values that were not obtained by independent measurements can also be applied for the new conditions.

Tests on previous tanks may be used as testing evidence if the scaling requirement given above are fulfilled. Materials and production process should also be identical.

Table 5.3 Summary of test requirements

Name of test	Description	Reference
Design phase		
Pressure test	1 test to failure	D.5.6
Pressure fatigue of tank	2 tests to 5 × actual number of cycles or survival test to about 100 000 cycles, followed by burst test.	D.5.7 and D.5.8
Stress rupture test of tank if matrix properties are critical or fibres can creep	2 tests to 50 × actual lifetime or survival test to about 1 000 hours	D.5.9
If the inner liner is bonded to the laminate	Test bond between liner and laminate	D.5.10
If impact requirement	Impact tests	D.5.11
Process Prototype Testing	System test	D.5.12
After fabrication		
Pressure test	Test to 1.3 times design pressure for each tank component	D.4.1
System acceptance test	Test to 1.3 times design pressure for each tank component	D.4.2

5.6 Burst pressure test: A burst test shall be done and the burst pressure shall be at least the predicted μ-σ, where μ is the mean prediction and σ is standard deviation of the predicted burst pressure. If more than one test is done the requirements are given in ASME Section X.

5.7 Pressure fatigue testing: Fatigue tests shall be carried out with a typical pressure load sequence. Axial tension or bending should be added if relevant. The most relevant test should be found by evaluating the design analysis. At least two survival tests shall be carried out. The specimen shall not fail during the survival test and it shall not show unexpected damage. The requirements to the testing are:

- Tests shall be carried out up to five times the maximum number of design cycles with realistic amplitudes and mean loads that the component will experience.
- If realistic pressure sequences cannot be tested or if the anticipated lifetime exceeds 10^5 cycles, the test procedure may be changed as given in ASME Section X.
- All tests shall be completed with a pressure test. The failure load or pressure shall be at least the predicted $\mu - \sigma$, where μ is the mean prediction and σ is one standard deviation of the predicted load.

5.8 In some cases high amplitude fatigue testing may introduce unrealistic failure modes in the structure. In other cases, the required number of test cycles may lead to unreasonable long test times. In these cases, an individual evaluation of the test conditions should be made that fulfils the requirements of D.5.7 as closely as possible.

5.9 Stress rupture testing: Only if the performance of the metal composite interface depends on matrix properties or adhesives, or if the fibres in the laminate can creep, long term static testing should be performed. Two survival tests should be carried out.

Stress rupture tests should be carried out with a typical load sequence or with a constant load. If a clearly defined load sequence exists, load sequence testing should be preferred. The specimen should not fail during the survival test and it should not show unexpected damage. The requirements to the test results are:

- Tests should be carried out up to five times the maximum design life with realistic mean pressure loads that the component will experience. If constant load testing is carried out tests should be carried out up to 50 times the design life to compensate for uncertainty in sequence effects.

- If the anticipated lifetime exceeds 1000 hours testing up to 1000 hours may be sufficient. The load levels should be chosen such that testing is completed after 103 hours. The logarithms of the two test results shall fall within μ -σ of the logarithm of the anticipated lifetime, where μ is the mean of the logarithm of the predicted lifetime and σ is one standard deviation of the logarithm of the predicted lifetime, both interpreted from a $\log$(stress) - $\log$(lifetime) diagram for the anticipated lifetime. If more tests are made the requirements are given in ASME Section X.
- All tests should be completed with a pressure test. The failure load or pressure should be at least the predicted μ -σ, where μ is the mean prediction and σ is one standard deviation of the predicted load.

5.10 Liner bond testing: If the design relies on a bond between liner and composite laminate, the quality of the bond shall be tested. Tests can be done on the pipe or representative smaller specimens. If the laminate may have cracks, it shall be ensured that the cracks do not propagate into the liner or reduce the bond quality between liner and laminate.

5.11 Impact testing: The tank should be exposed to typical impact damage, like damage from a dropped hammer etc. Subsequently a pressure test and a fatigue test should be carried out. The testing may be combined with the tests specified above.

5.12 Process prototype testing shall be carried out to document that the system functions as specified with respect to accumulation and disposal of liquids. It shall be verified that liquid hammering does not occur in the piping system during any operation. Where it is impractical to perform full scale testing, successful operation can be simulated computationally and in small scale testing to provide adequate assurance of functionality.

6. Non-destructive testing (NDT)

Composites laminates shall be inspected according to ASME Section X.

7. Composite - metal connector interface

7.1 The interface between the metal connector and the composite pipe is a critical part of the tank design. The interface is basically a joint and all general requirements given in ASME Section VIII Div.1 Joints should be considered.

7.2 The composite metal connector interface shall be strong enough to transfer all loads considered for the connector and the pipe section.

7.3 Internal or external pressure on the tank system may be beneficial or detrimental to the performance of the joint. This effect shall be considered in the analysis.

7.4 Creep of any of the materials used in the joint may reduce friction, open up potential paths for leakage or lead to cracks. Effects of creep shall be considered.

Note

It is highly recommended to design the joint in a way that it also functions if the matrix of the composite laminate is completely degraded. In that case the joint can perform as long as the fibres are intact and sufficient friction between fibres and the fibre metal interface exists. Such a joint does not rely on the usually uncertain long-term properties of the matrix.

7.5 Metal parts should be designed in a way that they do not yield to ensure no changes in the geometric arrangement of the joint. If any yielding can occur a non-linear analysis shall be done taking all relevant load histories and accumulated plastic deformations into account. Local yielding in thin sections or near welds shall be evaluated.

7.6 Possible effects of corrosion on metals and interfaces shall be evaluated.

7.7 Possible galvanic corrosion between different materials shall be considered. An insulating layer between the different materials can often provide good protection against galvanic corrosion.

7.8 Leak tightness of the joint shall be evaluated. In particular possible flow along interfaces should be analysed.

8. Inner liner.

8.1 Most composite tanks have an inner liner as a fluid barrier. The liner may also carry parts of the pressure load. This inner liner is typically made of metal or polymeric materials.

8.2 It shall be shown that the inner liner remains fluid tight throughout the design life, if it is used as a fluid barrier.

8.3 The inner liner may contribute to the overall stiffness and strength of the tank system depending on its stiffness and thickness.

8.4 If the inner liner is only a fluid barrier it usually follows the deformations of the main load bearing laminate. It shall be shown that the inner liner has sufficiently high strains to failure and yield strains to follow all movements of the tank system.

8.5 If the inner liner is designed to carry also part of the pressure loads all requirements from D.8.4 shall be fulfilled. In addition, the load bearing capability of the liner shall be checked according to C. The inner liner needs to deform somewhat and press against the composite laminate before the laminate can support the liner and reduce the loads in the liner. This effect shall be considered. Its magnitude depends on how tightly the laminate is wound around the liner and on how stiff the laminate is in relation to the liner.

8.6 The inner liner should be operated in its elastic range. Neither operational conditions nor test conditions should bring it to yield. An exception is the first pressure loading called autofrettage. Autofrettage is common practice to pressurize a vessel initially at the manufacturer to such high pressures that the inner liner yields. This creates a tight fit between the liner and laminate. The liner will subsequently be compressed by the outer laminate when the high pressure is removed.

8.7 Autofrettage of the inner liner is common practice. The tank is pressurized initially at the manufacturer to such a high pressure that the inner liner yields. After removing the pressure, the inner liner will be compressed by the outer laminate. This procedure ensures a tight fit between inner liner and laminate. It shall be shown that the inner liner does not buckle due to the compressive loads. The yielding of the inner liner during autofrettage also causes the liner’s welds to yield. This may reduce stress concentrations, but it can also cause local thinning around the weld. Any thickness variations in the inner liner may cause localised yielding. The weld zone may have lower yield strength than the main part of the inner liner. Due to this the inner liner may yield locally close to the welds. The strain in the localised yield region can be very high, possibly leading to instant rupture, lower fatigue performance, enhanced creep. The inner liner and its welds shall be analysed taking all these effects into account.

Note

A small thin area in the inner liner can be worse than a larger thin area, because the inner liner may only deform by yielding in the thin section. In that case the small thin section will have much higher strains than the large section, if the total deformation is the same.

8.8 If the inner liner material can creep, then creep will happen especially in the thin highly strained regions. The effect of creep with respect to fatigue, stress rupture and buckling shall be evaluated.

8.9 If the inner liner is under compression, local yielding may create deformations resulting in local or global buckling.

8.10 Buckling of the liner due to hoop compression shall be considered as a potential failure mechanism. The following two phenomena should be considered as a minimum:

- Rapid decompression causes a pressure to build up suddenly between the liner and the composite tank tube, at the same time as the pressure inside the liner suddenly drops. This effect can happen if gas or liquid can diffuse through the inner liner and accumulate in the interface between liner and laminate or inside the laminate. This effect can be ignored for metal liners, since they are diffusion tight, provided no other diffusion path through seals etc. exists in the system.
- As a result of the sustained internal pressure, the liner yields plastically (or undergoes creep deformation) in tension in the hoop direction. Decompression causes the composite tank cylinder to contract, compressing the liner and causing it to buckle. This effect can be prevented by using initially the autofrettage process (D.8.7) and by keeping the liner below yield during operation.

8.11 Inner liner specifications with respect to acceptable thickness variations, weld quality, and maximum misalignments should be consistent with the worst cases evaluated in the analysis.

8.12 Polymeric inner liners, like thermoplastic inner liners may be evaluated against the yield criterion in ASME Section X.

8.13 The liner may be bonded to the composite laminate or it may be un-bonded.

8.14 A different layer of material may also be placed between the laminate and the liner.

8.15 All possible failure modes of the interface and their consequence to the performance of the system shall be evaluated.

8.16 If a bond is required between laminate and liner, for example to obtain good buckling resistance of the liner, the performance of the bond shall be tested D.5.10.

8.17 If interfaces only touch each other, friction and wear should be considered.

The wear depth may be calculated based on the sliding distance, using the length related wear rate $\dot{w}$ for the corresponding wear system. The wear rate varies with the surfaces in contact, the magnitude of the contact pressure and the environment. The wear depth dy (thickness of removed material) is given by:

$$\dot{w} = \frac{dy}{dx} \qquad \text{(m/m)}$$

The total sliding distance dx shall be calculated assuming one contact point for the entire duration of the wear phase.

Another option is to calculate the wear depth based on the sliding time, using the time related wear rate $\dot{w}_t$ for the corresponding wear system. The wear rate varies with the surfaces in contact, the magnitude of the contact pressure and the environment. The wear depth dy (thickness of removed material) is given by:

$$\dot{w}_t = \frac{dy}{dt} \qquad \text{(m/s)}$$

The total sliding time dt shall be calculated assuming the same contact point for the entire duration of the wear phase.

The consequences of removing material with respect to all other failure mechanisms shall be evaluated.

8.18 If the liner is not totally fluid tight, fluids may accumulate between interfaces. They may accumulate in voids or de-bonded areas and or break the bond of the interface. They may also accumulate in the laminate. The effect of such fluids should be analysed.

The fluid should diffuse more rapidly through the laminate than through the inner liner, and more rapidly through the outer liner then through the laminate. Possible effects of rapid decompression of gases should be considered.

The effect of the slight gas leaks due to diffusion shall be considered in the system analysis.

8.19 If the laminate may have matrix cracks, but the liner shall not crack (or vice versa), it shall be shown that cracks cannot propagate from one substrate across the interface into the other substrate. Possible de- bonding of the interface due to the high stresses at the crack tip should also be considered.

8.20 It is recommended to demonstrate by experiments that cracks cannot propagate across the interface from one substrate to the other. It should be shown that by stretching or bending both substrates and their interface that no cracks form in the one substrate even if the other substrate has the maximum expected crack density.

Note

A weak bond between the substrates is beneficial to prevent crack growth across the interface. However, it means that the risk of de-bonding increases.

8.21 The inner liner should be strong enough to withstand possible shear, scraping and torsional loads from equipment running inside tank.

8.22 The inner liner shall be resistant to the internal environment. Possible accumulation of water or other liquids on the bottom of the tank shall be considered. A possible combination of water and H_2S from the gas shall also be considered.

9. Outer liner

9.1 An outer liner is usually applied for keeping out external fluids, for protection from rough handling and the outer environment and for impact protection.

9.2 If no outer liner is applied the outer layers of the laminate have to take the functions of the outer liner.

9.3 The outer liner material shall be chosen so that it is resistant to the external environment, e.g., seawater, temperature, UV etc.

9.4 If the outer liner is exposed to UV radiation in service or during storage, it should be UV resistant.

9.5 Outer liners are not exposed to autofrettage. They should be kept below yielding.

9.6 Resistance of the outer liner to handling and the external environment shall be considered. The outer liner may get some damage from handling, but the structural layer underneath should not be affected.

9.7 The performance requirements to the outer liner should not be affected by a possible impact scenario.

9.8 If fluids can diffuse through the inner liner into the load bearing laminate the outer liner may suffer from blow out if the external pressure is lower than the pressure inside the laminate. Blow out can be prevented by a venting mechanism.

9.9 Blow-out will also not happen if it can be shown that the fluids will diffuse from the laminate through the outer liner into the external environment more rapidly than from the inside of the tube through the inner liner into the laminate. In addition, the remaining fluid concentration should be low enough that even under low external pressure the outer liner cannot blow out.

10. Installation

10.1 A procedure for handling of the composite cargo tanks shall be submitted for information. The procedure shall describe how the tanks will be handled to avoid external impacts and point loads.

10.2 The installation procedure shall as a minimum address the following issues:

- How can impact loads be avoided?
- How can impact loads be detected, if they should happen?
- What are the loads during installation and handling, point loads should be avoided?
- What shall be done in case of fire during installation?
- What is the effect of weld spatter, sparks, naked flames, how can it be avoided?

Possible excessive moments and forces from the manifold system during installation should be addressed.

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Section 6 Piping Systems in Cargo Area

A. General

1. Bilge, ballast fuel oil piping

For piping systems in cargo area not forming a part of the cargo piping the requirements given in Rules for Machinery Installations (Pt. 1, Vol. III) and Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec. 5 apply. Piping systems common to multiple holds shall be arranged so that release of gas from one hold space shall not leak into other hold spaces.

2. Cargo piping, general

2.1 Structure and supports shall be suitably shielded from leak from flanges and valves and other possible leak sources if the cool down effect cannot be shown to be negligible.

2.2 If cargo piping enters enclosed spaces above main deck in process area, these spaces shall be provided with overpressure protection in case of high pressure leak or explosion.

3. Cargo valves

3.1 All remotely operated valves shall be capable of local manual operation.

3.2 The cargo tanks shall be connected to the cargo piping in accordance with the following principles:

- Each cargo tank shall be segregated from the cargo piping by a manually operated stop valve and a remotely operated valve in series. A combined manually and remotely operated stop valve is acceptable provided means are available to check the integrity of the valve.
- The loading/unloading connection point shall be equipped with a manually operated stop valve and a remotely operated valve in series.
- The remotely operated cargo tank valves and load/unload valves required above shall have emergency shut-down (ESD) functions. The valves shall close smoothly so that excessive pressure surges do not occur.
- The ESD valves shall be arranged so that they close automatically in case of high pressure, sudden pressure drop during loading/unloading operations and in the event of fire. The ESD valves shall be arranged to be operated manually from cargo control room and other suitable locations.
- The cargo compressors shall shutdown automatically if the ESD system is activated.

4. Cargo piping design

4.1 The cargo piping system shall as a minimum meet the requirements given in Rules for Machinery Installations (Pt. 1, Vol. III) and Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec. 5 or a standard acceptable to BKI with the following additional requirements:

- The design temperature shall be the minimum temperature achieved during all normal and emergency procedures e.g. loading/unloading and pressure relieving shall be considered.
- The design pressure is the maximum pressure to which the system may be subjected to in service e.g. the set point of the safety relief valve, see Section 7 A.1.

- The pipes shall be seamless or equivalent.
- Only butt welded and flanged connections of the welding neck type are allowed. Flange connections shall be limited as far as possible.
- All butt welds shall be subject to 100% radiographic testing.
- Welding procedure tests and production weld test are required for cargo piping as specified in Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX).
- After assembly, the piping system shall be pressure tested to at least 1.5 times design pressure prior to installation.
- After assembly on board the complete cargo piping shall be subjected to a leak test using air, halides or other suitable medium according to an approved procedure.
- The effects of vibrations imposed on the piping system shall be evaluated.
- A complete stress analysis for each branch of the piping system shall be conducted according to ANSI/ ASME B31.3.

4.2 Procedures for cargo transfer including emergency procedures shall be submitted for approval. The procedures shall address potential accidents related cargo transfer, and information regarding emergency disconnection, emergency shutdown, communication with offshore/onshore terminals etc. shall be included.

Section 7 Overpressure Protection of Cargo Tanks and Cargo Piping System

A. General

1. Cargo Piping

A pressure relief valve for preventing overpressure in the cargo piping shall be provided. The set point of the safety relief valve shall not be more than the design pressure of the cargo piping, less the tolerance of the relief valve.

2. Cargo tanks

2.1 The cargo tanks shall be provided with a blow down system and an automatic pressure relief system. The system shall ensure safe collection and disposal of pressurised gas during normal operation and during emergency conditions

The gas from the vent may be cold vented or ignited. If there are provisions for cold venting a gas dispersion analysis shall be conducted in order to evaluate the extent of the gas dangerous area.

2.2 The blow down system shall meet the following principles:

- The blow down system shall provide means for pressure relieving of individual cargo tanks due to leakage.
- The blow down system shall be provided with remote control for blowing down individual cargo tanks.
- It shall be possible to determine which of the cargo tanks is leaking based on input from e.g. gas detection system, pressure sensors in cargo tank sections, temperature in hold space, and pressure in hold space.
- Cold venting will be acceptable provided it does not impose an unacceptable risk. There shall be two blow down valves fitted in series with a common control signal. One of the valves may be common for all cargo tanks. It shall be possible to check the integrity of the valves.
- The capacity of the blow down system shall be sufficient to ensure that rupture of cargo tank or cargo tank piping will not occur in case of heat input from a fire or cool down from a gas leak.

Note:

The capacity of the system should be based on evaluation of:

- *system response time*
- *heat input from defined accident scenarios*
- *material properties and material utilisation ratio*
- *other protection measures, e.g. active and passive fire protection*
- *system integrity requirements.*

Fire water systems are not normally regarded as reliable protection measures for systems exposed to jet fires. Physical separation and passive fire protection should be the preferred means of preventing escalation.

2.3 The cargo tanks shall be provided with a pressure relief system appropriate to the design of the cargo tank. The set point of the safety relief valve shall not be higher than the design pressure of the cargo tanks, less the tolerance of the relief valve.

2.4 If it proves impractical to install the blow down valves required in 2.2 and the safety relief valve required in 2.3, then alternative measures may be considered. These include high integrity pressure protection systems (HIPPS) where the cargo valve may also serve as blow down valve and a safety relief valve. The acceptability of such systems shall be considered on a case by case basis and will be dependent upon demonstration of adequate reliability and response of the complete system from detector to actuated device(s). The reliability target shall be an order of magnitude higher than critical failure of a typical relief device.

Section 8 Gas-Freeing of Cargo Containment System and Piping System

A. General

1. Application

1.1 Arrangements for gas freeing shall be provided for all parts of the cargo system. A detailed procedure describing this routine shall be included in the cargo handling manual and submitted to BKI for review.

1.2 Atmospheric control within the Cargo containment system

1.2.1 A piping system shall be arranged to enable each cargo tank to be safely gas-freed, and to be safely filled with gas cargo from a gas-free condition.

The system shall be arranged to minimize the possibility of pockets of gas or air remaining after changing the atmosphere.

1.2.2 The system shall be designed to eliminate the possibility of a flammable mixture existing each cargo tank during any part of the atmosphere change operation by utilizing an inerting medium as an intermediate step.

1.2.3 Inert gas utilized for gas freeing of cargo tanks may be provided externally to the ship

1.2.4 Bunkering lines shall be arranged for inerting and gas freeing. When not engaged in bunkering, the bunkering pipes shall be free of gas, unless the consequences of not gas freeing is evaluated and approved.

1.2.5 Piping system which may contain cargo gas are to be capable of being gas-freed and purged after use. When not in use, the spool pieces are to be removed and the pipe ends be blank-flanged. The vent pipes connected with the purge are to be located in the cargo area.

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Section 9 Mechanical Ventilation in Cargo Area

A. General

1. Application

1.1 The ship shall meet the requirements given in Rules for Ships Carrying Liquefied Gas in Bulk (Pt. 1, Vol. IX) Sec. 8 and Sec. 12 as applicable.

1.2 Shut down philosophy for gas detection in cargo area, air ventilation intakes for accommodation and machinery spaces shall be evaluated and submitted for information.

2. Ventilation in hold space

In order to provide for aeration of hold space an efficient ventilation system shall be provided. The ventilation system shall discharge to outlets ensuring safe environment for crew during release of inert gas.

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Section 10 Fire Protection and Extinction

A. General

1. General

The ship shall meet the requirements for gas carriers given in The Rules for Ship Carrying Liquefied Gases in Bulk (Pt.1, Vol.XI) Sect.11 with additional requirements specified in this section. For new concepts, the fire loads shall be determined as a part of the Quantitative Risk Assessment referred to in Section 1 Table 1.2.

B. Structural fire preventive measures

1. Exterior boundaries of superstructures and deckhouses, and including any overhanging decks, shall be A-60 fire-protected for the portions facing the cargo area, the fuel oil storage wing tanks area and the process plant area, and for 3 metres away of any such boundary line.

2. If a process plant or any other potential release sources with gas under high pressure is located in the vicinity of accommodation, additional means of fire protection shall be considered.

Note:

Additional fire protection may be:

- *H-60 insulation of the boundaries described in B.1*
- *Physical protection preventing a jet from a gas leak exposing accommodation.*

3. Hold space covers facing the process area shall be protected from the process area by a transverse firewall of not less than H-0. Hold space covers facing the engine room area and flare mast aft shall be constructed with a transverse fire class division of not less than A-0.

Hold space covers shall have:

- fire integrity to withstand exposure of a standard fire test used for A-class divisions with exposure from outside
- surface flammability characteristics according to resolution A.653(16) (towards weather deck)
- sufficient strength and tightness to ensure effective inert atmosphere within hold space for one hour.

4. Hold spaces below the weather deck shall be protected from the turret area or process area by A-0 class division.

For cargo tanks made of materials with fire resistance properties not equivalent to steel, the hold space cover shall be insulated to "A-60" class standard. In addition, hold space covers which are facing a process area or equipment with pressurised hydrocarbons shall be insulated to "H-60" class standard.

5. Accommodation, service spaces and engine room below the weather deck shall be separated from the process area, turret and cargo holds by means of cofferdams. The minimum distance between the bulkheads shall be 600 mm.

6. Any external boundaries of the engine room or service spaces, casings and the vent mast shall be made of steel.

7. Hold space covers or other essential areas or equipment which may be exposed to heat loads from and ignited leak from the cargo tanks/piping shall be adequately protected for the time it takes to depressurise the cargo tanks.

8. Divisions formed by bulkheads and decks which comply with the following are regarded as Class H fire division:

- They shall be constructed of steel or other equivalent material.
- They shall be suitably stiffened.
- They shall be constructed as to be capable of preventing the passage of gas, smoke and flames up to the end of the two-hour standard test for hydrocarbon fires. The relevant exposure model is implemented in the revised edition of ISO 834 (HC curve).
- They shall be insulated with approved non-combustible materials or equivalent passive fire protection such that the average and maximum temperature of the unexposed side will not rise to more than 140°C and 180°C respectively above the original temperature, within the time listed below:

class H-120	120	minutes
class H-60	60	minutes
class H-0	0	minutes

C. Means of escape

1. Means of escape shall be provided from the engine room or service spaces to accommodation by means of enclosed shelter, preferably without having to be exposed to the weather deck.

2. Escape routes shall be arranged from the process area and other working zones in the cargo area to the muster area in the accommodation.

3. The transverse firewalls required in B.1 shall provide protection against heat radiation for lifeboats.

D. Firefighter's outfit

1. 4 sets of firefighter's outfits shall be placed in 2 separate fire stations, within the accommodation.

2. For concepts where the cargo area is dividing the accommodation and engine room or service spaces, 2 sets of firefighter's outfits are required in the engine room or service spaces in addition to the sets required in D.1.

E. Fire main

1. The basic requirements for fire pumps, hydrants and hoses, as given in SOLAS Ch. II-2/10.2, apply with the additional requirements given in E.2 to E.8.

2. The arrangement shall be such that at least 2 jets of water, not emanating from the same hydrant, are available, one of which shall be from a single length of hose that can reach any part of the deck and external surfaces of the hold space covers. The minimum pressure at the hydrants with 2 hoses engaged shall be 5.0 bar. Hose lengths shall not exceed 33 m.

3. The fire main shall be arranged either as:

- a ring main port and starboard or
- as a single line along the center line through the cargo area provided the fire main is shielded from possible jet fire occurring from within the cargo piping.

4. Two main fire pumps shall be installed, each with 100% capacity. One pump shall be located forward of the cargo area and one pump aft of the cargo area and both pumps shall be arranged with remote control from both the bridge and the engine room.

5. Both main fire pumps shall at any time during operation, when the ship is not gas-free, be available for start and delivery of water. The fire main shall be pressurized for immediate delivery of water at hydrants for engaging at least two effective jets of water onto the weather deck. The fire pumps shall start automatically upon low pressure detection in the fire main.

6. Remote controlled isolation valves shall be arranged on the weather deck at each end of the fire main leading into the cargo or process area. The isolation valves shall be on the protected side of the fire wall or boundary. Manual operated stop valves shall be provided between each cargo hold space, and the distance between the valves shall not exceed 40 m.

7. All pipes, valves, nozzles and other fittings in the fire-fighting system shall be resistant to corrosion by seawater and to the effect of fire.

8. The mooring equipment installed within the gas dangerous area is to be protected by a sprinkler system with a capacity not less than 5 1/min per m^2. The sprinkler system is to be ready to use especially before the use of any mooring arrangement and prior to cargo handling operations. Where in this case the mooring equipment only on one ship's side is used, the sprinkler system capacity may be designed taking into consideration operation of the mooring equipment on one ship's side. The sprinkler system may be fed from the water fire main.

9. The cargo load and unload area on the open deck shall be covered by water monitors which can be remotely controlled from a safe location.

F. Dual agent (water and powder) for process and load/unload area

1. The system shall be capable of delivering water and powder from at least two widely separated connections to the process area, cargo load and unload area and any other high fire risk areas located on the open deck. The length of the hoses shall be 25 m to 30 m.

2. Water supply may be taken from the main fire pumps and fire main if the added capacity of the system is included in capacity calculation for the main fire pumps. Powder shall be arranged in two separate units, each with the following discharge capacities:

- 3.5 kg/s powder for not less than 60 seconds for one hand held hose.

G. Water spray

1. Water spray is not an acceptable means for complying with the minimum structural fire integrity given in B.

2. The following shall be protected by water spray:

- process area
- turret
- unprotected and pressurized cargo tank/deck piping
- Emergency Shut Down (ESD) valves
- other important equipment for controlling the pressure in the cargo tanks due to fire
- the part of accommodation facing the cargo area
- external bulkheads of hold space covers facing the engine room and the flare mast.

3. The system shall be capable of covering all areas mentioned in G.2 with a uniformly distributed water spray of at least 10 l/m^2 per minute for horizontal projected surfaces and 4 l/m^2 per minute for vertical surfaces.

4. The outlets of gas disposal systems, e.g. cold vent or pressure relief valves shall be led to an area where radiation, heat or gases will not cause any hazard to the vessel, personnel or equipment.

5. The water spray main shall be arranged either as:

- a ring main port and starboard or
- as a single line along the center line through the cargo area provided the fire main is shielded from possible jet fire occurring from within the cargo piping.

6. Both water spray pumps shall be available for immediate start up and delivery of water.

7. 2 water spray pumps shall be installed, each with 100% capacity. One pump shall be located forward of the cargo area and one pump aft of the cargo area and both pumps shall be arranged with remote control from both the bridge and the engine room.

8. Each water spray pump capacity shall be based on simultaneous demand for water spray to all areas required in G.2, G.3 and G.4.

9. Remote controlled isolation valves shall be arranged on the weather deck at each end of the fire main leading into the cargo or process area. The isolation valves shall be on the protected side of the fire wall or boundary. Manual operated stop valves shall be provided between each cargo hold space, and the distance between the valves shall not exceed 40 m.

H. Spark arrestors

1. Exhaust outlet from internal combustion machinery and boilers shall be provided with spark arrestors.

Section 11 Electrical Installation

A. General

1. The ship shall meet the requirements given in The Rules for Ship Carrying Liquefied Gases in Bulk (Pt.1, Vol. IX) Sec.10 as applicable.

2. For the use of cold gas discharge to the additional pressure relief system see Section 1.A.5.2.

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Section 12 Control and Monitoring

A. General

1. The ship shall meet the applicable requirements given in the Rules for Ships Carrying Liquefied Gases in Bulk (Pt.1, Vol.IX) Sec.13 with the additional requirements given in this section.

2. Alarms shall be located on the navigating bridge and in the cargo control room.

3. Means for detection of moisture and Hydrogen Sulphide (H_2S) at the load/unload or shore connection shall be provided.

4. As a minimum the following location or spaces shall be monitored for gas:

- suitable positions in each hold space
- deck piping (line sensors)
- ventilation inlets for non-hazardous area
- ventilation outlets for hazardous area
- air inlets to machinery spaces
- manifold area.

5. As a minimum, the following location or spaces shall be fitted with pressure indicators and alarm:

- each hold space
- each cargo tank
- cargo piping at load/unload connection.

6. Temperature sensors and oxygen indicators shall be fitted in the hold space.

7. Means for temperature measurement of the cargo within the cargo tanks shall be provided.

8. The temperature in the cargo tanks shall be monitored at a representative location during pressure relief, e.g. during unloading, blow-down. It shall be controlled that the temperature does not fall below the minimum design temperature.

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Section 13 Test After Installation

A. General

1. Application

1.1 All systems shall be tested before the ship is taken into service. Testing and trials of all Rule-required systems is to be verified by the attending Surveyor in accordance with the agreed step-by-step procedures e.g. test procedure for machinery part, test procedure for electrical part, test procedure for outfitting and mooring system, test procedure for loading and off-loading system, procedure for sea trial and other related procedure. The Surveyor is to be permitted access to critical/hold points to verify that the procedures are satisfactorily accomplished. The surveyor is to be observe operation under various capacities and conditions.

1.2 Sea trials are to be carried out as required by the Rules for Machinery Installations (Pt.1, Vol.III) and the Guidance for Sea Trials of Motor Vessels (Pt.1, Vol.B) with reviewed procedures and the satisfaction of the Surveyor.

1.3 Approved Compressed Natural Gas loading and unloading operations, including emergency procedures, are to be verified to the extent deemed necessary by the attending Surveyor. The overall performance of the Compressed Natural Gas containment system is to be verified for compliance with the design parameters during the initial loading and discharge operations. Record of all these performance are to be maintained and are to be made available to BKI.

1.4 Similarly, the safe and satisfactory performance of all process systems covered under the Compressed Natural Gas carrier’s classification will be verified by the Surveyor as part of the commissioning survey.

B. Service Test

1. All cargo tanks, thermal protection, any insulation and the cargo-handling equipment are to be tested under service conditions prior to final action with regard to classification. The cargo tanks are to be filled to the normal capacity with cargo at the operating service temperature and service pressure.

2. The effectiveness of the insulating arrangements (for low temperature Compressed Natural Gas) is to be confirmed under operating conditions. If the service test or subsequent operation are not satisfactory, changes in the insulating arrangements may be required.

3. For a Compressed Natural Gas carrier with substantial process equipment for conditioning of cargo, refer to the Rules for Facilities on Offshore Installations (Pt.5, Vol.XII) Sec.5, for startup and commissioning.

C. Test Agenda

1. The agenda for the test of cargo tank design using pressure vessel codes or limit state approach, the testing agenda with complete details is to be submitted to support the design and high material usage factor.

2. The tests are to be witnessed by a Surveyor and a complete report of the results is to be submitted for consideration prior to final approval of the cargo tank

D. Personnel Safety

Personnel safety precautions, which should include check of operational readiness of all personal protection, fire and gas detection and fire fighting equipment, ESD systems, unobstructed escape routes and establishment of communication procedures, are to be taken during trials and are required to be verified by the attending Surveyor. All such emergency procedures are to be capable of dealing with any contingencies such as fire and other hazards.

Section 14 Filling Limits for Cargo Tanks

A. General

1. Application

The pressure in the cargo tanks, after filling, shall be limited so that the pressure does not increase above 95% of the design pressure at any time during transport or unloading taking into account:

- for a system without cooling, the ambient temperature conditions given in the Rules for Ships Carrying Liquefied Gas in Bulk (Pt. 1, Vol. IX) Sec. 7.2.
- for a system provided with a cooling system, the capacity of the cooling system and the ambient temperature conditions given in the Rules for Ships Carrying Liquefied Gas in Bulk (Pt. 1, Vol. IX) Sec. 7.2.

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Section 15 Survey

A. General

1. Scope and Application

This section applies to requirement for survey for Ship and Cargo Containment system during construction and after construction for maintenance of class.

B. Survey for Ship

Surveys for Hull, Machinery and Electrical installations are to be carried out according to Rules for Classification and Surveys (Pt. 1, Vol.1) Section 4.II.A.

C. Survey for Cargo Containment System

1 Survey During construction

1.1 CNG Cargo Tank, CNG Piping System Fabrication

All CNG cargo tanks and CNG piping systems are to be fabricated in accordance with approved plans to the satisfaction of the Surveyor and in compliance with the manufacturer's approved quality assurance program and fabrication procedures. The Surveyor will verify the use of BKI certified materials for the CNG cargo tank and CNG piping systems. Welders, weld procedures, non-destructive examination procedures, equipment and personnel will all be qualified by the Surveyor, who will monitor all phases of CNG cargo tank construction and review fabrication reports and NDE records. The Surveyor will attend and report on all pressure testing and tightness testing during the entire fabrication period.

1.2 Piping

All piping installation/testing is to be in accordance with BKI-approved drawings and procedures. All welds are to be visually inspected and non-destructively tested, as required and to the satisfaction of the attending Surveyor. Upon completion of satisfactory installation, the piping system is to be proven tight by hydrostatic testing to the required pressure, but not less than its normal working pressure. Where sections of pipes are hydrostatically tested at the fabrication shops, an onboard test is to be conducted to confirm proper installation and tightness of the flanged and/or welded connections.

1.3 Electrical

All electrical wiring, equipment and systems are to be installed/tested in accordance with BKI approved drawings and procedures. Proper support for all cables and suitable sealing of cable entries to equipment are to be verified. Upon completion of wire connections, the affected sections of the equipment and cabling are to be insulation-tested and proven in order. All grounding is also to be verified in order.

1.4 Instrumentation

All instrumentation installation/testing is to be in accordance with BKI approved drawings and procedures. All supports are to be verified. Upon completion, all systems are to be functionally tested and proven in order.

1.5 Mechanical

All mechanical equipment installation/testing is to be in accordance with BKI approved drawings and procedures, including the grounding of the equipment. Upon completion, all equipment is to be functionally tested and proven in order.

2. Survey After Construction

2.1 Periodical Survey

2.1.1 Cargo Containment System

Periodical survey for CNG cargo tank are to be carried out based on the inspection test plan from the manufacturer of CNG Tank and continuous survey program which prepared by owners. The program are to be submitted to BKI for review.

Periodical survey for cargo containment system are to be carried according to Rules for Ship carrying Liquefied Gases in Bulk (Pt.1, Vol.IX).

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