RULES FOR CLASSIFICATION OF

Ships

PART 5 CHAPTER 15

SPECIAL SERVICE AND TYPE – ADDITIONAL CLASS

Compressed Natural Gas Carriers

JULY 2011

DET NORSKE VERITAS AS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

The Rules lay down technical and procedural requirements related to obtaining and retaining a Class Certificate. It is used as a contractual document and includes both requirements and acceptance criteria.

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CHANGES

General

The present edition of the rules includes amendments and additions approved by the Executive Committee as of June 2011 and supersedes the January 2011 edition of the same chapter.

The rule changes come into force as described below.

Text affected by the main rule changes is highlighted in red colour in the electronic pdf version. However, where the changes involve a whole chapter, section or sub-section, only the title may be in red colour.

This chapter is valid until superseded by a revised chapter.

Main changes coming into force 1 January 2012

- **Sec.1 General Requirements**

— Deleted damage stability documentation requirements from C205.

- **Sec.3 Damage Stability and Ship Arrangements**

— Deleted damage stability requirements.

Corrections and Clarifications

In addition to the above stated rule requirements, a number of corrections and clarifications have been made to the existing rule text.

CONTENTS

SECTION 1
GENERAL REQUIREMENTS

A. General

A 100 Application

101 The rules in this chapter apply to ships engaged in the transportation of compressed natural gases (CNG). For liquefied gas carriers reference is made to Ch.5.

102 The vessel must be accepted by the flag state and the respective port authorities.

A 200 Fundamental safety requirements

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

202 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. 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.

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

— life (crew and third party personnel)
— property (damage to ship, off-hire)
— environment (oil pollution, gas release to the atmosphere).

204 The safety level on a LNG carrier represents the minimum acceptable safety level for a CNG vessel. The targets shall therefore be based on historical experience and as shown in Table A1.

Table A1 Safety target values for CNG carriers (annual risk)

	Historical [1] data LNG	*Target Safety Values for CNG*	*Comment*
Individual risk for crew members (due to major accidents)	1.2×10^{-4}	1×10^{-4}	Does not include occupational risks and work place accidents
Total loss due to collision	1.2×10^{-4}	1×10^{-4}	Total loss frequency – generic LNG vessel
Total loss due to cargo hazards (fires and explosions)	2.4×10^{-4}	1×10^{-4}	Total loss frequency – generic LNG vessel
Individual risk from cargo cylinder failure		1×10^{-5}	Safety Class High, DNV-OS-F101
Individual risks for public ashore		1×10^{-5}	IMO MSC 72/16 Annex 1

1) The historical data for LNG vessels has been taken from DNV Technical Report No. 2001-0858.

In addition, the As Low As Reasonably Practicable (ALARP) principle shall be adopted as a safety philosophy to ensure:

— focused and continuous safety efforts
— that the overall (and absolute) targets are not misused to argue that sound safety measures are not implemented.

Guidance note:

ALARP is applied on a project specific basis and applies the principles that:

- Intolerable risk cannot be justified and the vessel cannot be built or continue to operate.
- Where the risk is below this level but higher than the broadly acceptable risk, then the risk is tolerable provided that the risk is ALARP, i.e. further risk reduction is impracticable or its cost is grossly disproportional to the risk improvement gained. This means that the owner or operator shall take all reasonably practicable precautions to reduce the risk, either by ensuring the faults do not occur, or that if they do then their consequences are not serious.
- In the broadly acceptable region, the risk is so low that further risk assessment or consideration of additional precautions is unnecessary.

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A 300 Classification

301 The requirements in this chapter are supplementary to those for assignment of main class. Ships built according to these rules may be assigned the class notation **1A1 Tanker for Compressed Natural Gas**.

The following special features notations will be stated in the register of vessels classed with DNV: (**... bar**, **..temp**), which refers to the design pressure and minimum operating temperature. In the case of carriage of the gas in the chilled condition the carriage temperature will be stated. If no chilling is provided ambient temperature will be stated.

302 Ships having offshore loading arrangements shall comply with the requirements in Ch.3 Sec.14.

303 The process plant, relief and flare system shall be designed according to a standard recognised by the Society.

B. Definitions

B 100 Terms

101 *Blow down* is depressurising or disposal of an inventory of pressurised gas.

102 *Cargo area* is 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.

103 *Cargo hold vent pipes* are low pressure pipes for venting of cargo hold spaces to vent mast.

104 *Cargo load/unload valve* is the valve isolating the cargo piping from external piping.

105 *Cargo piping* is the piping between the cargo tank valve and the cargo load and or unload valve.

106 *Cargo tank* consists of the storage system for the compressed gas, i.e. all pressurised equipment up to the cargo tank valve.

107 *Cargo tank valve* isolates the cargo tank from the cargo piping.

108 *Cargo vent piping* is the piping from the cargo relief valve to the vent mast.

109 *“Class H fire division”*: divisions formed by bulkheads and decks. See Sec.10 A207.

110 *Coiled type cargo tank* is a cargo tank consisting of long lengths of small diameter coiled piping.

111 *Cylinder type cargo tank* is 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 standard offshore pipe 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.

112 The following pressure definitions are used:

— *design pressure* is the maximum gauge gas pressure at the top of the cargo tank which has been used in the calculation of the scantlings of the cargo tank and cargo piping.
  Design pressure defined in these rules is synonymous with “incidental pressure” as used in DNV–OS-F101.
— *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.

113 *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 Sec.2 A200.

114 Regarding the definitions of *gas dangerous area and zones* the principles of Ch.5 Sec.1 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.

115 *Hold space* is the space enclosed by the ship's structure in which a cargo tank is situated.

116 *Hold space cover* is the enclosure of hold space above main deck ensuring controlled environmental conditions within hold space.

C. Documentation

C 100 General

101 200 specifies the plans and particulars that shall normally be submitted. The drawings shall show clearly that the requirements of this chapter have been fulfilled.

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

103 For general requirements for documentation of control and monitoring systems, see Pt.4 Ch.9 Sec.1.

C 200 Plans and particulars

201 General safety documentation shall be submitted for information:

— 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. shall be submitted for information.

202 A general arrangement shall be submitted for approval giving the 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
— ventilating pipes, doors and openings to gas-dangerous spaces
— doors, air locks, hatches, ventilating pipes and openings, hinged scuttles which can be opened, and other openings to gas-safe spaces within and adjacent to the cargo area
— entrances, air inlets and openings to accommodation, service and control station spaces
— gas-safe spaces and zones and gas-dangerous spaces and zones to be clearly identified. If cold venting a gas dispersion analysis shall be conducted in order to evaluate the extent of the gas dangerous area
— information on gas specification to be carried on the ship
— drawings showing ventilation systems in cargo area with capacities.

203 Cargo tank. The following plans and particulars shall be submitted for approval:

— drawing of tanks with information on non-destructive testing of welds and strength and tightness testing of tanks
— specification of materials and welding in cargo tanks
— specification of design loads and structural analysis of cargo tanks
— detailed arrangement of cargo tank system with description on operation modes
— calculation of maximum and minimum design temperature for materials in the cargo tank, supporting structure and inner hull due to loading/unloading/depressurising
— the cooling effect from gas released as a result of a leakage or rupture of piping
— proposal for prototype testing with full scale fatigue and burst test for cargo tank
— drawings and calculation of stresses in the cargo tank piping as per Ch.5 Sec.6 including vibrations and fatigue analysis
— fatigue crack propagation calculations for the cargo tank piping using leak-before-failure principle
— detailed drawings of all pressurised parts of the cargo tank system
— documentation and calculations for hull and cargo tank using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Vibration analysis as outlined in Ch.5 Sec.5
— stresses in the cargo tank cylinders as per DNV-OS-F101 for safety class high
— fatigue analysis for cylinders as per DNV-OS-F101 and in agreement with criteria that will be specified by DNV
— relevant fatigue crack propagation calculations for cargo tank cylinders in agreement with criteria that will be specified by DNV
— drawings of supports for cargo tank cylinders with calculations including collision loads defined in Ch.5 sec.5.

204 Piping systems in cargo area. The following plans and particulars shall be submitted for approval:

— schematic drawings with materials, fittings and thickness for the following piping systems:

  - bilge and ballast systems and air pipes
  - cargo deck piping
  - emergency shut down
  - inert gas
  - heating, if any
  - systems for refrigeration, if any

- a complete stress analysis for each branch of the cargo deck piping system shall be conducted according to ANSI/ASME B31.3
- operational and emergency procedures for possible incidents in the cargo tank
- drawings showing overpressure protection for cargo tank, including details of pressure relief devices
- arrangements and procedure for gas freeing
- arrangements for mechanical ventilation in cargo area
- specification of pressure tests.

205 Ship arrangements. The following plans and particulars shall be submitted for approval:

- drawing showing protection of cargo tank system with double hull and minimum distance to ship bottom
- 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) from penetrating the inner hull as defined in Sec.3 A302 and A303.

206 Environmental control in hold spaces. The following plans and particulars shall be submitted for approval:

- 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
- drawings showing the following:

  - inerting of cargo hold space
  - instrumentation in hold spaces
  - drainage in hold spaces
  - overpressure protection.

207 Fire protection and extinction. The following plans and particulars shall be submitted for approval:

- for new concepts documentation of fire loads based on risk analysis and fire and explosion analysis
- drawings showing means of escape
- fire fighting systems drawings related to cargo area including fire mains, sprinkler and water spray and water and or powder systems
- heat radiation from the flare towards cargo holds and other important areas and equipment.

208 Electrical Installations

- drawings as per Ch.5 Sec.12, as applicable.

209 Control and Monitoring

- drawings as per Ch.5 Sec.13.

210 In- service inspection

- in-service inspection and monitoring philosophy.

211 Reference documents are the latest version of:

- Ch.5, Pt.2, Pt.3 and Pt.4
- DNV-OS-F101 Submarine Pipeline Systems
- International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, IGC Code
- ASME VIII Div.2 - ASME Boiler and Pressure Vessel Code - Alternative Rules for Pressure Vessels
- ASME B31.3 - Process Piping
- API RP521 - Guide for Pressure Relieving and Depressurizing Systems
- DNV-OS-C501 - Composite Components.

SECTION 2
MATERIALS

A. General

A 100 Materials

101 The materials used in the hull structure shall comply with the requirements for manufacture, survey and certification given in Pt.2 and Pt.3 Ch.1.

102 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 DNV-OS-F101. Due regard shall be given to corrosion protection.

Guidance note:
The use of suitable protective coating or liners can be an acceptable means of corrosion protection.

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103 For the coiled type cargo tank the materials used shall comply with the requirements for manufacture, survey and certification given in DNV-OS-F101 or a recognised standard acceptable to DNV.

104 The materials used in the cargo tank piping, cargo piping and all valves and fittings shall be of quality NV 316L or equivalent (equivalent with respect to ductility, fatigue and corrosion resistance) and shall comply with the requirements for manufacture survey and certification given in Pt.2 and Ch.5.

Guidance note:
Unprotected piping on open deck is recommended to be painted.

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

106 Composite materials will be specially considered. Composite material used in cargo tanks shall comply with Sec.5 D.

107 All material used in the cargo tank and cargo piping shall be provided with DNV material certificate.

A 200 Design temperature

201 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.

202 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 ARRANGEMENTS

A. General

A 100 General

101 The ship shall meet the requirements given in Ch.5 Sec.3. In addition the below requirements applies.

102 A CNG ship shall 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 tank against indentations and the same energy absorption capabilities as conventional double bottom design. (See raking damage calculations in A301.)

A 200 Divisions

201 The cargo holds shall be segregated from engine rooms and accommodation spaces and similar spaces, by cofferdams.

A 300 Collision and grounding

301 For conventional double bottom designs the double bottom height shall at least be B/15 or 3 m whichever is less, but not less than 1.0 m.

A safe maximum navigating speed where by 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.

Guidance note:

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

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302 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 the Society may be used.

303 Collision damage analysis shall be conducted to demonstrate that:

— For the ship sizes and energies determined in 302 the energy absorption capability of the ship side shall be sufficient to prevent the bow of the striking vessel(s) from penetrating the inner hull, 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 5000 tonnes standard supply vessel with a raking bow and a stem angle of 65 degrees may be used. It shall be demonstrated by calculations that the side of the CNG carrier has an energy absorption capability according to 302, but not less than given by the formula in 304 without the bow penetrating the inner hull.

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

$$\max.\ [13\ (L_{pp}\ /\ 100)^2\ /\ (1 + 0.8\ \Delta_1\ /\ \Delta_{CNG});\ 10]\quad [MJ]$$

L_{pp} = length between perpendiculars of the CNG vessel in (m)
Δ_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.

305 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, the same energy absorption capabilities as conventional double side designs and complies with the energy absorption requirements in 302, 303 and 304 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.

306 Due to changing ship lines at the ends of the cargo area it will be acceptable to apply the minimum double bottom height in 301 and the minimum double side width in 305 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. 1.

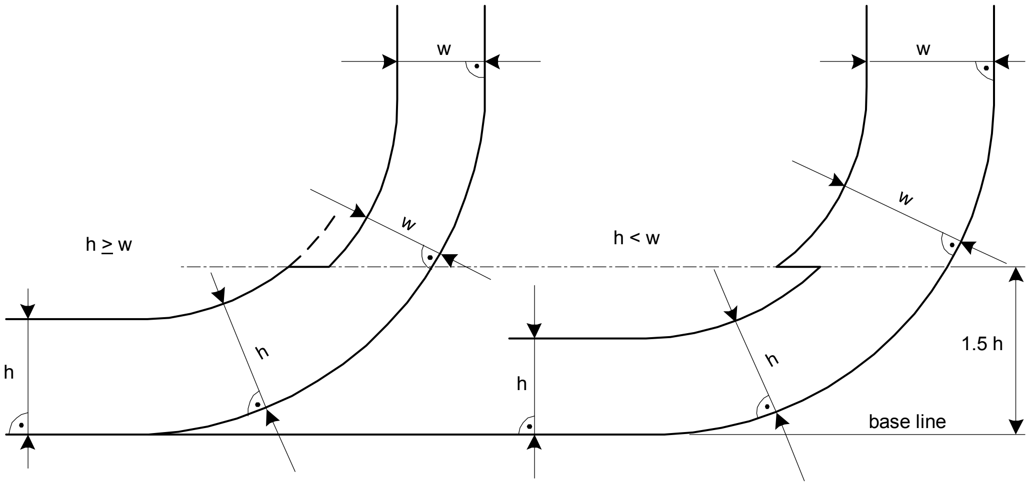

Fig. 1

SECTION 4
ARRANGEMENTS AND ENVIRONMENTAL CONTROL IN HOLD SPACES

A. General

A 100 General

101 The principles for access for inspection given in Ch.5 Sec.4 A 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.

102 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.

103 The cargo tank valve shall be mounted outside the hold space.

For enclosed hold spaces the provisions in A200 and A300 apply.

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

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104 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.

A 200 Inerting of hold spaces

201 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 hold space. The nitrogen system shall be designed with redundancy to the extent necessary for maintaining the safe operation of the vessel.

202 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 0.3LEL (Lower Explosion Limit).

A 300 Overpressure protection of hold spaces

301 Hold space shall be fitted with a overpressure protection system. The following functional requirements apply:

a) Pressure control of inerted atmosphere with positive pressure automatically adjusted between 0.05 and 0.15 bar above atmospheric pressure shall be provided.
b) Pressure relief device, normally set to open at 0.25 bar, 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.
c) The discharge from the hold spaces shall be routed to a safe location.
d) In addition to the relief system required by b) relief hatches, normally set to open at 0.4 bar shall be provided in each hold space cover.
e) 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.

A 400 Drainage

401 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.

A 500 Area classification

501 The extent of gas dangerous zones and gas dangerous spaces shall follow the principles in Pt.5 Ch.5.

502 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

A 100 General

101 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.

102 The cargo tank together with supports and other fixtures shall be designed taking into account all relevant loads listed in Ch.5 Sec.5 A.

103 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).

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

104 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.

105 Vibration analysis shall be carried out as outlined in Ch.5 Sec.5.

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

107 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.

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

109 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

B 100 General

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

C. Cylinder Type Cargo Tank

C 100 Cargo tank cylinder

101 The stresses in the cargo cylinder and the hemispherical end caps shall fulfil the requirements given in DNV-OS-F101 for safety class high. Recognised standards such as the ASME BPV VIII Div. 3 may also be used. The pressure used for calculating the wall thicknesses is the design pressure defined in Sec.1 B112. The maximum operating pressure shall be 5% or more below 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:

$$1.0\sqrt{Rt}$$

R = radius of hemispherical end
t = thickness of hemispherical end.

For elliptical or torispherical end-caps additional requirements may apply subject to agreement with DNV.

102 The cargo tank cylinder shall be subject to fatigue analysis. The S-N curve 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.

Guidance note:

The test specimens can be either coupon tests or full ring test specimens cut from fabricated pipes at the actual production line. Normally, ring tests will provide the more realistic results.

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Two alternative formulations are given based on the following definitions of characteristic value for log10N for the system of n_s 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 log10N for the system of n_s 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 $\log_{10}$S-$\log_{10}$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 S, then the characteristic value of $\log_{10}$N at this stress level is to be taken as:

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

in which $\overline{\log_{10} N}$ is the mean value of the n observed values of $\log_{10}$N, $\hat{\sigma}_{\log N}$ is the standard deviation of the n observed values of $\log_{10}$N, and $c_3(n)$ is a factor whose value depends on n and is tabulated in Table C1.

The Miner sum (for both dynamic ship loads and fatigue loads due to loading and unloading) is not to be higher than 0.1 (i.e. using a Design Fatigue Factor DFF=10). The minimum calculated fatigue life using the Alternative 1 S-N curve approach shall not be less than 200 years.

Alternative 2:

takes system information into account and provides an estimate of the characteristic value of log10N for the system based on "mean value minus two standard deviations" of the test data.

$$\log_{10} \hat{N}_{C,system} = \overline{\log_{10} N} - (c_2(n) + \frac{1}{2} \cdot \log_{10}(\frac{l_{weld}}{l_{ref}} \cdot n_s)) \cdot \hat{\sigma}$$

where

$c_2(n)$ = factor whose value depends on n and is tabulated in Table C1 corresponding to a 97.725% probability of survival. It is noted that for $\hat{\sigma}$ =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 with system effects given in DNV-RP-C203 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. l_{ref}= 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 number of load cycles to be used for design is number of cycles expected during design life multiplied by a Design Fatigue Factor (DFF) in order to achieve an appropriate safety level.

The Miner sum (for both dynamic ship loads and fatigue loads due to loading and unloading) is not to be higher than

1) 0.2 (DFF=5) for pipes with enhanced control in fabrication with respect to production tolerances and where out-of-roundness has not been specifically considered in the design of the longitudinal welds.
2) 0.33 (DFF=3) at areas with local high stresses such as at pipe supports provided that all local stresses are accounted for in the analyses together with the S-N curves in DNV-RP-C203.

The minimum calculated fatigue life using the *Alternative 2* S/N curve approach shall not be less than 20×DFF years.

Table C1 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

The fatigue damage effects from filling and emptying of the pipes and the damage contribution from support stresses originating from the accelerations the ship in the seaway can be combined as given in Appendix D in DNV-RP-C203.

Guidance note:

The main contribution to the fatigue loading comes normally from filling and emptying of the pipes.

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103 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 (m + 2s). 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 60 years. 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.

104 If the necessary number of load cycles for the crack to propagate through the wall thickness required in 103 cannot be shown 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 is detected and the tank pressure relieved (blown-down). The fracture mechanics assessments may be carried out according to e.g. BS 7910:1999. "Guide on methods for assessing the acceptability of flaws in metallic structures." Applied fracture toughness values shall be documented for the base material, heat affected zone and weld metal for relevant operation temperature.

105 The cargo tank cylinders shall be supported by the hull in a manner which will prevent bodily movement of the cylinders under static and dynamic loads while allowing contraction and expansion of the cylinders under temperature and pressure variations and hull deflections without undue stressing of the cargo tank and of the hull. The following loads shall be taken into account:

— the most probable largest resulting acceleration as detailed in Ch.5 Sec.5 A, or accelerations calculated by direct hydrodynamic calculations, taking into account rotational as well as translational effects
— static angle of heel of 30 degrees
— collision load defined in Ch.5 Sec.5 A1100.

If the cargo tank will have positive buoyancy when the weight of the cargo is not being considered and the cargo tank is submerged to the summer load line, then anti flotation devices shall be provided. The antiflotation arrangements shall be designed to withstand the upward force caused without plastic deformation likely to endanger the hull structure.

The support structure in the hold space shall be suitably protected against cool down due to direct impingement of a gas leak.

106 The local equivalent stress in the cargo tank cylinders according to von Mises at the supports (primary bending + membrane stress) shall not exceed 0.8 x yield stress of the material. The cargo containment cylinders at supports shall be included in the fatigue calculation required by 102.

C 200 Cargo tank piping

201 The stresses in the cargo tank piping shall fulfil the requirements given in Ch.5 Sec.6. 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 Sec.6 A400 applies also for the cargo tank piping.

202 The cargo tank piping shall be subject to a 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 $\log_{10}N$. The Miner sum (from combined dynamic loads and fatigue loads due to loading and unloading) shall not be higher than 0.1.

203 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 103 apply.

204 The cargo tank piping shall be adequately supported so that the reaction force from a complete rupture of a top pipe will not lead to the 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.

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

C 300 Welding requirements

301 *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 DNV-OS-F-101. 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 DNV-OS-F-101.

C 400 Pressure testing and tolerances

401 Fabrication tolerances and hydraulic testing of the complete cargo tank shall be in accordance with DNV-OS-F101 or Ch.5 as applicable.

Guidance note:
A test pressure equal to 1.2 times the design pressure is considered appropriate.

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C 500 Non-destructive testing (NDT)

501 All welds in cylinders and cargo tank piping shall be 100% NDT tested in accordance with an approved NDT program. Reference is made to 103 regarding required detectable crack size.

C 600 Post weld heat treatment

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

C 700 Prototype testing

701 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 must 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 pressure induced stress cycles. A minimum of 3 tests must be performed.

One burst test after having being subjected to twice the anticipated number of stress cycles and 2 fatigue tests to document that the fatigue capacity is for *Alternative 1* in excess of 15 × the number of stress cycles for the cylinders during the design life time or for *Alternative 2* in excess of 10 × the number of stress cycles for the cylinders during the design life time.

D. Composite Type Cargo Tank

D 100 General

101 All general requirements from Sec.5 A100 apply also to composite tanks.

102 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 Figure 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 short term and long term material properties must be sufficiently characterized. Requirements for the characterization of composite materials are given in DNV-OS-C501 "Composite Components". The outer liner is a protective layer against external loads environments. It does typically not carry any loads.

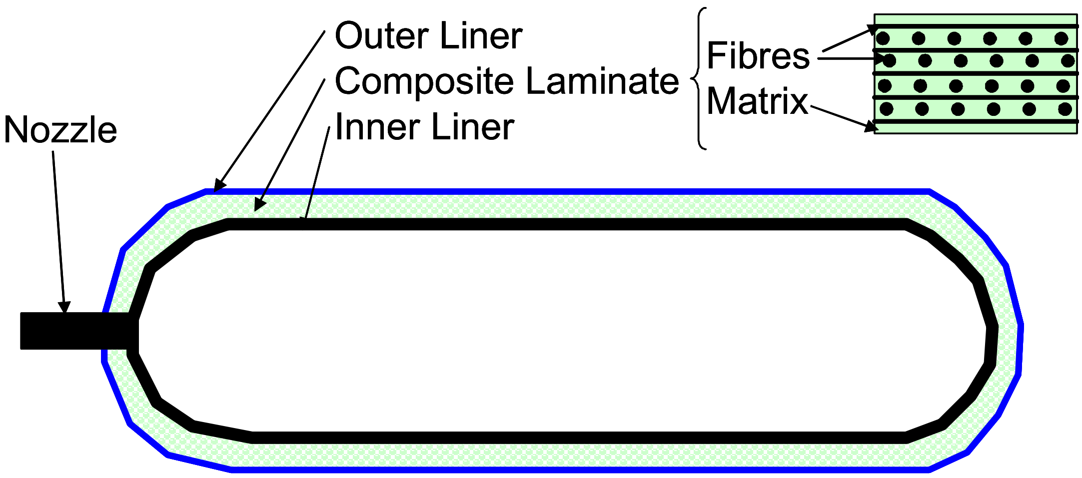

Fig. 1
Typical simplified composite pressure vessel

103 All metal parts shall be designed according to the requirements given in Sec.5 C. If the liner is made of polymeric materials DNV-OS-C501 can be used. Additional requirements are also given in D800-D900.

104 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.

105 The requirements given here are mainly related to cylindrical cargo tanks. 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.

D 200 Cargo tank cylinder - calculations

201 As a minimum requirement, the composite tanks shall be designed for (not limited to) the potential modes of failures as listed in Table D1 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 D1 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.

202 The pressure used for calculating the composite lay-up is the design pressure defined in Sec.1 B114. 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 DNV-OS-C501 Sec.7.

203 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 C102. The Miner sum (for both dynamic loads and fatigue loads due to loading and unloading) shall not be higher than 0.02.

204 Fatigue calculations shall be carried out for the laminates in the fibre directions and for all relevant interface properties as described in DNV-OS-C501.

205 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.

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

207 The cargo tank cylinders shall be supported as described in C105.

208 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 203.

209 Different expansion coefficients of steel, composite and other materials shall be considered.

210 The resonance frequencies shall be checked, see also A105. Vibrations from machinery and wave loading should not coincide with the resonance frequencies of the pressure vessel (filled or unfilled).

211 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 DNV-OS-C501 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.

Guidance note:

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.

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Guidance note:

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.

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D 300 Cargo tank piping

301 It is assumed here that piping is made of metal and the same requirements as given in C200 apply.

302 Composite piping may be considered on an individual basis.

D 400 Production requirements and testing after installation

401 Fabrication tolerances and hydraulic testing of the complete cargo tank shall be in accordance with DNV-OS-F101 Ch.5 or DNV-OS-C501 Sec.11 as applicable.

Guidance note:

A test pressure equal to 1.25 times the design pressure is considered appropriate.

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402 The cargo tanks shall be tested on the ship after installation as a final acceptance test. The test pressure shall be 1.25 times the design pressure.

D 500 Full scale prototype pressure testing and tolerances

501 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 must 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 504. 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 D2.

502 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. The procedure given in DNV-OS-C501 should be followed for testing.

503 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.

Guidance 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.

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504 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 D2.

505 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 x 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 or similar. Similarity should be evaluated based on the requirements in DNV-OS-C501 Sec.4.

Table D2 Summary of test requirements

Name of test	*Description*	*Reference*
Design phase		
Pressure test	1 test to failure	506
Pressure fatigue of tank	2 tests to 5 × actual number of cycles or survival test to about 100 000 cycles, followed by burst test.	507 - 508
Stress rupture test of tank if matrix properties are critical or fibres can creep	2 tests to 50 x actual lifetime or survival test to about 1 000 hours	509
If the inner liner is bonded to the laminate	Test bond between liner and laminate	510
If impact requirement	Impact tests	511
Process Prototype Testing	System test	512
After fabrication		
Pressure test	Test to 1.3 times design pressure for each tank component	401
System acceptance test	Test to 1.3 times design pressure for each tank component	402

506 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 DNV-OS-C501 Sec.10 C200.

507 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 DNV-OS-C501 Sec.10 C300.
— All tests shall be completed with a pressure test. The failure load or pressure shall be at least the predicted μ - σ, where μ is the mean prediction and σ is one standard deviation of the predicted load.

508 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 507 as closely as possible.

509 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 1 000 hours testing up to 1 000 hours may be sufficient. The load levels should be chosen such that testing is completed after 10^3 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 DNV-OS-C501 Sec.10 C300.
— 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.

510 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 insured that the cracks do not propagate into the liner or reduce the bond quality between liner and laminate.

511 **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.

512 **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 hammer 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.

D 600 Non-destructive testing (NDT)

601 Composites laminates shall be inspected according to DNV-OS-C501 Sec.12 B.

D 700 Composite - metal connector interface

701 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 DNV-OS-C501 Section for “Joints” should be considered.

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

703 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.

704 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 carefully considered.

Guidance 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.

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705 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.

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

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

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

D 800 Inner liner

801 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.

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

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

804 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.

805 If the inner liner is designed to carry also part of the pressure loads all requirements from 804 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.

806 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 autofretage. Autofretage is common practice to pressurize a vessel initially at the factory 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.

807 Autofretage of the inner liner is common practice. The tank is pressurized initially at the factory 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 autofretage 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.

Guidance 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.

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808 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.

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

810 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 autofretage process (807) and by keeping the liner below yield during operation.

811 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.

812 Polymeric inner liners, like thermoplastic inner liners may be evaluated against the yield criterion in DNV-OS-C501 Sec.6 F.

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

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

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

816 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 D510.

817 If interfaces only touch each other friction and wear should be considered (DNV-OS-C501 Sec.6 M).

818 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.

819 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.

820 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.

Guidance note:
A weak bond between the substrates is beneficial to prevent crack growth across the interface. However, it means that debonding may happen easily.

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

822 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.

D 900 Outer liner

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

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

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

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

905 Outer liners are not exposed to autofretage. They should be kept below yielding.

906 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.

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

908 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.

909 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.

D 1000 Installation

1001 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.

1002 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.

SECTION 6
PIPING SYSTEMS IN THE CARGO AREA

A. General

A 100 Bilge, ballast fuel oil piping

For piping systems in cargo area not forming a part of the cargo piping the requirements given in Pt.4 Ch.1, Pt.4 Ch.6 and Ch.5 Sec.6 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.

A 200 Cargo piping, General

201 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.

202 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.

A 300 Cargo valves

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

302 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 shutdown (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.

A 400 Cargo piping design

401 The cargo piping system shall as a minimum meet the requirements given in Pt.4 Ch.6 and Ch.5 Sec.6 or a standard acceptable to DNV 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 Sec.7 A101).
- 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 Ch.5 Sec.6 C600.
- After assembly the piping system shall be hydrostatic 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.

402 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 THE CARGO TANK AND CARGO PIPING SYSTEM

A. General

A 100 Cargo piping

101 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.

A 200 Cargo tanks

201 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.

202 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 blowdown 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.

Guidance 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.

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203 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.

204 If it proves impractical to install the blow down valves required in 202 and the safety relief valve required in 203, 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

A 100 General

101 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 DNV for review.

SECTION 9
MECHANICAL VENTILATION IN CARGO AREA

A. General

A 100 General

101 The ship shall meet the requirements given in Ch.5 Sec.10.

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

A 200 Ventilation in hold spaces

201 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.

SECTION 10
FIRE PROTECTION AND EXTINCTION

A. General

A 100 General

101 The ship shall meet the requirements for gas carriers given in Ch.5 Sec.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 Sec.1 A202.

A 200 Structural fire preventive measures

201 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.

202 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.

Guidance note:
Additional fire protection may be:

- H-60 insulation of the boundaries described in 201
- Physical protection preventing a jet from a gas leak exposing accommodation.

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203 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.

204 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.

205 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.

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

207 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.

208 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.

A 300 Means of escape

301 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.

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

303 The transverse firewalls required in 201 shall provide protection against heat radiation for lifeboats.

A 400 Firefighter's outfit

401 4 sets of firefighter's outfits shall be placed in 2 separate fire stations, within the accommodation.

402 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 401.

A 500 Fire main

501 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 502 to 508.

502 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.

503 The fire main shall be arranged either as:

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

504 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.

505 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 pressurised 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.

506 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.

507 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.

508 Mooring equipment positioned within gas dangerous zone shall be protected by a water sprinkler system with a capacity of not less than 5 l/m^2/minute. The sprinkler system shall be activated prior to any simultaneously use of the mooring equipment and cargo handling. If only one side of the mooring equipment is used at a time, the capacity for the water supply may be based on one side in operation only. The water sprinkler system may be served from the fire main.

509 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.

A 600 Dual agent (water and powder) for process and load/unload area

601 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.

602 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.

A 700 Water spray

701 Water spray is not an acceptable means for complying with the minimum structural fire integrity given in 200.

702 The following shall be protected by water spray:

— process area
— turret
— unprotected and pressurised 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.

703 The system shall be capable of covering all areas mentioned in 702 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.

704 The outlets of gas disposal systems, e.g. flare, 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. The heat radiation from the flare towards the cargo holds or other important equipment or areas shall be calculated to verify that the heat load does not lead to high temperatures in the cargo holds or equipment failure. The flare shall comply with API RP521 or equivalent.

705 The water spray main shall be arranged either as:

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

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

707 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.

708 Each water spray pump capacity shall be based on simultaneous demand for water spray to all areas required in 702, 703 and 704.

709 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.

A 800 Spark arrestors

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

SECTION 11
ELECTRICAL INSTALLATIONS

A. General

A 100 General

101 The ship shall meet the requirements given in Ch.5 Sec.12 as applicable.

SECTION 12
CONTROL AND MONITORING

A. General

A 100 General

101 The ship shall meet the applicable requirements given in Ch.5 Sec.13 with the additional requirements given in this section.

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

103 Means for detection of moisture and H_2S at the load/unload or shore connection shall be provided.

104 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 gas safe spaces
— ventilation outlets for gas dangerous spaces
— air inlets to machinery spaces
— manifold area.

105 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.

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

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

108 The temperature in the cargo tanks shall be monitored at a representative location during pressure relief (e.g. during unloading, blowdown). It shall be controlled that the temperature does not fall below the minimum design temperature.

SECTION 13
TESTS AFTER INSTALLATION

A. General

A 100 General

101 All systems shall be tested before the ship is taken into service.

SECTION 14
FILLING LIMITS FOR CARGO TANKS

A. General

A 100 General

101 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 Ch.5 Sec.7 A104
— for a system provided with a cooling system, the capacity of the cooling system and the ambient temperature conditions given in Ch.5 Sec.7 A104.

SECTION 15
GAS SPECIFICATION

A. General

A 100 General

101 The gas shall have a water dew point that during all operation modes does not lead to formation of hydrates or corrosion due to free water in the system.

102 Sour services shall be handled in compliance with supplementary requirements in DNV-OS-F101.

SECTION 16
IN SERVICE INSPECTION

A. General

A 100 General

101 An inspection and monitoring philosophy shall be established, and this shall form the basis for a detailed inspection and monitoring program.

102 For the cylinder type cargo tank the program shall as a minimum address:

— number of cargo tank cylinders to monitor
— inspection tools and accuracy
— periodical surveys
— NDT requirements
— destructive testing of cargo tank cylinders if found necessary
— cargo tank piping, fittings and supports
— cargo piping, fittings and supports.

The inspection plan shall ensure that cracks and corrosion are detected with high reliability.