1 Introduction
ABS has been requested by various designers to review their proposed design scenarios for the transportation of compressed natural gas (CNG) by sea. The proposed CNG carrier designs considered thus far are considered somewhat novel in that they differ from any one of the vessels that are currently transporting methane by sea, not only in that the methane will not be transported as a cryogenic liquid, LNG, but also in several key areas, including the following:

- Pressure and temperature of the cargo being carried
- Possible storage of cargo above the main deck
- Proposed method for loading and off-loading the cargo
- Proposed deviations from the IMO Gas Code factors of safety for hoop stress in independent Type B and C tanks.

This Guide provides requirements for design, construction and periodic surveys required for maintenance of classification that would be applicable to CNG carriers, where it is intended to obtain ABS class for the vessels. These requirements may also serve to satisfy Port State and Flag State Regulations as they develop. As these projects are still at the concept stage and various scenarios are being considered at this time, the objective will be to establish an overall philosophy or approach to provide a framework of reference material and cite precedence, where applicable, as to what methodologies followed by designers in similar projects have proven successful in the past.

While it is certainly not the intent of ABS to in any way prevent or stifle creative development of new ideas and concepts, ABS will point out where a proposal appears to go beyond the bounds of what has been accepted practice in the past. In such cases, ABS will provide the designer with a list of steps considered necessary to establish that such a proposal, in fact, does not compromise the level of safety well established in the published Rules of the American Bureau of Shipping and those of applicable national and international Regulatory bodies.

2 Applicability of Existing ABS Rules and Regulatory Requirements for LNG Carriers to CNG Carriers

It is recognized that the ABS “Rule Requirements for Vessels Intended to Carry Liquefied Gases in Bulk” (Part 5C, Chapter 8 of the ABS Rules for Building and Classing Steel Vessels), which is in full agreement with the IMO IGC Code, do not envisage the carriage of Compressed Natural Gas (CNG) as compared to LNG. However, it is considered that that these requirements are an excellent starting point for ABS as a Classification Society seeking to establish requirements for the safe transport of CNG by sea. Also, IMO Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process, MSC/Circ. 1023, MEPC/Circ., should be used to qualify such a novel concept.

Some of the hazards applicable to LNG carriers, such as methane vapor release, fire, explosion, toxicity, collision and grounding, would also be applicable to CNG carriers. However, there are a number of additional hazards or possible increased risk from the same hazards due to the differences identified in Paragraph 1 above. These would include the following:

- While there is no cryogenic liquid being transported or handled, the possibility of critical structure being exposed to low temperatures from impingement of auto-cooled escaping gas must be provided for in the design.
- While the existing requirements for LNG carriers establish hazardous areas around potential sources of gas release, it will be required that a gas dispersion analysis be carried out to demonstrate that areas normally considered gas safe will not be engulfed during a venting or blow-down of high pressure gas or during an upset condition. Depending on the results of the gas dispersion analysis, a vessel Emergency Shut-down system may be required to protect against the migration of methane gas into spaces normally containing a source of vapor ignition.
● While a gas detection system in the cargo holds warns of a gas leak, since the gas is stored at high pressure in containers in cargo holds, a rapid gas release due to container or piping system failure could result in an overpressure condition in the cargo hold jeopardizing the integrity of the vessel’s hull. Accordingly, overpressure protection for cargo hold spaces should be provided. The relief devices should have sufficient capacity to handle a rupture of the largest cargo tank, assuming rupture at any location. In addition to these relief devices, hatches shall be provided in each hold space cover. Discharge from the hold spaces shall be routed to a safe location.

● While the IMO Gas Code includes requirements for active and passive fire protection systems applicable for liquid methane fires, it does not envisage a high pressure (jet) fire which could result from the ignition of a high pressure gas flow from a ruptured pipe. Accordingly, means to protect against such an occurrence will be required to be demonstrated for CNG carriers.

Regarding the appropriate application of the requirements of Chapters 2 and 3 of the IGC Code to the damage assumptions and segregation of the cargo area, please note that in accordance with Chapter 19 of the IGC Code, a vessel transporting methane is required to comply with the requirements for a type 2G ship, or 2PG if of 150 meters in length or less, as defined in 2.1.2 of the Code. Accordingly, ABS would consider the same to be applicable for the CNG carriers.

3 Flag State Requirements

ABS cannot speculate with regard to the requirements that would be applied to the proposed CNG carrier concept by an Administration. ABS can, however, offer the following insights based on the knowledge of past practices and the workings of the IMO Organization.

i) Since the IMO IGC Code became effective in 1975, it has been adopted and implemented by almost every maritime nation in the world and since that time virtually all of the LNG and LPG cargos that have been transported have been carried in vessels in full, or at least substantial, agreement with the Code.

ii) While the transportation of natural gas in a gaseous state rather than a liquid state was never envisaged by the IMO IGC Code, it would be reasonable to assume that any Administration signatory to the IGC Code, such as the United States, would seek to establish some level of compliance with the Code, at least as a starting point or frame of reference.

iii) The LNG community is a relatively small community that meets in various forums such as SIGTTO (Society of Gas Tanker and Terminal Operators) and exchanges information readily. This community takes great pride in the fact that there has never been a major LNG incident at sea. Owners and operators of gas carriers and terminals can influence their respective Flag States and they should be expected to rightfully demand that there be no reduction in overall safety as a result of this new means of transporting natural gas.

iv) Reliability-based engineering and other methodologies have not been used heretofore to justify designs in the marine community, so many Administrations may not initially be prepared to consider designs that significantly differ from what has been done in the past on the basis of such studies. Administrations that are “Coastal States” for offshore activities may be more familiar with reliability-based engineering methods.

v) Paragraph 1.4 of the IGC Code provides for Equivalents, which gives certain latitude toward the acceptance of alternative provisions, procedures or arrangements if such has been determined to be not less effective.
GUIDE FOR VESSELS INTENDED TO CARRY COMPRESSED NATURAL GASES IN BULK

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CHAPTER 1 Introduction

SECTION 1 General

1 Classification

See Chapters 1 and 10 of the separate ABS Rules for Conditions of Classification (Part 1) for the requirements for conditions of classification for vessels intended to carry compressed natural gases in bulk.

2 Hazards

Hazards considered in this Guide are fire, corrosion, temperature, and pressure.

3 Conditions for Survey After Construction (1 January 2008)

See Sections 7-3-2 and 7-6-2 of the ABS Rules for Survey After Construction (Part 7) for survey requirements for vessels in service intended to carry liquefied gases. See also Section 1-1-8 of the ABS Rules for Conditions of Classification (Part 1) for requirements for conditions for surveys after construction. The following requirements are specific to vessels carrying compressed natural gases in bulk.

3.1 Temporary Installation, Maintenance, Modification, Repair or Replacements

ABS is to be notified of the Owner’s intention to install temporary equipment or machinery that can affect the safety or intended functioning of the system. Depending on circumstances, ABS may require design review, surveys and individual certification of such equipment or machinery.

Where a major modification or replacement is made to the structure, equipment or machinery of the CNG carrier, ABS is to be notified and the applicable requirements of this Guide are to be met.
CHAPTER 1 Introduction

SECTION 2 Definitions

Except where expressly provided otherwise, the following definitions apply to this Guide. Additional definitions are given in Chapter 5.

1 Accommodation Spaces

Accommodation Spaces are those spaces used for public spaces, corridors, lavatories, cabins, offices, hospitals, cinemas, games and hobbies rooms, barber shops, pantries containing no cooking appliances and similar spaces. Public Spaces are those portions of the accommodation which are used for halls, dining rooms, lounges and similar permanently enclosed spaces.

2 ‘A’ Class Divisions

‘A’ Class Divisions means divisions as defined in regulation II-2/3.3 of the 1983 SOLAS amendments.

3 Administration

Administration means the Government of the State whose flag the ship is entitled to fly.

4 Port Administration

Port Administration means the appropriate authority of the country in the port of which the ship is loading or unloading.

5 Blow Down

Blow Down is depressurizing or disposal of a pressurized cargo inventory from a cargo tank, process vessels, cargo and process piping in a controlled manner via the vent system.

6 Boiling Point

Boiling Point is the temperature at which a product exhibits a vapor pressure equal to the atmospheric pressure.

7 Breadth

Breadth (B) means the maximum breadth of the ship, measured amidships to the molded line of the frame in a ship with a metal shell and to the outer surface of the hull in a ship with a shell of any other material. The breadth (B) is to be measured in meters.

8 Cargo Area

Cargo Area is that part of the ship which contains the cargo containment system and cargo handling systems and equipment and includes deck areas over the full length and breadth of the part of the ship over the above-mentioned spaces. Where fitted, the cofferdams, ballast or void spaces at the after end of the aftermost hold space or at the forward end of the forwardmost hold space are excluded from the cargo area.

9 Cargo Containment System

Cargo Containment System is the arrangement for containment of cargo including, where fitted, thermal protection, associated insulation and any intervening spaces, and adjacent structure if necessary for the support of these elements.
9.1 Containment System Component

Containment System Component is the CNG Cargo Tank (see 1-2/13) and its support. This includes individual cargo cylinders, associated manifold piping up to first stop valve and support.

10 Cargo Control Room

Cargo Control Room is a space used in the control of cargo handling operations and complying with the requirements of Section 4-4.

11 Cargo – Compressed Natural Gas

Compressed Natural Gas constituents are Methane, Natural Gas Liquids (ethane, propane, butane, pentane, etc), water, carbon dioxide, nitrogen and other non-hydrocarbon contaminants. CNG that is transported is to have the water, carbon dioxide, nitrogen and other contaminants removed and are pipeline quality where no additional treatment is done prior to delivery to the pipeline. Cargo is the various compositions of natural gas that will be carried.

12 Cargo Service Spaces

Cargo Service Spaces are spaces within the cargo area used for workshops, lockers and storerooms of more than 2 m² in area, used for cargo handling equipment.

13 Cargo Tank

A Cargo Tank is all pressurized equipment up to the cargo tank first stop valve of a cargo containment system that stores compressed gas within cargo holds. Cargo Tank includes the storage container and associated manifold piping up to first stop valve. Cargo tanks can be either coiled type or multiple cylinder type, as defined below:

i) Coiled Cargo Tank is a long continuous coiled pipe inside the cargo hold supported independently up to first stop valve.

ii) Cylindrical Cargo Tank is an assembly of multiple individual cargo cylinders connected by a common manifold and supported individually inside the cargo hold up to first stop valve.

13.1 Cargo Cylinder

Cargo Cylinder is an individual pressure vessel for storage of CNG.

13.2 Cargo Tank Piping

Cargo Tank Piping is the piping manifolds connecting main pressurized components of the cargo tank and the cargo tank first stop valve, i.e., headers connecting the cargo cylinder, coselle, etc. Cargo tank piping is within the cargo hold and there should be no valve or flow-restricting devices.

13.3 Cargo Tank First Stop Valve

Cargo Tank First Stop Valve isolates the cargo tank from the cargo piping.

14 Cofferdam

Cofferdam is the isolating space between two adjacent steel bulkheads or decks. This space may be a void space or a ballast space.

15 Contiguous Hull Structure

Contiguous Hull Structure means hull structure that includes the inner deck, the inner bottom plating, longitudinal bulkhead plating, transverse bulkhead plating, floors, webs, stringers and all attached stiffeners.
16 **Control Stations**

*Control Stations* are those spaces in which ships’ radio or main navigating equipment or the emergency source of power is located or where the fire-recording or fire-control equipment is centralized. This does not include special fire-control equipment which can be most practically located in the cargo area.

17 **Design Temperature**

*Design Temperature*. See Section 5-2/5.

18 **Design Pressure**

*Design Vapor Pressure*. See Section 5-2/2.

19 **Flammability Limits**

*Flammability Limits* are the conditions defining the state of fuel-oxidant mixture at which application of an adequately strong external ignition source is only just capable of producing flammability in a given test apparatus.

20 **Flammable Range**

*Flammable Range* means the range between the minimum and maximum concentrations of vapor in air which form a flammable mixture.

21 **Compressed Gas Carrier**

*Compressed Gas Carrier* is a cargo ship constructed or adapted and used for the carriage in bulk of compressed natural gas.

22 **Gas-dangerous Space or Zone**

*Gas-dangerous Space or Zone* is:

i) A space in the cargo area which is not arranged or equipped in an approved manner to ensure that its atmosphere is at all times maintained in a gas-safe condition;

ii) An enclosed space outside the cargo area through which any cargo piping liquid or gaseous process passes, or within which such piping terminates, unless approved arrangements are installed to prevent any escape of product vapor into the atmosphere of that space;

iii) A cargo containment system and cargo piping;

iv) A hold space where cargo is carried;

v) A space separated from a hold space by a single gastight steel boundary;

vi) A room containing cargo handling systems and equipment;

vii) A zone on the open deck, or semi-enclosed space on the open deck, within 3 m of any cargo tank outlet, gas or vapor outlet, cargo pipe flange or cargo valve or of entrances and ventilation openings to rooms containing cargo handling systems and equipment;

viii) The open deck over the cargo area and 3 m forward and aft of the cargo area on the open deck with no limit on height;

ix) A zone within 2.4 m of the outer surface of a cargo containment system where such surface is exposed to the weather;

x) An enclosed or semi-enclosed space in which pipes containing products are located;

xi) A compartment for cargo hoses; or
xii) An enclosed or semi-enclosed space having a direct opening into any gas-dangerous space or zone.

23 **Gas-safe Space**

_Gas-safe Space_ is a space other than a gas-dangerous space.

24 **Heat Affected Zone (HAZ)**

_Heat Affected Zone_ in a weldment is considered to be a part of the base material of the weldment, where deterioration in mechanical properties is expected due to weld heat input and certain metallurgical changes occurring in the material.

25 **Hold Space**

_Hold Space_ is the space enclosed by the ship’s structure in which a cargo containment system is situated.

25.1 **Hold Space Cover**

_Hold Space Cover_ is the enclosure of hold space above main deck protecting cargo tanks and providing controlled environmental conditions within hold space and is gastight.

26 **IMO**

IMO means International Maritime Organization

27 **Independent**

_Independent_ means that a piping or venting system, for example, is in no way connected to another system and there are no provisions available for the potential connection to other systems.

28 **Insulation Space**

_Insulation Space_ is the space, outside a cargo bottle, occupied wholly or in part by insulation.

29 **Length**

_Length_ (\(L\)) means 96% of the total length on a waterline at 85% of the least molded depth measured from the top of the keel, or the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that be greater. In ships designed with a rake of keel, the waterline on which this length is measured is to be parallel to the designed waterline. The length (\(L\)) is to be measured in meters.

30 **Machinery Spaces of Category A**

_Machinery Spaces of Category A_ are those spaces and trunks to such spaces which contain:

i) Internal combustion machinery used for main propulsion; or

ii) Internal combustion machinery used for purposes other than main propulsion where such machinery has in the aggregate a total power output of not less than 375 kW; or

iii) Any oil-fired boiler or oil fuel unit.

31 **Machinery Spaces**

_Machinery Spaces_ are all machinery spaces of category A and all other spaces containing propelling machinery, boilers, oil fuel units, steam and internal combustion engines, generators and major electrical machinery, oil filling stations, refrigerating, stabilizing, ventilation and air-conditioning machinery, and similar spaces; and trunks to such spaces.
32 **MARVS**

*MARVS* is the maximum allowable relief valve setting of a cargo tank.

33 **Nondestructive Testing (NDT)**

*Nondestructive Testing (NDT)* is any test conducted on materials and products without altering their product usefulness or end use.

34 **Oil Fuel Unit**

*Oil Fuel Unit* is the equipment used for the preparation of oil fuel for delivery to an oil-fired boiler, or equipment used for the preparation for delivery of heated oil to an internal combustion engine, and includes any oil pressure pumps, filters and heaters dealing with oil at a pressure of more than 1.8 bar gauge.

35 **Organization**

*Organization* is the International Maritime Organization (IMO).

36 **Permeability**

*Permeability* of a space means the ratio of the volume within that space which is assumed to be occupied by water to the total volume of that space.

37 **Process Pressure Vessel**

*Process pressure vessel* means a pressure vessel that is used in a reliquefaction system, cargo heating/cooling system, cargo processing/cleaning system or other system that processes cargo onboard.

38 **Relative Density**

*Relative Density* is the ratio of the mass of a volume of a product to the mass of an equal volume of fresh water.

39 **Separate**

*Separate* means that a cargo piping system or cargo vent system, for example, is not connected to another cargo piping or cargo vent system. This separation may be achieved by the use of design or operational methods. Operational methods are not to be used within a cargo tank and are to consist of one of the following types:

i) Removing spool pieces or valves and blanking the pipe ends.

ii) Arrangement of two spectacle flanges in series with provisions for detecting leakage into the pipe between the two spectacle flanges.

40 **Service Spaces**

*Service Spaces* are those spaces used for galleys, pantries containing cooking appliances, lockers, mail and specie rooms, storerooms, workshops other than those forming part of the machinery spaces, and similar spaces and trunks to such spaces.

The *service spaces* refer to normal stores for hotel services and other similar spaces. Boatswain stores, lamp lockers and carpenter shops would not be considered “service spaces”.

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**ABS GUIDE FOR VESSELS INTENDED TO CARRY COMPRESSED NATURAL GASES IN BULK • 2020**
41 Shut-off Valve

Shut-off valve means a valve in a cargo liquid or vapor line that fully closes a pipeline and provides nominal metal-to-metal contact between the valve operating parts, including the disc and gate, and the valve body.

42 1974 SOLAS Convention


43 1983 SOLAS Amendments


44 Thermo-Mechanically Controlled Processing/Processed (TMCP)

Thermo-Mechanically Controlled Processing/Processed is a specialized controlled material processing method/technique in which mechanical deformation and heat treatment are combined together to achieve very fine-grained microstructure with improved mechanical, impact and fracture toughness properties in the material. Reheating TMCP materials to above certain critical levels would result in loss of these properties due to coarsening of grains in the material, and therefore, post-thermal treatments on TMCP materials are generally prohibited.

45 Vapor Pressure

Vapor pressure is the equilibrium pressure of the saturated vapor above the liquid expressed in bars absolute at a specified temperature.

46 Void Space

A Void Space is an enclosed space in the cargo area external to a cargo containment system, other than a hold space, ballast space, fuel oil tank, cargo pump or compressor room, or any space in normal use by personnel.

47 Units

This Guide is written in three systems of units, viz., SI units, MKS units and US customary units. Each system is to be used independently of any other system.

Unless indicated otherwise, the format of presentation in this Guide of the three systems of units is as follows:

SI units (MKS units, US customary units)
Chapter 1 Introduction

Section 3 Abbreviations and References

1 Abbreviations

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<tr>
<th>Abbreviation</th>
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<td>American Bureau of Shipping</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>AWS</td>
<td>American Welding Society</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>NFPA</td>
<td>National Fire Protection Association</td>
</tr>
<tr>
<td>SIGTTO</td>
<td>Society of International Gas Tanker and Terminal Operators Ltd.</td>
</tr>
<tr>
<td>LBF</td>
<td>Leak Before Failure</td>
</tr>
<tr>
<td>JT</td>
<td>Joule Thompson Effect</td>
</tr>
<tr>
<td>CVN</td>
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<td>Quality Assurance</td>
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<tr>
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<td>Compressed Natural Gas</td>
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2 References

i) ABS Rules for Building and Classing Marine Vessels (Marine Vessel Rules)

ii) ABS Rules for Materials and Welding (Part 2)

iii) ABS Rules for Building and Classing Single Point Moorings

iv) ABS Rules for Building and Classing Facilities on Offshore Installations

v) ABS Guide for Automatic or Remote Control and Monitoring for Machinery and Systems (other than Propulsion) on Offshore Installations

vi) ABS Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries

vii) ABS Guide for Risk Evaluations for the Classification of Marine-Related Facilities

viii) ABS Guidance Notes on Review and Approval of Novel Concepts

ix) ABS Guide for Risk-Based Inspection for Floating Offshore Installations

x) ABS Guide for Surveys Based on Machinery Reliability and Maintenance Techniques
ABS is prepared to consider other appropriate alternative methods and recognized codes of practice.
CHAPTER 2  Risk Assessment and Special Studies

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Chapter 2  Risk Assessment and Special Studies

Section 1  General

Risk methods are increasingly being used for Rule-making, particularly when the Rules pertain to novel systems or to systems for which there is limited experience, such as those inherent in the design and construction of a CNG carrier. This Chapter provides general guidance on the risk assessments that will normally be required as part of the overall CNG carrier design approval. The methods outlined in this Chapter generally follow the guidelines published in IMO Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process, MSC/Circ. 1023 and MEPC/Circ. 392 and are considered an integral part of the design development process.

The requirements detailed herein are a reflection of the novelty of significant parts of CNG marine transportation systems and as such tend to parallel the approaches described in the ABS Guidance Notes on Review and Approval of Novel Concepts. The risk assessments are intended to compliment the engineering and testing regime, from the initial FEED (front end engineering and development) up to detailed design, with the ultimate objective of ensuring all aspects of the CNG carrier are fit-for-purpose for the specific operations. In order to do this, both qualitative and quantitative risk methods are required. Note that as knowledge and experience are gained from the design, fabrication and actual operation of the CNG carriers, the requirements outlined in this Chapter may be reduced.

In addition to the risk assessments, the novel aspects of the CNG carrier will require certain special studies be conducted which will feed the engineering, testing and risk assessment process. Special studies generally include consequence analysis (e.g., gas dispersion, fire analysis, etc.), as well as special operability, engineering assessment, prototype testing or other studies (e.g., cargo tank inspectibility assessment, fracture mechanics evaluations, etc.) which are not normally required for typical class approval.

This Chapter is intended to provide a general understanding of the class requirements as they relate to risk as well as special studies required to address the novel aspects of the CNG carrier.

The risk assessments and special studies described in this Chapter will be required regardless of whether the containment system is designed using design codes or limit state design methods of Chapter 5 of this Guide. Furthermore, this Chapter describes the minimum risk assessments and special studies requirements for class approval. Other studies, in addition to those described in this Chapter, may be required by class depending on the features inherent in the proposed CNG carrier system.
CHAPTER 2 Risk Assessment and Special Studies

SECTION 2 Requirements

1 Risk Assessment Plan

As part of the CNG carrier design development, an overall risk assessment plan is required to be developed by the client that identifies the specific assessment techniques and systems that will be evaluated during the course of the project. This plan should be submitted to ABS for review during the early stages of the design development outlining the particular risk assessment methods and estimated time when the various assessments, in relation with the design development, will be conducted. The risk assessment plan services multiple objectives including:

- Provides a clear road map on how each aspect of the system will be addressed with regard to risk.
- Initiates the process of identifying and describing the novel aspects of the system as well as the associated interfaces with other conventional aspects of the ship.
- Provides the framework for ensuring all hazards and failure modes are identified and adequately addressed during the design development.

1.1 Risk Plan Submittal

In order to review the proposed risk assessments plan, the plan submittals are required to include design basis documents as well as available preliminary design documents. These documents are necessary to understand of the overall system and how the proposed risk assessments are to be incorporated to address the various aspects of the design. The risk assessment plan submittal must contain the following items:

**Engineering/Design Documents**

- Design basis documents that include the “operating envelope”, working environment, design life, etc.
- Functional description to include descriptions of all of the key systems (containment, marine, structural, propulsion, cargo handling, etc.) and general outline of the interfaces between the systems.
- Preliminary general arrangements/layout drawings
- Other relevant preliminary drawings related to the containment and cargo handling systems (e.g., piping, safety systems, etc.)

**Risk Assessment and Special Study Plan**

- Description of proposed risk assessments to be conducted over the course of the design development. The descriptions must include:
  - Proposed method or methods to be used and when (e.g., HAZID, HAZOP, QRA, etc.)
  - Proposed scope of the risk assessment (i.e., covering what system and/or systems, operating conditions, etc.)
  - Objectives of the assessment and how the results will be used in the overall design development
- Management and organization of hazard register. Note that a master hazard register will be required to document all major hazards and mitigation and/or actions required during the design development. The risk assessment plan must clearly state what will be contained in the register and how it will be managed and updated over the course of the design development.
- Proposed risk acceptance criteria. For qualitative risk assessments, a risk ranking methodology or risk matrix must be provided. The use of the organization’s risk matrix may be acceptable provided it is in general compliance with ABS’s safety, environmental and operability philosophies. For quantitative
risk assessments, proposed risk criteria should be provided. ABS will review and verify that the criteria are generally in line with similar applications. Note that it is envisioned that these criteria would be related to total risk and be applicable when comparing calculated overall health and safety risks as they relate to the entire CNG ship system. In cases where quantitative risk assessments are used for subsystems of the CNG ship, adjustments to the total risk criteria may be warranted such that it is representative of the fractional contribution to the total risk.

- Description of proposed special studies to be conducted over the course of the design development. The descriptions must include:
  - Proposed analysis methods (e.g., dispersion analysis, jet fire analysis, etc.)
  - Proposed scope of the study (i.e., covering what system and/or systems, operating conditions, etc.)
  - Objectives of the assessment and how the results will be used in the overall design development as well as the risk assessment defined above

The plan submittals must show a holistic approach to risk assessment for all stages of the project with the understanding that as knowledge is gained from the pre-FEED/FEED engineering and testing as well as in the initial risk assessments, adjustments to this plan may be warranted. Any adjustments to the risk assessment plan will be submitted to ABS for review and approval.

1.2 Minimum Requirements

ABS will require specific qualitative and quantitative risk assessments as well as consequence studies to be conducted in order to obtain class approval. Specifically, the submitted risk assessment plan must as a minimum contain the following studies:

- **Hazard Identification (HAZID)** – A global HAZID which will include the major systems (i.e., containment, offloading, structural, propulsion, etc.) must be conducted. The HAZID needs to cover the various operating conditions (i.e., loading, discharging, transit, drydock, containment system start-up and shut-down) that the vessel will experience over the service life.

- **Containment and Cargo Handling System Hazard and Operability Study (HAZOP)** – The HAZOP must assess in detail the various containment and cargo handling control systems required in the operation of a CNG carrier. Key interfaces between these systems and other systems, such as marine, propulsion, etc., must be included in this assessment.

- **Quantitative Risk Assessment (QRA) of CNG Carrier Critical Systems** – The QRA must analyze the containment system and loading and cargo handling systems as a minimum. Additional systems may be included in the QRA as deemed appropriate based on the findings from the HAZID, HAZOP or other risk and engineering studies.

In addition to the risk assessments, special studies related to potential failure consequences of the containment system and the system for loading and discharging the cargo will be required. Specific consequence studies required as part of the design approval process are described in Section 2.2.3.

2-2/Figure 1 contains a general chart showing the typical design development stages of a project. Included in the figure are some of the key risk assessments and special studies described above that are considered to be minimum requirements for class approval. The placement of the risk assessment and special studies boxes on the figure generally indicates when during the design development these studies would typically be conducted. The later Sections of this Chapter provide further detail on these required studies as well as submittal requirements.

If the concept has obtained Approval-in-Principle (AIP) in accordance with the ABS Guidance Notes on Review and Approval of Novel Concepts and no major modifications to the concept have occurred since the AIP approval, the risk assessment plan, as described above, will have already been developed and approved by ABS as part of the AIP process. Furthermore, some of the risk assessment requirements (e.g., HAZID, HAZOP, etc.) described in this Chapter may have already been completed for the AIP approval.
process. In this case, ABS may accept these evaluations in lieu of the one described in this Chapter provided no major design evolution or changes have taken place since the studies were carried out. If the above is not true, then a revision to these studies may be warranted.

**FIGURE 1**
Typical Design Development Process and Associated Risk Studies

<table>
<thead>
<tr>
<th>Concept Design Basis</th>
<th>Engineering Prototype Development and Testing</th>
<th>Equipment Purchasing/Fabrication</th>
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<td>• Gas dispersion</td>
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<td>• Thermal radiation effects</td>
<td>• Smoke and gas ingress</td>
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<td>overpressure effects)</td>
<td>• Others</td>
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<td>• Fires</td>
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2 **Approach**

As described in section 2-2/1, specific risk assessment and special studies are required to obtain class approval for the design. The overall requirements to conduct these assessments and studies are described in this Section. The assessment types are broken into two types of assessments which relate to the engineering design development; Pre-FEED/FEED Risk Assessments and Detailed Design Risk Assessments. Generally, the pre-FEED assessments relate to qualitative or high-level risk assessments. The primary objective of these assessments is to identify critical elements of the CNG carrier that warrant more detailed risk assessment treatment, elements that are considered novel, and elements that have the greatest degree of uncertainty. The detailed design assessments tend to be more focused, covering the system of interest in more detail in an effort to understand the sensitivities and reduce the overall uncertainty of the system.

The procedures and methods described in the ABS *Guidance Notes on the Review and Approval of Novel Concepts* and the ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities* compliment the approach described in this Section and can be referred to for additional detail.

2.1 **Pre-FEED/FEED Risk Assessments**

During the Pre-FEED/FEED stage of development, the initial concept is further refined. The engineering evaluations at this stage generally are used to verify that the design is feasible with respect to the intent and overall level of safety required by Rules, Guides and statutory requirements in all phases of operation. Generally, preliminary design drawings are being produced for the key CNG carrier systems and structures.
Similar to the engineering, the risk assessments conducted at this stage of the development are also used to verify the feasibility of the system and lay the groundwork for further more detailed risk analysis or special studies. At this stage in the design, qualitative risk assessments tend to be more applicable due to the level of detail of the design (i.e., still in the concept or development stages). As described in section 2/1.2, as a minimum of two qualitative risk assessments are required as part of the design development. These are a HAZID covering the main systems of the CNG carrier and a HAZOP covering the containment system as well as the gas loading and discharge systems.

2.1.1 HAZID

For the HAZID exercise, the objective is to identify all major hazards associated with the CNG carrier and prioritize them based on perceived risk. The HAZID exercise is used to ensure there are no “showstoppers” early in the design process and to identify areas requiring further testing, analysis, in-service monitoring or design enhancements and, if necessary, additional risk mitigation measure requirements for safe operation of the systems. The exercise will also identify key interfaces and novel features of the design.

Another important feature of the exercise is that it initiates the development of a master hazard register which is used to track identified issues through the resolution process and eventually to closure. This document is updated throughout the design process up until final class approval of the vessel. Submittal of this document will be part of the class approval process.

The HAZID scope must cover all the major CNG carrier systems and interfaces to include as a minimum;

- Ship arrangement
- Containment system
- Cargo handling systems
- Safety systems
- Power systems
- Marine systems
  - Structural
  - Propulsion
  - Steering

The evaluation of these systems must address the various operating conditions (i.e., loading, discharging, transit, drydock, containment system start-up and shut-down) that the vessel will experience over the service life.

2.1.2 HAZOP

For the HAZOP exercise, the objective is to identify the hazards and potential operating problems of the gas containment system and cargo handling systems. Generally, this exercise is conducted near the end of the FEED phase or at the beginning of detailed engineering since by this time the initial concept is beginning to form and many of the aspects of the design are well-defined. A HAZOP evaluation requires well-defined systems and procedures related to the operations in order for it to be useful. The exercise is used to ensure all relevant safety and operability aspects of the system are being addressed in the design and is a further refinement on the HAZID defined above with respect to the containment and cargo handling systems.

The HAZOP scope must cover the following CNG carrier systems and interfaces:

- Containment system, including
– Systems to handle inadvertent gas releases
– Monitoring and inspection systems
● System for loading and discharging gas
● Systems for station-keeping while at an offshore discharge buoy, as applicable
● Safety systems, including means or features that aid in escape and evacuation

The findings of the HAZOP will be logged in the master hazard register and addressed via further engineering/testing or risk studies or modifications to the design. The HAZOP also provides a framework for quantitative risk assessment of the above systems by identifying operation hazards, failure modes and potential consequences as well as active and passive safeguards.

Both the HAZID and HAZOP evaluations provide valuable input to the design to ensure all aspects, particularly those that are considered novel, are adequately addressed. Additionally the evaluations involve team brainstorming sessions that provide a unique forum for designers and operational and safety personnel, as well as ABS representatives, to discuss the concept in a structured manner. ABS does not mandate that ABS personnel be part of the risk assessment team. However, benefits can be derived by the participation of an ABS representative that will be directly involved in the reviewing the risk assessment to support the approval process.

2.1.3 Other Risk Assessments

Note that the aforementioned risk assessments represent the minimum risk assessment requirements to be conducted early in the design development. Other risk assessment methods and/or work scope expansions may be required as part of the overall risk assessment plan described in Subsection 2/1 depending on the proposed CNG carrier design. Furthermore, additional risk assessments may be necessary to address the risk assessment findings.

2.1.4 Submittal Requirements

Documentation supporting the qualitative risk assessment must be submitted for review and approval. The minimum submittal requirements are as follows:

● Identified hazards related to the evaluated system and its potential impact on other systems
● Assessed risks associated with the system (i.e., perceive likelihood, consequence and risk ranking)
● Risk matrix
● Recommended mitigation strategies or safeguards not currently in the design intended to improve safety or operability of the system (as applicable)
● Identified inspectability/operability issues that may impact maintenance of class requirements or operations (as applicable)
● Identified issues related to the system that warrants further analysis, testing and/or risk evaluations (as applicable).
● Initial and/or updated master hazard register containing results of risk assessment.

2.2 Detailed Design Risk Assessments

The engineering evaluations and testing are used to confirm that all aspects of the design are feasible and fit-for-purpose for the intended service. Aspects related to the manufacturing of special components and ship construction, as well as the detailed design of the various systems that make up the CNG carrier, are carried out during this stage. The additional information generated as part of the engineering and testing effort enable more detailed and system-focused risk assessments to be conducted.
The same as the engineering and testing, the risk assessments conducted at this stage are also used to confirm that all aspects of the design are being addressed such that they provide acceptable levels of risk. As described in section 2/1.2, as a minimum, a quantitative risk assessment will be required as part of the design approval process until such time as sufficient experience has been obtained with CNG transportation.

2.2.1 Quantitative Risk Assessment

For the QRA, the primary objectives are to refine the understanding and quantify identified failure modes as they relate to the CNG carrier containment system and loading and discharging systems. The QRA is used to determine the failure probabilities associated with different failure modes and potential consequences by modeling in detail the designed system, associated interfaces and safeguards. The assessment enables interactions and sensitivities to be calculated to assist in prioritizing system hazards and preventative barriers.

As a minimum, the QRA scope must cover the following CNG carrier systems and interfaces:

- Containment system, including
  - Systems to handle inadvertent gas releases
  - Monitoring and inspection systems
- System for loading and discharging gas

Note that depending on the CNG carrier features and intended service, other systems may require a QRA. For example, if the carrier is to load or discharge from offshore buoys, it is likely that a QRA will be required on the loading and discharging system, as well as the station-keeping systems. Systems requiring QRAs will be identified and included as part of the risk assessment plan.

The QRA results will be compared to the approved acceptance criteria. Key findings, sensitivities and associated recommendations should be summarized, and logged in the master hazard register to be subsequently addressed through further engineering/testing, risk studies or modifications to the design.

2.2.2 Other Risk Assessments

Note that the aforementioned QRA represents the minimum risk assessment requirements to be conducted during the detailed design development stage. Other risk assessment methods and/or work scope expansions may be required as part of the overall risk assessment plan described in section 2-2/1, depending on the proposed CNG carrier design. Furthermore, additional risk assessments may be necessary to address the risk assessment findings.

2.2.3 Submittal Requirements

Documentation supporting the quantitative risk assessment must be submitted for review and approval. The minimum submittal requirements are as follows:

- System description and risk assessment scope.
- Risk assessment assumptions and data references.
- Description and demonstration of calibration of quantitative method. This is a very important step to ensure that consistent results are obtained using the method. The calibration step also increases the confidence of the quantitative risk analysis.
- Description of uncertainties and sensitivities of risk assessment.
- Risk assessment worksheets, fault trees, event trees and supporting calculations.
Conclusions, which summarize the results and clearly indicate the risks relative to the risk acceptance criteria.

Identified areas or issues related to the system that may warrant further analysis, testing or risk evaluations (if applicable).

Identified potential mitigation strategies or safeguards not currently in the design that could improve the safety, or operability of the concept (if applicable).

Identified potential inspectability/operability/accessability issues related to the design that might impact requirements for the maintenance of class or operations (if applicable).

### 2.3 Special Studies (Consequence Modeling)

Consequence modeling provides valuable input into the design and risk analyses in understanding the potential effects of specific failures. Consequence modeling helps identify potential escalation scenarios related to the design, as well as assisting in verifying appropriate layout of equipment, normally manned locations and emergency escape routes. Additionally, if limit state methods are being used in the containment system design, consequence modeling results are required to assist in determining the appropriate acceptance criteria (i.e., maximum allowable failure probabilities permissible for the containment system). How the risk assessments and consequence analyses are used in conjunction with limit state design are discussed later in Section 2-4. Also more information on limit state design and the associated requirements is contained in Appendix 5-A1.

The results of the analyses also feed directly into the aforementioned risk analyses (e.g., HAZOP, QRA, etc.), allowing a more definitive understanding of the potential health and safety, environmental and economic implications of the failure.

As a minimum, ABS requires the following consequence modeling as it relates to the containment, loading and discharging systems to be conducted as part of the overall CNG carrier design development:

- **Gas dispersion** – Of particular interest are the dispersion characteristics and the potential for explosive fuel air mixtures covering both “normal” and inadvertent release scenarios.

- **Smoke and gas ingress** – Of particular interest is the potential impact on accommodations or other normally-manned spaces.

- **Explosions** (fragmentation and overpressure effects, as applicable).

- **Jet fires** – Particular focus should be placed on flame impingement on containment system components and ship structure which may result in escalation as applicable.

- **Thermal radiation effects** – Of particular interest is the potential impact on normally-manned spaces, such as the accommodations, emergency routes and muster areas, as well as the potential impact on adjacent gas-retaining components and tank and structure which may result in escalation.

Additionally, other consequence modeling or special studies may be required as part of the class approval process. The requirement of these analyses will be contingent on the specific features of the CNG carrier design. The need for additional studies may be identified early in the design development and included in the risk assessment plan, or in other cases, the results of the risk analyses may indicate that further analyses are required to understand the implications of particular risk scenarios. For example, risks associated with grounding, collision or dropped objects may warrant special studies to evaluate not only the consequences but also the susceptibility of the design to these events. This may entail the use of specialty structural analysis to evaluate the resistance characteristics of the design to these types of accident scenarios.

#### 2.3.1 Submittal Requirements

Documentation supporting the consequence modeling or special studies must be submitted for review and approval. The minimum submittal requirements are as follows:

- Description of the modeling or study scope. This must clearly describe the modeling/load cases and the basis for the selection of these cases.
● Description of the analysis methods and tools (e.g., computational fluid dynamics, finite element analysis, etc.)

● Analysis assumptions, limitations and data references.

● Supporting calculations and analysis results and conclusions.

● Identified areas or issues related to the system that may warrant further analysis, testing or risk evaluations (if applicable).

● Identified potential mitigation strategies or safeguards not currently in the design that could improve the safety, or operability of the concept (if applicable).
The designer is responsible for setting the acceptance criteria to be applied to risk assessments required by this Guide. These criteria should be consistent with the principles described in this Chapter. ABS will consider the proposed acceptance criteria within the context of the evaluation of the novelty of the overall CNG transportation concept and would either approve the criteria or recommend changes to render the criteria acceptable.

The broad objective is to ensure that the CNG transportation systems assessed according to the requirements of this Guide yield designs that have safety levels comparable to those of other similar systems, such as LNG transportation systems. The assessment must take due regard of the higher uncertainties associated in evaluating CNG transportation system.

As noted elsewhere in this Chapter, the range of risk assessment methodologies available is broad and ranges from simple qualitative methods to highly quantitative detailed techniques. The acceptance criteria that are appropriate to each methodology will similarly vary.

General guidance on establishing acceptance criteria for novel systems can be found in the ABS Guidance Notes on the Review and Approval of Novel Concepts.
CHAPTER 2 Risk Assessment and Special Studies

SECTION 4 Limit State Design Interaction

As described in Chapter 5, the designer can choose to design the containment system by complying with recognized pressure vessel codes (i.e., code-based design) or applying probabilistic limit state design principles. As described in section 2/1.2, the risk assessment requirements described in this Chapter will apply to both containment system design methods. However, in the case of the limit design approach, it is important to highlight the interactions between the risk and special studies described in this chapter and the limit state design described in Appendix 5-A1.

Limit states are conditions in which the structural system or component fails to meet its performance requirements. The performance requirements may be related to ultimate strength or fatigue or some other serviceability or accidental parameter required by the system component to ensure it is fit-for-purpose. In general, the limit state design approach entails evaluating load and resistance variables associated with the system or component to determine the probability that the design fails to meet a specific performance requirement. To determine if the design is acceptable, the probability of failure is compared to an acceptance criterion for the particular failure mode in question. In order to conduct this design process, there are three important steps which require input from risk assessments and consequence analysis.

i) The initial steps of the limit state design approach are the identification and definition of the key limit states that must be addressed in the design. The specific limit states that must be evaluated are driven by the potential failure modes associated with the system or concept. To identify these potential failure modes, a qualitative risk assessment (e.g., HAZID) must be conducted on the system of interest. In the case of the CNG carrier, the system of interest is generally the containment system and cargo handling systems and associated interfaces. The risk assessment provides the necessary input for the selection of the appropriate limit states that must be addressed in the design. 2-4/Figure 1 provides a schematic of key interactions between the risk and special studies and the limit state design.

ii) Another important interface point for the limit state design is the selection of acceptance criteria. In general, the acceptance criteria are related to the criticality of the component (i.e., the potential consequences related to the failure of the component). For example, a component that is considered safety-critical (i.e., failure may result in severe consequences) would require more stringent acceptance criteria (i.e., lower failure probabilities) than for a component determined to have minimal consequence as a result of failure. Therefore, to assist in determining the appropriate acceptance criteria, consequence modeling results and detailed understanding of the applicable failure modes related to the system are required as part of the limit state design process. More information on consequence categories and associated acceptance criteria are contained in Appendix 5-A1.

iii) One other important interaction is between the quantitative risk assessment and the limit state design. As defined in this Guide, the limit state design option generally relates to component design and not to the overall system evaluation. In this regard, the acceptance criteria in Appendix 5-A1 relate only to a defined containment component and are intended to be used for the express purpose of evaluating the compliance of an individual component using limit state design.

The overall system failure probability is an important aspect that must also be addressed. However, it is considered more appropriate to address the overall system performance in the context of risk rather than setting specific system failure probability targets. To evaluate the system and better understand the system performance, a QRA is conducted. This assessment compliments the limit state design conducted on the components. The limit state calculations provide important information on the structural and pressure retaining capability associated hazards of the cargo tanks which is one contributor to the many potential hazards that influence the overall risk to the containment system. Other hazards, such as accidental loading
or human error, as well as other system failures (electrical, mechanical, process control, instrumentation failure, etc.), also contribute to the overall risk and are addressed in the QRA.

FIGURE 1
Key Interaction between Risk Studies and Limit State Design

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<th>Required Information</th>
<th>Limit State Design</th>
</tr>
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<tr>
<td>Hazard Identification</td>
<td>Determine Appropriate Limit States Based on Identified Failure Modes</td>
<td>Select Limit States to Address in Design</td>
</tr>
<tr>
<td>Special Studies (Consequence Analysis)</td>
<td>Determine Appropriate Acceptance Criteria Based on Consequence Analysis</td>
<td>Select Acceptance Criteria</td>
</tr>
<tr>
<td>Quantitative Risk Assessment</td>
<td>Confirm Overall System Risk Acceptable</td>
<td>Component Design is Fit-for-Purpose</td>
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# Chapter 3  
Ship Survival Capability and Location of Cargo Tanks

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SECTION 1  General

1

Vessels subject to the Guide requirements are to survive the normal effects of flooding following assumed hull damage caused by some external force. In addition, to safeguard the vessel and the environment, the cargo tanks are to be protected from penetration in the case of minor damage to the vessel (resulting, for example, from contact with a jetty or tug) and given a measure of protection from damage in the case of collision or stranding by locating them at specified minimum distances inboard from the vessel’s shell plating.

2

Vessels subject to this Guide are compressed natural gas carriers intended to transport CNG that require significant preventive measures to preclude the escape of the cargo.
1. Vessels subject to the Guide may be assigned the minimum freeboard permitted by the International Convention on Load Lines in force. However, the draft associated with the assignment is not to be greater than the maximum draft otherwise permitted by this Guide.

2. The stability of the ship in all seagoing conditions and during loading and unloading cargo is to be to a standard which is acceptable to ABS.

3. When calculating the effect of free surfaces of consumable liquids for loading conditions, it is to be assumed that, for each type of liquid, at least one transverse pair or a single center tank has a free surface and the tank or combination of tanks to be taken into account is to be those where the effect of free surfaces is the greatest. The free surface effect in undamaged compartments is to be calculated by a method acceptable to ABS.

4. Solid ballast is not normally to be used in double bottom spaces in the cargo area. Where, however, because of stability considerations, the fitting of solid ballast in such spaces becomes unavoidable, then its disposition is to be governed by the need to ensure that the impact loads resulting from bottom damage are not directly transmitted to the cargo tank structure.

5. A Loading and Stability Information booklet is required to be submitted for review. This booklet is to contain details of typical service conditions, loading, unloading and ballasting operations, provisions for evaluating other conditions of loading and a summary of the ship’s survival capabilities. In addition, the booklet is to contain sufficient information to enable the master to load and operate the ship in a safe and seaworthy manner.

When a CNG Carrier is designed to operate for certain sea state conditions due to design restrictions, all necessary information for safe operation such as loading, unloading, processing, etc., is to be included in the booklet.


The use of onboard computers for stability calculations is not a requirement of class. However, if stability software is installed onboard vessels contracted on or after 1 July 2005, it should cover all stability requirements applicable to the vessel and is to be approved by the Bureau for compliance with the requirements of Appendix 3-3-A1, “Onboard Computers for Stability Calculations”.

CHAPTER  3  Ship Survival Capability and Location of Cargo Tanks

SECTION  3  Shipside Discharges Below the Freeboard Deck

1  The provision and control of valves fitted to discharges led through the shell from spaces below the freeboard deck or from within the superstructures and deckhouses on the freeboard deck fitted with weathertight doors are to comply with the requirements of the relevant regulation of the International Convention on Load Lines in force, except that the choice of valves is to be limited to:

i) One automatic non-return valve with a positive means of closing from above the freeboard deck; or

ii) Where the vertical distance from the summer load waterline to the inboard end of the discharge pipe exceeds 0.01L, two automatic non-return valves without positive means of closing, provided that the inboard valve is always accessible for examination under service conditions.

2  For the purpose of this Guide, “summer load waterline” and “freeboard deck” have the meanings defined in the International Convention on Load Lines in force.

3  The automatic non-return valves referred to in 3-3/1i) and 3-3/1ii) are to be of a type acceptable to ABS and are to be fully effective in preventing admission of water into the ship, taking into account the sinkage, trim and heel in survival requirements in Chapter 3, Section 9.
Damage survival capability is to be investigated on the basis of loading information submitted to ABS for all anticipated conditions of loading and variations in draft and trim. The survival requirements need not be applied to the ship when in the ballast condition*, provided that any cargo retained onboard is solely used for cooling, circulation or fueling purposes.

* The cargo content of small independent purge tanks on deck need not be taken into account when assessing the ballast condition.
CHAPTER 3 Ship Survival Capability and Location of Cargo Tanks

SECTION 5 Damage Assumptions for Stability Assessment

1 Assumed Maximum Extent of Damage

ABS is prepared to consider a probabilistic approach to determining the effects of a collision or grounding. Where probabilistic damage assessment has not been done, the assumed maximum extent of damage to be used in the stability assessment is to be:

1.1 Side Damage

1.1.1 Longitudinal Extent

\[(\frac{1}{3})L^{2/3} \text{ or } 14.5 \text{ m (47.57 ft)}, \text{ whichever is less}\]

1.1.2 Transverse Extent

Measured inboard from the ship’s side at right angles to the centerline at the level of the summer load line: \[B/5 \text{ or } 11.5 \text{ m (37.73 ft)}, \text{ whichever is less}\].

1.1.3 Vertical Extent

From the molded line of the bottom shell plating at centerline: Upwards without limit.

1.2 Bottom Damage

1.2.1 Longitudinal Extent

For 0.3L from the forward perpendicular of the ship: \[\left(\frac{1}{3}\right)L^{2/3} \text{ or } 14.5 \text{ m (47.57 ft)}, \text{ whichever is less}\]

Any other part of the ship: \[\left(\frac{1}{3}\right)L^{2/3} \text{ or } 5 \text{ m (16.4 ft)}, \text{ whichever is less}\]

1.2.2 Transverse Extent

For 0.3L from the forward perpendicular of the ship: \[B/6 \text{ or } 10 \text{ m (32.8 ft)}, \text{ whichever is less}\]

Any other part of the ship: \[B/6 \text{ or } 5 \text{ m (16.4 ft)}, \text{ whichever is less}\]

1.2.3 Vertical Extent

For 0.3L from the forward perpendicular of the ship: \[B/15 \text{ or } 2 \text{ m (6.56 ft)}, \text{ whichever is less, measured from the molded line of the bottom shell plating at centerline (see 3-6/2).}\]

Any other part of the ship: \[B/15 \text{ or } 2 \text{ m (6.56 ft)}, \text{ whichever is less, measured from the molded line of the bottom shell plating at centerline (see 3-6/2).}\]

2 Other Damage

2.1 If any damage of a lesser extent than the maximum damage specified in 3-5/1 would result in a more severe condition, such damage is to be assumed.
2.2

Local side damage anywhere in the cargo area extending inboard 760 mm (30 in.) measured normal to the hull shell is to be considered, and transverse bulkheads are to be assumed damaged when also required by the applicable paragraphs of 3-8/1.
CHAPTER 3  Ship Survival Capability and Location of Cargo Tanks

SECTION 6  Location of Cargo Tanks

1

The cargo containment system is to be located at the following distances inboard:

i)  *Bottom Shell.* From the bottom shell plating at centerline, not less than the vertical extent of damage specified in 3-5/1.2.3 or as otherwise justified on the basis of a probabilistic damage assessment.

ii)  *Side Shell.* From the side shell, nowhere less than 760 mm (30 in.).

2

For the purpose of the cargo containment system, the vertical extent of bottom damage is to be measured to the bottom of the cargo tanks. The transverse extent of side damage is to be measured to the side of the cargo tanks (see 3-7/Figure 1).

Where the cargo tanks are located within the extent of damage assumed in Chapter 3, Section 5, the stability is to be investigated assuming the cargo tanks are damaged and also with the cargo tanks undamaged (3-5/2). Deck cargo tanks are to be located not less than 760 mm (30 in.) inboard from the side shell.
CHAPTER 3 Ship Survival Capability and Location of Cargo Tanks

SECTION 7 Flooding Assumptions

1

The requirements of Chapter 3, Section 9 are to be confirmed by calculations which take into consideration the design characteristics of the ship; the arrangements, configuration and contents of the damaged compartments; the distribution, relative densities and the free surface effects of liquids; and the draft and trim for all conditions of loading.

2

Where direct calculations are not submitted, the permeabilities of spaces assumed to be damaged are to be as follows:

<table>
<thead>
<tr>
<th>Spaces</th>
<th>Permeabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriated to stores</td>
<td>0.60</td>
</tr>
<tr>
<td>Occupied by accommodation</td>
<td>0.95</td>
</tr>
<tr>
<td>Occupied by machinery</td>
<td>0.85</td>
</tr>
<tr>
<td>Voids</td>
<td>0.95</td>
</tr>
<tr>
<td>Intended for consumable liquids</td>
<td>0 to 0.95*</td>
</tr>
<tr>
<td>Intended for other liquids</td>
<td>0 to 0.95*</td>
</tr>
</tbody>
</table>

* The permeability of partially filled compartments is to be consistent with the amount of liquid carried in the compartment.

3

Wherever damage penetrates a tank containing gas/liquids, it is to be assumed that the contents are completely lost from that compartment and replaced by salt water up to the level of the final plane of equilibrium.
Where the damage between transverse watertight bulkheads is envisaged as specified in 3-8/1.3, transverse bulkheads are to be spaced at least at a distance equal to the longitudinal extent of damage specified in 3-5/1.1.1 in order to be considered effective. Where transverse bulkheads are spaced at a lesser distance, one or more of these bulkheads within such extent of damage is to be assumed as non-existent for the purpose of determining flooded compartments. Further, any portion of a transverse bulkhead bounding side compartments or double bottom compartments is to be assumed damaged if the watertight bulkhead boundaries are within the extent of vertical or horizontal penetration required by Chapter 3, Section 5. Also, any transverse bulkhead is to be assumed damaged if it contains a step or recess of more than 3 m (9 ft-10 in.) in length located within the extent of penetration of assumed damage. The step formed by the after peak bulkhead and after peak tank top is not to be regarded as a step for the purpose of this Subsection.

The ship is to be so designed as to keep unsymmetrical flooding to the minimum consistent with efficient arrangements.
Equalization arrangements requiring mechanical aids such as valves or cross-leveling pipes, if fitted, are not to be considered for the purpose of reducing an angle of heel or attaining the minimum range of residual stability to meet the requirements of 3-9/1, and sufficient residual stability is to be maintained during all stages where equalization is used. Spaces which are linked by ducts of large cross-sectional area may be considered to be common.

If pipes, ducts, trunks or tunnels are situated within the assumed extent of damage penetration, as defined in Chapter 3, Section 5, arrangements are to be such that progressive flooding cannot thereby extend to compartments other than those assumed to be flooded for each case of damage.

The buoyancy of any superstructure directly above the side damage is to be disregarded. The unflooded parts of superstructures beyond the extent of damage, however, may be taken into consideration provided that:

1. They are separated from the damaged space by watertight divisions and the requirements of 3-9/1.1 with respect to these intact spaces are complied with.
2. Openings in such divisions are capable of being closed by remotely-operated sliding watertight doors and unprotected openings are not immersed within the minimum range of residual stability required in 3-9/2.1. However, the immersion of any other openings capable of being closed weathertight may be permitted.
Chapter 3  Ship Survival Capability and Location of Cargo Tanks

Section 8  Standard of Damage

1

Ships are to be capable of surviving the damage indicated in Chapter 3, Section 5 with the flooding assumptions in Chapter 3, Section 7 according to the following standards:

1.1

Ship of more than 150 m (492 ft) in length is to be assumed to sustain damage anywhere in its length.

1.2

Ship of 150 m (492 ft) in length or less is to be assumed to sustain damage anywhere in its length, except involving either of the bulkheads bounding a machinery space located aft.

1.3

The longitudinal extent of damage to superstructure in the instance of side damage to a machinery space aft under 3-8/1.1 to 3-8/1.2 is to be the same as the longitudinal extent of the side damage to the machinery space (see 3-8/Figure 1).

2

In the case of small ships which do not comply in all respects with the appropriate requirements of 3-8/1.2 and 3-8/1.3, special dispensations may only be considered by ABS in consultation with the Administration, provided that alternative measures can be taken which maintain the same degree of safety. The nature of the alternative measures is to be approved and clearly stated and be available to ABS.

**FIGURE 1**

Longitudinal Extent of Damage to Superstructure
(3-7/8 and 3-8/1)
Ships subject to this Guide are to be capable of surviving the assumed damage specified in Chapter 3, Section 5 to the standard provided in Chapter 3, Section 8 in a condition of stable equilibrium and are to satisfy the following criteria.

1 **In Any Stage of Flooding**

1.1 The waterline, taking into account sinkage, heel and trim, is to be below the lower edge of any opening through which progressive flooding or downflooding may take place. Such openings are to include air pipes and openings which are closed by means of weathertight doors or hatch covers and may exclude those openings closed by means of watertight manhole covers and watertight flush scuttles, small watertight tank hatch covers which maintain the high integrity of the deck, remotely operated watertight sliding doors and sidescuttles of the non-opening type.

1.2 The maximum angle of heel due to unsymmetrical flooding is not to exceed 30°.

1.3 The residual stability during intermediate stages of flooding is to be to the satisfaction of ABS.

2 **At Final Equilibrium After Flooding**

2.1 The righting lever curve is to have a minimum range of 20° beyond the position of equilibrium in association with a maximum residual righting lever of at least 0.1 m (3.937 in.) within the 20° range; the area under the curve within this range is not to be less than 0.0175 m-rad. The 20° range may be measured from any angle commencing between the position equilibrium and the angle of 25° (or 30° if no deck immersion occurs). Unprotected openings are not to be immersed within this range unless the space concerned is assumed to be flooded. Within this range, the immersion of any of the openings listed in 3-9/1.1 and other openings capable of being closed weathertight may be permitted.

2.2 The emergency source of power is to be capable of operating.
CHAPTER 3  Ship Survival Capability and Location of Cargo Tanks

APPENDIX 1  Computer Software for Onboard Stability Calculations

1  General

1.1  Scope

The scope of stability calculation software is to be in accordance with the stability information as approved by the flag Administration or ABS on behalf of the flag Administration. The software is at least to include all information and perform all calculations or checks as necessary to ensure compliance with the applicable stability requirements.

Approved stability software is not a substitute for the approved stability information, and is used as a supplement to the approved stability information to facilitate stability calculations.

1.2  Design (1 July 2020)

The input/output information is to be easily comparable with approved stability information so as to avoid confusion and possible misinterpretation by the operator relative to the approved stability information.

An operation manual is to be provided for the onboard computer stability software.

The language in which the stability information is displayed and printed out as well as the operation manual is written is to be the same as used in the vessel’s approved stability information. The primary language is to be English.

The onboard computer for stability calculations is to be vessel specific equipment and the results of the calculations are to be only applicable to the vessel for which it has been approved.

In case of modifications implying changes in the main data or internal arrangement of the vessel, the specific approval of any original stability calculation software is no longer valid. The software is to be modified accordingly and reapproved.

2  Calculation Systems

This Appendix covers either system, a passive system that requires manual data entry or an active system, which replaces the manual with the automatic entry with sensors reading and entering the contents of tanks, etc., provided the active system is in the off-line operation mode. However, an integrated system, which controls or initiates actions based on the sensor-supplied inputs is not within the scope of this Appendix.

3  Types of Stability Software (1 July 2020)

Four types of calculations performed by stability software are acceptable depending upon a vessel’s stability requirements

- Type 1: Software calculating intact stability only (for vessels not required to meet a damage stability criterion)
- Type 2: Software calculating intact stability and checking damage stability on basis of a limit curve or checking all the stability requirements (intact and damage stability) on the basis of a limit curve
- Type 3: Software calculating intact stability and damage stability by direct application of preprogrammed damage cases based on the relevant Conventions or Codes for each loading condition
● Type 4: Software calculating damage stability associated with an actual loading condition and actual flooding case, using direct application of user defined damage, for the purpose of providing operational information for safe return to port (SRtP).

Damage stability of both Type 3 and Type 4 stability software is to be based on a hull form model, that is, directly calculated from a full three-dimensional geometric model.

4 Functional Requirements

4.1 Calculation Program (1 July 2020)
The calculation program is to present relevant parameters of each loading condition in order to assist the Master in their judgment on whether the vessel is loaded within the approval limits. The following parameters are to be presented for a given loading condition:

● Deadweight data
● Lightship data
● Trim
● Draft at the draft marks and perpendiculars
● Summary of loading condition displacement, VCG, LCG and, if applicable, TCG
● Downflooding angle and corresponding downflooding opening (not applicable for Type 2 software which uses limit curve for checking all the stability requirements. However, if intact stability criteria are given in addition to the limit curve, downflooding angle and the corresponding downflooding opening is to be indicated).
● Compliance with stability criteria: Listing of all calculated stability criteria, the limit values, the obtained values and the conclusions (criteria fulfilled or not fulfilled) (not applicable for Type 2 software which uses limit curve for checking all the stability requirements. However, if intact stability criteria are given in addition to the limit curve, the limit values, the obtained values and the conclusion is to be indicated).

4.2 Direct Damage Stability Calculations
If direct damage stability calculations are performed, the relevant damage cases according to the applicable rules are to be pre-defined for automatic check of a given loading condition.

4.3 Warning (1 July 2020)
A clear warning is to be given on screen and in hard copy printout if any of the loading limitations are not complied with.

As applicable, loading limitations are to include, but may not be limited to:

● Trim, draft, liquid densities, tank filling levels, initial heel
● Use of limit KG/GM curves in conjunction with above for Type 2

4.4 Data Printout
The data are to be presented on screen and in hard copy printout in a clear unambiguous manner.

4.5 Date and Time
The date and time of a saved calculation are to be part of the screen display and hard copy printout.

4.6 Information of Program
Each hard copy printout is to include identification of the calculation program with version number.
4.7 **Units**

Units of measurement are to be clearly identified and used consistently within a loading calculation.

4.8 **Computer Model (1 July 2020)**

For Type 3 and Type 4 software, the system is to be pre-loaded with a detailed computer model of the complete hull, including appendages, all compartments, tanks and the relevant parts of the superstructure considered in the damage stability calculation, wind profile, down-flooding and up-flooding openings, cross-flooding arrangements, internal compartment connections and escape routes, as applicable and according to the type of stability software.

For Type 1 and Type 2 software, in case a full three dimensional model is used for stability calculations, the requirements of the computer model are to be as per the paragraph above to the extent as applicable and according to the type of stability software.

4.9 **Further Requirements for Type 4 Stability Software (1 July 2020)**

4.9.1 The normal (Type 1, 2 and 3) and SRtP (Type 4) software need not be “totally separated”. Where the normal and SRtP software are not totally separated:

- The function of switching between normal software and Type 4 software is to be provided.
- The actual intact loading condition is to be the same for both functions (normal operation and SRtP); and
- The SRtP module needs only to be activated in case of an incident.

Approval of Type 4 (SRtP) software is for stability only.

4.9.2 Each internal space is to be assigned its permeability as shown below, unless a more accurate permeability has been reflected in the approved stability information.

<table>
<thead>
<tr>
<th>Spaces</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Default</td>
</tr>
<tr>
<td>Cargo spaces</td>
<td>0.95</td>
</tr>
<tr>
<td>Intended for consumable liquids</td>
<td>0.95</td>
</tr>
<tr>
<td>Stores</td>
<td>0.95</td>
</tr>
<tr>
<td>Occupied by machinery</td>
<td></td>
</tr>
<tr>
<td>Void spaces</td>
<td></td>
</tr>
<tr>
<td>Occupied by accommodation</td>
<td></td>
</tr>
</tbody>
</table>

4.9.3 The system is to be capable of accounting for applied moments such as wind, lifeboat launching, and cargo shifts.

4.9.4 The system is to account for the effect of wind by using the method in SOLAS regulation II-1/7-2.4.1.2 as the default, but allow for manual input of the wind speed/pressure if the on-scene
pressure is significantly different \((P = 120 \text{ N/m}^2)\) equates to Beaufort 6; approximately 13.8 m/s or 27 knots).

4.9.5

The system is to be capable of assessing the impact of open main watertight doors on stability (e.g., for each damage case provided for verification, additional damage stability calculation is to be done and presented, taking into account any watertight door located within the damaged compartment(s)).

4.9.6

The system is to utilize the latest approved lightship weight and center of gravity information.

4.9.7

The output of the software is to be such that it provides the master with sufficient clear unambiguous information to enable quick and accurate assessment of the stability of the vessel for any actual damage, the impact of flooding on the means of escape and the controls of devices necessary for managing and/or controlling the stability of the vessel.

When the actual loading condition is input in the SRtP software, the following output (intact stability) is to be available:

- Deadweight data
- Lightship data
- Trim
- Heel
- Draft at the draft marks and perpendiculars
- Summary of loading condition displacement, VCG, LCG and, if applicable, TCG
- Downflooding angle and corresponding downflooding opening
- Free surfaces
- GM value
- GZ values relevant to an adequate range of heeling (not less than 60°) available indicatively at the following intervals: 0 5 10 15 20 25 30 40 50 60 deg
- Compliance with relevant intact stability criteria (i.e., 2008 IS Code): listing of all calculated intact stability criteria, the limiting values, the obtained values and the evaluation (criteria fulfilled or not fulfilled)
- GM/KG limiting curve according to SOLAS, Ch II-1, Regulation 5-1

When the actual loading condition is associated to the actual damage case(s) due to the casualty, the following output (damage stability) is to be available:

- Trim
- Heel
- Draft at the draft marks and perpendiculars
- Progressive flooding angle and corresponding progressive flooding openings
- GM value
- GZ values relevant to an adequate range of heeling (not less than 60°) available indicatively at the following intervals: 0 5 10 15 20 25 30 40 50 60 deg
• Compliance with stability criteria: listing of all calculated stability criteria, the limit values, the obtained values and the conclusions (criteria fulfilled or not fulfilled)

• The survivability criteria for Type 4 software (SRtP) are left to the discretion of the Administration

• Relevant flooding points (unprotected or weathertight) with the distance from the damage waterline to each point

• List of all flooded compartments with the permeability considered

• Amount of water in each flooded compartment

• Escape route immersion angles

• A profile view, deck views and cross-sections of the vessel indicating the flooded water-plane and the damaged compartments

5 Acceptable Tolerances (1 July 2020)

Depending on the type and scope of programs, the acceptable tolerances are to be determined differently, according to 3-A1/5.1 or 3-A1/5.2. In general, deviation from these tolerances is not to be accepted unless a satisfactory explanation for the difference is submitted for review and the same is satisfactorily confirmed by ABS that there would be no adverse effect on the safety of the vessel.

Examples of pre-programmed input data include the following:

• Hydrostatic data: Displacement, LCB, LCF, VCB, KMt and MCT vs. draft

• Stability data: KN or MS values at appropriate heel/trim angles vs. displacement, stability limits or allowable VCG.

• Compartment data: Volume, LCG, VCG, TCG and FSM/Grain heeling moments vs. level of the compartment’s contents.

Examples of output data include the following:

• Hydrostatic data: Displacement, LCB, LCF, VCB, KMt and MCT versus draft, as well as actual drafts, trim.

• Stability data: FSC (free surface correction), GZ-values, KG, GM, KG/GM limits, allowable grain heeling moments, derived stability criteria (e.g., areas under the GZ curve), weather criteria.

• Compartment data: Calculated Volume, LCG, VCG, TCG and FSM/Grain heeling moments vs. level of the compartment’s contents

The computational accuracy of the calculation program results is to be within the acceptable tolerances specified in appendices 3-A3/5.1 or 3-A3/5.2, of the results using an independent program or the approved stability information with identical input.

5.1 Calculation Program of the Approved Stability Information

Programs which use only pre-programmed data from the approved stability information as the basis for stability calculations are to have zero tolerances for the printouts of input data.

Output data tolerances are to be close to zero. However, small differences associated with calculation rounding or abridged input data are acceptable. Additionally differences associated with the use of hydrostatic and stability data for trims that differ from those in the approved stability information are acceptable subject to review by ABS.
5.2 Independent Program for Assessment of Stability

Programs which use hull form models as their basis for stability calculations are to have tolerances for the printouts of basic calculated data established against either data from the approved stability information or data obtained using the approval authority’s model. Acceptable tolerances shall be in accordance with 3-A1/Table 1.

**Table 1**
**Acceptable Tolerances (1 July 2020)**

<table>
<thead>
<tr>
<th>Hull Form Dependent</th>
<th>Acceptable Tolerance (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>±2%</td>
</tr>
<tr>
<td>Longitudinal center of buoyancy, from AP</td>
<td>±1% or 50 cm, whichever is greater</td>
</tr>
<tr>
<td>Vertical center of buoyancy</td>
<td>±1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Transverse center of buoyancy</td>
<td>±0.5% of B or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Longitudinal center of flotation, from AP</td>
<td>±1% or 50 cm, whichever is greater</td>
</tr>
<tr>
<td>Moment to trim 1 cm</td>
<td>±2%</td>
</tr>
<tr>
<td>Transverse metacentric height</td>
<td>±1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Longitudinal metacentric height</td>
<td>±1% or 50 cm, whichever is greater</td>
</tr>
<tr>
<td>Cross curves of stability</td>
<td>±5 cm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compartment Dependent</th>
<th>Acceptable Tolerance (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume or deadweight</td>
<td>±2%</td>
</tr>
<tr>
<td>Longitudinal center of gravity, from AP</td>
<td>±1% or 50 cm, whichever is greater</td>
</tr>
<tr>
<td>Vertical center of gravity</td>
<td>±1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Transverse center of gravity</td>
<td>±0.5% of B or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Free surface moment</td>
<td>±2%</td>
</tr>
<tr>
<td>Shifting moment</td>
<td>±5%</td>
</tr>
<tr>
<td>Level of contents</td>
<td>±2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trim and Stability</th>
<th>Acceptable Tolerance (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drafts (forward, aft, mean)</td>
<td>1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>GMT (both solid and corrected for free surfaces)</td>
<td>1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>GZ values</td>
<td>1% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Downflooding angle</td>
<td>2°</td>
</tr>
<tr>
<td>Equilibrium angles</td>
<td>1°</td>
</tr>
<tr>
<td>Distance from WL to unprotected and weathertight openings, or other relevant point, or other relevant point, if applicable</td>
<td>±5% or 5 cm, whichever is greater</td>
</tr>
<tr>
<td>Areas under righting arm curve</td>
<td>5% or 0.0012 mrad</td>
</tr>
</tbody>
</table>
Notes:
1 Deviation in % = [(base value – applicant’s value)/base value] × 100
   where the “base value” may be from the approved stability information or the society’s computer model
2 When applying a tolerance in 3-A1/5.1 TABLE 1 that contains two values, the allowable tolerance is the greater of the two values.
3 Where differences in calculation methodology exist between the programs used in the comparison, this may be a basis for accepting deviations greater than that specified in the table above provided a software examination is carried out in sufficient detail to clearly document that such differences are technically justifiable.
4 Deviation from these tolerances are not to be accepted unless ABS considers that there is a satisfactory explanation for the difference and that it is clearly evident from ABS’s stability calculations that the deviation does not impact compliance with the required stability criteria for the vessel under consideration.

6 Approval Procedure

6.1 Conditions of Approval of the Onboard Software for Stability Calculations
(1 July 2020)

The onboard software used for stability calculations is subject to approval, which is to include:

- Verification of type approval, if any,
- Verification that the data used is consistent with the current condition of the vessel (see appendix 3-A1/6.3),
- Verification and approval of the test conditions, and
- Verification that the software is appropriate for the type of vessel and stability calculations required.
- Verification that the software is installed so that failure of the primary computer or server does not prevent the stability calculation from being carried out (this is to be demonstrated onboard as noted below).
- Verification of functional requirements under 3-A1/4.

The satisfactory operation of the software for stability calculations is to be verified by testing upon installation on the primary computer or server and at least one back-up computer or redundant server onboard (see appendix 3-A1/8). A copy of the approved test conditions and the operation manual for the computer/software are to be available onboard.

6.2 General Approval (optional)

Upon receipt of application for general approval of the calculation program, ABS may provide the applicant with test data consisting of two or more design data sets, each of which is to include a vessel’s hull form data, compartmentation data, lightship characteristics and deadweight data, in sufficient detail to accurately define the vessel and its loading condition.

Acceptable hull form and compartmentation data may be in the form of surface coordinates for modeling the hull form and compartment boundaries (e.g., a table of offsets) or in the form of pre-calculated tabular data (e.g., hydrostatic tables, capacity tables) depending upon the form of data used by the software being submitted for approval. Alternatively, the general approval may be given based on at least two test vessels agreed upon between the applicant and ABS.

In general, the software is to be tested for two types of vessels for which approval is requested, with at least one design data set for each of the two types. Where approval is requested for only one type of vessel, a minimum of two data sets for different hull forms of that type of vessel are required to be tested.
For calculation software which is based on the input of hull form data, design data sets are to be provided for three types of vessels for which the software is to be approved, or a minimum of three data sets for different hull forms if approval is requested for only one type of vessel. Representative vessel types are those which, due to their different hull forms, typical arrangements and nature of cargo, require different design data.

The test data sets are to be used by the applicant to run the calculation program for the test vessels. The results obtained, together with the hydrostatic data and cross-curve data developed by the program, if appropriate are to be submitted to ABS for the assessment of the program’s computational accuracy. ABS is to perform parallel calculations using the same data sets and a comparison of these results will be made against the applicant’s submitted program’s results.

6.3 **Specific Approval** *(1 July 2020)*

ABS is to verify the accuracy of the computational results and actual vessel data used by the calculation program for the particular vessel on which the program will be installed.

Upon receipt of application for data verification, ABS and the applicant are to agree on a minimum of four loading conditions, taken from the vessel’s approved stability information, which are to be used as the test conditions.

Within the test conditions each compartment is to be loaded at least once. The test conditions normally are to cover the range of load drafts from the deepest envisaged loaded condition to the light ballast condition and are to include at least one departure and one arrival condition.

For Type 4 stability software for SRtP, ABS is to examine at least three damage cases, each of them associated with at least three loading conditions taken from the vessel’s approved stability information. Output of the software is to be compared with results of corresponding load/damage case in the approved damage stability booklet or an alternative independent software source.

ABS is to verify that the following data, submitted by the applicant, is consistent with arrangements and most recently approved lightship characteristics of the vessel according to current plans and documentation on file with ABS, subject to possible further verification onboard:

- Identification of the calculation program including version number.
- Main dimensions, hydrostatic particulars and, if applicable, the vessel profile.
- The position of the forward and after perpendiculars, and if appropriate, the calculation method to derive the forward and after drafts at the actual position of the vessel’s draft marks.
- Vessel lightweight and center of gravity derived from the most recently approved inclining experiment or light weight check.
- Lines plan, offset tables or other suitable presentation of hull form data if necessary for ABS to model the vessel.
- Compartment definitions, including frame spacing, and centers of volume, together with capacity tables (sounding/ullage tables), free surface corrections, if appropriate
- Cargo and Consumables distribution for each loading condition.

Verification by ABS does not absolve the applicant and shipowner of responsibility for ensuring that the information programmed into the onboard computer software is consistent with the current condition of the vessel.
7 Operation Manual

A simple and straightforward operation manual is to be provided, containing descriptions and instructions, as appropriate, for at least the following:

- Installation
- Function keys
- Menu displays
- Input and output data
- Required minimum hardware to operate the software
- Use of the test loading conditions
- Computer-guided dialogue steps
- List of warnings

8 Installation Testing *(1 July 2020)*

To ensure correct working of the computer after the final or updated software has been installed, it is the responsibility of the vessel’s master to have test calculations carried out according to the following pattern in the presence of the Surveyor:

- From the approved test conditions at least one load case (other than lightship) is to be calculated.

  *Note:*
  Actual loading condition results are not suitable for checking the correct working of the computer.

- Normally, the test conditions are permanently stored in the computer.

Steps to be performed:

- Retrieve the test load case and start a calculation run; compare the stability results with those in the documentation.

- Change several items of deadweight (tank weights and the cargo weight) sufficiently to change the draft or displacement by at least 10%. The results are to be reviewed to ensure that they differ in a logical way from those of the approved test condition.

- Revise the above modified load condition to restore the initial test condition and compare the results. **Confirm that the relevant input and output data of the approved test condition have been replicated.**

- Alternatively, one or more test conditions shall be selected and the test calculation performed by entering all deadweight data for each selected test condition into the program as if it were a proposed loading. The results shall be verified as identical to the results in the approved copy of the test conditions.

9 Periodical Testing

It is the responsibility of the vessel’s master to check the accuracy of the onboard computer for stability calculations at each Annual Survey by applying at least one approved test condition.

If the Surveyor is not present for the computer check, a copy of the test condition results obtained by the computer check is to be retained onboard as documentation of satisfactory testing for the Surveyor’s verification.

At each Special Periodical Survey, this checking for all approved test loading conditions is to be done in presence of the surveyor.
The testing procedure is to be carried out in accordance with appendix 3-A1/8.

10 Other Requirements

The following features are to be provided to the software:

- Protection against unintentional or unauthorized modification of programs and data is to be provided.
- The program is to monitor operations and activate an alarm when the program is incorrectly or abnormally used.
- The program and any data stored in the system are to be protected from corruption by loss of power.
- Error messages with regard to limitations such as filling a compartment beyond capacity, or exceeding the assigned load line, etc. are to be included.
# 4 Ship Arrangements

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CHAPTER 4 Ship Arrangements

SECTION 1 Segregation of the Cargo Area

1

Hold spaces are to be segregated from machinery and boiler spaces, accommodation spaces, service spaces and control stations, chain lockers, drinking and domestic water tanks and from stores. Hold spaces are to be located forward of machinery spaces of category A, other than those deemed necessary by ABS for the safety or navigation of the ship. Bow thrusters, if fitted, may be located forward of the hold spaces.

2

Segregation of hold spaces from spaces referred to in section 4-1/1 (or spaces either below or outboard of the hold spaces which contain a source of ignition or fire hazard) is to be effected by cofferdams or fuel oil tanks. If there is no source of ignition or fire hazard in the adjoining space, segregation may be by a steel bulkhead which is gastight up to the bulkhead or freeboard deck. Separation of hold spaces is to be gastight for full height of the hold space.

Hold spaces are to be segregated from the sea by a double bottom and longitudinal bulkhead forming side tanks.

A fire analysis, as mentioned in Section 2-1, may require a blast wall be provided at the fore and aft ends of the cargo space.

3

Any piping system which may contain cargo is to:

i) Be segregated from other piping systems, except where interconnections are required for cargo-related operations such as purging, gas-freeing or inerting. In such cases, precautions are to be taken to ensure that cargo cannot enter such other piping systems through the interconnections.

ii) Except as provided for a fuel gas system, not pass through any accommodation space, service space or control station or through a machinery space other than a cargo pump room or cargo compressor space.

iii) Except for bow or stern loading and unloading arrangements, in accordance with Section 4-8, and except as provided for fuel gas systems, be located in the cargo area above the open deck.

iv) Except for athwartship shore connection piping not subject to internal pressure at sea, be located inboard of the transverse tank location requirements of Section 3-6.

4

Means provided for the emergency release of cargo (blow down) are to meet the requirements of section 4-1/3. Such emergency cargo release systems are to be designed and located based on a gas dispersion analysis and the associated piping is not to pass through accommodations.

Gas dispersion analysis is to be carried out. Vent stack location and height need to be determined based on the dispersion analysis. For dispersion analysis, the ABS Rules for Building and Classing Facilities on Offshore Installations and API RP 500 series guidelines are to be followed.

Where a vent stack is provided for safe discharge of cargo during emergency release, the associated piping is not to pass through accommodations.
Arrangements are to be made for sealing the weather decks in way of openings for cargo containment systems. Hold space covers are to be designed to prevent any leakage of water or water vapor into the hold which could allow the formation of ice or loss of inert gas.

The number of hold spaces should be determined based upon damage and intact stability criteria specified in Chapter 3.

Further total cargo volume stored in each hold space should be subdivided by providing multiple cargo tanks in a hold space. Each cargo tank volume must not exceed the relieving capacity for blow down, normal operation, emergency operation and accidental events as specified in this Guide.
CHAPTER 4 Ship Arrangements

SECTION 2 Accommodations, Service and Machinery Spaces and Control Stations

No accommodation space, service space or control station is to be located within the cargo area. The bulkheads of accommodation spaces, service spaces or control stations which face the cargo area are to be so located as to avoid the entry of gas from the hold space to such spaces through a single failure of a deck or bulkhead.

<table>
<thead>
<tr>
<th>Accommodation Space</th>
<th>Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>hold space where cargo is carried in a cargo containment system</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accommodation Space</th>
<th>Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>hold space where cargo is carried in a cargo containment system</td>
<td></td>
</tr>
</tbody>
</table>

1

In order to guard against the danger of hazardous vapors, due consideration is to be given to the location of air intakes and openings into accommodation, service and machinery spaces and control stations in relation to cargo piping, cargo vent systems and machinery space exhausts from gas burning arrangements.

Compliance with other relevant paragraphs of the Guide and in particular with sections 4-2/4 and 4-8, where applicable, would also ensure compliance with this Subsection.

2

Access through doors, gastight or otherwise, is not to be permitted from a gas-safe space to a gas-dangerous space, except for access to service spaces forward of the cargo area through air-locks, as permitted by section 4-6/1, when accommodation spaces are aft.

3

Entrances, air inlets and openings to accommodation spaces, service spaces, machinery spaces and control stations are not to face the cargo area. They are to be located on the end bulkhead not facing the cargo area or on the outboard side of the superstructure or deckhouse or on both at a distance of at least 4% of the length ($L$) of the ship, but not less than 3 m from the end of the superstructure or deckhouse facing the cargo area. This distance, however, need not exceed 5 m. Windows and sidescuttles facing the cargo area and on the sides of the superstructures or deckhouses within the distance mentioned above are to be of the fixed (non-opening) type.

Wheelhouse windows may be non-fixed and wheelhouse doors may be located within the above limits, so long as they are so designed that a rapid and efficient gas and vapor tightening of the wheelhouse can be ensured.

Air outlets are subject to the same requirements as air inlets and air intakes.
Sidescuttles in the shell below the uppermost continuous deck and in the first tier of the superstructure or deckhouse are to be of the fixed (non-opening) type.

All air intakes and openings into the accommodation spaces, service spaces and control stations are to be fitted with closing devices.

5.1 When internal closing is required, this is to include both ventilation intakes and outlets.

5.2 The closing devices are to give a reasonable degree of gas tightness. Ordinary steel fire-flaps without gaskets/seals are normally not to be considered satisfactory.
CHAPTER 4 Ship Arrangements

SECTION 3 Cargo Pump Room and Cargo Compressor Rooms

1

Rooms containing cargo handling systems and equipment are to be situated above the weather deck and located within the cargo area, unless specially approved by ABS. Such spaces are to be treated as cargo pump rooms for the purpose of fire protection according to regulation 11-2/58 of the 1983 SOLAS amendments.

Cargo and fuel gas handling equipment is to be located in the process area. Any enclosed space in the process area handling cargo gas is to be treated as a cargo pump rooms for the purpose of fire protection according to regulation 11-2/58 of the 1983 SOLAS amendments.

Alternate arrangements are to be specially considered by ABS and details are to be submitted for review and approval.

2

When rooms containing cargo handling systems and equipment are permitted to be fitted above or below the weather deck at the after end of the aftermost hold space or at the forward end of the forwardmost hold space, the limits of the cargo area as defined in 1-2/8 are to be extended to include such spaces for the full breadth and depth of the ship and deck areas above those spaces.

3

Where the limits of the cargo area are extended by appendix 4-3/2, the bulkhead which separates the rooms containing cargo handling systems and equipment from accommodation and service spaces, control stations and machinery spaces of category A is to be so located as to avoid the entry of gas to these spaces through a single failure of a deck or bulkhead.

When rooms containing cargo handling systems and equipment are permitted to be fitted at the after end of the aftermost hold space, the bulkhead which separates such spaces from accommodation and service spaces, control stations and machinery spaces of category A is to be so located as to avoid the entry of gas to these spaces through a single failure of a deck or bulkhead. The same condition is also to be satisfied when such spaces fitted within the cargo area have a bulkhead in common with accommodation and service spaces, control stations and machinery spaces of category A.

4

Arrangements of rooms containing cargo handling systems and equipment are to be such as to ensure safe, unrestricted access for personnel wearing protective clothing and breathing apparatus, and in the event of injury, to allow unconscious personnel to be removed. All valves necessary for cargo handling are to be readily accessible to personnel wearing protective clothing. Suitable arrangements are to be made to deal with gas freeing of such spaces.
CHAPTER 4  Ship Arrangements

SECTION 4  Cargo Control Rooms

1

Any cargo control room is to be above the weather deck and may be located in the cargo area. The cargo control room may be located within the accommodation spaces, service spaces or control stations provided the cargo control room is a gas-safe space and the following conditions are complied with:

The cargo control room is a gas-safe space, and:

i) If the entrance complies with section 4-2/3, the control room may have access to the spaces described above.

ii) If the entrance does not comply with section 4-2/3, the control room is to have no access to the spaces described above and the boundaries to such spaces are to be insulated to “A-60” class integrity.

2

If the cargo control room is designed to be a gas-safe space, instrumentation, as far as possible, is to be by indirect-reading systems and, in any case, is to be designed to prevent any escape of gas into the atmosphere of that space. Location of the gas detector within the cargo control room will not violate the gas-safe space if installed in accordance with section 14-6/5.

3

If the cargo control room is a gas-dangerous space, sources of ignition are to be excluded. Consideration is to be paid to the safety characteristics of any electrical installations.
CHAPTER 4  Ship Arrangements

SECTION 5  Access to Spaces in the Cargo Area

1

Visual inspection is to be possible of at least one side of the inner hull structure without the removal of any fixed structure or fitting. If such a visual inspection is only possible at the outer face of the inner hull, the inner hull is not to be a fuel-oil tank boundary wall.

2

Inspection of one side of any insulation in hold spaces is to be possible. If the integrity of the insulation system can be verified by inspection of the outside of the hold space boundary when tanks are at service temperature, inspection of one side of the insulation in the hold space need not be required.

3

Arrangements for hold spaces, void spaces and other spaces that could be considered gas-dangerous and cargo tanks are to be such as to allow entry and inspection of any such space by personnel wearing protective clothing and breathing apparatus, and in the event of injury, to allow unconscious personnel to be removed from the space and are to comply with the following:

3.1

Access is to be provided:

i) If there is no access for inspection of individual cargo tank pressure container from inside, then a risk-based inspection program is to be developed based on design requirements. The designer is to show how they are planning to perform the periodic inspection of each individual cargo tank bottle required by the ABS Rules and verify integrity of pressurized containers for safe service.

ii) The inspection program is to address inspection from inside and outside, and the validity of the results.

iii) Through horizontal openings, hatches or manholes, the dimensions of which are to be sufficient to allow a person wearing a breathing apparatus to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. The minimum clear opening is to be not less than 600 mm by 600 mm; and

iv) Through vertical openings, or manholes providing passage through the length and breadth of the space, the minimum clear opening of which is to be not less than 600 mm by 800 mm at a height of not more than 600 mm from the bottom plating, unless gratings or other footholds are provided.

3.2

The requirements of 4-5/3.1iii) and 4-5/3.1iv) do not apply to spaces described in 1-2/22.v. Such spaces are to be provided only with direct or indirect access from the open weather deck, not including an enclosed gas-safe space.

4

Access from the open weather deck to gas-safe spaces is to be located in a gas-safe zone at least 2.4 m above the weather deck unless the access is by means of an air-lock in accordance with Section 4-6.
5

Designated passageways below and above cargo tanks are to have at least the cross sections as required by 4-5/3.1iv).

6

6.1

Where the Surveyor requires to pass between the surfaces to be inspected, flat or curved, and structural elements such as deck beams, stiffeners, frames, girders etc., the distance between that surface and the free edge of the structural elements is to be at least 380 mm. The distance between the surface to be inspected and the surface to which the above structural elements are fitted, e.g., deck, bulkhead or shell, is to be at least 450 mm in case of a curved tank surface. (See 4-5/Figure 1.)

FIGURE 1

6.2

Where the Surveyor does not require to pass between the surface to be inspected and any part of the structure, for visibility reasons, the distance between the free edge of that structural element and the surface to be inspected is to be at least 50 mm or half the breadth of the structure’s face plate, whichever is the larger. (See 4-5/Figure 1.)

6.3

If for inspection of a curved surface the Surveyor requires to pass between that surface and another surface, flat or curved, to which no structural elements are fitted, the distance between both surfaces is to be at least 380 mm. (See 4-5/Figure 2.) Where the Surveyor does not require to pass between that curved surface and another surface, a smaller distance than 380 mm may be accepted, taking into account the shape of the curved surface. If smaller distances are proposed in design, that is to be addressed by means of inspection.
If necessary for inspection, fixed or portable staging is to be installed. This staging is not to impair the distances otherwise required.

The term “minimum clear opening of not less than 600 ×600 mm” means that such openings may have corner radii up to 100 mm maximum.

The term “minimum clear opening of not less than 600 ×800 mm” also includes an opening of the following size:
CHAPTER 4  Ship Arrangements

SECTION 6  Air-locks

1 An air-lock is only to be permitted between a gas-dangerous zone on the open weather deck and a gas-safe space and is to consist of two steel doors substantially gastight spaced at least 1.5 m, but not more than 2.5 m, apart.

2 The doors should be self-closing and without any holding back arrangements.

3 An audible and visual alarm system to give a warning on both sides of the air-lock is to be provided to indicate if more than one door is moved from the closed position.

4 Electrical equipment which is not of the certified-safe type in spaces protected by air-locks is to be de-energized upon loss of overpressure in the space (see also Section 11-2/4.5). Electrical equipment which is not of the certified safe type for maneuvering, anchoring and mooring equipment as well as the emergency fire pumps is not to be located in spaces to be protected by air-locks. The following means are considered acceptable alternatives to differential pressure sensing devices in spaces having a ventilation rate not less than 30 air changes per hour:

   i) Monitoring of current or power in the electrical supply to the ventilation motors; or
   ii) Air flow sensors in the ventilation ducts.

In spaces where the ventilation rate is less than 30 air changes per hour and where one of the above alternatives is fitted, in addition to the alarms required, arrangements are to be made to de-energize electrical equipment which is not of the certified safe type, if more than one air-lock door is moved from the closed position.

5 The air-lock space is to be mechanically ventilated from a gas-safe space and maintained at an overpressure to the gas-dangerous zone on the open weather deck.

6 The air-lock space is to be monitored for cargo vapor.

7 Subject to the requirements of the International Convention on Load Lines in force, the door sill is not to be less than 300 mm in height.
CHAPTER 4  Ship Arrangements

SECTION 7  Bilge, Ballast and Fuel Oil Arrangements

1

Suitable drainage arrangements for dealing with any leakage into the hold or insulation spaces through adjacent ship structure are to be provided. The suction is not to be led to pumps inside the machinery space. Means of detecting such leakage are to be provided.

2

Ballast spaces, fuel oil tanks and gas-safe spaces may be connected to pumps in the machinery spaces. Duct keels may be connected to pumps in the machinery spaces, provided the connections are led directly to the pumps and the discharge from the pumps led directly overboard with no valves or manifolds in either line which could connect the line from the duct keel to lines serving gas-safe spaces. Pump vents are not to be open to machinery spaces.
CHAPTER 4 Ship Arrangements

SECTION 8 Athwartships, Bow, Stern and Turret (Internal/External) Loading and Unloading Arrangements

1 Subject to the approval of ABS and to the requirements of this Section, in addition to a midship manifold, cargo piping may be arranged to permit bow, stern and Turret (Internal/External) loading and unloading.

2 Portable arrangements are not to be permitted.

3 In addition to the requirements of Section 4-5, the following provisions apply to cargo piping and related piping equipment:

3.1 Cargo piping and related piping equipment outside the cargo area are to have only welded connections. The piping outside the cargo area is to run on the open deck and is to be at least 760 mm inboard, except for athwartships shore connection piping. Such piping is to be clearly identified and fitted with a shutoff valve at its connection to the cargo piping system within the cargo area. At this location, it is also to be capable of being separated by means of a removable spool piece and blank flanges when not in use.

3.2 The piping is to be full penetration butt welded and fully radiographed, regardless of pipe diameter and design temperature. Flange connections in the piping are only permitted within the cargo area and at the shore connection.

3.3 Arrangements are to be made to allow such piping to be purged and gas-freed after use. When not in use, the spool pieces are to be removed and the pipe ends be blank-flanged. The vent pipes connected with the purge are to be located in the cargo area.

4 Entrances, air inlets and openings to accommodation spaces, service spaces, machinery spaces and control stations are not to face the cargo shore connection location of bow or stern loading and unloading arrangements. They are to be located on the outboard side of the superstructure or deckhouse at a distance of at least 4% of the length of the ship, but not less than 3 m from the end of the superstructure or deckhouse facing the cargo shore connection location of the bow or stern loading and unloading arrangements. This distance, however, need not exceed 5 m. Sidescuttles facing the shore connection location and on the sides of the superstructure or deckhouse within the distance mentioned above are to be of the fixed (non-opening) type. In addition, during the use of the bow or stern loading and unloading arrangements, all doors, ports and other openings on the corresponding superstructure or deckhouse side are to be kept closed. Where in the case of small ships, compliance with Section 4-2/4 and this Subsection is not possible, ABS may approve relaxations from the above requirements with supporting technical data.

5 Deck openings and air inlets to spaces within distances of 10 m from the cargo shore connection location are to be kept closed during the use of bow or stern loading or unloading arrangements.
6

Electrical equipment within a zone of 3 m from the cargo shore connection location is to be in accordance with Chapter 11.

7

Fire-fighting arrangements for the bow or stern loading and unloading areas are to be in accordance with Sections 12-3/1.iii) and 12-4/7.

8

Means of communication between the cargo control station and the shore connection location are to be provided and, if necessary, certified safe.

9

For loading through single point mooring utilizing an internal or external turret, please refer to the ABS Rules for Building and Classing Single Point Moorings for additional requirements. Also, for piping within the turret area, please refer to the ABS Rules for Building and Classing Facilities on Offshore Installations for further requirements.
CHAPTER 4 Ship Arrangements

SECTION 9 Hull Structure

All hull structure is to be in accordance with Part 3 of the ABS Marine Vessel Rules.

i) CNG carriers are to have still-water bending moments submitted for all anticipated conditions such as full load, empty and loading and discharge.

ii) Loading guidance is to be provided.

iii) Hull structure in way of cargo tank foundations, chocks, keys and braces is to be of sufficient strength to support the containment system when subject to design loads.

iv) Material of the hull structure is to be to the ABS Marine Vessel Rules.

v) Where thermal protection is required by Section 5-7, the temperature of the material is to be determined.
Satisfactory arrangements are to be provided to safeguard the crew in reaching all parts used in the necessary work of the ship. See Section 3-2-17/3 of the ABS Marine Vessel Rules.

For process plant forward, appropriate arrangements are to be made. Please see the ABS Rules for Building and Classing Facilities on Offshore Installations in addition to the above for further details.
CHAPTER 4  Ship Arrangements

SECTION 11  Emergency Escape and Safe Refuge

Requirements of applicable Rules and Regulations (ABS, SOLAS, administration such as USCG, etc.) are to apply as primary requirements. Also, substantial special studies are to be carried out to provide safe escape routes and refuge. Such studies are to consider, as applicable, height of cargo tanks, location of process areas and presence of a turret system forward. Results of all studies conducted are to be submitted for ABS approval. ABS participation in such studies, where possible, would normally be beneficial.
### CHAPTER 5 Cargo Containment

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CHAPTER 5  Cargo Containment

SECTION 1  General

1

In addition to the definitions in Appendix 1-A1, the definitions given in this Chapter apply throughout the Guide.

2

For CNG carriers, the cargo containment system is comprised of Type 1, Type 2, Type 3 and Type 4 cargo tanks. ABS will consider cargo tank designs based on the following:

- **Type 1.** Compliance with Probabilistic Limit State Design in accordance with the principles outlined in Appendix 5-A1 and agreed upon a recognized standard by ABS.

- **Type 2, Type 3 and Type 4:**

  Compliance with a recognized pressure vessel code

  or

  In substantial agreement with a recognized pressure vessel code and any deviations from the latter are supported by Probabilistic Limit State Design in accordance with the principles outlined in Appendix 5-A1 and as agreed upon to a recognized standard by ABS.
CHAPTER 5 Cargo Containment

SECTION 2 Definitions

1 Cargo Tanks

1.1 Cargo Tanks are self-supporting. They do not form part of the ship’s hull and are not essential to the hull strength. There are four types of cargo tanks referred to in Sections 5-2/1.2 to 5-2/1.5. Cargo tanks are to be designed using pressure vessel design codes, prototype tests, refined analytical tools and other analysis methods to determine stress levels, fatigue life and crack propagation characteristics.

Where cargo tanks are primarily constructed using design principles based on a recognized pressure vessel code, the acceptable design pressure, $P_o$, is to be based on limitations of the applicable design code. Where the design of cargo tanks is based on Limit State and Reliability-based principles, guidelines from Appendix 5-A1 are to be followed for the acceptable design pressure, $P_o$.

1.2 Type 1 Cargo Tanks are metallic tanks with nominal diameter 200 mm (8 in.) or less with length-to-diameter ratio greater than or equal to 1000.

1.3 Type 2 Cargo Tanks are metallic tanks with nominal diameters above 200 mm (8 in.) or greater with length-to-diameter ratio less than or equal to 100.

1.4 Type 3 Cargo Tanks are tanks constructed from composite materials or combination of metallic and nonmetallic materials.

1.5 Type 4 Cargo Tanks are tanks constructed with an inside metal liner and wrapped outside with high strength steel wires.

1.6 Cargo tank designs which are not covered by above types, must be fully evaluated to determine the design criteria that are to be followed for acceptance on a case-by-case basis.

2 Pressure

2.1 Design Pressure

2.1.1 The Design Pressure, $P_o$, is the maximum gauge pressure at the top of the cargo tank and which, together with the applicable coincident metal temperature, is used in the design of the tank. The pressure at the top of the cargo tank is also the basis for the pressure setting of the relief devices protecting the cargo tank.

2.1.2 For cargo tanks where there is no temperature control, $P_o$ should assume that the cargo has warmed up to 45°C from the loading condition. However, lesser values of this temperature may be
acceptable by ABS for ships operating in restricted areas or on voyages of restricted duration and account may be taken in such cases of any insulation of the tanks.

Such calculations are to be based on the greater of the expected voyage time plus two days or twice the expected voyage time. Conversely, higher values of this temperature may be required for ships permanently operating in areas of high ambient temperature.

2.1.3

In all cases, $P_o$ is not to be less than MARVS.

2.2 **Maximum Allowable Operating Pressure (MAOP)**

The *Maximum Allowable Operating Pressure (MAOP)* is the maximum sustained storage/loading/unloading pressure that is allowed during service at coincident fluid/gas temperature. The normal operating pressure shall not exceed the maximum allowable operating pressure. MAOP is less than design pressure.

2.3 **Normal Storage Pressure**

The *Normal Storage Pressure* is the design storage pressure at storage temperature during voyage.

2.4 **Pipe Mill Test Pressure**

The *Pipe Mill Test Pressure* is the pressure of the hydrostatic pressure test performed at pipe mill during pipe manufacture.

2.5 **Pressure Test**

*Pressure Test* is performed on each cargo cylinder and each cargo tank after fabrication of cargo cylinder and cargo tank.

2.6 **Burst Pressure**

The *Burst Pressure* is the pressure at which the cargo cylinder and cargo tank has no capacity left to withstand pressure and will lead to bursting.

3 **Pressure Regulating System (PRS)**

The *Pressure Regulating System (PRS)* is the system that controls the pressure in the cargo containment system during loading, unloading and storage below MAOP during normal operation.

4 **Pressure Safety/Relief System (PSR)**

The *Pressure Safety/Relief System (PSR)* is an independent system that maintains the pressure of the cargo containment system at or below design pressure in any event. This is independent of PRS.
5 Design Temperatures

5.1 Minimum Design Metal Temperature (MDMT)
The *Minimum Design Metal Temperature (MDMT)* is the lowest temperature to which the cargo tank will be exposed. This temperature is to be determined considering the lowest temperature to which the cargo tank will normally be exposed in service during loading, unloading and storage, along with any process upsets. Provision is to be made to the satisfaction of ABS to ensure that the cargo tank or cargo temperature cannot be reduced below the design temperature during operation.

5.2 Minimum Accidental Design Metal Temperature (MADMT)
The *Minimum Accidental Design Metal Temperature (MADMT)* is the lowest temperature to which the cargo tank will be exposed during accidental events such as blowdown, dumps, jet impingement, etc. The design temperatures for accidental events or blow-down, such as release of cargo, that will result in JT effect must be considered in the design at the point of jet impingement and at the crack tip, using appropriate material properties at the lowest expected metal temperature. The designer is to submit appropriate calculations or experimental results demonstrating the result of these events, including expected frequency of occurrence.

5.3 Maximum Design Temperature
The *Maximum Design Temperature* is the maximum anticipated temperature of cargo at design pressure under all normal operating conditions. In accordance with Section 5-2/2.2 above, the maximum design temperature is normally not less than 45°C, unless there are means provided for cargo temperature control.
CHAPTER 5 Cargo Containment

SECTION 3 Design Loads

1 General

1.1 Cargo tanks, together with their supports, connected manifold piping and other fixtures are to be designed taking into account proper combinations of the following loads:

- Design Internal Pressure at the top of the tank, \( P_o \)
- External Pressure
- Dynamic Loads due to the motions of the ship
- Thermal Loads
- Loads corresponding to ship deflection and due to Relative Motion
- Cargo tank and cargo weight with the corresponding reactions in way of supports
- Insulation Weight
- Cyclic Internal Pressure
- Liquid Static Head (if applicable)
- Header Loads at Nozzles
- Vibrations
- Load due to process parameters
- Accidental Loads
- Additional Loads resulting from design layout
- Residual loads due to fabrication

The extent to which these loads are to be considered depends on the type of tank, and is more fully detailed in the following paragraphs.

1.2 Account is to be taken of the loads corresponding to the pressure test referred to in Section 5-10/4 and any loads that may result during handling, transportation, installation and commissioning.

1.3 The tanks and their supports are to be designed for the most unfavorable static heel angle within the range 0° to 30° without exceeding allowable stresses given in Section 5-5.

2 Internal Pressure

2.1 The internal pressure, \( P_{eq} \) in bars gauge, resulting from the design cargo pressure, \( P_o \), and the internal fluid pressure, \( P_{gd} \) defined in Section 5-3/2.2, is to be calculated as follows:

\[
P_{eq} = P_o + (P_{gd})_{max} \quad \text{(bar)}
\]
Internal pressure, $P_{eq}$, is to be considered in determining cargo tank thickness as per Section 5-4.

### 2.2 Where fluid is used for transfer of cargo from the cargo tank and dense phase fluid or condensate being stored in the cargo tank, then the internal fluid pressures ($P_{gd,max}$) is the sum of static and dynamic components due to:

- Static fluid pressure head, and
- Those resulting from the acceleration of center of gravity of the cargo due to the motions of the ship referred to in Section 5-3/4.1.

### 3 External Pressure

External design pressure loads are to be based on the difference between the minimum internal pressure (vacuum) and the maximum external pressure to which any portion of the tank may be simultaneously subjected.

### 4 Dynamic Loads Due to Ship Motions

#### 4.1

The determination of dynamic loads is to take into consideration the long-term distribution of ship motions in irregular seas, including the effects of surge, sway, heave, roll, pitch and yaw, which the ship will experience during its operating life (normally taken as corresponding to $10^8$ wave encounters). Account may be taken of reduction in dynamic loads due to necessary speed reduction and variation of heading when this consideration forms a part of the hull strength assessment.

When CNG carrier loading and unloading operation is done offshore using SPM or Turret, appropriate dynamic loads are to be determined for the duration of this operation using the ABS Rules for Building and Classing Single Point Moorings or ABS Rules for Building and Classing Offshore Installations.

#### 4.2

For design against plastic deformation and buckling, dynamic loads are to be taken as the most probable largest loads that the ship will encounter during its operating life (normally taken as corresponding to a probability level of $10^{-8}$). Guidance formulae for acceleration components are given in Section 5-12.

#### 4.3

When design against fatigue is to be considered, the dynamic spectrum is to be determined by long-term distribution calculation based on the operating life of the ship (normally taken as corresponding to $10^8$ wave encounters). If simplified dynamic loading spectra are used for the estimation of the fatigue life, these will be specially considered by ABS.

#### 4.4

Ships for restricted service will be given a special consideration.

#### 4.5

The accelerations acting on tanks are estimated at their center of gravity and are to include the following components:

- **Vertical acceleration**: motion accelerations of heave, pitch and, possibly, roll (normal to the ship base)
- **Transverse acceleration**: motion accelerations of sway, yaw and roll; and gravity component of roll
- **Longitudinal acceleration**: motion accelerations of surge and pitch; and gravity component of pitch
5 **Thermal Loads**

5.1 Transient thermal loads during cooling down periods, loading and unloading are to be considered for tanks intended for low temperature or ambient temperature cargo, as may be applicable.

5.2 Stationary thermal loads are to be considered for cargo tanks where the design supporting arrangement, manifolds and operating temperature may give rise to significant thermal stresses.

6 **Loads on Supports**

The loads on supports are covered in Section 5-6.

7 **Vibration**

Vibration caused by propeller, machinery, waves and any other sources acting on the hull, as well as those that may be induced by cargo operations, are to be considered in the vibration analysis for the cargo tanks. This vibration analysis shall be carried out to ensure that fatigue and other stresses are within acceptable limits and do not lead to fatigue failure for cargo tanks, manifold, supports and associated piping.
CHAPTER 5 Cargo Containment

SECTION 4 Structural Analyses

1 Type 1, Type 2 Type 3 and Type 4 Cargo Tanks

For cargo tanks of these types, the following are applicable:

1.1 Cargo Tank Design Criteria

1.1.1 Where cargo tanks are designed based on a recognized pressure vessel code and material requirements as given in Chapter 7, the requirements of the codes are to be fully complied with. ABS will review the design to verify compliance.

The thickness and form of all pressure-containing parts of cargo tanks under internal pressure are to be determined according to a standard acceptable to ABS. These calculations in all cases are to be based on generally-accepted pressure vessel design theory. Openings in pressure-containing parts of cargo tanks are to be reinforced in accordance with a standard acceptable to ABS.

Where a certain aspect of the design is not in full compliance with a recognized pressure vessel code, the specific variations are to be advised and justified and will be reviewed by ABS on a case-by-case basis. Alternatively, design can be accepted for compliance with Section 5-4/1.1.2 requirements.

1.1.2 When Section 5-4/1.1.1 is not applicable, analyses are to be carried out to demonstrate the validity of the design using a probabilistic limit state approach (Appendix 5-A1) and the following deterministic analysis requirements.

1.1.2(a) The cargo tank is to be subject to fatigue analysis, considering all fatigue loads and their appropriate combinations for the life of the cargo tanks. Design S-N curves used in the analysis shall be applicable to the materials and weldments, construction details, fabrication procedures and applicable state of the stress envisioned. Fatigue testing of the cargo tank as per Section 5-10/11 is required to validate S-N curve analysis. The cumulative fatigue damage due to loads, as defined in Section 5-3/1, is not to exceed 0.1. The minimum design life of a CNG carrier is not to be less than 20 years, and the calculated fatigue life based on the S-N curve approach is to have a minimum factor of safety of 10.

1.1.2(b) Additional fatigue analysis using fracture mechanics crack propagation calculations shall be carried out for the cargo tank. The analysis may be carried out in accordance with ASME B & PV, API 579 or BS 7910 guidelines. The analysis is to assume crack-like defects located in parent metal, weld metal and HAZ. The assumed initial defect size in the analysis is to reflect guaranteed NDT sensitivity limit.

i) If the analysis shows a “leak before failure (LBF)” condition, then the requirements demonstrated in Section 5-4/1.1.2(a) are adequate for the acceptance of the design.

LBF is defined herein from a practical standpoint of view. In fracture mechanics terms, it means that critical flaw depth for a selected aspect ratio is much higher than the material wall thickness of the cargo containment system. However, in practical terms, it is defined as a surface/embedded flaw grown into a through-thickness flaw or a through-thickness flaw itself is stable enough to detect an observable leak and the flaw is stable over a period of time in spite of JT effect prevailing at the crack tip. Fast uncontrolled fracture of the cargo tank does not occur during this period and the leak can be mitigated effectively through cargo hold vent and blow down systems.
When a LBF condition is not demonstrated, the following requirements are to be satisfied for the validity of the design.

The calculated number of design load cycles is to be computed based on an allowable assumed initial surface flaw size (with minimum depth-to-length ratio of 1:3) grown under all fatigue loads and their appropriate combinations to that of an allowable final crack depth relative to critical crack depth and wall thickness of the material. Critical crack depth for a given loading condition is defined as: the crack depth at which the stress intensity becomes equal to material toughness value, $K_{IC}$, i.e., onset of unstable crack growth occurs. The calculated number of design load cycles is to be taken as the lesser of the following:

- The number of cycles corresponding to one-half the number of cycles required to propagate a crack from the initial assumed flaw size to the theoretical critical crack depth.
- The number of cycles required to propagate a crack from the initial assumed flaw size to a depth equal to 25% of the theoretical critical crack or 25% of wall thickness, whichever is smaller.

Only in the case of a Type 1 cargo containment system, if the above requirement in Section 5-4/1.1.2(b)ii) is not demonstrated by analysis, then experimental demonstration of three times the design number of cycles by actual prototype testing shall be acceptable.

1.1.2(c) In the above analysis, as per Section 5-4/1.1.2(b)ii), ductile failure mode is mandatory and is to be demonstrated during prototype testing of the cargo cylinder/cargo tank as given in Section 5-10/11. In ductile failure mode, no physical separation of material into fragments is expected. Whenever small fragments are observed during prototype testing, scanning electron microscopic examination of fractured surfaces is to be carried out to demonstrate complete ductile failure mode at the microstructural level at service and JT temperatures.

1.1.3 When LBF design criterion is not demonstrated in the design analysis, provision for monitoring subcritical crack growth in the cargo tanks is required. The full scheme of monitoring subcritical crack growth must be submitted for ABS review and approval, prior to application of this paragraph.

The consequence of failure will form the basis for the extent of monitoring required.

1.2 Analysis

The effects of all static and dynamic loads as stated in Section 5-3 under all operating conditions are to be used to determine the suitability of the cargo tank with respect to:

- Local Yielding
- Plastic Collapse
- Crack Propagation (Stable and unstable)
- Fatigue Failure
- Burst

Note:

The above analyses can be either deterministic or probabilistic in approach. The probabilistic analysis is to follow guidelines as given in Appendix 5-A1. However, inspection and testing as specified in this Chapter are mandatory minimum requirements for both approaches.
1.2.1 A three-dimensional analysis is to be carried out to evaluate the stress levels contributed by the ship’s hull. The model for this analysis is to include the cargo tank with its supporting and keying system as well as a reasonable part of the hull.

1.2.2 A complete analysis of the particular ship accelerations and motions in irregular waves and of the response of the ship and its cargo tanks to these forces and motions is to be performed unless these data are available from similar ships.

1.2.3 A buckling analysis is to consider the maximum construction tolerances.

1.2.4 Where cargo tanks have not had prior service experience, a model/prototype test will be required. The model/prototype test program is to be submitted for review to determine that it covers as a minimum, the following for the cargo tank:

- Static Strength Capacity
- Fatigue Performance
- Burst Capacity

1.3 Buckling
The thickness and form of cargo tanks subject to external pressure and other loads causing compressive stresses are to be designed to a standard acceptable to ABS. In all cases, these calculations are to be based on generally accepted pressure vessel buckling theory and are to adequately account for the difference in theoretical and actual buckling stress as a result of plate edge misalignment, straightness, ovality and deviation from true circular form over a specified arc or chord length.

1.4 Material Property Data
The following material property data are to be generated as per the requirements of Chapter 7.

1.4.1 Mechanical Properties
Mechanical property data of material (such as yield strength, tensile strength, elongation, impact toughness etc.) used in the above design analysis are to meet the applicable design code or standard and as approved by ABS.

1.4.2 Fracture Toughness Data
Whenever fracture toughness data (such as $K_{IC}$, $J_{IC}$ and CTOD) are used in the design analysis, these are to be experimentally determined for the materials and weldments at appropriate service temperatures and temperature ranges to establish a ductile-brittle transition zone.

1.4.3 Fatigue Design S-N Curves
High cycle fatigue data are to be generated over a wide range of applicable stress ranges and design S-N curves (mean – 3 × standard deviation) are to be established for the base material, head material and their weldments. These design curves are to be used in the analysis. Whenever corrosion fatigue is of major concern in the application, design corrosion fatigue curves are to be established and used in the analysis. These curves are to be developed using full size ring or full size cut specimens where ever possible and subjected to applicable cyclic load conditions. When full size rings or full size cut specimens are not possible due to size and curvature restrictions, then machined specimens are permitted to be used for evaluation.
1.4.4 Fatigue Crack Growth Data

When required, fatigue crack growth data used in the design analysis are to be generated experimentally based on mean plus 2 standard deviation values for the crack propagation data.
CHAPTER 5 Cargo Containment

SECTION 5 Allowable Stresses and Corrosion Allowances

1 Allowable Stresses

1.1 Where cargo tanks are designed based on recognized pressure vessel codes and material requirements in Chapter 7, the requirements of the codes are to be fully complied with. The allowable stress criteria of design codes are to be followed. ABS will review the design to verify compliance. The cargo tank is to be prototype tested for verification of design and pressure integrity as required by Section 5-10/11.

1.2 For cargo tanks designed using the probabilistic limit state approach, ABS will evaluate the design on a case-by-case basis using the guidelines as given in Appendix 5-A1.

1.3 Fatigue and fracture mechanics criteria as given in Section 5-4/1.1 are applicable to Section 5-5/1.2.

1.4 During hydrostatic test, handling, transportation, installation and commissioning of the cargo tanks, stresses up to 90% of the yield stress are permissible.

2 Corrosion Allowances

2.1 An appropriate corrosion allowance is to be used in the design. Stress corrosion cracking and corrosion fatigue issues on materials as described in Chapter 7 are to be addressed to the satisfaction of ABS.

No minimum corrosion allowance is included in the cargo tank design criteria in Section 5-4/1. However, an addition to the thickness resulting from the structural analysis for the cargo tank would be required, except that where it is demonstrated that the contents of the cargo tank are noncorrosive and the external surface is protected by inert atmosphere, no corrosion margin will be necessary.

A suitable gas quality monitoring instrumentation system for major impurities (water vapor, hydrogen sulfide and carbon dioxide) and minor impurities (as may be specified) is to be incorporated to monitor for quality acceptance when cargo is being loaded. It is expected that the instrumentation system will have proper calibration and necessary robustness where redundant systems are not provided. A minimum of two locations onboard the CNG carrier with continuous readings, preferably at inlet to CNG carrier and prior to inlet to cargo tank header, are to be provided.

Where a design is accepted with no additional thickness margin for corrosion, a suitable and acceptable means of thickness monitoring is to be provided to confirm that there is no corrosion during the service life of the CNG carrier.
CHAPTER 5 Cargo Containment

SECTION 6 Installation of Cargo Tanks and Supports

1 Supports
   i) Cargo tanks are to be supported by the hull in a manner which will adequately restrict bodily movement of the cargo tank under static and dynamic loads while allowing contraction and expansion of the cargo tank under temperature variations and hull deflections without undue stressing of the tank and of the hull.
   ii) The cargo tanks with supports are also to be designed for a static angle of heel of 30° without exceeding allowable stresses given in the applicable pressure vessel code.
   iii) The supports are to be calculated for the most probable largest resulting acceleration, taking into account rotational as well as translational effects.
   iv) Suitable supports are to be provided to withstand a collision force acting on the cargo tank corresponding to one half the weight of the cargo tank and cargo in the forward direction and one quarter weight of the tank and cargo in the aft direction without deformation likely to endanger the tank structure.
   v) The loads mentioned in ii) and iv) need not be combined with each other nor with wave-induced loads.
   vi) Provision is to be made to key the cargo tanks against the rotational effects referred to in Section 5-6/3.
   vii) Anti-flotation arrangements are to be provided for cargo tanks. The anti-flotation arrangements are to be suitable to withstand an upward force caused by an empty cargo tank in a hold space flooded to the summer load draft of the ship without plastic deformation likely to endanger the hull structure.
   viii) A design analysis fulfilling the above requirements is to be submitted.

2 Foundations – All Cargo Tanks
The calculations required by Sections 5-4 and 5-6/1 are to include the effects of vertical deflections imposed upon the cargo tank through the cargo tank/hull girder interaction for all contemplated loading conditions.

3 Vertical Cargo Tanks
Foundations and supports for vertical cargo tanks and cargo cylinders are to be designed for loads from all hull deflections and, if supported at intermediate points, then loads from deflection to the deck support are to be fully evaluated. See Sections 5-4 and 5-6/1 for applicable loading and requirements.

4 Chocks
In addition to the cargo tank supports, suitable chocks are to be provided to prevent excessive movement or shifting of the tanks on their supports.
CHAPTER 5  Cargo Containment

SECTION 7  Thermal Protection

1

Means are to be provided to protect the hull structure and critical components of the cargo tank support system against:

- Low temperature of cargo
- Direct impingement of JT effect cooled gases on hull and support structure due to accidental release of cargo

Such protection is to be designed to withstand the worst envisaged sustained high pressure and load due to gas flow from a ruptured section of the containment system.

2

If the thermal protection is not capable of withstanding any jet impact from a leaking CNG cargo tank, the designer is to show that any resulting cold spot on the hull structure will be limited in nature and will not cause extensive damage and put the CNG carrier at risk. For this purpose, leakage can be assumed at any part of the cargo containment system, especially that closest to the ship and support structure.
CHAPTER 5 Cargo Containment

SECTION 8 Insulation

1

Where CNG is carried at a temperature below -10°C, suitable insulation, as detailed in Section 5-9, is to be provided to ensure that the temperature of the hull structure does not fall below the minimum allowable design temperature as given in the ABS Rules for Materials and Welding (Part 2) for the grades of steels involved. Insulation calculations are to assume cargo tanks are at their design temperature and the ambient temperatures are 5°C for air and 0°C for seawater. These conditions may generally be used for worldwide service. However, higher values of the ambient temperatures may be accepted by ABS for ships operated in restricted areas. Conversely, lesser values of the ambient temperatures may be fixed by ABS for ships trading occasionally or regularly to areas in latitudes where such lower temperatures are expected during the winter months.

2

For CNG carriers, calculations are to be made with the assumptions in Section 5-8/1 to check that the temperature of the hull structure does not fall below the minimum allowable design temperature given in ABS Rules for Materials and Welding (Part 2) for the grades of steel involved, as detailed in Section 5-9.

3

Calculations required by Sections 5-8/1 and 5-8/2 are to be made assuming still air and still water, and except as permitted by Section 5-8/4, no credit is to be given for means of heating. In the case referred to in Section 5-8/2, the cooling effect of the leaked cargo (due to JT effect, low storage temperature, etc.) is to be considered in the heat transfer studies. For members connecting inner and outer hulls, the mean temperature may be taken for determining the steel grade.

4

In all cases referred to in Sections 5-8/1 and 5-8/2 and for ambient temperature conditions of 5°C for air and 0°C for seawater, approved means of heating transverse hull structural material may be used to ensure that the temperatures of this material do not fall below the minimum allowable values. If lower ambient temperatures are specified, approved means of heating may also be used for longitudinal hull structural material, provided this material remains suitable for the temperature conditions of 5°C for air and 0°C for seawater without heating. Such means of heating are to comply with the following requirements:

i) Sufficient heat is to be available to maintain the hull structure above the minimum allowable temperature in the conditions referred to in Sections 5-8/1 and 5-8/2.

ii) The heating system is to be so arranged that, in the event of a failure in any part of the system, standby heating could be maintained equal to not less than 100% of the theoretical heat load.

iii) The heating system is to be considered as an essential auxiliary.

iv) The design and construction of the heating system are to be to the satisfaction of ABS.

5

Any hull heating system is to be contained solely within the cargo area, or the drain returns from the hull heating coils in the wing tanks, cofferdams and double bottom are to be led to a degassing tank. The degassing tank is to be located in the cargo area, where possible, and the vent outlets are to be located in a safe position and fitted with a flame screen.
6

In determining the insulation thickness, due regard is to be paid to the cooling system onboard.

7

The insulation materials should be suitable for loads which may be imposed on them by the adjacent structure.

8

Where applicable, due to location or environmental conditions, insulation materials should have suitable properties of resistance to fire and flame spread and should be adequately protected against penetration of water vapor and mechanical damage.
CHAPTER 5 Cargo Containment

SECTION 9 Insulation Materials

1

1.1

Materials used for thermal insulation are to be tested for the following properties, as applicable, to ensure that they are adequate for the intended service:

i) Compatibility with the cargo
ii) Solubility in the cargo
iii) Absorption of the cargo
iv) Shrinkage
v) Aging
vi) Closed cell content
vii) Density
viii) Mechanical properties
ix) Thermal expansion
x) Abrasion
xi) Cohesion
xii) Thermal conductivity
xiii) Resistance to vibrations
xiv) Resistance to fire and flame spread.

1.2

The above properties, where applicable, are to be tested for the range between the expected maximum temperature in service and 5°C below the minimum design temperature.

2

The procedure for fabrication, storage, handling, erection, quality control and control against harmful exposure to sunlight of insulation materials is to be to the satisfaction of ABS.

3

Where powder or granulated insulation is used, the arrangements are to be such as to prevent compacting of the material due to vibrations. The design is to incorporate means to ensure that the material remains sufficiently buoyant to maintain the required thermal conductivity and also prevent any undue increase of pressure on the cargo containment system.
CHAPTER 5 Cargo Containment

SECTION 10 Cargo Tank Fabrication and Testing

1 Manufacture and Workmanship

All manufacturing and fabrication processes including welding, destructive and nondestructive testing and inspection are to follow applicable standards/codes used in the design of cargo tanks. Tolerances relating to manufacture, such as surface finish, out-of-roundness, local deviations from the true form, alignment of welded joints and tapering of plates having different thicknesses, are to comply with applicable standards/codes used in the design of cargo tanks. Workmanship is to be to the satisfaction of the Surveyor.

Where cargo tanks are designed in accordance with the Probabilistic Limit State Approach, all parameters considered in the assessment must be confirmed and monitored during fabrication.

For all methods of design, fatigue and fracture mechanics parameters must be monitored and confirmed during fabrication.

The specific requirements listed below are supplemental to the above.

i) Edges and other parts may be cut to shape and size by mechanical means such as machining, shearing and grinding.

Where thermal cutting is permitted to prepare edges, a procedure is to be submitted to ABS for approval. When thermal cutting is used, the effect of heat on mechanical properties is to be taken into consideration. When allowed, the resulting heat-affected zone shall be removed by mechanical means suitable to the material.

ii) No surface tacks and attachment welds are permitted on the cargo tanks.

iii) Care is to be exercised during fabrication and handling to avoid accidental arc striking or sparking on unintentional areas of the cargo tank. When sparking or arc strikes are observed, they are to be documented and the affected areas are to be inspected for possible mitigations and acceptance.

iv) Where materials are magnetized due to electromagnetic testing, lifting and handling or by any other means, the materials are to be demagnetized before the welding operation.

v) In case of TMCP steels, surface grinding is to be avoided as far as possible. Where required, the surface is to be wet ground and the final surface finish should be within the design specified requirements. The fluid used is to be noncorrosive and to be removed and dried completely after the operation.

vi) Any repair operation on cargo tanks should not result in thinning of the base material below the design limit; this is to be ensured by suitable gauging measurements. Repair and NDT procedures are to be submitted as per Section 7-4/1 requirements.

2 Welding

Weld joint details for cargo tanks are to be as follows:

i) All longitudinal and circumferential joints of cargo tanks are to be of butt welded, full penetration type. The butt weld joints are generally to be made without backing material. When permitted, the backing material is to be removed and the root profile is to be ground and examined for acceptance.

ii) All welds connecting heads, nozzles or other penetrations into the cargo tank are to be full penetration welds extending through the entire thickness of the cargo tank wall or nozzle wall, unless specially approved by ABS for small connections.
iii) The edge preparation of the welded joints is to be designed in accordance with a pressure vessels code acceptable to ABS.

iv) The finished weld shall be ground or machined to blend with the surfaces of the parts being joined. Both the blend radii and the surface finish of the weld deposit shall be inspected to ensure they comply with the design requirements. When grinding is not carried out, the joint design is to be justified by analysis and testing, and is to be reviewed and approved by ABS.

v) When pipes are used for Type 1, Type 2, Type 3 and Type 4 cargo tanks fabrication, the manufacturing, testing and inspection of the pipes are to be in accordance with Chapter 7.

3 Nondestructive Testing (NDT) and Inspection

NDT and inspection are to be as follows:

i) Inspection and nondestructive testing of welds for cargo tanks are to be in accordance with the design requirements given in Section 5-10/1 above and as detailed in Chapter 7.

ii) All materials used in the construction of cargo tanks are be examined before and after forming and during fabrication for the purpose of detecting defects by NDT techniques and are not to exceed the acceptable limits as required by the design.

iii) All edges cut during fabrication for openings, circumferential welds, longitudinal welds etc., shall be examined using appropriate NDT techniques. All defects exceeding the limits shall be documented and repaired, when permitted.

iv) All weld joints in cargo tank pressurized parts are to be subjected to 100% surface and volumetric NDT inspection, and permanent records are to be maintained for verification. Major defects, such as incomplete penetration, lack of fusion and weld center line cracking, are not permitted. Nonlinear defects, such as slag inclusions, isolated and clustered shrinkages, gas, pin-hole porosities and spacing between the defects, are to conform to ASME Section VIII, Div. 3 or equivalent. Linear surface and embedded cracks with different aspect ratios are to be in conformance with fatigue and fracture mechanics analysis. However, the allowable limits for the defects can not be less stringent than applicable design code minimum requirements. All NDT of longitudinal and circumferential welds is to include weld volumes with a minimum of 50 mm (2 in.) of the base material on either side of the weld seam covered.

The manufacturer has the option of selecting any suitable combination of NDT techniques, such as radiography, ultrasonic, magnetic particle and dye penetrant examinations. This Section is to be complemented for any additional/special requirements as may be stipulated in Chapter 7.

4 Pressure Testing

Each cargo cylinder/tank is to be pressure tested for final acceptance. In the case of cargo tank Types 3 and 4, depending on the material and design, pressure testing procedures are to be developed and submitted for review and may include burst test in addition to pressure testing on a lot basis for acceptance. Whereas, cargo tank Types 1 and 2 are to be subjected to a hydrostatic or hydropneumatic test as follows:

i) Each cargo tank, when completely manufactured, is to be subjected to a hydrostatic test at a pressure measured at the top of the cargo tanks of not less than $1.25P_o$, but in no case during the pressure test is the calculated primary membrane stress to exceed 90% of the yield stress of the material. To ensure that this condition is satisfied, where calculations indicate that this stress will exceed 75% of the yield strength, the test is to be monitored by the use of strain gauges or other suitable equipment.

ii) The test pressure shall be increased in increments of no more than 20% of the test pressure and stabilized before proceeding to the next incremental level. When final test pressure is attained, pressure is to be stabilized and held for a minimum of 5 minutes. The pressure shall then be reduced and held at the design pressure to allow for thorough inspection for leaks.
iii) For Type 2 cargo tanks, each individual cargo cylinder may be tested separately and only a tightness test will be required for the full assembly.

iv) Only fluid medium which is noncorrosive to the cargo tank material and liquid at the test pressure and temperature shall be used in pressure testing. Care is to be exercised to ensure the noncorrosive nature of the liquid medium. If required, corrosion inhibitors are to be added. After the hydrostatic test, cargo tanks are to be inspected to ensure that the fluid medium and other debris are completely removed from the tanks and the tanks are completely dried.

In order to minimize risk of brittle fracture, the test temperature shall be at least 20°C (36°F) above the material impact test temperature.

v) When specially approved by ABS, pneumatic tests can be carried out on cargo tanks with the conditions as prescribed in Sections 5-10/4i) and 5-10/4ii). This testing is permitted when cargo tanks are so designed or supported that they cannot be safely hydrostatically tested using a liquid medium. The air or gas medium used during the testing shall be free from moisture, carbon dioxide and other deleterious contaminants that may cause corrosion in the cargo tank.

vi) After completion and assembly, each cargo containment system and its related fittings are to be subjected to an adequate tightness test.

vii) After completion of the above pressure testing, cargo tanks are to be filled with inert/noncorrosive medium to avoid any internal corrosion problems and stored in dry/noncorrosive inerted atmosphere to avoid any external corrosion problems.

viii) Cargo tanks are to be protected from internal and external corrosion, abrasion, and physical damage of any kind during storage, transportation, installation and commissioning in the cargo hold.

5

The required level of inspection for thermal protection will be determined by ABS in each case on the basis of the arrangement.

6

At least one cargo tank per hold and its support are to be instrumented to confirm stress levels and loads, unless the design and arrangement for the size of ship involved are supported by full-scale experience. The cargo tank to be instrumented will be selected on the basis of the stress analysis.

7

The overall performance of the cargo containment system is to be verified for compliance with the design parameters during the initial loading and discharging of the cargo. Records of the performance of the components and equipment essential to verify the design parameters are to be maintained and available to ABS.

8

Heating arrangements, if fitted in accordance with Section 5-8/4, are to be tested for required heat output and heat distribution.

9

Where cargo is carried at temperature below ambient, the hull is to be visually inspected for cold spots to the satisfaction of the Surveyor following the first loaded voyage.
Any markings of cargo tanks are to be made by methods which do not cause unacceptable local stress raisers.

## 11 CNG Cargo Tank Prototype Testing

Prototype testing is required for all new cargo tank designs. The intent of this testing program is to validate the design experimentally. The test program is to be submitted for review to determine that it covers, as a minimum, the following for the cargo tank:

- Static Strength Performance
- Fatigue Performance
- Burst Performance

The prototype qualification program is to include, but is not limited to, the following.

### 11.1

A minimum of four (4) cargo cylinder/tanks are to be prototype tested. These cargo cylinder/tanks are to be tested for a combination of loads to prove fatigue and burst performance as indicated in the following table:

<table>
<thead>
<tr>
<th>Test Cargo Cylinder/Tank No.</th>
<th>Type of Test</th>
<th>Test Temperature</th>
<th>Artificial Surface Flaws</th>
<th>Number of Cycles</th>
<th>Pressure</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (^{(1)})</td>
<td>Fatigue</td>
<td>Operating</td>
<td>None (As fabricated)</td>
<td>Minimum 10 times design cycles</td>
<td>Operating</td>
<td>10 times design life cycle and no failure</td>
</tr>
<tr>
<td>2</td>
<td>Burst (^{(1)})</td>
<td>Operating</td>
<td>None (As fabricated)</td>
<td>None</td>
<td>Failure</td>
<td>Test pressure to exceed code predicted burst pressure and ductile failure mode</td>
</tr>
<tr>
<td>3 (^{(2)})</td>
<td>Fatigue</td>
<td>Operating</td>
<td>Yes</td>
<td>3 times design life</td>
<td>Operating</td>
<td>Cracks should not exceed critical sizes</td>
</tr>
<tr>
<td></td>
<td>Burst (^{(1)})</td>
<td></td>
<td></td>
<td></td>
<td>Failure</td>
<td>Exceed design pressure and ductile failure mode</td>
</tr>
<tr>
<td>4 (^{(2)})</td>
<td>Fatigue</td>
<td>Operating</td>
<td>Yes</td>
<td>3 times design life</td>
<td>Operating</td>
<td>Cracks should not exceed critical sizes</td>
</tr>
<tr>
<td></td>
<td>Burst (^{(1)})</td>
<td>JT (^{(4)})</td>
<td></td>
<td></td>
<td>Failure</td>
<td>Exceed design pressure and ductile failure mode</td>
</tr>
</tbody>
</table>
Notes:

1. To be used for residual mechanical properties evaluation.
2. Burst test is to follow after fatigue test.
3. Prototype testing is to establish ductile mode of failure (fractographic evidence) in the burst test without any major fragmentations (physical events). See Section 5-4/1.1.2(c)
4. JT Temperature shall be in accordance with theoretical gas dynamic or experimental study.

11.2

Sufficient numbers of material test coupons are to be taken from the material used in the fabrication of each pressure-retaining part of the test cylinder/tank. Using these coupons, base material, weld and HAZ are to be tested to evaluate the following mechanical properties:

i) Tensile properties
ii) Impact transition curves
iii) Fracture toughness parameter
iv) Fatigue life

The properties obtained are to meet design property requirements as stipulated in the material and cargo tank manufacturing procedure specifications.

11.3

The prototype test program can be conducted on full length or reduced length cargo cylinders/tanks. Test cylinders/tanks with reduced length may be used, provided the diameter, thickness, heads, nozzles and number of longitudinal and circumferential welds are the same as those of the full size cargo cylinder/tank. In the case of Type 1 cargo tank prototype testing, the length and number of circumferential welds should be proportionately reduced and agreed by ABS.

Where length is reduced, the size selected must be adequate to validate the design in all aspects.

Fabricated prototype cylinders/tanks are to be representative of the full size cargo cylinders/cargo tanks in all respects and should represent design and NDT tolerance requirements of the cargo cylinder/cargo tank fabrication specifications.

11.4

Pressure testing as per Section 5-10/4 is to be carried out before prototype testing. Artificially embedded surface defects in prototype test cylinders/tanks are to be introduced only after pressure testing and inspection.

11.5

Strain gauges* (biaxial and triaxial) are to be mounted at all critical and highly-stressed areas of the cargo cylinders/cargo tanks to validate the design and are to be monitored during prototype testing. Strain gauges are to be monitored for their response during repeated pressure cycles and it is to be demonstrated that a linear relationship is achieved between pressure and strain parameters.

Note:

* Upon application by the manufacturer, ABS will consider and review a reduction in the number of cargo cylinders/ cargo tanks to be instrumented and tested, provided satisfactory test results are obtained and demonstrated to the satisfaction of ABS with the lower number of instrumented cargo cylinders/cargo tanks tested.
11.6

Some prototypes (see Table above) are to be tested with artificially introduced surface defects (on both inside and outside surfaces of the cargo cylinder/cargo tank) with orientations and sizes (aspect ratios) as established and specified based on fracture mechanics analysis and ensured during the inspection of cargo cylinder/cargo tank.

11.7

During fatigue testing of prototypes at service temperature, appropriate combinations of loads are to be considered such as:

\textit{i)} Pressure cycles

\textit{ii)} Point load cycles

\textit{iii)} Bending cycles

\textit{iv)} Combined load cycles

11.8

Where deemed necessary, crack growth is to be monitored during fatigue cycling at periodic intervals.

11.9

At the end of each testing mode, the prototype cargo cylinder/cargo tank is to be inspected nondestructively for internal, sub-surface and surface nucleated and/or grown flaws. The flaw sizes are not to exceed the critical sizes as set forth by the fracture mechanics analysis.

11.10

Test cargo cylinder/cargo tank No: 1 as given in the test matrix table above is to be used for assessing the residual mechanical property estimates under strain-hardened conditions. Mechanical properties that are to be evaluated are to follow requirements stated in Section 5-10/11.2.

11.11 \textbf{Type 1, Type 3 and Type 4 Tanks}

Due to difference in material, design principles, configuration and arrangements, the above prototype testing requirements will be suitably modified, and additional testing may be required. The prototype testing procedure will be specially considered, and a detailed testing procedure is to be submitted for review.
CHAPTER 5 Cargo Containment

SECTION 11 Stress Relieving for Cargo Tanks

1

1.1

Stress relieving of cargo tanks of Type 1, Type 2, and Type 3 and Type 4 (metallic parts only) is to be carried out by thermal means.

1.1.1

For cargo tanks of carbon and carbon-manganese steels, post-weld heat treatment is to be performed after welding. Post-weld heat treatment in all other cases and for materials other than those mentioned in Chapter 7 is to be to the satisfaction of ABS. The soaking temperature and holding time are to be to the satisfaction of ABS.

1.1.2

For TMCP steels, thermal stress relieving operations are generally prohibited unless specially approved by ABS.

1.2

Where the size of the cargo tanks and/or metallurgical characteristics of materials are adversely affected due to thermal treatment (may occur for TMCP Steels), alternative methods of stress relieving will be considered.

1.2.1

When residual stresses are removed by stress relieving method(s) other than thermal means, the effectiveness of the method used is to be demonstrated to the satisfaction of ABS.

1.2.2

When alternate methods of stress relieving other than thermal means are used, residual stress measurements and verifications are required using appropriate experimental techniques and to the satisfaction of ABS.

1.2.3

When residual stresses are not removed by alternative means other than thermal, the effect of residual stress is to be addressed in the design analysis and appropriate testing on cargo tanks and materials are to be carried out to validate design and fabrication aspects.

2

See Section 2-4-2/17 of the ABS Rules for Materials and Welding (Part 2) for post-weld heat treatment requirements in all other cases and for materials other than those mentioned in Chapter 7.
Ship motions are to be calculated for ship operating life in the North Atlantic. This corresponds to an encounter probability level of $10^{+8}$. The following formulae may be used for the components of acceleration due to ship’s motions corresponding to a probability level of $10^{+8}$ in the North Atlantic and apply to ships with a length exceeding 50 m.

Vertical acceleration as defined in Section 5-3/4.5:

$$a_z = \pm a_o \sqrt{1 + \left(5.3 - \frac{45}{L_o}\right)^2 \left(\frac{x}{L_o} + 0.05\right)^2 \left(\frac{0.6}{L_o B}\right)^{1.5} + \left(\frac{0.6 y K^{1.5}}{B}\right)^2}$$

Transverse acceleration as defined in Section 5-3/4.5:

$$a_y = \pm a_o \sqrt{0.6 + 2.5 \left(\frac{x}{L_o} + 0.05\right)^2 + K \left(1 + 0.6 K \frac{z}{B}\right)^2}$$

Longitudinal acceleration as defined in Section 5-3/4.5:

$$a_x = \pm a_o \sqrt{0.06 + A^2 - 0.25 A}$$

with:

$$A = \left(0.7 - \frac{L_o}{1200} + 5 \frac{z}{L_o} \right) \left(\frac{0.6}{L_o B}\right)$$

where

$L_o$ = length of the ship for determination of scantlings as defined in Recognized Standards, in m  
$C_B$ = block coefficient  
$B$ = greatest molded breadth of the ship, in m  
$x$ = longitudinal distance, in m, from amidships to the center of gravity of the tank with contents; $x$ is positive forward of amidships, negative aft of amidships  
$y$ = transverse distance, in m, from centerline to the center of gravity of the tank with contents  
$z$ = vertical distance, in m, from the ship’s actual waterline to the center of gravity of tank with contents; $z$ is positive above and negative below the waterline.

$$a_o = 0.2 \frac{V}{\sqrt{L_o}} + \frac{34 - 600}{L_o}$$

where

$V$ = service speed, in knots  
$K$ = 1, in general. For particular loading conditions and hull forms, determination of $K$ according to the formula below may be necessary.
\[ K = \frac{13GM}{B}, \text{ where } K \geq 1.0 \text{ and } GM = \text{metacentric height, in m} \]

\[ a_x, a_y \text{ and } a_z = \text{maximum dimensionless accelerations (i.e., relative to the acceleration of gravity) in the respective directions, and they are considered as acting separately for calculation purposes. } a_z \text{ does not include the component due to the static weight, } a_y \text{ includes the component due to the static weight in the transverse direction due to rolling and } a_x \text{ includes the component due to the static weight in the longitudinal direction due to pitching. The accelerations derived from the above formulae are applicable only to ships at or near service speed, not while at anchor or otherwise near stationary in exposed locations.} \]
CHAPTER 5  Cargo Containment

SECTION 13 Stress Categories

For the purpose of stress evaluation referred to in Section 5-5/1.2, stress categories are defined in this Section.

1

Normal stress is the component of stress normal to the plane of reference.

2

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average value of the stress across the thickness of the section under consideration.

3

Bending stress is the variable stress across the thickness of the section under consideration after the subtraction of the membrane stress.

4

Shear stress is the component of the stress acting in the plane of reference.

5

Primary stress is a stress produced by the imposed loading and which is necessary to balance the external forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or at least in gross deformations.

6

Primary general membrane stress is a primary membrane stress which is so distributed in the structure that no redistribution of load occurs as a result of yielding.

7

Primary local membrane stress arises where a membrane stress produced by pressure or other mechanical loading and associated with a primary or discontinuity effect produces excessive distortion in the transfer of loads for other portions of the structure. Such a stress is classified as a primary local membrane stress although it has some characteristics of a secondary stress.

A stress region may be considered as local if:

\[ S_1 \leq 0.5\sqrt{Rt} \]

and

\[ S_2 \geq 2.5\sqrt{Rt} \]

where

\[ S_1 = \text{distance in the meridional direction over which the equivalent stress exceeds } 1.1f \]

\[ S_2 = \text{distance in the meridional direction to another region where the limits for primary general membrane stress are exceeded} \]
Secondary stress is a normal stress or shear stress developed by constraints of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur.
CHAPTER 5  Cargo Containment

APPENDIX 1  Probabilistic Limit State Design Approach

1  General

The design of engineering systems is generally undertaken with the support of codes and standards. In the case of the design of systems that have a degree of novelty associated with them, it is often possible to adapt and otherwise modify existing codes and standards. There are several approaches that can be used as a starting point for the development of design methodologies specific to CNG containment systems. The most relevant technology is that associated with the design of pressure vessels. The majority of these codes and standards are prescriptive in nature and are based on working stress design methods. The applicability of pressure vessel approaches is based on the Tank Type defined within Chapter 5.

The other acceptable methodology for containment system design is to use a limit state design approach. For this approach, the structural design is driven by load and resistance variables represented by probabilistic distributions and in association with a particular failure mode (or limit state) in comparison with the acceptance criteria for the failure mode in question (i.e., target probability of failure). The novel aspects of CNG containment systems and the new considerations needed for the various failure modes and associated consequences tend to enhance the benefits of using the limit state approach, since it can directly account for many of the specific containment system features (i.e., different loading regime, system inspectability, materials, construction tolerances, failure consequences, etc.) which will tend to result in a more application-specific design. Additionally, the approach enables sensitivities to be determined which can be fed back into the design to target critical aspects.

This Appendix provides guidance on the application of the limit state approach to the CNG containment system components. This Appendix is intended to provide a general understanding of the class requirements should the limit state approach be used in lieu of code-based design methods. The Appendix provides:

- General introduction to the component limit state approach and related definitions
- Requirements for the associated reliability analyses
- Key load and resistance variables
- Steps for conducting a probabilistic limit state analysis
- Acceptance criteria guidance

Note that the limit state approach and associated criteria described in this Appendix relate to a process of evaluating the pressure-retaining components of the CNG containment system in lieu of application of code-based requirements. The evaluation of the design philosophy and organization of the overall containment system, regardless of the containment system design approach, will be covered by the formal safety assessment (FSA) as required in Chapter 2 of this Guide.

Furthermore, the application of the limit state approach in the containment system design will still require the structural analyses, inspection and testing as specified in Section 5-4. In some cases, the limit state approach may require broader analyses or testing scopes, or both, described in Chapter 5, in order to develop/define the limit state function variables and associated probability distributions for the system.
Limit State Design Process

2.1 General Design Process

Limit states are conditions in which a structural component fails to meet its performance requirements. The performance requirements may be related to ultimate strength or fatigue or some other serviceability or accidental parameter required by the system component to ensure it is fit-for-purpose. Performance requirements are discussed later in this Appendix.

Limit state design is a process where specific design limits that constitute failure (i.e. failure modes) of the component or system are defined. For example, one limit state may be the ultimate burst pressure of a cargo tank and another buckling or collapse of a pipe. Once the design limit states are set, a reliability analysis is conducted on the component to determine the probability of failure at this design limit. This probability of failure is then compared to an acceptance criterion. If the probability of failure is lower than the acceptance criteria, then the component design is deemed fit-for-purpose for this specific limit state. If the probability of failure is above the acceptance criteria, then adjustments to the design, for example increased tank wall thickness, may be required to reduce the probability of failure. Note that other factors (e.g., variable uncertainties) may drive the reliability analysis failure probabilities. This may in turn indicate the need for specific structural analysis or testing to be conducted. Therefore, as part of the limit state design approach, the results of the reliability analysis feed back into the design engineering and testing regime. These features of the limit state design approach make it a very powerful tool in the overall design development.

5-A1/Figure 1 provides a flowchart of the general limit state approach process as it relates to a CNG containment system. The figure shows the typical design analysis and testing input as well as data requirements. It is important to highlight that there are a number of the steps in the process that require interface between ABS and the client. These steps are imperative to ensuring that the process runs smoothly and all parties understand the specific requirements of the analysis. Note also that the limit state process should start earlier in the concept development (i.e., pre-FEED (front end engineering and design) and FEED engineering stages). This is to ensure that the required engineering and testing activities will provide the limit state design with the necessary data at the necessary time of the design development.

The remainder of this Appendix provides further descriptions and guidance on each of the steps shown in this flowchart.
FIGURE 1
Overview of General Limit State Design Process

1. The Bureau and client agree upon limit states that must be addressed based on concept design (ABS Submittal 1)
2. Initial Design Dimensions
3. Develop Limit State Functions
4. Baseline Reliability Calculation/Calibration (ABS Submittal 2)
5. The Bureau and client agree on acceptance criteria based on consequence analyses results (ABS Submittal 3)
6. Define/Calculate Case Specific Random Variables
7. Case Specific Reliability Analysis
8. Is Failure Probability Less Than Acceptance Criteria?
   - No: Modifications to Design, Testing and/or Inspection Parameters
   - Yes: Design is Fit for Purpose for Given Limit State (ABS Submittal 4)

Pre-Feed/Feed Risk Assessments
- Hazard Identification
- Other Studies

Pre-Feed/Feed Engineering
- Structural Analysis
- Testing Plan
- Service/Operating Conditions
- System Inspectability

Preliminary Random Variables

Design Codes

Detailed Risk Assessments
- Consequence Analysis
- Quantitative Risk Analyses
- Other Studies

Detailed Design Engineering
- Structural Analysis
- Testing
- Service/Operating Conditions
- In-service Inspection & Monitoring Plan

Case Specific Limit State Analysis

Preliminary Limit State Analysis
2.2 Limit State Types

A key requirement in evaluating the integrity of any structural component, particularly those without a history of use, is ensuring that the analyses are performed for all potential failure modes. Generally these failure modes relate to a particular design limit state that may warrant evaluation.

To identify these potential failure modes, as a minimum, a qualitative risk assessment should be conducted on the containment system, such as a Hazard Identification exercise (HAZID), in the initial design stages. Note that the assessment of the containment “system” needs to cover the containers themselves as well as associated piping, valves, etc. The qualitative risk assessment must address the various operating conditions (loading, offloading, transit, etc.) and cover interfaces between the CNG containment system and other systems (e.g., structural, marine, propulsion, etc.) in order to ensure that all possible failure modes have been addressed. Chapter 2 provides general guidance and associated references related to qualitative risk assessments.

The information obtained from the risk assessments will be used to identify and define the key limit states that must be addressed in the design. The specific limit states that must be analyzed will be determined on a case-by-case basis. 5-A1/Table 1 provides a list of some of the typical limit states of interest. It is envisioned that, as a minimum, the ultimate limit states will need to be analyzed and the serviceability and accidental limit states may be required if deemed necessary based on the results of other risk assessments. Specific requirements are covered in Appendix 5-A1/4.

### TABLE 1

<table>
<thead>
<tr>
<th>Ultimate Limit States</th>
<th>Serviceability Limit States</th>
<th>Accidental Limit States</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Burst</td>
<td>● Vibration</td>
<td>● Collisions</td>
</tr>
<tr>
<td>● Local buckling and collapse</td>
<td>● Excessive Deflection</td>
<td>● Grounding</td>
</tr>
<tr>
<td>● Fracture</td>
<td>● Local overstress (yielding)</td>
<td>● Dropped Objects</td>
</tr>
<tr>
<td>● Fatigue</td>
<td></td>
<td>● Fire and Explosion</td>
</tr>
</tbody>
</table>

3 Reliability Analysis

This Subsection provides descriptions and general guidance associated with the probabilistic limit state analysis steps shown in 5-A1/Figure 1.

3.1 Preliminary Calculations and Calibration

The first step of the limit state analysis is the selection of initial dimensions and properties for the containment system. Generally, the components would be initially sized based on an industry-accepted pressure vessel code, reliability-based codes, as applicable, or other applicable codes that relate to the specific CNG containment system.

3.1.1 Limit State Function and Preliminary Random Variables

With the initial design parameters selected, the limit state function is defined. This is a function that represents the success or failure of a particular limit state, where the success state is represented when the limit state function is greater than zero and a failure state is represented when the function is less than or equal to zero. The function represents the physical interaction of the design variables, which can be grouped in two broad categories: load and resistance.

5-A1/Table 2 lists many of the key design variables that may be considered in the limit state analyses. The specific combination of loads and resistance variables used in an analysis is dependent upon the limit state of interest (i.e., the function used to represent the physical load and structural response interaction). For example, if the fracture limit state was being assessed, design
variables such as material toughness, initial crack size and other relevant variables should be considered.

### TABLE 2

**Typical Design Load and Resistance Variables (Random Variables)**

<table>
<thead>
<tr>
<th><strong>Load Variables</strong></th>
<th><strong>Resistance Variables</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational</strong></td>
<td></td>
</tr>
<tr>
<td>• Internal pressure –static and cyclic</td>
<td>• Young’s modulus</td>
</tr>
<tr>
<td>• Fluid pressure –static and cyclic</td>
<td>• Yield strength</td>
</tr>
<tr>
<td>• Inertial forces induced by gravity and ship motion</td>
<td>• Ultimate strength</td>
</tr>
<tr>
<td>• Forces induced by relative displacements</td>
<td>• Elastic-plastic stress-strain curve</td>
</tr>
<tr>
<td>• Fluid header loads</td>
<td>• Strain rate dependent properties</td>
</tr>
<tr>
<td>• Thermal loads</td>
<td>• Strain aging behavior</td>
</tr>
<tr>
<td>• Vibration loads</td>
<td>• Impact strength</td>
</tr>
<tr>
<td><strong>Accidental</strong></td>
<td></td>
</tr>
<tr>
<td>• Fire</td>
<td>• Fatigue properties</td>
</tr>
<tr>
<td>• Grounding</td>
<td>• Fracture toughness</td>
</tr>
<tr>
<td>• Collision</td>
<td>• Corrosion properties</td>
</tr>
<tr>
<td>• Projectile and shock waves</td>
<td>• Weldment properties</td>
</tr>
<tr>
<td>• Dropped objects</td>
<td></td>
</tr>
<tr>
<td><strong>Fabrication / Transportation and Testing</strong></td>
<td></td>
</tr>
<tr>
<td>• Internal pressure (hydro testing)</td>
<td></td>
</tr>
<tr>
<td>• Residual stresses:</td>
<td></td>
</tr>
<tr>
<td>- Forming</td>
<td></td>
</tr>
<tr>
<td>- Alignment welding</td>
<td></td>
</tr>
<tr>
<td>- Welding</td>
<td></td>
</tr>
<tr>
<td>• Transport and installation loads</td>
<td></td>
</tr>
<tr>
<td>• Welding residual stresses</td>
<td></td>
</tr>
</tbody>
</table>

Since this is a probabilistic analysis, most of the design variables that make up the limit state function must be defined in probabilistic terms (i.e., most design variables must be characterized statistically as a random variable). Generally, as a minimum, the mean and standard deviation of all load and resistance parameters need to be established. Depending on the method used to compute the probability of failure, the probability density functions for each of the design variables may require definition. In the preliminary stages of the limit state analysis, the random design variables will likely be “generic”, drawing from engineering results from activities prior to and during the FEED work as well as published statistics. As the design is refined and additional analysis results and testing become available, case-specific random variables will be used. This is discussed further in Appendix 5-A1/3.2.

The probabilistic characterization of the design variables (i.e., design variables’ mean, standard deviation, etc.) must be consistent with industry standards and known conditions of the system of
interest. Note that the probabilistic characterization, namely the statistical representation of the design variables used in the limit state function will be of particular importance, specifically as these statistics represent planned fabrication processes and in-service inspections. This is because the fabrication processes and inspection will directly influence the probabilistic distribution of the resistance variables. For example, the planned fabrication inspections (e.g., NDT of welds) will influence the probable defect/crack sizes in the cargo cylinder which in turn impacts the resistance variables related to the fracture limit state.

Another example of the above is the in-service inspectability of the containment system. Based on the planned access to the containment system and inspection methods that will be employed while the ship is in-service, some of the resistance design variable statistics, such as corrosion resistance and fatigue resistance, may vary greatly, due to the ability or inability, as the case may be, to collect information on the damage that may be occurring. Statistical variations of these variables will be driven by the uncertainty of the condition of the system over time.

Due to their importance, all proposed probabilistic characterization of the design variables will be required to have adequate documentation acceptable to ABS and should represent the planned fabrication and service conditions.

3.1.2 Baseline Calculation and Calibration

With the initial limit state functions and associated preliminary random variables defined, baseline reliability calculations should be conducted prior to moving on to the more refined case-specific analysis. It is envisioned that the calculations will be conducted using first-order reliability method (FORM), second-order reliability method (SORM) or Monte Carlo simulation techniques.

By conducting the baseline calculation the results can be compared to existing design codes. If the initial dimensions of the component are proportioned from a design code, then the failure probability calculated should be less than or equal to the reliability level implied in the chosen design code. By demonstrating this equivalency, the quality of the reliability formulations is ensured. If the initial dimensions are proportioned from a working stress design code in which the reliability level is not explicitly given, the reliability calculation still provides baseline reliability to the code used for the initial proportioning of the component and the quality of the calculations can be inferred from the process. Furthermore, when the case-specific calculations are performed later, these results provide a meaningful baseline for comparison.

The baseline calculations and code comparisons are considered an important step in vetting the preliminary design and a step toward ultimately obtaining ABS approval for the design. The baseline calculations and calibration analysis provide the initial framework for the limit state design by:

- Ensuring the quality of the chosen limit state function and the associated reliability formulation
- Identifying specific variable sensitivities (i.e., critical variables) and potential design issues
- Understanding how planned fabrication processes, design tolerances, operational/process parameters, and in-service inspections may impact the design
- Identifying where specific data is lacking (i.e., drive design variable uncertainties) and where targeted testing and/or special studies are necessary in order to hone the calculations or gather more accurate data

At this stage of the design development, a preliminary reliability calculation and calibration submittal to ABS will be required. The submittals will be reviewed to confirm the analysis methods and design variable statistics are consistent with industry standards for computing the probability of failure. The submittal requirements are detailed in Appendix 5-A1/4.
3.2  **Acceptance Criteria**

The acceptance criteria is the maximum allowable annual probability of failure that the component can have in order to be considered fit-for-purpose for a given limit state. ABS has set general acceptance criteria limits for the pressure-retaining component failure probabilities which are discussed in detail in Part 5. However, ABS can make adjustments to these criteria depending on the known consequences related to the potential failure modes. For example, if the consequence modeling (e.g., gas dispersion modeling, jet fire modeling, etc.) of the containment system indicates that a particular failure cannot result in catastrophic consequences (e.g., loss of primary structure, migration of gas into normally manned spaces, etc.), then higher acceptable failure probabilities may be justified. For each containment design, these considerations will be taken on a case-by-case basis.

During the preliminary limit state analyses, discussions related to the acceptance criteria should be initiated by the client with ABS. It is important that these discussions are initiated early in the design process to ensure that no unforeseen issues with respect to the limit state design and associated class approvals are evident. Early discussions related to the limit state acceptance criteria are also important with regard to the broader aspects of the design. In particular, discussions related to the acceptance criteria will:

- Identify key consequence modeling requirements for the design. These should be done in conjunction with the risk assessment plan for the overall vessel.
- Allow criteria to be compared to preliminary reliability calculation results (gauge detailed engineering/testing level of effort required to define specific random variables).
- Ensure no "showstoppers", insurmountable issues or significant design modifications are required to achieve required acceptance criteria prior to initiating detailed design engineering.

Details on submittal requirements related to documentation supporting adjustments to the general acceptance criteria are covered in Appendix 5-A1/4.

3.3  **Case-specific Limit State Analysis**

With the acceptance criteria set and detailed design analysis and associated testing available, the case-specific reliability analyses can be performed. For this analysis, the load and resistance variables appropriate for the current design will be calculated and documented. The analysis process will be similar to the preliminary calculations described in Appendix 5-A1/3.1. The main difference is that the limit state functions and associated random variable data will be further refined, reflecting the engineering and testing development that has been performed on the containment system.

For example, the environmental loads acting on the CNG containment system would draw from seakeeping analysis or model testing of the specific ship, as well as short-term and long-term response of the environmental load. These analyses and testing would reflect the sea state probabilities of the worldwide or intended service and be used to calculate the probability distribution of the short and long-term structural response of the component. With regard to the resistance of the component, examples of case-specific distributions may include wall thickness fabrication tolerances and/or material strength properties.

With the case-specific random variables, the limit state analyses would be conducted. The results would be compared to the agreed-upon component acceptance criteria. In cases where the failure probabilities are not met, modifications may be required to the design, testing and/or inspection parameters. Once modified, revisions are made and the analysis rerun to determine if the failure probability is less than the acceptance criteria. This process is repeated as necessary to obtain an acceptable failure probability. Note that it is envisioned that through proper vetting of the design during the preliminary limit state analysis, the number of design iterations at the detailed design stage is expected to be minimal.
4 Limit State Design Analyses Requirements

This Subsection describes the minimum analysis and class submittal requirements. The submittals are generally provided in four stages during different steps of the design progresses. Each submittal is indicated on 5-A1/Figure 1 (i.e., Submittal 1, etc.).

4.1 Submittal 1 – Background Information

To ensure the proposed probabilistic limit state analyses address all of the key failure modes associated with the design concept the following must be submitted:

- Preliminary ship general arrangements/layout drawings.
- Overall transportation system design basis indicating proposed containment system “operating envelope”, working environment, design life, etc.
- Preliminary arrangements and layout of containment system, including proposed materials, structural properties and planned fabrication methods.
- Planned containment system fabrication quality assurance and inspections.
- Proposed in-service inspection methodologies (i.e., identified inspection restrictions and/or proposed inspection methods and frequencies).
- Identification of all interfaces between containment system and other ship systems (propulsion, steering, marine, inerting, structural, etc.). This includes either systems or operations whose functionality or performance could be affected by the containment system as well as systems and operations that could in turn affect the functionality or performance of the containment system.
- Risk assessment plan for project (described in Chapter 2). In addition to the plan, the results of a qualitative risk assessment (e.g., hazard identification and its associated hazard register) of the overall system must be provided. Specific supporting documentation requirements for the qualitative risk assessment are provided in Section 4.4.3 of the ABS Guidance Notes on Review and Approval of Novel Concepts. Note that the project risk assessment plan should provide an initial start on how the failure modes identified in the qualitative risk assessment will be addressed over the course of the project. Additionally, the plan should call out specific consequence modeling that will be part of the proposed risk assessments.

Submittal 1 is intended to lay the ground work for determining what specific limit state analyses will be required and/or accepted by ABS in lieu of the code requirements and/or requirements stipulated in Chapter 5. The specific limit state analysis requirement will be based on the proposed design (i.e., new/novel aspects and operating parameters) and the identified failure modes, as well as the overall risk assessment plan for the project. The specific need for other limit states (e.g., serviceability or accidental) will be determined on case-by-case basis.

However, as a minimum, ABS will require the ultimate limit states related to strength and fatigue design of the containment system) to be evaluated in lieu of code-based containment system design. The ultimate limit states will include:

- Burst
- Local overstress
- Local buckling and collapse
- Fracture
- Fatigue

It is important to note that although specific design aspects (e.g., pipe tank strength or fatigue design) may gain ABS approval via probabilistic limit state design techniques, other prescribed requirements stipulated in Chapter 5 will still be required to obtain overall ABS design approval. ABS will review and comment
on the scope of limit state analyses proposed by the designer that will be used to substantiate the containment system design in lieu of a demonstration of compliance with code-based requirements. The intent at this stage of the development is to clearly establish where the limit state design is applicable and where other code-based or prescriptive requirements still pertain. This provides for clear direction in the design development.

4.2 Submittal 2 – Preliminary Limit State Calculations/Code Calibration

The next stage of the design development is the preliminary reliability calculations and baseline calibration for the specified limit states. The following supporting documentation must be provided for review to confirm the analysis methods and design variable statistics are consistent with industry standards for computing the probability of failure:

- Description of probabilistic analysis technique and associated software used in the analysis.
- Definition of limit state functions.
- Definition of all random variables and the associated probabilistic characteristics (mean, standard distribution, distribution profile, etc.). Note that for each random variable, the basis (i.e., data sources) for the values and distribution used in the reliability analyses must be provided. In cases where “generic” data or assumptions were used in the analysis these must be clearly stated.
- Analysis results and calculated variable sensitivities.
- Results of code comparison/calibration exercise.
- Summary of case-specific random variables that will supersede the “generic” variables used in the preliminary limit state analyses. The proposed data sources (e.g., structural analysis, testing, special studies, etc.) that will be used for the case-specific random variables must be provided.

Submittal 2 is intended to confirm the validity and calibrate the proposed analysis approach and limit state functions as well as identify specific source data requirements for the case specific limit state analyses.

4.3 Submittal 3 – Consequence Justification

As shown in 5-A1/Figure 1 and discussed in Appendix 5-A1/3.2, the required acceptance criteria for the containment system components will be contingent on potential failure consequences associated with the containment system, subsystems of the containment system and/or containment support systems (e.g., power systems, etc.). ABS recognizes that there may be significant variations in the potential failure modes and resulting consequences for the different containment system design (i.e., Types I-III). Accordingly, ABS will be prepared to consider adjustments in the acceptance criteria in terms of annual probability of failure based on the differing resulting consequence. As part of the process of determining the acceptance criteria for the specific containment system pressure-retaining components, the following items must be submitted for review by ABS:

- Overall summary of the consequence analyses conducted on the containment system and results.
- For each consequence analysis, the following items must be clearly contained in the submitted report:
  - Description of the consequence analysis and associated failure it was intended to represent
  - Modeling parameters and key assumptions
  - Modeling analysis approach and supporting calculations
  - Modeling results and conclusions

Following the review, a meeting will be set up with client representatives to discuss the results of the review and whether there is adequate evidence from the consequence analysis to warrant a deviation from the specific acceptance criteria described in Appendix 5-A1/5. If the review of the consequence analysis
indicates that adjustments to the failure probabilities are acceptable, the Bureau evaluation team will prepare a letter describing the design-specific acceptance criteria that may be used in the design of the containment system. The letter will list the supporting documentation for the acceptance criteria provided by the client, as well as specific conditions that must be satisfied in order to achieve class approval.

4.4 Submittal 4 – Final Limit State Analysis

The final submittal will contain all of the supporting calculations and analysis, testing results and engineering used to conduct the limit state design analysis. The following support documentation must be provided for review:

- Description of probabilistic analysis technique and associated software used in the analysis
- Definition of final limit state functions
- Definition of all random variables and the associated probabilistic characteristics (mean, standard distribution, distribution profile, etc.). For each random variable, the basis (i.e., data sources) for the values and distribution used in the reliability analyses must be provided.
- Analysis results and calculated variable sensitivities

Submittal 4 completes the limit state design process. As discussed in Appendix 5-A1/4.1, the overall design approval will also be contingent on other code-based or prescribed requirements of this Guide not covered by the limit state analysis. Note that the above submittals will be in addition to other submittal requirements stipulated within other Chapters of this Guide.

5 Acceptance Criteria for the Containment Systems

Similar to the code-based designs, the primary objective of the limit state design approach is to ensure the structural design is fit-for-purpose for the specific operating conditions that it will be exposed to over the intended design life. The main differences between the approaches are the means at which we arrive with the results and the general form of the results. For the limit state approach, the results are generally in the form of probability of failure rather than a calculated stress or fatigue life value typically required for code-based methods. In order to determine if the design is acceptable, the acceptance criteria must be in the same form as the results.

In the case of a limit state design approach, the probability of failure (i.e., ultimate limit state) is calculated and compared to acceptance failure criteria based on existing standards and failure statistics. For the containment system components, the failure criteria, described in Appendix 5-A1/5.1, are based on studies conducted on failure statistics for pipelines and pressure vessels which are considered most applicable to the CNG containment systems with regards to service and structural configuration. Additionally, the pipeline and pressure vessel industries have long histories and well-established design standards. Therefore, the failure statistics represent experiences with code-based designs with the applicable design safety factors.

5.1 Acceptance Criteria for High and Normal Consequence Levels

The acceptance criteria presented in this Paragraph represent target failure probabilities associated with containment systems that would fall into a high consequence category. For the CNG containment system, the high consequence category would be required if the consequences of failure can result in potential loss of life, extensive environmental impact and/or possible loss of the vessel due to damage to primary hull structure or ingress of water from the sea. This consequence criteria represents the most severe acceptance criteria requirements (i.e., the lower bound target failure probability requirements).

5-A1/Table 3 provides the definitions for two consequence categories. In general, the containment will be considered a high consequence if the results of the consequence modeling indicate failure can result in one or more of the consequences defined in the high consequence row of 5-A1/Table 3.
For the high consequence class, the maximum annual probability of failure for an individual component in the containment system must be equal to, or less than, the following:

Ultimate limit state: $10^{-6}$

Fatigue limit state: $10^{-6}$

For other limit states, such as serviceability or accidental, appropriate targets will be agreed upon by the client and ABS and be dependent on the assigned consequence category for the system. Also, it is important to note that the acceptable limits described above for the high consequence class are applicable to individual cargo tanks (i.e., the primary containment component that is the largest volume of gas that could escape as the result of a single failure in the pressure boundary).

If it is shown that none of the high consequences will result when containment failure occurs, the component may be placed in the lower consequence category (i.e., Normal). If there is sufficient evidence that the component resides in the Normal consequence category, higher component probability of failure targets, up to an increase of an order-of-magnitude, may be considered.

It is important to note that the above consequence criteria must be met via passive systems or inherently safe design. Specifically, the consequence modeling cannot take advantage of safety systems that may either require manual intervention or involve the use of automated powered control systems to reduce flow, disperse gas, and suppress fire or other active mitigation measures. The consequence modeling should confirm the design has inherent features (e.g., arrangement or spacing, operating pressure, isolation/limited inventory, restricted flow due to size, etc.) that prevent the aforementioned consequences from occurring in the event loss of containment (i.e., failure) occurs. Acceptance of a lower limit state acceptance criteria will be subject to the review of the consequence modeling results, described in Appendix 5-A1/4.3.
### TABLE 3
Consequence Category Definitions

<table>
<thead>
<tr>
<th>Consequence Category</th>
<th>Health &amp; Safety Impact To Crew and/or Personnel at Nearby Facilities</th>
<th>Loss of Asset</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure to Gas</td>
<td>Exposure to Thermal Radiation</td>
<td>Hull Integrity</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>Migration of gas to normally manned space at concentrations that would cause asphyxiation</td>
<td>Severe radiant heat levels on ship causing death, major injury or long term health effects within very short time exposure, or high radiant levels causing minor injury or short term health effects beyond the boundaries of the ship.</td>
<td>The development of an average concentration of methane in air of 50% LEL at a distance within 100 ft of the CNG carrier. (Note: This may be modified where operations are limited to loading and discharge at offshore terminals only.)</td>
</tr>
<tr>
<td><strong>Normal</strong></td>
<td>Migration of gas to normally manned space at low concentrations (i.e., minor injury but would not cause asphyxiation)</td>
<td>High radiant levels on the ship, or low radiant levels causing minor injury or short term health effect during prolonged exposure beyond the boundaries of the ship.</td>
<td>Average concentration of methane in air of 50% LEL will not exceed beyond the CNG carrier side shell and/or electrical classification boundaries which extend beyond the side shell.</td>
</tr>
</tbody>
</table>

**Note:**

1. The requirements for hull plate thicknesses (Appendix 7-A-4/5 of the ABS Rules for Survey After Construction (Part 7)) may be used as a guide. The requirement is that a reduction in area of greater than 10% in top section, bottom section, or internals is not permitted. If this occurs, the damage is regarded as “significant”. This percentage may be lowered at the ABS’s discretion.
5.2 System Failure

One other important aspect related to the limit state analysis approach is the distinction between component failure probability and a system failure probability. The acceptance criteria in Appendix 5-A1/5.1 relates only to a defined containment component and is intended to be used for the express purpose of evaluating the compliance of an individual component using limit state design.

The overall system failure probability is an important aspect that must also be addressed. However, with regard to sizing the piping and/or cargo tanks using the limit state design approach in lieu of a code-based approach, it is more appropriate to address the overall system performance in the context of risk rather than setting specific system failure probability targets. The system failure probability, as it relates to structural failure, can be obtained from the component limit state analysis, described in this Chapter. This can be calculated by conservatively assuming direct correlation between each component or by more sophisticated methods where correlations between individual components are calculated based on actual loading characteristics. However, this calculation relates only to structural hazards of the cargo tanks which is but one contributor of the many potential hazards that influence the overall risks to the containment system. Other hazards, such as accidental loading or human error, as well as other system failures (electrical, mechanical, etc.), also contribute to the risk.

Therefore, in this context, the system failure probabilities, to include the structural failure of the cargo tanks, are more appropriately addressed in the formal safety assessment (FSA) (i.e., quantitative risk assessment) which is stipulated in Chapter 2 of this Guide as a requirement for the overall approval process. For code-based design, the same process for evaluating the overall system performance in the context of risk is also addressed via the FSA.

5.3 Case-specific Acceptance Criteria

ABS recognizes that there are significant variations in the potential failure modes and resulting consequences for the different containment system designs (i.e., Types I-IV) and will allow adjustments for case-specific acceptance criteria other than those specified in Appendix 5-A1/5.1 based on the actual design characteristics. The adjustment of the criteria will be based on the results of consequence modeling stipulated in Chapter 2 as well as other modeling requirement deemed necessary by ABS based on the design and associated failure modes.
# 6 Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

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CHAPTER 6  Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION 1  General

1  The requirements for process pressure vessels are to meet recognized pressure vessel codes and the ABS Rules for Building and Classing Facilities on Offshore Installations.

2  Emergency blowdown for each cargo tank is required and is to be designed in accordance with the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations.

3  Vent and relief headers and their capacity for each cargo tank are to be determined in accordance with the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations and Chapter 9 of this Guide.
CHAPTER 6  Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION 2  Cargo and Process Piping

1  General

For ships with cargo processing plants, the requirements of the ABS Rules for Building and Classing Facilities of Offshore Installations for process piping apply.

1.1  The requirements of Chapter 6, Sections 2 to 4 apply to product cargo piping and vent lines of safety valves or similar piping. Instrument piping not containing cargo is exempt from these requirements.

1.2  Provision is to be made by the use of offsets, loops, bends and mechanical expansion joints or similar suitable means to protect the piping, piping system components and cargo tanks from excessive stresses due to thermal movement and from movements of the cargo tank and hull structure.

1.3  Low-temperature piping is to be thermally isolated from the adjacent hull structure, where necessary, to prevent the temperature of the hull from falling below the design temperature of the hull material.

1.4  Where cargo tanks or piping are separated from the ship’s structure by thermal isolation, provision is to be made for electrically bonding both the piping and the cargo tanks. All gasketed pipe joints and other nonconductive connections are to be electrically bonded.

1.5  Suitable means are to be provided to relieve the pressure from cargo loading and discharging headers and other cargo pressurized lines to the suitable location prior to disconnecting from the loading or offloading facility.

1.6  All piping or components that are pressurized with cargo and may be isolated are to be provided with relief valves.

1.7  Relief valves discharging cargo from the cargo piping system are to discharge into the cargo vent system.

2  Scantlings Based on Internal Pressure

Subject to the conditions stated in Section 6-2/4, the wall thickness of pipes is not to be less than:

\[ t + \frac{t_o + b + c}{1 - \frac{a}{100}} \text{mm} \]

where

\[ t_o = \text{theoretical thickness} \]
\[ t_o = PD(20Ke+ P) \text{mm} \]
Design Pressure

3.1

The design pressure, $P$, in the formula for $t$ in Section 6-2/2 is the maximum gauge pressure to which the system may be subjected in service:

3.2

The greatest of the following design conditions is to be used for piping, piping systems and components, as appropriate:

- $i)$ The MARVS of the cargo tanks and cargo processing systems; or
- $ii)$ The pressure setting of the associated pump or compressor discharge relief valve; or
- $iii)$ The relief valve setting on a cargo piping system and where liquid loading or discharge is used, the maximum total discharge or loading head on the cargo piping system.

Permissible Stresses

4.1

For pipes, the permissible stress to be considered in the formula for $t$ in Section 6-2/2 is the lower of the following values:

$$\frac{R_m}{A} \text{ or } \frac{R_e}{B}$$

where

- $P$ = design pressure, in bar, referred to in 6-2/3
- $D$ = outside diameter, in mm
- $K$ = allowable stress, in N/mm$^2$, referred to in 6-2/4
- $e$ = efficiency factor equal to 1.0 for seamless pipes and for longitudinally or spirally welded pipes, delivered by approved manufacturers of welded pipes, which are considered equivalent to seamless pipes when nondestructive testing on welds is carried out in accordance with recognized standards. In other cases an efficiency factor of less than 1.0, in accordance with recognized standards, may be required depending on the manufacturing process.
- $b$ = allowance for bending, in mm. The value of $b$ is to be chosen so that the calculated stress in the bend due to internal pressure only does not exceed the allowable stress. Where such justification is not given, $b$ may be taken as:
  $$b = \frac{D t_o}{2.5r} \text{ mm}$$
- $r$ = mean radius of the bend, in mm
- $c$ = corrosion allowance, in mm. If corrosion or erosion is expected, the wall thickness of the piping is to be increased over that required by other design requirements. This allowance is to be consistent with the expected life of the piping.
- $a$ = negative manufacturing tolerance for thickness, %.
\[ R_m = \text{specified minimum tensile strength at room temperature, in N/mm}^2 \]

\[ R_y = \text{specified minimum yield stress at room temperature, in N/mm}^2. \text{ If the stress-strain curve does not show a defined yield stress, the 0.2\% proof stress applies.} \]

The values of \( A \) and \( B \) are to be at least \( A = 2.7 \) and \( B = 1.8 \).

### 4.2

The minimum wall thickness is to be in accordance with recognized standards.

### 4.3

Where necessary for mechanical strength to prevent damage, collapse, excessive sag or buckling of pipes due to superimposed loads from supports, ship deflection or other causes, the wall thickness is to be increased over that required by Section 6-2/2, or, if this is impracticable or would cause excessive local stresses, these loads are to be reduced, protected against or eliminated by other design methods.

### 4.4

Flanges, valves and other fittings are to comply with recognized standards, taking into account the design pressure defined in Section 6-2/3.

### 4.5

For flanges not complying with a standard, the dimensions of flanges and related bolts are to be to the satisfaction of the Bureau.

Design calculations, materials, dimensions and gasket data are to be submitted for nonstandard flanges.

### 5 Stress Analysis

A complete stress analysis, taking into account all the stresses due to weight of pipes (including acceleration loads if significant, internal pressure, thermal contraction, vibrations and loads induced by hog and sag of the ship for each branch of the piping system) is to be submitted to ABS. In any case, consideration is to be given to thermal stresses, even though calculations are not submitted. The analysis may be carried out according to ASME/ANSI B 31.3 or equivalent acceptable to ABS.

### 6 Materials

The choice and testing of materials used in piping systems are to comply with the requirements of the ABS Rules for Materials and Welding (Part 2) or Chapter 7 of this Guide, if low temperature applications are involved, taking into account the minimum design temperature. Materials having a melting point below 925°C are not to be used for piping.
CHAPTER 6 Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION 3 Piping Fabrication and Joining Details

1

The following direct connection of pipe lengths without flanges may be considered:

1.1 Butt-welded joints with complete penetration at the root may be used in all applications. Butt welds are to be either double-welded or equivalent to a double-welded butt joint. This may be accomplished by use of a backing ring, consumable insert or inert gas back-up on the first pass. Backing rings are to be removed.

1.2 Slip-on welded joints with sleeves and related welding having dimensions in accordance with recognized standards are only to be used for open-ended lines with external diameter of 50 mm or less.

1.3 Screwed couplings complying with recognized standards are only to be used for accessory lines and instrumentation lines with external diameters of 25 mm or less.

2

2.1 Flanges in flange connections are to be of the welded neck type.

2.2 Flanges are to comply with recognized standards as to their type, manufacture and testing.

3 Welding, Post-weld Heat Treatment and Nondestructive Testing

3.1 Welding is to be carried out in accordance with Chapter 7 for cargo piping.

3.2 Post-weld heat treatment is to be in accordance with Section 2-4-4 of the ABS Rules for Materials and Welding (Part 2) or as per ASME/ANSI B 31.3 requirements for all butt welds of pipes made with carbon, carbon-manganese and low alloy steels for cargo tank piping.

3.3 All butt joints should be 100% radiographed or UT with permanent recordings.
CHAPTER 6 Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION 4 Testing of Piping

1 The requirements of this Chapter apply to piping inside and outside the cargo tanks. However, ABS may accept relaxations from these requirements for piping inside cargo tanks.

2 After assembly, all cargo and process piping is to be subjected to a hydrostatic test to at least 1.5 times the design pressure. When piping systems or parts of systems are completely manufactured and equipped with all fittings, the hydrostatic test may be conducted prior to installation aboard ship. Joints welded onboard are to be hydrostatically tested to at least 1.5 times the design pressure. Where water cannot be tolerated and the piping cannot be dried prior to putting the system into service, proposals for alternative testing fluids or testing means are to be submitted to ABS for approval.

3 After assembly onboard, each cargo and process piping system is to be subjected to a leak test using air or other suitable medium to a pressure depending on the leak detection method applied.

4 All piping systems, including valves, fittings and associated equipment for handling cargo, are to be tested under normal operating conditions not later than at the first loading operation.
CHAPTER 6  Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION 5  Cargo System Valving Requirements

1

Every cargo piping system and cargo tank is to be provided with the following valves, as applicable:

1.1

For cargo tanks, all connections, except safety relief valves and liquid level gauging devices, are to be equipped with a manually operated stop valve and a remotely controlled emergency shutdown valve. These valves are to be located as close to the cargo tank as practicable. A single valve may be substituted for the two separate valves, provided the valve complies with the requirements of Section 6-5/3, is capable of local manual operation and provides full closure of the line.

1.2

Cargo compressors are to be arranged to shut down automatically if the emergency shutdown valves required by Section 6-5/1.1 are closed by the emergency shutdown system required by Section 6-5/3.

2

One remotely operated emergency shutdown valve is to be provided at each cargo transfer manifold connection.

3

The control system for all required emergency shutdown valves is to be so arranged that all such valves may be operated by single controls situated in at least two remote locations on the ship. One of these locations is to be the control position required by Section 14-1/3 or cargo control room. The control system is also to be provided with fusible elements designed to melt at temperatures between 98°C and 104°C which will cause the emergency shutdown valves to close in the event of fire. Locations for such fusible elements are to include the cargo tank valving manifolds and loading stations. Emergency shutdown valves are to be of the fail-closed (closed on loss of power) type and be capable of local manual closing operation. Emergency shutdown valves in cargo piping should fully close under all service conditions within 30 seconds of actuation. Information about the closing time of the valves and their operating characteristics is to be available onboard and the closing time is to be verifiable and reproducible. Such valves are to close smoothly.
CHAPTER  6  Process Pressure Vessels and Liquid, Vapor and Pressure Piping Systems

SECTION  6  Ship’s Cargo Hoses

1

Cargo hoses used for cargo transfer are to be suitable for the cargo, pressure and temperature of the cargo.

2

Flexible pipes used in transfer operations offshore with buoys are to follow the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations.
CHAPTER 7 Materials of Construction for Cargo Tanks

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2 Steel Materials
3 Material Evaluation Basis
4 Manufacturers’ Qualification Requirements
5 Traceability of Materials and Products
6 Process of Manufacture
6.1 Chemical Analysis

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TABLE 2 (Metallic Materials) Plates, Pipes, Coiled Pipes (Seamless and Welded \(^{(1)}\), and Formed/Forged \(^{(2)}\) Heads and Nozzles for Type 1, 2, 3 for Design Temperatures Below 0°C (32°F) and Down to –50°C (–58°F)...

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1.3 Ultrasonic Examination of Plate Materials
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4. Welding Procedure Tests for Heads and Nozzles

**FIGURE 1** Orientation of Weld Test Specimen
CHAPTER 7 Materials of Construction for Cargo Tanks

SECTION 1 General Material Requirements

1 Material Classes

Materials used in the construction of CNG cargo tanks are identified and treated either as: carbon-manganese steels and low-alloy steels (metallic materials), composite materials (non-metallic materials), or hybrid materials (combination: metallic and nonmetallic materials).

Metallic materials covered in this Section are suitable for use in the construction of CNG cargo tanks of Type 1, Type 2, Type 3 and Type 4, as defined in Chapter 5, within a service temperature range of +50°C (+122°F) to –50°C (–58°F) and at pressures as determined in accordance with the requirements of Chapter 5.

Type 3 and Type 4 CNG cargo tanks designed and built using metallic/composite/hybrid materials will be specially considered and are to be designed and constructed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Sections VIII and X, or equivalent. ABS will review the materials (composite and/or hybrid) proposed to be used in the construction of the cargo tank for any additional requirements as may be deemed necessary considering the specific application. The additional requirements needed, if any, will be communicated to the manufacturer by ABS.

2 Steel Materials

Carbon-manganese steels and low-alloy steels used in the construction of CNG cargo tanks are to conform to the requirements of recognized codes or standards such as ASME, ASTM, API, BS or any other material specifications as may be approved by ABS on review. These materials are to be produced, tested, inspected and certified in accordance with the applicable codes or standards at the place of manufacture.

The general requirements for these steel materials are given in 7-1/6.1 TABLE 1 (Metallic Materials) and 7-1/6.1 TABLE 2 (Metallic Materials). Additional requirements for processing, inspection and testing as stipulated in this Chapter, over and above the requirements of the applicable codes or standards for the materials, are to be followed by the manufacturer. In the case of any conflict in requirements between this Guide and the applicable code or standard, the more stringent requirements are to be applied, depending on the criticality of the application and as agreed with ABS.

3 Material Evaluation Basis

The complete designation or specification of all steel materials used for manufacturing of pressure-retaining parts or components of CNG cargo tanks is to be submitted by the manufacturer for review and approval by ABS.

The steel materials used in the manufacturing of cargo tanks are to meet the minimum property requirements used in the design at the design temperature and pressure with respect to:

- Yield and tensile strengths
- Impact toughness
- Fracture toughness
- Strain-aged mechanical properties
- Fatigue
- Corrosion and Corrosion Fatigue (sour gas)
- Weldability
The steel material selected is to be resistant to dynamic strain aging, cyclic softening and general and pitting corrosion problems. Where it is intended that the CNG carrier be suitable for carrying sour gas, the selected steel materials are to be resistant to hydrogen embrittlement, sulfide cracking, stress corrosion cracking and corrosion fatigue problems, in addition to general and pitting corrosion resistance. Suitability of the selected material for sour gas transportation is to be demonstration based on engineering critical analysis using the BS7910/API 579 specification under corrosion-assisted fatigue crack growth conditions.

The use of suitable protective coating(s) or liners can be an acceptable means of corrosion protection if the selected material is not intrinsically corrosion-resistant in the case of sour gas transportation. Whenever protective coating(s) or liners are used to mitigate corrosion problems, these will be evaluated for their effectiveness and suitability in the intended application. Based on these requirements, the chemical composition, manufacturing processes, mechanical properties and microstructural and corrosion-resistant aspects of the steels will be considered and evaluated in the review. ABS will also review the submitted material specifications for any alloying element(s) deemed to be deleterious with regard to embrittlement problems, welding, fracture toughness and/or corrosion resistance of the selected materials and notify the manufacturer of any such concerns.

It will not be necessary that the designer demonstrate material suitability with regard to general corrosion and corrosion-assisted cracking problems under static and dynamic loading conditions of the materials where the following provisions are satisfied:

- The design basis clearly states that the CNG carrier will not be used for the transportation of sour gas.
- The manufacturer demonstrates with adequate test data on the material that contamination of deleterious species (corrodants) responsible for the above-listed phenomena and ambient conditions in and around the cargo systems do not warrant such a consideration.
- Adequate corrosion allowance and protection measures have been adopted to alleviate corrosion-related problems.
- Deleterious species are to be determined and their assay levels demonstrated to be well below the specified threshold limits for the cargo by the manufacturer and as reviewed and approved by ABS for the intended application and to the satisfaction of the Surveyor.

4 Manufacturers’ Qualification Requirements

CNG cargo tanks are to be manufactured only at the ABS-approved or recognized plate mills, pipe mills, head forming and welding shops, material testing and prototype testing centers. Prior to certification of cargo tanks in production, the manufacturer(s), the processes used for manufacturing and the test centers are to be qualified on similar lines as given in Appendix 4 of the ABS Rules for Materials and Welding (Part 2). The certification of these centers under the ABS Quality Assurance (QA) program is required in all cases in view of the criticality of the application involved and to remove concerns regarding quality at the mills, fabrication shops and centers by periodic quality audits.

5 Traceability of Materials and Products

The manufacturer is to evolve a system of traceability for plate materials and other product forms (pipes, heads and nozzles). The system evolved is to address traceability of materials with regard to heat number, plate number, batch number, product number, composition, mechanical properties, process details, destructive and nondestructive testing, other mechanical tests as may be applicable, and the associated documentation requirements. Electronic documentation is preferred and recommended for ABS certification of CNG cargo tanks.

6 Process of Manufacture

The steel is to be made by one or more of the following processes: open-hearth, basic-oxygen or electric arc furnace. Processing may also involve primary and secondary melting and refining techniques, such as
electro-slag re-melting (ESR), vacuum degassing and ladle treatments, to achieve clean steel with ultra low sulfur (≤ 0.008%) and phosphorus (≤ 0.02) practices* and gaseous contents (≤ 80 ppm nitrogen and ≤ 5 ppm hydrogen each), as well as treatment with any special additives to minimize grain coarsening on welding of the material. The use of such specialized techniques/treatments/ methods during manufacturing may be stated by the designer in support of design justification for the intended application and will be considered during the ABS materials review process. The steel may be cast into ingots or may be strand (continuous) cast. The area reduction ratio from strand (continuous) cast billet or slab to finished plate is to be a minimum of 3:1, unless specially approved. Manufacturing process details are to be submitted by the steel mill to ABS for approval. Steel manufacturing processes are to clearly address the following issues to the satisfaction of ABS review and are to be confirmed by ABS survey during steel mill qualification to produce materials for pressure-retaining parts of CNG cargo tanks. The qualification report submitted for ABS review and approval is to include qualitative and quantitative information on material processing such as steel making, deoxidation and fine grain practices and their contents, ladle analysis, casting technique, centerline segregation, prevention, evaluation and acceptance criteria in accordance with ASTM E381 or equivalent, photo-macrographs on centerline segregation assessments (cross section of ingot/ billet/plate), mechanical working/heat treatment schedules, product analysis, prior austenitic grain size measurement, ferrite/pearlite grain size measurements, inclusion ratings (inclusions type, size, shape and ratings), sulfur prints, dimensional tolerances of plates as per ASTM A6 or equivalent, tensile properties and as-rolled/heat treated and strain aged impact and fracture toughness weldability properties data.

Note:

* Sulfur and phosphorus limits, as given in 7-1/Table 1 and 7-1/Table 2 by ABS, may be allowed by ABS depending on the criticality of the material in a specific application.

6.1 Chemical Analysis

The manufacturer is to carry out chemical analysis on samples taken from each ladle of heat of steel produced. The analysis is to include carbon, manganese, silicon, sulfur, phosphorus and other intentionally-added alloying elements, as well as restricted residual elements: Pb, Sn, Sb, Bi and As. The residual element contents are to be determined and reported during ladle analysis only. For materials other than rolled products, such as forgings, chemical composition limits are to be reviewed and approved by ABS.

6.1.1 Ladle Analysis

An analysis of each heat of steel is to be made by the manufacturer, as per ASTM A 830 or equivalent specification, to determine the weight percent of the specified elements. This analysis is to be made from a test sample taken during pouring of each heat of steel. The chemical analysis report is to be provided to the Surveyor for verification and to conform to the ABS-approved material specification.

6.1.2 Check Analysis

Chemical composition, as determined by check analysis (product analysis), is to conform to the requirements as specified in the ABS-approved material specification and is to be provided to the Surveyor for verification and conformance.

### TABLE 1 (Metallic Materials)

Plates, Pipes, Coiled Pipes (Seamless and Welded (1)), and Formed/Forged Heads/Nozzles

for Type 1, 2, 3 and 4 Cargo Tanks for Design Temperatures Greater than or Equal to 0°C (32°F)

<table>
<thead>
<tr>
<th>PROCESS, CHEMICAL COMPOSITION AND HEAT TREATMENT REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon–manganese Steel</td>
</tr>
</tbody>
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### TENSION AND IMPACT TOUGHNESS TEST REQUIREMENTS

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.16% max</td>
<td>0.70 – 1.60%</td>
<td>0.10 – 0.50%</td>
<td>0.035% max.</td>
<td>0.035% max.</td>
</tr>
</tbody>
</table>

Plates
- See Section 7-2/1.13.1(a)

Pipes
- See Section 7-2/1.13.1(b)

Formed/Forged Heads and nozzles
- See Section 7-2/1.13.2

Tensile properties
- Specified minimum yield stress not to exceed 410 MPa (60 ksi) \(^{(4)}\)

### CHARPY-V NOTCH (CVN) IMPACT TEST

<table>
<thead>
<tr>
<th>Plates</th>
<th>Longitudinal or transverse test pieces</th>
<th>Minimum average energy value (E) is to conform to design requirement based on CVN energy and fracture toughness correlation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipes</td>
<td>Transverse test pieces</td>
<td></td>
</tr>
<tr>
<td>Formed/forged heads/nozzles</td>
<td>Transverse test pieces</td>
<td></td>
</tr>
</tbody>
</table>

**CVN sample location**
- \(t/2\) position, where \(t\) = thickness

**CVN test temperature**
- \(10^\circ\text{C} (18^\circ\text{F})\) below design temperature or \(-10^\circ\text{C} (14^\circ\text{F})\), whichever is less, for thickness: \(t \leq 19\) (0.75 in.)
- \(20^\circ\text{C} (36^\circ\text{F})\) below design temperature or \(-10^\circ\text{C} (14^\circ\text{F})\), whichever is less, for thickness: \(19 < t \leq 50\) (2 in.)
- For \(t > 50\) mm (2 in.), impact transition curve is to be established corresponding to \(t/2\) location.

**Special Testing Requirements:** See Section 7-2

### Notes:

1. For seamless pipes and fittings, normal practices apply as per ASTM 749 or equivalent.
2. Composition limits are to be reviewed and approved by ABS.
3. TMCP procedure may be used as an alternative to normalizing or quenching and tempering.
4. Materials with specified minimum yield stress exceeding 410 MPa (60 ksi) may be specially approved by ABS. For these materials, particular attention is to be paid to the hardness of the weld, heat affected zone and delayed cracking problems and inspection procedures.

### TABLE 2 (Metallic Materials)

Plates, Pipes, Coiled Pipes (Seamless and Welded \(^{(1)}\)), and Formed/Forged \(^{(2)}\) Heads and Nozzles for Type 1, 2, 3 for Design Temperatures Below 0°C (32°F) and Down to –50°C (–58°F)

**Material maximum Thickness:** 25 mm \(^{(3)}\)

### PROCESS, CHEMICAL COMPOSITION AND HEAT TREATMENT REQUIREMENTS

| Carbon-manganese Steel | Basic oxygen process, fully killed, and fine grain practiced. Normalized or quenched and tempered \(^{(4)}\) |

### CHEMICAL COMPOSITION (LADLE AND PRODUCT ANALYSES)

<table>
<thead>
<tr>
<th>C</th>
<th>Mn (^{(5)})</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>N</th>
</tr>
</thead>
</table>
Grain refining and alloying elements(6) may be generally in accordance with the following:

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>Nb</th>
<th>V</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>max.</td>
<td>0.80%</td>
<td>0.25%</td>
<td>0.08%</td>
<td>0.35%</td>
<td>0.05%</td>
<td>0.10%</td>
<td>0.005</td>
</tr>
</tbody>
</table>

TENSION AND IMPACT TOUGHNESS TEST REQUIREMENTS

Plates
See Section 7-2/1.13.1(a)

Pipes
See Section 7-2/1.13.1(b)

Formed/forged heads/nozzles
See Section 7-2/1.13.2

Charpy V-notch test temperature
Test temperature: 10°C (18°F) below the design temperature or –20°C (–29°F), whichever is lower

CVN sample location
\( \frac{t}{2} \) position, where \( t \) = thickness

Plates
Longitudinal or transverse test pieces

Minimum average energy value (E) is to conform to design requirement based on CVN energy and fracture toughness correlation

Pipes
Transverse test pieces

Formed/Forged Heads and nozzles (1)
Transverse test pieces

Special Testing Requirements: See Section 7-2

Notes:

1. For seamless pipes and fittings, normal practices apply as per ASTM 749 or equivalent.
2. Chemistry requirements for forgings may be specially considered by ABS.
3. For material thickness of more than 25 mm, Charpy V-notch tests are to be conducted as follows:

   **Material thickness (mm)**

   **Test temperature, °C (°F)**

   \( 25 < t \leq 30 \)
   15°C (27°F) below design temperature or –20°C (–29°F), whichever is lower

   \( 30 < t \leq 35 \)
   20°C (36°F) below design temperature or –20°C (–29°F), whichever is lower

   \( 35 < t \leq 50 \)
   25°C (45°F) below design temperature or –20°C (–29°F), whichever is lower

   Materials for cargo tanks which are thermally stress relieved after welding may be tested at a temperature 10°C (18°F) below design temperature. For the thermally stress relieved reinforcements and other fittings, the test temperature is to be the same as that required for the adjacent tank-shell thickness.

4. TMCP procedure may be used as an alternative to normalizing, or quenching and tempering.
5. For each reduction 0.01% carbon below the specified maximum carbon content, an increase of 0.06% manganese above the specified maximum manganese will be permitted up to a maximum of 1.8% manganese.
6. Fine grain practices and any other intentionally-added alloying element contents are to follow Section 2-1-3/5 and 2-1-3/Table 1 of the ABS Rules for Materials and Welding – Part 2, respectively. Any deviation from the rule requirements may be accepted on review.
CHAPTER 7 Materials of Construction for Cargo Tanks

SECTION 2 Special Processing and Testing Requirements

1 General
The following special processing and testing requirements are to be followed during qualification and production of materials and products used for pressure retaining parts or components of cargo tanks by the manufacturer.

1.1 Carbon Equivalent
The carbon equivalent, $C_{eq}$, is to be determined from the ladle analysis in accordance with the following equation, unless otherwise agreed with ABS:

$$C_{eq} = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15} (%)$$

$C_{eq}$ for the steel is not to exceed 0.48.

1.2 Cold Cracking Susceptibility
The cold cracking susceptibility, $P_{cm}$, is to be calculated in accordance with the following equation, unless otherwise agreed with ABS:

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B (%)$$

The $P_{cm}$ value for the steel is not to exceed 0.22.

1.3 Ultrasonic Examination of Plate Materials
All plate materials used in the manufacturing of pipes, heads and nozzles for CNG cargo tanks are to be subjected to 100% surface and volumetric ultrasonic examination on a “piece” basis for injurious surface and internal defects and gross internal inhomogenities, such as shrinkages, blow holes and delaminations, at the plate mill, in accordance with a recognized specification such as ASTM A435 or equivalent with acceptance criteria as stipulated in the ABS-approved material specification. The Surveyor is to verify material test certificates prior to the start of any subsequent fabrication processes on the plate materials.

1.4 Resistance to Cyclic Softening
Whenever steel material selected in the CNG containment system design has a yield/tensile strength ratio exceeding 0.7 based on specified minimum yield and ultimate tensile strengths, then the steel is to be subjected to low cycle fatigue (LCF) tests. LCF tests are to be carried out in accordance with ASTM E 606 or equivalent. These tests are required in the CNG material selection approval process in order to demonstrate that the material does not undergo cyclic softening under fatigue loading conditions. Two tests are to be carried out at a total strain amplitude range of 1% and 3%, respectively. The tests are to be witnessed by the Surveyor, and the results are to be submitted for ABS engineering review.

1.5 Impact and Fracture Toughness Correlation
Impact transition curves for base metal, weld metal and HAZ with proper notch orientations are to be established in accordance with ABS-approved material and pipe manufacturing procedure specifications. Each transition curve is to consist of at least seven points (inclusive of service temperature) selected above and below the service temperature with a temperature difference of at least 10°C (18°F) between any two consecutive points on the curve. The temperature range selected in the correlation exercise should result in the identification of ductile-brittle transition temperature, which is taken as the temperature at which the material exhibits 50% shear (ductile) and 50% crystalline (brittle) fracture modes on metallographic evaluation of the fractured specimens.
The fracture toughness parameter is to be evaluated at the same set of temperatures as selected in
establishing the impact transition curves for base metal, weld metal and HAZ. A correlation between the
impact energy data and fracture toughness parameter is to be established based on nonlinear regression
analysis during initial qualification stages for plate, pipe and fabrication mills and is to be based on at least
three production heat batches. The correlation is to be based on mean minus three times standard deviation
analysis. Once the correlation is established between the two toughness parameters, only impact energy
data are to be used in the production process qualifications of materials used in the CNG containment
system.

1.6 Strain-aged Mechanical Properties
When parent materials used in the manufacturing of pressure retaining parts of CNG cargo tanks are cold
deformed to produce various product forms such as pipes, heads or nozzles, then materials are to be
subjected to accelerated strain-aged tests. The samples are to be cut and taken from the product form and
heated to 250°C, air cooled and then machined specimens are to be tested for tensile, impact and fracture
toughness properties at an appropriate service temperature. If the toughness properties decrease by 10% as
compared to the undeformed material, then the strain-aged property data are to be used in the design. Also,
design data on the materials used in the CNG cargo containment system are to be established
corresponding to the strain-aged condition of the materials and products.

1.7 Design S-N Curves
When a CNG cargo tank design is to be verified for fatigue life based on a conventional S-N curve
approach, design S-N curves are to be established by conducting high cycle fatigue (HCF) tests on base
material and weldments. HCF tests are to be based on at least three production heats of base material and
weldments. The fatigue tests carried out are to reflect the same factors, such as surface condition and
profiles (weld seam), specimen size, load type and test temperatures, as compared to the actual cargo tank
deployed in the real application. The HCF tests are to be conducted in accordance with ASTM E 468 or
equivalent and the data obtained are to be analyzed statistically as per ASTM E739 or equivalent, to arrive
at mean minus three times standard deviation design fatigue curve.

1.8 Fracture Toughness Data
When a CNG cargo tank is designed based on a fracture mechanics approach, fracture toughness parameter
data used for pressure-retaining parts of the tank are to be determined as per 7-4/7. The data are to be
generated on at least three production heats for the base material, weld and HAZ regions of the
containment system. The data obtained are to be statistically analyzed to arrive at mean minus two times
standard deviation analysis, and the value obtained is to meet the minimum specified design requirement.

1.9 Fatigue Crack Growth Data
When a CNG cargo tank is designed based on a fracture mechanics approach and LBF design condition is
not demonstrated, fatigue crack growth rate (FCGR) data are to be generated on at least three production
heats on base material, weld and HAZ regions of the containment system. FCGR tests are to be carried out
in accordance with ASTM E 647 or equivalent specification. The data obtained are to be statistically
analyzed to arrive at mean plus two times the standard deviation design curve.

1.10 Head and Nozzle Qualifications
Where heads and nozzles are manufactured in accordance with ASME code or equivalent, the evaluation
process and testing frequency are to follow the applicable code requirements. In all other cases, the
following requirements are to be satisfied.

The material used for manufacturing heads and nozzles shall have the same level of mechanical properties
(hardness, tensile, impact and fracture toughness, and fatigue) as that of the welded cylindrical shell base
material. The manufacturer is to provide detailed documentation on the head fabrication process. If hot/
cold straining of the material exceeds 3% total strain (elastic plus plastic) during the operation, then the
material is to be re-qualified as per 7-4/5.
The maximum percent strain imparted to the material and thermal stress-relief operation, if any, used to relieve residual stresses and their effects on recrystallization and grain growth are to be documented and reported. Also, the qualification of the forming operation is to be supported with adequate microstructural and fractographic analyses. The formed heads and nozzles are to be nondestructively tested and documented to ensure that injurious surface or internal defects are not introduced during forming operations. The allowable defect levels in the formed parts are to be as set forth by deterministic fracture mechanics analysis on the CNG containment system for head and nozzle materials.

Prior to manufacturing, the manufacturer is to submit to ABS for approval detailed documentation covering head forming operations and the material qualification test program before and after forming operations. Qualification tests are to be witnessed by the Surveyor. The qualification test results are to be reviewed and approved by the appropriate ABS Engineering department prior to production.

1.11 Electric Welded Pipe

Electric resistance welded pipes are allowed only in the case of Type 1 cargo tank construction. Electric resistance welding is to be performed with a minimum weld frequency of 100 kHz. For all grades of steels, the weld seam and the entire HAZ are to be suitably post weld heat treated to reduce residual stresses introduced during the welding process. Details on the heat treatment process used and its effectiveness on stress relieving of welded pipes are to be submitted to ABS for review and approval prior to the start of production welding.

1.12 Hydrogen Embrittlement

Hydrogen pick-up during various stages of manufacturing may lead to brittle cracking problems in materials and products. Hydrogen pick-up is to be monitored and controlled and is not to exceed 5 ppm. Quality checks on materials and products are to be made at regular intervals on heat basis to overcome the problem. The measures adopted are to be submitted by the manufacturer and to be reviewed and approved by ABS.

1.13 Production Testing Frequency

1.13.1 Pipes

1.13.1(a) Pipe Body Material. Chemical, tension and impact tests on plate material used in the manufacturing of pipe body for a CNG cargo cylinder/cargo tank are to be carried out for every 25 tons of the plate material used in each production batch and are to meet the Bureau-approved material specification. Where this testing frequency requirement is satisfied by the plate mill, the mill certificates provided by the plate mill may be accepted by the Surveyor.

1.13.1(b) Welded Pipe. Welded pipes are to be tested for tension, bend and impact properties in production and are to meet the ABS-approved pipe manufacturing procedure specification. For non-heat treatable grades, such as TMCP pipes, the testing frequency is to be 5% per heat or one test per every 50 standard lengths of pipe, whichever gives the maximum testing frequency. For heat treatable pipes, testing frequency is to be 1 per heat treatment batch or 1 per 50 pipes in a heat treatment batch, whichever gives the maximum testing frequency. In all cases, pipes are to be selected for testing on a random selection basis.

1.13.2 Heads and Nozzles

Where heads and nozzles are not produced and tested in accordance with ASME code or equivalent, each mother plate/stock used in forming/forging operations of heads and nozzles is to be subjected to chemical, tension and impact testing and NDT and is to meet the ABS-approved manufacturing procedure specification for the product. In the case of forgings, prolongations from each forged product are to be used for testing purposes. The prolongations are to receive the same mechanical and thermal treatments as those of the final forged products. Formed products other than forgings, presented in a batch are to be tested for tension and impact properties as given in...
the table below, and all the products in the batch are to undergo 100% surface and volumetric NDT inspection.

<table>
<thead>
<tr>
<th>Number of Heads or Nozzles per Batch</th>
<th>Number of Sample Heads or Nozzles to be Selected for Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 50</td>
<td>1</td>
</tr>
<tr>
<td>51 to 200</td>
<td>2</td>
</tr>
<tr>
<td>201 to 1500</td>
<td>3</td>
</tr>
<tr>
<td>Over 1500</td>
<td>1% of total number of finished heads or nozzles in the batch but not to exceed 20</td>
</tr>
</tbody>
</table>

* Note: Samples are to be selected on a random basis. In a batch, if the selected heads or nozzles do not pass the required destructive tests, double the number of test specimens is to be taken from the same cut head or nozzle and retested and is to meet specified minimum properties. Otherwise, the batch is liable to be rejected.

1.13.3 Welded Cargo Tank

On every 100 m of production girth welds (pipe-to-pipe, pipe-to-head or nozzle-to-head) during mass production of cargo tanks, hardness, bend, tension and impact tests, as given in 7-5/4, are to be performed using test plates or rings.
CHAPTER 7 Materials of Construction for Cargo Tanks

SECTION 3 Tests and Test Data

1 Witnessed Tests

The designation \( W \) indicates that the Surveyor is to witness the testing. In view of the criticality of the application, the ABS-QA Program and Certification will not be applied as an alternative to witnessing the tests by the Surveyor during manufacturing of the CNG cargo tanks.

2 Manufacturers’ Data

The designation \( M \) indicates that test data is to be provided by the manufacturer without Surveyor verification of the procedures used or the results obtained. 7-3/Table 1 gives \( W \) and \( M \) designations for all product forms (plate, pipe, coiled pipes, formed heads and nozzles, prototypes and production cargo tanks). Witnessing of tests by the Surveyor during qualification \( Q \) and production \( P \) are also differentiated and indicated with \( Q \) and \( P \) notations in the same table.

These are to be followed during the ABS survey on materials and products subject to destructive and nondestructive testing for quality conformance in accordance with the ABS-approved material, manufacturing and fabrication specifications.

<table>
<thead>
<tr>
<th>Type of Test (^{(1)})</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plate</td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td>M (Q &amp; P)</td>
</tr>
<tr>
<td>Tension</td>
<td>W (Q)</td>
</tr>
<tr>
<td>Impact</td>
<td>W (Q &amp; P)</td>
</tr>
<tr>
<td>Fracture Toughness (^{(3)})</td>
<td>W (Q)</td>
</tr>
</tbody>
</table>

\(^{(1)}\) \text{Type of Test; \( W \) = Witnessed, \( M \) = Manufacturer’s Data, \( Q \) = Qualification, \( P \) = Production.}

\(^{(2)}\) \text{Blank indicates no requirement.}

\(^{(3)}\) \text{Additional test requirements for fracture toughness are specified in the } ABS \text{ Guide for Vessels Intended to Carry Compressed Natural Gases in Bulk - 2020.}
<table>
<thead>
<tr>
<th>Type of Test (1)</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plate</td>
</tr>
<tr>
<td>Weld Qualification (Longitudinal &amp; Girth)</td>
<td>–</td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td>–</td>
</tr>
<tr>
<td>Diffusible hydrogen content (4)</td>
<td>–</td>
</tr>
<tr>
<td>Hardness</td>
<td>–</td>
</tr>
<tr>
<td>Tension</td>
<td>–</td>
</tr>
<tr>
<td>Impact</td>
<td>–</td>
</tr>
<tr>
<td>Bend</td>
<td>–</td>
</tr>
<tr>
<td>Fracture Toughness (3)</td>
<td>–</td>
</tr>
<tr>
<td>Macro and microsections</td>
<td>–</td>
</tr>
<tr>
<td>Delayed NDT Inspection</td>
<td>–</td>
</tr>
<tr>
<td>HCF (5)</td>
<td>M (Q)</td>
</tr>
<tr>
<td>LCF (6) (For non-heat treatable steels and deformation exceeding 3% total strain)</td>
<td>W (Q)</td>
</tr>
<tr>
<td>Hydrostatic (7)</td>
<td>–</td>
</tr>
<tr>
<td>NDT (8) (Surface and Volumetric)</td>
<td>M (Q &amp; P)</td>
</tr>
</tbody>
</table>

**Notes:**

1. The applicability of a test and its extent of witnessing by the Surveyor are governed by the ABS-approved and stamped materials, manufacturing, and fabrication specification documents and drawings.

2. “–” indicates not applicable.

3. After witnessing one set of tests, affidavits may be accepted by the Surveyor.

4. The diffusible hydrogen content of the weld metal is to be determined in accordance with AWS A4.3, BS 6693 or equivalent. This requirement may be waived by the Surveyor if appropriate ABS-approved filler materials are used in the fabrication.

5. HCF stands for high cycle fatigue. Affidavits may be accepted in lieu of witnessing of the tests by the Surveyor.
LCF stands for low cycle fatigue.

Affidavits on hydrostatic tests in production may be accepted in lieu of witnessing by the Surveyor.

a) When acoustic emission signatures are recorded on cargo tanks, each tank signature report is to be stamped and endorsed by the Surveyor after witnessing the tests.

b) When automatic ultrasonic testing is substituted for radiography, the reports are to be stamped by the Surveyor after witnessing the tests. Affidavits may be accepted by the Surveyor in lieu of witnessing all the tests during production but not during prototype testing.

c) After 48 hours of completion of each weld joint, delayed visual and magnetic particle inspections are to be carried out for any hydrogen embrittlement cracking problems.
CHAPTER 7 Materials of Construction for Cargo Tanks

SECTION 4 General Requirements on Testing and Inspection

The general requirements for materials and products testing and inspection of metallic materials and products for CNG cargo tanks are to comply with the requirements of Section 2-1-1 of the ABS Rules for Materials and Welding (Part 2), with exceptions and modifications as stated and given below.

1 Defects

All materials and weldments in the CNG cargo system are to be generally free from linear, planar and volumetric physical defects, such as embedded and through thickness flaws, laminations and injurious surface flaws. Minor imperfections are allowed to the extent permitted as specified in the materials and product fabrication specifications. Except as indicated for specific materials, repair welding or dressing for the purpose of remedying defects is not permitted on most pressure-retaining components of the cargo tanks. Any requests for material and product to be so treated are to be directed to the appropriate ABS engineering department responsible for approval of the cargo tank system, along with the repair procedure including NDT requirements, for technical review.

When approved, the Surveyor will signify such approval by providing the manufacturer with an identification mark to be transferred onto materials and products.

2 Standard Test Specimens

2.1 General

Unless otherwise specified in the material, manufacturing and fabrication specifications, tension test specimens are to be of full thickness or section, that is, the same thickness as rolled plates or fabricated product forms. Specimens are to receive no other preparation than that prescribed and are to receive similarly and simultaneously all the treatments given to the material from which they are cut. Straightening of test coupons before machining into test specimens is to be carried out while the piece is cold and under compressive load only. The load is not to exceed compressive yield strength of the material that is being tested.

2.2 Test Specimen Orientation

Unless otherwise specified, tension test specimens are to be taken as follows:

- For plates, in a direction longitudinal or transverse to the final rolled direction.
- For pipes, pipe coils and formed heads and nozzles, both in the transverse and longitudinal directions.
- For weldments, test specimens are to be taken transverse to the welding direction.
- In the case of shapes and bars, specimens are to be taken longitudinal to the final direction of rolling.

2.3 Tension Test Specimens for Plates, Pipes, and Shapes

2.3.1 Flat Specimens

Tension test specimens for rolled plates, fabricated pipes and shapes (formed heads and nozzles) are to be cut from the finished material and machined to the form and dimensions referred to in 2-1-1/Figure 1 of the ABS Rules for Materials and Welding (Part 2) (footnote 1 is to be disregarded). Alternatively, tension test specimens of dimensions other than described may be specially approved at the request of the manufacturer.
2.3.2 Round Specimens

For material over 19 mm (0.75 in.) in thickness, round tension test specimens may be machined to dimensions referred to in 2-1-1/Figure 1 of the ABS Rules for Materials and Welding (Part 2). The axis of each round specimen is to be located as nearly as practicable midway between the center and the surface of the material. Tension test specimens of dimensions other than described above may be approved at the request of the manufacturer.

2.3.3 Impact Test Specimens

An impact test is to consist of three specimens taken from a single test coupon or test location. Impact test specimens are to be machined to the form, dimensions and tolerances as shown in 2-1-1/Figure 3 of the ABS Rules for Materials and Welding (Part 2). Test pieces are to be located with their longitudinal axes at quarter thickness or at half thickness if product (plate, pipe, weldments, head and nozzle) thickness is greater than 19 mm (0.75 in.), respectively. These test specimens are to be cut with their longitudinal axes parallel or transverse to the final direction of rolling, unless a specific orientation is specified. The length of the notch is to be perpendicular to the original rolled surface.

Full-size standard specimens are to be used unless the section thickness of the product is less than 12 mm (0.5 in.). The impact energy (E) requirement of full-size specimens is to follow the ABS-approved specifications. Sub-size specimens of the same material/product are to be in accordance with the requirements of the following table.

<table>
<thead>
<tr>
<th>Specimen Size Designation</th>
<th>Charpy V-notch Specimen Size</th>
<th>Minimum Absorbed Energy* (Average of three specimens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Size</td>
<td>10 × 10 mm</td>
<td>E</td>
</tr>
<tr>
<td>3/4 Size</td>
<td>10 × 7.5 mm</td>
<td>(3/4)E</td>
</tr>
<tr>
<td>1/2 Size</td>
<td>10 × 5.0 mm</td>
<td>(3/4)E</td>
</tr>
</tbody>
</table>

* Only one individual value may be below the specified average minimum value, provided it is not less than 75% of specified average minimum value. Percent ductile fracture is not to be less than 60%.

3 Definitions

3.1 Piece

The term “piece” is understood to mean the rolled product from a single slab, billet or ingot if this is rolled directly into plates, sections or bars.

3.2 Batch

A number of similar pieces produced from the same heat of material and presented as a group for acceptance tests.

4 Test Samples

4.1

All material in a batch presented for acceptance tests is to be of the same product form, e.g., plates, straight pipes, coiled pipes, heads, nozzles, sections, etc., from the same heat and in the same condition of supply.

4.2

Test samples are to be fully representative of the material/product and, where appropriate, are not to be cut from the material/product until heat treatment has been completed.
4.3  Test specimens are not to be separately heat treated in any way.

5  Formed Materials and Products

Full/process annealing/stress-relieving of cold or warm or hot formed (above recrystallization temperature) steel material and products exceeding 3% total strain (elastic plus plastic) is a mandatory requirement. When not carried out, the materials and products are to be re-qualified with confirmatory chemical, physical and mechanical properties to demonstrate that the formed materials and products meet the specified minimum properties as per CNG cargo containment design.

The properties can be evaluated on the samples taken directly from the product form or on pre-strained specimens taken from the coupons of the material imparted with same amount of deformation as used in the forming operation and are to be evaluated at least 10°C (18°F) lower than the CNG cargo service temperature.

6  Weld Qualifications

6.1  Test Requirements

6.1.1  Tension Tests

Generally, tensile strength is not to be less than the specified minimum tensile strength of the parent materials. ABS may also require that the transverse weld tensile strength is not to be less than the specified minimum tensile strength of the weld metal where the weld metal has a lower tensile strength than that of the parent material. In every case, the fracture location is to be reported for information.

6.1.2  Bend Tests

Bend tests are to be carried out in accordance with 2-4-3/Figures 5 and 7 of the ABS Rules for Materials and Welding (Part 2), with mandrel and bend radii to follow the footnote of 2-4-3/Figure 7. After bending, the specimen is not to show any cracking or other open defect exceeding 3.2 mm (1/8 in.) on the convex side, except at corners.

6.1.3  Impact Toughness Test

When specified, impact toughness testing of the material corresponding to the notch location in the plate material, weld, fusion line and in heat-affected zone (HAZ) of the weldments are to be carried out at 10°C (18°F) below the CNG service temperature. The notch locations in the specimens are to follow 7-5/4 FIGURE 1.

7  Fracture Toughness Testing

When specified, testing of CNG cargo tank materials and weldments is to be carried out for evaluating fracture toughness of the materials and weldments, such as plain strain fracture toughness parameter ($K_{IC}$), elastic-plastic fracture toughness parameter ($J_{IC}$) or critical crack-tip opening displacement parameter (CTOD) for mode-I type of deformation. The tests are to be carried out in accordance with the requirements of the BS 7448 (Part I and II)/ASTM E1820 specification or any other recognized standard acceptable to ABS. The test is deemed to be valid and sufficient for acceptance of the materials and weldments provided post-test data analyses meets all validity criteria of BS 7448 (Part I and II)/ASTM E1820, or any other recognized standard, and the fracture toughness value determined is equal to or greater than the minimum specified value in the ABS-approved specifications. Some important aspects that are to be taken into considerations before testing is initiated are listed below:

i) Specimen geometry, notch orientation and load type (bend or tension) are to be selected as per the Bureau-approved material specification and are to be in conformity with BS 7448 (Part I and II)/ASTM E1823 or any other recognized standard. The notch orientation should be generally normal to the principal loading direction (mode-I deformation), unless specially approved in the material specification.
Cut samples for machining test specimens are to be extracted from test coupons or locations with proper orientation identified as specified in the material specification for plates and as given in the manufacturing procedure specification for welds. Orientation mark, heat number, plate number, etc., based on the manufacturer’s evolved traceability system are to be transferred onto the samples using a template and paint, local chemical etching or mechanical means, but not by using metal punches of letters and numbers with a hammer. No plastic deformation or distortion of the specimen is permitted during this process. This process is to be repeated on the finished, inspected and accepted specimens before the testing program is initiated. Mix-up of specimens without proper identification would call for rejection of test results.

If straightening of the samples is needed, then it is to be carried out between the platens of a suitable press (mechanical or hydraulic) under the slowest possible loading rate, and the compressive load applied is not to exceed the compressive yield stress of the material. It is the responsibility of the manufacturer during this operation to ensure complete safety to personnel and the witnessing Surveyor.

In the case of weldment testing, the residual stresses are not to be altered in any way by pre-compression crack front straightening method(s), unless specially permitted in the ABS-approved material and product manufacturing procedure specifications.

Dimensions, machined notch root radius, side grooving and other fine details (such as specimen surface finish, centerline offset of loading pins, etc.) in the test specimens are to be as per the approved specimen drawing and in conformity with ASTM E1820 or any other recognized standard.

Calibration certificates for servo-mechanical/hydraulic universal testing machine, load cells, transducers and recording equipment used in testing are to be provided to the Surveyor by the testing lab for verification and record. Selection of loading roller diameter and its alignment with the crack plane of the specimen in the case of bend specimen testing and proper alignment of the clevis for compact tension testing are to be ensured by the Surveyor prior to the beginning of a test.

Crack opening displacement (COD) gauges are be calibrated once per batch of testing in the presence of the Surveyor.

Fatigue pre-cracking loads and cyclic loading rate (applied stress intensity level/time) are to be as per the BS7448 (Part I and II)/ASTM E1820 specification, or to any other recognized standards, and the Surveyor is to witness at least one specimen in a batch of specimens being tested. For the rest, the test lab is to provide the loading history and certify that these were done in accordance with the BS 7448 (Part I and II)/ASTM E1820 specification or any other recognized standard requirements.

Crack length measurement can be made by compliance or electrical potential technique and may be complemented by optical means of measurements. The calibration method employed is to be verified by the Surveyor and has to be validated by nine (9) point measurements made on the broken specimen after the test as per BS 7448 (Part I and II)/ASTM E1820 or any other recognized standard. Heat tinting/etching/any other suitable method(s) used to reveal the crack front to estimate the final crack length in post-test analysis shall be to the satisfaction of the Surveyor. Photo-micro and macrographs of the broken samples are to be captured and documented along with the valid test report for each of the specimens tested.

8 Acceptance Criteria on CTOD Tests

The following acceptance criteria are to be applied whenever CTOD tests are specified and performed. If the scatter in CTOD ($\delta_c$, $\delta_u$, or $\delta_m$) data from a set of three tests is such that the minimum value is greater than or equal to 70% of the average value of the set, then the minimum value of the three specimens is to be taken as the characteristic CTOD value for a specified location (base metal, weld metal or HAZ) and is to be equal to or greater than the specified minimum CTOD value for the material for the location. If the minimum value is less than 70% of the average value of the set or if the minimum value of the three
specimens fails to meet the specified minimum CTOD value, then three additional specimens are to be machined and tested from the same previously tested plate, product or weldment. The second lowest of all six values is to be reported as the characteristic CTOD value and this has to be equal to or greater than the specified minimum CTOD value as stipulated in the ABS-approved material and fabrication specifications for the specified location.

9 General NDT Requirements

Rolled plates, pipes, formed heads, nozzles, coiled pipes and pipe tanks are to be inspected for internal and external defects by suitable NDT techniques, including visual examination. NDT is to be accomplished using a suitable combination of NDT techniques such as X-ray radiography (gamma radiography is permitted only when job thickness exceeds 75 mm and is beyond the capacity of X-ray machines), ultrasonic and magnetic particle methods to ensure that allowable defect sizes are as per the ABS-approved materials and manufacturing procedure specifications. Automatic ultrasonic testing with provision for permanent recording of defects can be substituted for film radiography.

Testing methods, calibration standards and procedures used, and the acceptance criteria are to be clearly specified in the NDT section of the ABS-approved manufacturing procedure specifications, along with the applicable international testing and evaluation specifications referenced in the document. The calibration blocks fabricated and used in the testing are to reflect the same surface finish, density, shape and thickness and all metallurgical conditions (such as extent of deformation and heat treatment imparted, if any, grain size and grain flow direction) as those of the materials and their product forms that are being tested.

10 Real Time Monitoring of Cargo Tanks

Whenever cargo tanks of Type 1 and 2 do not meet the “leak-before-failure (LBF)” design criteria, the tanks are to be monitored by a suitable NDT technique for sub-critical crack growth not to exceed critical sizes as set forth by the deterministic fracture mechanics analysis.

Acoustic emission technique (AET) is considered by ABS to be a well-recognized real-time technique for monitoring sub-critical flaws in the cargo tanks. Other methods selected must be capable of defining the crack size and be able to relate this size and growth to the critical size for the containment system.

11 Acoustic Emission Testing (AET)

When the AET method of monitoring of cargo tanks is specified, the acoustic emission (AE) characterization of pipe tank and head materials is to be carried out prior to the adoption of the technique. AE signature capturing is to be carried out during shop hydro-tests/fatigue cyclic tests and documented by the manufacturer for real-time retrieval, comparison and continuous monitoring of the CNG containment systems onboard ship to avoid growth of sub-critical flaws to critical sizes during the entire service period of the CNG cargo system.

The manufacturer is to submit detailed documentation on the AET of the CNG containment system to be carried out, which is to include, but is not limited to, the following:

- Base metal/weld/HAZ characterization for elastic properties
- Background noise (EMI/RF) and threshold level estimation
- Coupling/gluing material characterization for AE probes
- AE attenuation characterization for materials
- Number and location of probes per tank/probe frequency and range/band width estimation
- In-situ probe calibration procedure
- Detectability distance estimation
- Kaiser effect and AE test pressure requirement estimates
● Fluid flow rate requirement and AE signature capturing
● Data recording/acceptance criteria/ storage and retrievals

ABS approval of this document, which is to cover methodology, probe characteristics, instrumentation, hardware and software, materials characterization, testing and evaluation procedures, acceptance criteria and data storage and retrieval for AE signatures, is required for all CNG cargo systems that have not satisfied LBF criterion in the design justification. The effectiveness of the monitoring method is to be demonstrated to the satisfaction of the attending Surveyor during each annual survey.
CHAPTER 7 Materials of Construction for Cargo Tanks

SECTION 5 Qualification and Production Weld Testing

1 General

This Section contains requirements for acceptance and testing of weldments made of carbon-manganese steels and low alloy steels that are used in the construction of CNG cargo tanks.

All welding processes, groove designs and tolerances, misalignment, weld profiles, filler metals, welder qualifications, welding procedure specifications, procedure qualification records and nondestructive testing of weldments and its acceptance criteria are to be reviewed and approved by ABS, prior to production welding of the cargo tanks. These general requirements are to follow Section 2-4-2 of the ABS Rules for Materials and Welding (Part 2) and ASME code or equivalent. In the case of any conflicts between ASME or equivalent and ABS requirements, the more stringent requirements are to be applied. The additional requirements as stipulated in this Section are to be followed by the manufacturer. Pre-approved procedures and qualification records are normally not allowed, as the designs of the cargo tanks are generally based on fracture toughness of material, and the latter is to be evaluated during welding procedure qualification, at or below appropriate CNG service temperature, for acceptance and implementation during production welding. Only full-penetration butt welds with proper profiles as per a recognized standard, such as ASME or equivalent, are allowed on the pressure-retaining components of CNG cargo tanks. ERW welds, which are permitted only in the case of CNG cargo tanks of Type 1 will be treated as full-penetration welds, and the procedure qualification requirements of ERW welds will be same as that of the fusion welding processes and are to follow 7-5/3.2 of this Section.

2 Welding Consumables

Welding consumables intended for welding of cargo tanks are to be in accordance with recognized standards, unless specially approved by ABS. Deposited weld metal tests, diffusible hydrogen tests and butt weld tests are required for all welding consumables, unless otherwise specially approved by ABS. The results obtained from tension, impact and fracture toughness tests are to be in accordance with the ABS-approved material, manufacturing and fabrication specifications. The chemical composition of the deposited weld metal is to be recorded for review and approval.

3 Welding Procedure Tests for Pipes and Cargo Tanks

3.1 During welding procedure qualification, tests for longitudinal and circumferential (girth) welds of cargo tanks are all required to be carried out using full penetration groove welds. Test assemblies are to be representative of:

- Each base material
- Each type of consumable and welding process
- Each welding position

For butt welds in plates, test assemblies are to be prepared so that the rolling direction is parallel to the direction of welding. The range of thickness qualified by each welding procedure test is to be in accordance with a recognized standard, such as ASME or equivalent. Surface and volumetric radiographic and/or ultrasonic testing is to be performed as per the ABS requirements. The selected consumables are to exhibit satisfactory impact toughness properties at appropriate CNG service temperatures. Correlations between CTOD and Charpy V-notch (CVN) impact energy are to be established for weld metal, base metal and HAZ regions of the weldments, as stipulated in Section 7-2/1.5, during welding procedure
qualifications. However, during production welding qualifications, only CVN impact energy value as observed in the correlation for each of the regions in the weldments at the applicable service temperature is to be used for acceptance.

3.2

The following welding procedure tests for cargo tanks are to be made from each test assembly.

1) Cross-weld tension tests.

2) Transverse bend tests: two face and two root bend test are required.

3) One set of three Charpy V-notch impact and one set of three fracture toughness specimens at the service temperature, at each of the following locations and as shown in 7-5/Figure 1.

   - Centerline of the welds
   - Fusion line (F.L.)
   - 1 mm from the F.L.
   - 3 mm from the F.L.
   - 5 mm from the F.L.

4) Macrosection, microsection and hardness surveys are required to be submitted for review and approval.

4  Welding Procedure Tests for Heads and Nozzles

Welding procedure tests for CNG cargo heads and nozzles are to be carried out and are to be similar to those detailed for cargo tanks in Section 7-5/3.2. Unless otherwise specially agreed with ABS, the test requirements are to be in accordance with Section 7-5/3.2.
FIGURE 1
Orientation of Weld Test Specimen

Notch location:
1. Center of weld
2. On fusion line
3. In HAZ, 1 mm from fusion line
4. In HAZ, 3 mm from fusion line
5. In HAZ, 5 mm from fusion line
HAZ = heat affected zone

The largest size of Charpy specimens possible for the material thickness is to be machined with the center of the specimens located as near as practicable to a point midway between the surface and the center of the thickness. In all cases, the distance from the surface of the material to the edge of the specimen is to be approximately one (1) mm or greater. In addition, for double-V butt welds, specimens are to be machined closer to the surface of the second welded side.
## CHAPTER 8 Cargo Pressure/Temperature Control

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CHAPTER 8 Cargo Pressure/Temperature Control

SECTION 1 General

1 Unless the entire cargo system is designed to withstand the full gauge pressure of the cargo under conditions of the upper ambient design temperatures as required in Section 5-2/2.1.2, maintenance of the cargo tank pressure below the MARVS is to be provided by one or more of the following means, except as otherwise provided in this Chapter:

i) A system which regulates the pressure in the cargo tanks by the use of mechanical refrigeration:

ii) A system allowing the product to warm up and increase in pressure. The insulation or cargo tank design pressure or both is to be adequate to provide for a suitable margin for the operating time and temperatures involved. The system is to be acceptable to ABS in each case.

iii) Other systems acceptable to ABS.

2 The systems required by Section 8-1/1 are to be constructed, fitted and tested to the satisfaction of ABS. In general, such equipment is to comply with the requirements of Part 6, Chapter 2 of the Marine Vessel Rules and this Chapter. Materials used in their construction are to be suitable for use with the cargoes to be carried. For normal service, the upper ambient design temperature is to be:

2.1

Sea: 32°C

Air: 45°C

For service in especially hot or cold zones, these design temperatures are to be increased or reduced, as appropriate, by ABS.
A refrigeration system is to consist of one or more units capable of maintaining the required cargo pressure/temperature under conditions of the upper ambient design temperatures. Unless an alternative means of controlling the cargo pressure/temperature is provided to the satisfaction of ABS, a stand-by unit (or units) affording spare capacity at least equal to the largest required single unit is to be provided. A stand-by unit is to consist of a compressor with its driving motor, control system and any necessary fittings to permit operation independently of the normal service units. A stand-by heat exchanger is to be provided unless the normal heat exchanger for the unit has an excess capacity of at least 25% of the largest required capacity. Separate piping systems are not required.

Where cooling water is required in refrigeration systems, an adequate supply is to be provided by a pump or pumps used exclusively for this purpose. This pump or these pumps are to have at least two sea suction lines, where practicable, leading from sea-chests, one port and one starboard. A spare pump of adequate capacity is to be provided, which may be a pump used for other services so long as its use for cooling would not interfere with any other essential service.

All primary and secondary refrigerants must be compatible with each other and with the cargo with which they come into contact. The heat exchange may take place either remotely from the cargo tank or by cooling coils fitted inside the cargo hold.
## Chapter 9 Cargo Tank, Cargo Handling, Cargo Process and Piping Overprotection and Vent System

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CHAPTER 9 Cargo Tank, Cargo Handling, Cargo Process and Piping Overprotection and Vent System

SECTION 1 General

1 All cargo tanks are to be provided with a pressure relief system appropriate to the design of the cargo containment system and the cargo being carried. Hold spaces and cargo piping which may be subject to pressures beyond their design capabilities are also to be provided with a suitable pressure relief system. The pressure relief system is to be connected to a vent piping system so designed as to minimize the possibility of cargo vapor accumulating on the decks or entering accommodation spaces, service spaces, control stations and machinery spaces, or other spaces where it may create a dangerous condition. Pressure control systems specified by Chapter 8 are to be independent of the pressure relief valves.

The pressure relief system for cargo handling and cargo processing, if equipped, is to comply with the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations and additional requirements specified in this Chapter.

2 When determining the arrangements and capacity requirements for overprotection and relief/relieving capacity for cargo tanks and cargo holds, the following are to be considered.

- Loading rate for cargo tank from compressor or other pressure source
- Thermal load due to:
  - Cargo tank storage arrangement
  - Failure of insulation
  - Failure of refrigeration system
  - Cargo holds flooding
  - Diurnal effects (radiation from sun to be included)
- Normal/Emergency Blow Down of cargo tank with full pressure
- Rupture of cargo tank assuming all contents of cargo tank released in cargo hold and protection of cargo hold
- Fire load on cargo tank considering various fires
- Variation in ambient pressure and temperature

3 Total volume of cargo carried on the CNG carrier should be subdivided in an appropriate number of individual cargo tanks within cargo holds. Each cargo hold is to be separated as required in Chapter 4.

4 Each cargo tank should be provided with an independent relieving system connected to an appropriate relief header.
No cargo communication is allowed between holds in normal and emergency situations.
CHAPTER  9  Cargo Tank, Cargo Handling, Cargo Process and Piping Overprotection and Vent System

SECTION  2  Pressure Relief Systems

1

Each cargo tank is to be fitted with at least two pressure relief valves of approximately equal capacity, suitably designed and constructed for the prescribed service.

2

The setting of the pressure relief valves is not to be higher than the design pressure, as defined in Chapter 5, which has been used in the design of the tank less the tolerance of the relief/safety valve. This may result in a setting less than the design pressure.

3

Pressure relief valves are to be connected to the highest part of the cargo tank above deck level. Pressure relief valves on cargo tanks with a design temperature below 0°C are to be arranged to prevent their becoming inoperative due to ice formation when they are closed. Due consideration is to be given to the construction and arrangement of pressure relief valves on cargo tanks subject to low ambient temperatures.

4

Pressure relief valves are to be prototype tested to ensure that the valves have the capacity required. Each valve is to be tested to ensure that it opens at the prescribed pressure setting with an allowance not exceeding ±3%. Pressure relief valves are to be set and sealed by a competent authority acceptable to ABS and a record of this action, including the values of set pressure, is to be retained aboard the ship.

5

Stop valves or other means of blanking off pipes between tanks and pressure relief valves to facilitate maintenance are not to be fitted unless all the following arrangements are provided:

i) Suitable arrangements to prevent more than one pressure relief valve being out of service at the same time.

ii) A device which automatically and in a clearly visible way indicates which one of the pressure relief valves is out of service.

iii) Pressure relief valve capacities such that if one valve is out of service, the remaining valves have the combined relieving capacity required by 9-2/4. However, this capacity may be provided by the combined capacity of all valves if a suitably maintained spare valve is carried onboard.

6

Each pressure relief valve installed on a cargo tank is to be connected to a venting system, which is to be so constructed that the discharge of gas will be directed upwards and so arranged as to minimize the possibility of water or snow entering the vent system. The height of vent exits is to be not less than B/3 or 6 m, whichever is greater, above the weather deck and 6 m above the working area and the fore-and-aft gangway.

Actual vent height is to be determined from dispersion analysis using appropriate software. The requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations are to be followed for venting and dispersion, in addition to the requirements of this Chapter.
Cargo tank pressure relief valve vent exits are to be arranged at a distance at least equal to $B$ or 25 m, whichever is less, from the nearest air intake or opening to accommodation spaces, service spaces and control stations, or other gas-safe spaces. For ships less than 90 m in length, smaller distances may be permitted by ABS. All other vent exits connected to the cargo containment system are to be arranged at a distance of at least 10 m from the nearest air intake or opening to accommodation spaces, service spaces and control stations, or other gas-safe spaces.

All other cargo vent exits not dealt with in other Chapters are to be arranged in accordance with Sections 9-2/6 and 9-2/7.

In the vent piping system, means for draining liquid from places where it may accumulate are to be provided. The pressure relief valves and piping are to be so arranged that liquid can under no circumstances accumulate in or near the pressure relief valves.

Suitable protection screens are to be fitted on vent outlets to prevent the ingress of foreign objects. Protection screens need not be flame screens.

All vent piping is to be so designed and arranged that it will not be damaged by temperature variations (JT effect) to which it may be exposed or by the ship’s motions.

The back pressure in the vent lines from the pressure relief valves is to be taken into account in determining the flow capacity required by Section 9-4.

Pressure relief headers are to be sized to handle the maximum anticipated discharges that could occur at any time. Relief header sizing is to be sufficient so that excessive back-pressure does not develop in any situation which may prevent any pressure relief valve from relieving at its design rate.

Where necessary, separate high and low pressure relief headers are to be employed to meet this requirement.

Pressure relief valves are to be positioned on the cargo tank so that they will remain in the vapor phase under conditions of 15 degrees list and 0.015$L$ trim, where $L$ is as defined in 1-2/29. This is applicable to a design which uses liquid as a cargo transfer means.
CHAPTER 9 Cargo Tank, Cargo Handling, Cargo Process and Piping Overprotection and Vent System

SECTION 3 Pressure/Vacuum Protection for Cargo Hold

1 Hold Vacuum Protection

1.1 Cargo holds designed to withstand a maximum external pressure differential exceeding 0.25 bar and capable of withstanding the maximum external pressure differential need no vacuum relief protection.

1.2 Cargo holds not designed to withstand a maximum external pressure differential are to be fitted with:
   
i) Two independent pressure switches to sequentially alarm a low pressure situation, and
   
ii) Vacuum relief valves with a sufficient gas flow capacity, set to open at a pressure sufficiently below the external design differential pressure of the cargo hold; or
   
iii) Other vacuum relief systems acceptable to ABS.

Calculation for vacuum relief valve capacity is to be submitted for ABS review and approval.

1.3 The vacuum relief valves for a cargo hold are to admit an inert gas or air to the cargo hold and are to be arranged to minimize the possibility of the entrance of water or snow.

1.4 The vacuum protection system is to be capable of being tested to ensure that it operates at the prescribed pressure.

2 Cargo Hold Overpressure Protection

Cargo holds are to be protected from overpressure due to high inert gas pressure, accidental release of cargo in hold due to containment failure, variation in ambient pressure and temperature, etc.

For cargo tank failure, it is to be assumed that one cargo tank has failed in any cargo hold and the total volume of cargo from that tank is released in the cargo hold. Any deviation from the above will be of special consideration by ABS.
CHAPTER 9 Cargo Tank, Cargo Handling, Cargo Process and Piping Overprotection and Vent System

SECTION 4 Size of Valves

1 Pressure relief valves are to have a combined relieving capacity for each cargo tank to discharge cargo with not more than a 3% rise in cargo tank pressure above the MARVS:

Valves for cargo holds are to be sized to limit pressure rise within the design limit of the structure

2 Relief valve capacity calculation needs to follow the ABS Rules for Building and Classing Facilities on Offshore Installations and applicable API requirements.
# Chapter 10 Environmental Control

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CHAPTER 10 Environmental Control

SECTION 1 Environmental Control within Cargo Tanks and Cargo Piping Systems

1 A piping system is to be provided to enable each cargo tank to be safely gas-freed and to be safely purged with cargo gas from a gas-free condition. The system is to be arranged to minimize the possibility of pockets of gas or air remaining after gas-freeing or purging.

2 Gas sampling connections at the inlet and outlet above the main deck are to be provided for each cargo tank in order to adequately monitor the progress of purging and gas-freeing.

3 The system is to be arranged to minimize the possibility of a flammable mixture existing in the cargo tank during any part of the gas-freeing operation by utilizing an inerting medium as an intermediate step. In addition, the system is to enable the cargo tank to be purged with an inerting medium prior to filling with cargo vapor without permitting a flammable mixture to exist at any time within the cargo tank.

4 Piping systems which may contain cargo are to be capable of being gas-freed and purged, as provided in Sections 10-1/1 and 10-1/3.

5 Inert gas utilized in these procedures may be provided from the shore or from the ship.
Environmental Control within the Hold Spaces for Cargo Tanks

Hold spaces associated with cargo containment systems are to be inerted with a suitable dry inert gas and kept inerted with make-up gas provided by a shipboard inert gas generation system or by shipboard storage, which is to be sufficient for normal consumption for at least 30 days.
Inerting refers to the process of providing a noncombustible environment by the addition of compatible gases, which may be carried in storage vessels or produced onboard the ship or supplied from the shore. The inert gases are to be compatible chemically and operationally with the materials of construction of the spaces and the cargo at all temperatures likely to occur within the spaces to be inerted. The dew points of the gases are to be taken into consideration.

Where inert gas is also stored for fire-fighting purposes, it is to be carried in separate containers and is not to be used for cargo services.

Where inert gas is stored at temperatures below 0°C, either as a liquid or as a vapor, the storage and supply system is to be so designed that the temperature of the ship’s structure is not reduced below the limiting values imposed on it.

Arrangements suitable for the cargo are to be provided to prevent the backflow of cargo into the inert gas system.

The arrangements are to be such that each space being inerted can be isolated and the necessary controls and relief valves, hatches, etc., are to be provided for controlling pressure in these spaces.
CHAPTER  10 Environmental Control

SECTION  4 Inert Gas Production Onboard

1

The equipment is to be capable of producing inert gas with an oxygen content at no time greater than 5% by volume. A continuous-reading oxygen content meter is to be fitted to the inert gas supply from the equipment and is to be fitted with an alarm set at a maximum of 5% oxygen content by volume. Additionally, where inert gas is made by an onboard process of fractional distillation of air which involves the storage of the cryogenic liquefied nitrogen for subsequent release, the liquefied gas entering the storage vessel is to be monitored for traces of oxygen to avoid possible initial high oxygen enrichment of the gas when released for inerting purposes.

2

An inert gas system is to have pressure controls and monitoring arrangements appropriate to the cargo containment system. A means acceptable to ABS, located in the cargo area, of preventing the backflow of cargo gas is to be provided.

3

Spaces containing inert gas generating plants are to have no direct access to accommodation spaces, service spaces or control stations, but may be located in machinery spaces. If such plants are located in machinery spaces or other spaces outside of the cargo area, two non-return valves or equivalent devices are to be fitted in the inert gas main in the cargo area as required in Section 10-4/2. Inert gas piping is not to pass through accommodation spaces, service spaces or control stations.

4

Flame burning equipment for generating inert gas is not to be located within the cargo area. Special consideration may be given to the location of inert gas generating equipment using the catalytic combustion process.

5

Where a nitrogen generator system is installed, it is to comply with the requirements in Section 5C-1-7/25.41 of the Marine Vessel Rules [except Sections 5C-1-7/25.41.1, 5C-1-7/25.41.2(a) and 5C-1-7/25.41.2(c)] and where the connections to the cargo tanks, hold spaces or cargo piping are not permanent, the non-return devices required by Section 5C-1-7/25.41.4 may be substituted by non-return valves.
CHAPTER 11 Electrical Installations

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CHAPTER 11  Electrical Installations

SECTION 1  General

In addition to requirements of this Chapter, for a CNG carrier with cargo processing onboard, the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations are also to be followed.

1

The provisions of this Chapter are applicable to ships carrying flammable products and are to be applied in conjunction with part D of chapter II-1 of the 1983 SOLAS amendments.

2

Electrical installations are to be such as to minimize the risk of fire and explosion from flammable products. Electrical installations complying with this Chapter need not be considered as a source of ignition for the purposes of Chapter 4.

3

ABS will take appropriate steps to ensure uniformity in the implementation and application of the provisions of this Chapter with respect to electrical installations*.

* Reference is made to the Recommendations published by the International Electrotechnical Commission and in particular to Publication 92-502.

4

Electrical equipment or wiring is not to be installed in gas-dangerous spaces or zones unless essential for operational purposes when the exceptions listed in Section 11-2 are permitted.

5

Where electrical equipment is installed in gas-dangerous spaces or zones as provided in Section 11-1/4, it is to be to the satisfaction of ABS and approved by the relevant authorities recognized by ABS for operation in the flammable atmosphere concerned.

6  Cable Installation

A grounded distribution or a hull-return system is not to be used. Electric conductors are to be run with a view to avoiding, as far as practicable, gas-dangerous spaces and they are not to pass through gas-dangerous spaces, except that certain electrical devices, such as echo depth-sounding apparatus, cathodic protection anodes or safe instruments, will be specially considered for installation in these spaces. Complete-details and arrangements are to be submitted.

7  Cable Type

All cables installed within gas-dangerous spaces and zones are to be moisture-resistant jacketed (impervious-sheathed) and armored or mineral-insulated metal-sheathed and all metallic protective coverings are to be grounded in accordance with Section 4-8-4/23 of the Marine Vessel Rules.
CHAPTER 11 Electrical Installations

SECTION 2 Types of Equipment

Certified safe type equipment may be fitted in gas-dangerous spaces and zones in accordance with the following provisions:

1 Gas-dangerous Spaces and Zones, General

Intrinsically safe electrical equipment and wiring may be fitted in all gas-dangerous spaces and zones, as defined in 1-2/22.

2 Cargo Containment Systems

In hold spaces, no electrical systems or equipment may be installed, except intrinsically safe circuits.

In hold spaces where cargo is carried in type C independent tanks and in spaces described in 1-2/22.v., the following may be installed:

i) Through runs of cables.

ii) Lighting fittings with pressurized enclosures or of the flameproof type. The lighting system is to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and be located in a gas-safe space.

iii) Electrical depth sounding or log devices and impressed current cathodic protection system anodes or electrodes. These devices are to be housed in gas-tight enclosures and only in spaces described in 1-2/22.v.

iv) Flameproof motors for valve operation for cargo or ballast systems.

v) Flameproof general alarm audible indicators.

3 Cargo Handling Equipment and System

Lighting fittings are to have pressurized enclosures or are to be of the flameproof type. The lighting system is to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and be located in a gas-safe space.

General alarm audible indicators are to have flameproof enclosures.

4 Zones on Open Decks, Spaces Other Than Hold Spaces

4.1

In zones on open decks or non-enclosed spaces on the open deck within 3 m of any cargo tank outlet, gas outlet, cargo pipe flange, cargo valves or entrances and ventilation openings to cargo handling rooms and cargo compressor rooms; in zones on the open deck over the cargo area and 3 m forward and aft of the cargo area on the open deck and up to a height of 2.4 m above the deck; in zones within 2.4 m of the outer surface of a cargo containment system where such surface is exposed to the weather, the following may be installed:

i) Certified safe type equipment.

ii) Through runs of cables.
4.2 **Socket-Outlets (IEC 92-502)**
Certified safe-type socket-outlets may be considered for supplying portable cargo pumps which are used in emergency circumstances. In such cases, special additional precautions are to be taken, such as link connections or key interlocked changeover switches to disconnect and earth the cables to socket-outlets when they are not in use, also, a pilot indicator showing when these cables are energized. Such socket-outlets are to be supplied through an isolating transformer separating the circuit from the main supply. See also Section 11-1/5.

4.3 In enclosed or semi-enclosed spaces in which pipes containing cargoes are located, the following may be installed:

1) Lighting fittings with pressurized enclosures or of the flameproof type. The lighting system is to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and be located in a gas-safe space.

2) Through runs of cables.

4.4 In enclosed or semi-enclosed spaces having a direct opening into any gas-dangerous space or zone, there is to be installed electrical installations complying with the requirements for the space or zone to which the opening leads.

4.5 Electrical equipment within spaces protected by air-locks is to be of the certified safe type, unless arranged to be de-energized by measures required by Section 4-6/4.
# 12 Fire Protection and Fire Extinction

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**SECTION 6** Firemen’s Outfits ................................................................. 174
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1. The requirements for tankers in chapter II-2 of the 2000 SOLAS amendments are to apply to ships covered by this Guide, irrespective of tonnage, including ships of less than 500 tons gross tonnage.

2. For a CNG carrier with cargo processing capability and turret system for loading and unloading cargo, the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations are also to be applied.

3. All sources of ignition are to be excluded from spaces where flammable vapor may be present, except as otherwise provided in Chapters 11 and 15.

4. The provisions of this Section apply in conjunction with Chapter 4.

5. For the purposes of fire fighting, any open deck areas above cofferdams, ballast or void spaces at the after end of the aftermost hold space or at the forward end of the forwardmost hold space are to be included in the cargo area.
CHAPTER 12 Fire Protection and Fire Extinction

SECTION 2 Fire Water Main Equipment

1 All ships, irrespective of size, carrying products which are subject to this Guide are to comply with the requirements of regulation II-2/10 of the 2000 SOLAS amendments, except that the required fire pump capacity and fire main and water service pipe diameters are not to be limited by the provisions of regulations II-2/10.2.2.4.1 and II-2/10.2.1.3 of the 2000 SOLAS amendments when the fire pump and fire main are used as part of the water spray system as permitted by Section 12-3/3. In addition, the requirements of regulation II-2/10.2.1.6 of the 2000 SOLAS amendments are to be met at a pressure of at least 5.0 bar gauge.

2 The arrangements are to be such that at least two jets of water can reach any part of the deck in the cargo area and those portions of the cargo containment system and hold space covers above the deck. The necessary number of fire hydrants is to be located to satisfy the above arrangements and to comply with the requirements of regulations II-2/10.2.1.5.1 and II-2/10.2.3.3 of the 2000 SOLAS amendments, with hose lengths not exceeding 25 m.

3 Stop valves are to be fitted in any crossover provided and in the fire main or mains at the poop front and at intervals of not more than 40 m between hydrants on the deck in the cargo area for the purpose of isolating damaged sections of the main.

4 All water nozzles provided for fire-fighting use are to be of an approved dual-purpose type capable of producing either a spray or a jet. All pipes, valves, nozzles and other fittings in the fire-fighting systems are to be resistant to corrosion by seawater (for which purpose galvanized pipe, for example, may be used) and to the effect of fire.

5 Where the ship’s engine-room is unattended, arrangements are to be made to start and connect to the fire main at least one fire pump by remote control from the navigation bridge or other control station outside of the cargo area.
CHAPTER 12 Fire Protection and Fire Extinction

SECTION 3 Water Spray System

1

A water spray system for cooling, fire prevention and crew protection is to be installed to cover:

i) Exposed hold space covers and any exposed parts of cargo tanks.

ii) Exposed on-deck storage vessels for flammable or toxic products.

iii) Cargo discharge and loading manifolds and the area of their control valves and any other areas where essential control valves are situated.

iv) Boundaries of superstructures and deckhouses normally manned, cargo compressor rooms, cargo pump rooms, storerooms containing high fire risk items and cargo control rooms, all facing the cargo area.

Boundaries of unmanned forecastle structures not containing high fire risk items or equipment do not require water spray protection.

2

The system is to be capable of covering all areas mentioned in Section 12-3/1 with a uniformly distributed water spray of at least 10 $\text{ℓ}/\text{m}^2$ per minute for horizontal projected surfaces and 4 $\text{ℓ}/\text{m}^2$ per minute for vertical surfaces. For structures having no clearly defined horizontal or vertical surfaces, the capacity of the water spray system is to be the greater of the following:

i) Projected horizontal surface multiplied by 10 $\text{ℓ}/\text{m}^2$ per minute; or

ii) Actual surface multiplied by 4 $\ell/m^2$ per minute. On vertical surfaces, spacing of nozzles protecting lower areas may take into account anticipated rundown from higher areas. Stop valves are to be fitted at intervals in the spray main for the purpose of isolating damaged sections. Alternatively, the system may be divided into two or more sections which may be operated independently, provided that the necessary controls are located together aft of the cargo area. A section protecting any area included in Sections 12-3/1i) and 12-3/1ii) is to cover the whole of the athwartship tank grouping which includes that area.

The vertical distances between water spray nozzles for protection of vertical surfaces are not to exceed 3.7 m.

3

The capacity of the water spray pumps is to be sufficient to deliver the required amount of water to all areas simultaneously, or where the system is divided into sections, the arrangements and capacity are to be such as to supply water simultaneously to any one section and to the surfaces specified in Sections 12-3/1iii) and 12-3/1iv). Alternatively, the main fire pumps may be used for this service, provided that their total capacity is increased by the amount needed for the spray system. In either case, a connection through a stop valve is to be made between the fire main and water spray main outside of the cargo area.

4

Subject to the approval of ABS, water pumps normally used for other services may be arranged to supply the water spray main.
All pipes, valves, nozzles and other fittings in the water spray systems are to be resistant to corrosion by seawater (for which purpose galvanized pipe, for example, may be used) and to the effect of fire.

Remote starting of pumps supplying the water spray system and remote operation of any normally closed valves in the system are to be arranged in suitable locations outside of the cargo area, adjacent to the accommodation spaces and readily accessible and operable in the event of fire in the areas protected.
CHAPTER 12 Fire Protection and Fire Extinction

SECTION 4 Dry Chemical Powder Fire-extinguishing Systems

1

Ships in which the carriage of flammable products is intended are to be fitted with fixed dry chemical powder type extinguishing systems for the purpose of fighting fires on the deck in the cargo area and bow or stern cargo handling areas, if applicable. The system and the dry chemical powder are to be adequate for this purpose and satisfactory to ABS.

2

The system is to be capable of delivering powder from at least two hand hose lines or combination monitor/hand hose lines to any part of the above-deck exposed cargo area, including above-deck product piping. The system is to be activated by an inert gas such as nitrogen used exclusively for this purpose and stored in pressure vessels adjacent to the powder containers.

3

The system for use in the cargo area is to consist of at least two independent, self-contained dry chemical powder units with associated controls, pressurizing medium fixed piping, monitors or hand hose lines. For ships with a cargo capacity of less than 1,000 m³, only one such unit need be fitted, subject to approval by ABS. A monitor is to be provided and so arranged as to protect the cargo loading and discharge manifold areas and to be capable of actuation and discharge locally and remotely. The monitor is not required to be remotely aimed if it can deliver the necessary powder to all required areas of coverage from a single position. All hand hose lines and monitors are to be capable of actuation at the hose storage reel or monitor. At least one hand hose line or monitor is to be situated at the after end of the cargo area.

4

A fire-extinguishing unit having two or more monitors, hand hose lines, or combinations thereof, is to have independent pipes with a manifold at the powder container, unless a suitable alternative means is provided to ensure proper performance, as approved by ABS. Where two or more pipes are attached to a unit, the arrangement is to be such that any or all of the monitors and hand hose lines are capable of simultaneous or sequential operation at their rated capacities.

5

The capacity of a monitor is to be not less than 10 kg/s. Hand hose lines are to be non-kinkable and be fitted with a nozzle capable of on/off operation and discharge at a rate of not less than 3.5 kg/s. The maximum discharge rate is to be such as to allow operation by one person. The length of a hand hose line is to not exceed 33 m. Where fixed piping is provided between the powder container and a hand hose line or monitor, the length of piping is to not exceed that length which is capable of maintaining the powder in a fluidized state during sustained or intermittent use and which can be purged of powder when the system is shut down. Hand hose lines and nozzles are to be of weather-resistant construction or stored in weather-resistant housings or covers and are to be readily accessible.

6

A sufficient quantity of dry chemical powder is to be stored in each container to provide a minimum 45 seconds discharge time for all monitors and hand hose lines attached to each powder unit. Coverage from fixed monitors is to be in accordance with the following requirements:
Hand hose lines are to be considered to have a maximum effective distance of coverage equal to the length of hose. Special consideration is to be given where areas to be protected are substantially higher than the monitor or hand hose reel locations.

7

Ships fitted with bow or stern loading and discharge arrangements are to be provided with an additional dry chemical powder unit complete with at least one monitor and one hand hose line complying with the requirements of Sections 12-4/1 to 12-4/6. This additional unit is to be located to protect the bow or stern loading and discharge arrangements. The area of the cargo line forward or aft of the cargo area is to be protected by hand hose lines.
1 The cargo handling rooms of any ship are to be provided with a carbon dioxide system as specified in Chapter 5 of the International Code for Fire Safety Systems, (FSS Code). A notice is to be exhibited at the controls stating that the system is only to be used for fire-extinguishing and not for inerting purposes, due to the electrostatic ignition hazard. The alarms referred to Ch. 5/2.1.3.2 of the FSS Code are to be safe for use in a flammable cargo vapor-air mixture. For the purpose of this requirement, an extinguishing system is to be provided which would be suitable for machinery spaces. However, the amount of carbon dioxide gas carried is to be sufficient to provide a quantity of free gas equal to 45% of the gross volume of the rooms where cargo handling occurs in all cases.

2 Fixed Carbon Dioxide Systems

Fixed carbon dioxide systems are allowed to be used for smothering fires in gas-dangerous enclosed spaces provided that:

2.1 Alarms for the release of carbon dioxide into such spaces are to be of the pneumatic type or electric type.

2.1.1 Pneumatically Operated Alarms

In cases where the periodic testing of such alarms is required, CO₂-operated alarms are not to be used, owing to the possibility of the generation of static electricity in the CO₂ cloud. Air-operated alarms may be used provided the air supply is clean and dry.

2.1.2 Electrically Operated Alarms

When electrically-operated alarms are used, the arrangements are to be such that the electric actuating mechanism is located outside of the space, except where the alarms are certified intrinsically safe.
CHAPTER  12  Fire Protection and Fire Extinction

SECTION  6  Firemen’s Outfits

1  
Every ship carrying flammable products is to carry firemen’s outfits complying with the requirements of Ch. 3/2 of the FSS Code as follows:

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<th>Number of Outfits</th>
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<tr>
<td>above 5,000 m³</td>
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2  
Any breathing apparatus required as part of a fireman’s outfit is to be a self-contained air-breathing apparatus having a capacity of at least 1,200ℓ of free air.
# Chapter 13  Mechanical Ventilation in the Cargo Area

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CHAPTER 13 Mechanical Ventilation in the Cargo Area

SECTION 1 Spaces Required to be Entered During Normal Cargo Handling Operations

The requirements of this Chapter are to be substituted for regulation II-2/4.5.4 of the 2000 SOLAS amendments.

CNG carriers fitted with a cargo processing plant and a Single Point Mooring system for loading/unloading cargo are also to comply with the requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations and ABS Rules for Building and Classing Offshore Installations.

1 Electric motor rooms, cargo compressor and pump rooms, other enclosed spaces which contain cargo handling equipment and similar spaces in which cargo handling operations are performed are to be fitted with mechanical ventilation systems capable of being controlled from outside such spaces. Provision is to be made to ventilate such spaces prior to entering the compartment and operating the equipment, and a warning notice requiring the use of such ventilation is to be placed outside the compartment.

2 Mechanical ventilation inlets and outlets are to be arranged to ensure sufficient air movement through the space to avoid the accumulation of flammable or toxic gases and to ensure a safe working environment, but in no case is the ventilation system to have a capacity of less than 30 changes of air per hour based upon the total volume of the space. As an exception, gas-safe cargo control rooms may have eight changes of air per hour.

3 Ventilation systems are to be fixed and, if of the negative pressure type, permit extraction from either the upper or the lower parts of the spaces, or from both the upper and the lower parts, depending on the density of the vapors.

4 In rooms housing electric motors driving cargo compressors or pumps, spaces except machinery spaces containing inert gas generators, cargo control rooms if considered as gas-safe spaces and other gas-safe spaces within the cargo area, the ventilation is to be of the positive pressure type.

5 In cargo compressor and pump rooms and in cargo control rooms if considered gas-dangerous, the ventilation is to be of the negative pressure type.

6 Ventilation exhaust ducts from gas-dangerous spaces are to discharge upwards in locations at least 10 m in the horizontal direction from ventilation intakes and openings to accommodation spaces, service spaces and control stations and other gas-safe spaces.

7 Ventilation intakes are to be so arranged as to minimize the possibility of recycling hazardous vapors from any ventilation discharge opening.
Ventilation ducts from gas-dangerous spaces are to not be led through accommodation, service and machinery spaces or control stations, except as allowed in Chapter 15 when using cargo as fuel.

Electric motors driving fans are to be placed outside of the ventilation ducts for a flammable cargo. Ventilation fans are not to produce a source of vapor ignition in either the ventilated space or the ventilation system associated with the space. Ventilation fans and fan ducts, in way of fans only, for gas-dangerous spaces are to be of non-sparking construction. A fan is considered as non-sparking if in both normal and abnormal conditions it is unlikely to produce sparks:

i) Impellers or housing of nonmetallic construction, due regard being paid to the elimination of static electricity

ii) Impellers and housing of nonferrous materials

iii) Impellers and housing of austenitic stainless steel

iv) Ferrous impellers and housing with not less than 13 mm design tip clearance

9.1 Design Criteria

The air gap between the impeller and the casing shall be not less than 10% of the impeller shaft diameter in way of the bearing but not less than 2 mm. It need not be more than 13 mm.

Protection screens of not more than 13 mm square mesh are to be fitted in the inlet and outlet of ventilation ducts to prevent the entrance of objects into the fan housing.

9.2 Materials

9.2.1 Except as indicated in 13-1/9.2.3iii) below, the impeller and the housing in way of the impeller are to be made of alloys which are recognized as being spark-proof by appropriate test.

9.2.2 Electrostatic charges both in the rotating body and the casing are to be prevented by the use of anti-static materials. Furthermore, the installation onboard of the ventilation units is to be such as to ensure the safe bonding to the hull of the units themselves.

9.2.3 Tests referred to in 13-1/9.2.1 above are not required for fans having the following combinations:

i) Impellers and/or housings of nonmetallic material, due regard being paid to the elimination of static electricity;

ii) Impellers and housings of nonferrous materials;

iii) Impellers of aluminum alloys or magnesium alloys and a ferrous (including austenitic stainless steel) housing on which a ring of suitable thickness of nonferrous materials is fitted in way of the impeller;

iv) Any combination of ferrous (including austenitic stainless steel) impellers and housings with not less than 13 mm tip design clearance.

9.2.4 The following impellers and housings are considered as sparking and are not permitted:

i) Impellers of an aluminum alloy or a magnesium alloy and a ferrous housing, regardless of tip clearance;
ii) Housing made of aluminum alloy or a magnesium alloy and a ferrous impeller, regardless of tip clearance;

iii) Any combination of ferrous impeller and housing with less than 13 mm design tip clearance.

9.3 Type Test

Type tests on the finished product are to be carried out using an acceptable national or international standard. The tests need not to be witnessed by the Surveyor for individual fans produced on a production line basis, provided the Surveyor is satisfied from periodic inspections and the manufacturer’s quality assurance procedures that the fans are being satisfactorily tested to appropriate standards. See also 1-1-A3/5.3 of the ABS Rules for Conditions of Classification (Part 1).

10

Spare parts are to be carried for each type of fan onboard referred to in 13-1/9.

11

Protection screens of not more than 13 mm square mesh are to be fitted in outside openings of ventilation ducts.
CHAPTER 13 Mechanical Ventilation in the Cargo Area

SECTION 2 Spaces not Normally Entered

Hold spaces, void spaces, cofferdams, spaces containing cargo piping and other spaces where cargo vapors may accumulate are to be capable of being ventilated to ensure a safe environment when entry into the spaces is necessary. Where a permanent ventilation system is not provided for such spaces, approved means of portable mechanical ventilation are to be provided. Where necessary owing to the arrangement of spaces (such as hold spaces) essential ducting for such ventilation is to be permanently installed. Fans or blowers are to be clear of personnel access openings and are to comply with Section 13-1/9.

The ventilation system for spaces not normally entered shall have a capacity of not less than eight (8) changes per hour based on the total volume of the space.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

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CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 1 General

In addition to the requirements for instrumentation and control as described below, instrumentation is to be in compliance with requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations.

1 Each cargo tank is to be provided with means for indicating pressure and temperature of the cargo, and where liquid discharge is used, the liquid level must be measured. Pressure gauges and temperature-indicating devices are to be installed in the liquid (if applicable) and vapor piping systems, in cargo refrigerating installations and in the inert gas systems as detailed in this Chapter. Where it is possible that condensate can form in a cargo tank, provisions must be provided to measure the condensate level.

2 Permanently installed instrumentation is to be provided to detect when the containment system fails. This instrumentation is to consist of appropriate gas-detecting devices according to Section 14-6. The instrumentation is to be capable of locating the cargo tank from which cargo is leaking.

3 If the loading and unloading of the ship is performed by means of remotely controlled valves, compressor and pumps, all controls and indicators associated with a given cargo tank are to be located in one control position.

4 Instruments are to be tested to ensure reliability in the working conditions and recalibrated at regular intervals. Test procedures for instruments and the intervals between recalibration are to be sent to ABS.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 2 Level Indicators for Cargo Tanks (If Applicable)

1 Each cargo tank is to be fitted with at least one liquid level gauging device (if liquid is being carried or used for loading/unloading) designed to operate at pressures not less than the MARVS of the cargo tank and at temperatures within the cargo operating temperature range.

2 Cargo tank level gauges may be of the following types:

i) Indirect devices which determine the amount of cargo by means such as weighing or pipe flow meters.

ii) Closed devices which do not penetrate the cargo tank, such as devices using radioisotopes or ultrasonic devices.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 3 Overflow Control (If Applicable)

1

Except as provided in Section 14-3/2, each cargo tank is to be fitted with a high liquid level alarm operating independently of other level indicators and giving an audible and visual warning when activated. Another sensor operating independently of the high level alarm is to automatically actuate a shutoff valve in a manner which will both avoid excessive pressure in the loading line and prevent the tank from becoming overpressurized. The emergency shutdown valve referred to in Section 6-5/3 may be used for this purpose. If another valve is used for this purpose, the same information as referred to in Section 6-5/3 is to be available onboard. During loading, whenever the use of these valves may possibly create a potential excess pressure surge in the loading system, the Port State authority may agree to alternative arrangements, such as limiting the loading rate, etc.

2

A high level alarm and automatic shutoff of cargo tank filling need not be required when the cargo tank is:

i) A pressure tank with a volume not more than 200 m$^3$; or

ii) Designed to withstand the maximum possible pressure during the loading operation and such pressure is below that of the start-to-discharge pressure of the cargo tank relief valve.

3

Electrical circuits, if any, of level alarms are to be capable of being tested prior to loading.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 4 Pressure Gauges

1 The vapor space of each cargo tank is to be provided with a pressure gauge which is to incorporate an indicator in the control position required by Section 14-1/3. In addition, a high-pressure alarm and, if vacuum protection is required, a low-pressure alarm, are to be provided on the navigation bridge. Maximum and minimum allowable pressures are to be marked on the indicators. The alarms are to be activated before the set pressures are reached. For cargo tanks fitted with pressure relief valves which can be set at more than one set pressure in accordance with Section 9-2/5, high-pressure alarms are to be provided for each set pressure.

2 Each cargo pump discharge line and each liquid and vapor cargo manifold is to be provided with at least one pressure gauge.

3 Local-reading manifold pressure gauges are to be provided to indicate the pressure between stop valves and hose connections to the shore.

4 Hold spaces and interbarrier spaces without open connection to the atmosphere are to be provided with pressure gauges.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 5 Temperature-indicating Devices

1

Each cargo tank is to be provided with at least two devices for indicating cargo temperatures. If the devices are placed at inlet and/or outlet to the tank, they are to be located before the first shut-off valve so as to be in communication with the tank contents at all times. The temperature-indicating devices are to be marked to show the lowest temperature for which the cargo tank has been approved by ABS.

2

When a cargo is carried in a cargo containment system with a thermal protection, temperature-indicating devices are to be provided within the insulation or on the hull structure adjacent to cargo containment systems. The devices are to give readings at regular intervals and, where applicable, audible warning of temperatures approaching the lowest for which the hull steel is suitable.

3

If cargo is to be carried at temperatures lower than -5°C, the cargo hold boundaries are to be fitted with temperature-indicating devices as follows:

i) A sufficient number of devices to establish that an unsatisfactory temperature gradient does not occur.

ii) On one tank, a number of devices in excess of those required in Section 14-5/3i) in order to verify that the initial cool down procedure, if necessary, is satisfactory. These devices may be either temporary or permanent. When a series of similar ships is built, the second and successive ships need not comply with the requirements of this item.

4

The number and position of temperature-indicating devices are to be to the satisfaction of ABS.
CHAPTER 14 Instrumentation (Gauging, Gas Detection and Cargo Handling Controls)

SECTION 6 Gas Detection Requirements

1 Gas detection equipment acceptable to ABS and suitable for the gases to be carried is to be provided.

2 In every installation, the positions of fixed sampling heads are to be determined with due regard to the density of the vapors of the products intended to be carried and the dilution resulting from compartment purging or ventilation.

3 Pipe runs from sampling heads are not to be led through gas-safe spaces, except as permitted by Section 14-6/5.

4 Audible and visual alarms from the gas detection equipment, if required by this Chapter, are to be located on the navigation bridge, in the control position required by Section 14-1/3 and at the gas detector readout location.

5 Gas detection equipment may be located in the control position required by Section 14-1/3, on the navigating bridge or at other suitable locations. When such equipment is located in a gas-safe space, the following conditions are to be met:
   
i) Gas-sampling lines are to have shutoff valves or an equivalent arrangement to prevent cross-communication with gas-dangerous spaces; and
   
ii) Exhaust gas from the detector is to be discharged to the atmosphere in a safe location.

6 For gas monitoring of the cargo area, sampling type gas analyzing units which are not intended for a hazardous location may be located outside cargo areas (e.g., in cargo control room, navigation bridge or engine room) when mounted on the inside of the front bulkhead and subject to compliance with the following:

6.1 Sampling lines are not to pass through gas-safe spaces, unless permitted by Section 14-6/6.5.

6.2 The non-safe type gas analyzing unit is to be installed in a safe area and the gas sampling lines are to be fitted with flame arresters. Sample gas is to be led to the atmosphere. The outlets are to be fitted with flame screens and are to be located in a safe location. The area within 3 m (10 ft) of the outlet pipe is to be considered a hazardous location.
6.3

Where sampling pipes pass through bulkheads separating safe and dangerous areas, the penetrations are to be of an approved type having fire integrity at least as effective as the bulkhead. A manual isolation valve is to be fitted at each penetration on the gas-safe side.

6.4

The gas detection equipment, including sampling piping, sampling pumps, solenoids, analyzing units, etc., is to be contained in a reasonably gas-tight steel cabinet (e.g., fully enclosed steel cabinet with gasketed door) being monitored by its own sampling point. The entire gas analyzing unit is to be automatically shut down when the gas concentration inside the cabinet reaches 30% of the lower flammability limit.

6.5

Where it is impracticable to mount the cabinet on the front bulkhead, sampling pipes are to be of steel or other equivalent material and without any detachable connections, except for the isolating valves at the bulkhead and analyzing units. Runs of sampling pipes within safe spaces are to be the shortest possible length.

7

Gas detection equipment is to be so designed that it may readily be tested. Testing and calibration are to be carried out at regular intervals. Suitable equipment and span gas for this purpose are to be carried onboard. Where practicable, permanent connections for such equipment are to be fitted.

8

A permanently installed system of gas detection and audible and visual alarms is to be provided for:

i) Cargo handling machinery

ii) Cargo control rooms, unless designated as gas-safe

iii) Other enclosed spaces in the cargo area where vapor may accumulate, including hold spaces and interbarrier spaces for independent tanks other than type C

iv) Ventilation hoods and gas ducts where required by Chapter 15

v) Air-locks

9

The gas detection equipment is to be capable of sampling and analyzing from each sampling head location sequentially at intervals not exceeding 30 min, except that in the case of gas detection for the ventilation hoods and gas ducts referred to in Section 14-6/8iv), sampling is to be continuous. Common sampling lines to the detection equipment are not to be fitted.

10

In the case of products which are toxic or both toxic and flammable, ABS may authorize the use of portable equipment for detection of toxic products as an alternative to a permanently-installed system, if such equipment is used before personnel enter the spaces listed in Section 14-6/8 and at 30-minute intervals while they remain therein.

11

For the spaces listed in Section 14-6/8, alarms are to be activated for flammable products when the vapor concentration reaches 30% of the lower flammability limit.
In the case of flammable products, where cargo containment systems other than independent tanks are used, hold spaces and interbarrier spaces are to be provided with a permanently-installed gas detection system capable of measuring gas concentrations of 0 to 100% by volume. The detection equipment, equipped with audible and visual alarms, is to be capable of monitoring from each sampling head location sequentially at intervals not exceeding 30 minutes. Alarms are to be activated when the vapor concentration reaches the equivalent of 30% of the lower flammability limit in air or such other limit as may be approved by ABS in the light of particular cargo containment arrangements. Common sampling lines to the detection equipment are not to be fitted.

Hold spaces are to be provided with a permanently installed piping system for obtaining gas samples from the spaces. Gas from these spaces is to be sampled and analyzed from each sampling head location by means of fixed or portable equipment at intervals not exceeding four (4) hours and, in any event, before personnel enter the space and at 30-minute intervals while they remain therein.

Every ship is to be provided with at least two sets of portable gas detection equipment acceptable to ABS and suitable for the products to be carried.

A suitable instrument for the measurement of oxygen levels in inert atmospheres is to be provided.
CHAPTER 15 Use of Cargo as Fuel

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CHAPTER 15 Use of Cargo as Fuel

SECTION 1 General

For a CNG carrier with cargo processing capability, requirements of the ABS Rules for Building and Classing Facilities on Offshore Installations are also to be applied for fuel gas generation and use of cargo in open deck equipment.

1 CNG may be utilized in machinery spaces of Category A and in such spaces may be utilized only in boilers, inert gas generators, combustion engines and gas turbines.

2 These provisions do not preclude the use of gas fuels for auxiliary services in other locations, provided that such other services and locations are specially considered by ABS.

3 Plans and specifications covering the entire installation with all of the accessories are to be submitted (Section 4-1-1/5 of the Marine Vessel Rules) and are to include:

- General arrangement
- Gas piping, including details of all special valves and fittings
- Gas compressors
- Gas heaters
- Gas storage pressure vessels
- Schematic-wiring diagram
- Details of all electrical equipment
- Electric bonding arrangement
- Operating instruction manual
- A failure mode and effect analysis (FMEA) examining possible faults affecting the combustion process for internal-combustion engines

4 Where it is intended to use dual fuel engines, their installation is to comply with ABS Guide for Propulsion Systems for LNG Carriers.
# Operating Requirements

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CHAPTER 16 Operating Requirements

SECTION 1 Cargo Information

1

Information is to be onboard and available to all concerned, giving the necessary data for the safe carriage of cargo. Such information is to include:

   i) A full description of the physical and chemical properties necessary for the safe containment of the cargo
   ii) Action to be taken in the event of leaks or release
   iii) Fire-fighting procedures and fire-fighting media
   iv) Procedures for cargo transfer, gas-freeing, ballasting
   v) Minimum allowable inner hull steel temperatures
   vi) Emergency procedure

2

A copy of this Guide or national regulations incorporating the provisions of this Guide is to be onboard every ship covered by this Guide.

3

Detailed operational/maintenance manual should be submitted for ABS review and approval for class.
CHAPTER 16 Operating Requirements

SECTION 2 Personnel Training*

Note:

* Reference is made to the provisions of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, and in particular to the “Mandatory minimum requirements for the training and qualifications of masters, officers and ratings of liquefied gas tankers”-regulation V/3, chapter V of the Annex to that Convention and to resolution 12 of the International Conference on Training and Certification of Seafarers, 1978

1

Personnel involved in cargo operations are to be adequately trained in handling procedures.

2

All personnel are to be adequately trained in the use of protective equipment provided onboard and have basic training in the procedure, appropriate to their duties, necessary under emergency conditions.

3

Officers are to be trained in emergency procedures to deal with conditions of leakage, release, spillage or fire involving the cargo and a sufficient number of them are to be instructed and trained in essential first aid for the cargoes carried.
CHAPTER  16 Operating Requirements

SECTION  3 Entry into Spaces

1

Personnel are not to enter cargo tanks, hold spaces, void spaces, cargo handling spaces or other enclosed spaces where gas may accumulate unless:

i) The gas content of the atmosphere in such space is determined by means of fixed or portable equipment to ensure oxygen sufficiency and the absence of toxic atmosphere; or

ii) Personnel wear breathing apparatus and other necessary protective equipment and the entire operation is under the close supervision of a responsible officer.

2

Personnel entering any space designated as gas-dangerous on a ship carrying Compressed Natural Gas are not to introduce any potential source of ignition into the space unless it has been certified gas-free and is maintained in that condition.
When handling cargoes at low temperature:

i) If provided, the heating arrangements associated with cargo containment systems are to be operated in such a manner as to ensure that the temperature does not fall below that for which the material of the hull structure is designed.

ii) Loading is to be carried out in such a manner as to ensure that unsatisfactory temperature gradients do not occur in any cargo tank, piping or other ancillary equipment.

iii) When cooling down tanks from temperatures at or near ambient, the cool-down procedure laid down for that particular tank, piping and ancillary equipment is to be followed closely.
CHAPTER 16 Operating Requirements

SECTION 5 Protective Equipment

Personnel are to be made aware of the hazards associated with the cargo being handled and are to be instructed to act with care and use the appropriate protective equipment during cargo handling.
Cargo emergency shutdown and alarm systems involved in cargo transfer are to be tested and checked before cargo handling operations begin. Essential cargo handling controls are also to be tested and checked prior to transfer operations.
Transfer operations, including emergency procedures, are to be discussed between ship personnel and the personnel responsible at the receiving/delivering facility prior to commencement and communications maintained throughout the transfer operations.
# Chapter 17 Surveys

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CHAPTER 17 Surveys

SECTION 1 Surveys During Construction

1 General

This Section pertains to surveys and inspections during construction of a CNG carrier. A general quality plan highlighting required surveys together with ABS hold points is to be determined by the builder and agreed upon by the attending Surveyor.

2 Surveys During Construction

2.1 General

During construction of equipment components for a CNG carrier, the attending Surveyor is to have access to vendors’ facilities to witness construction and/or testing, as required by this Guide. The vendor is to contact the attending Surveyor to make necessary arrangements. If the attending Surveyor finds reason to recommend repairs or additional surveys, notice will be immediately given to the Owner or Owner’s Representative so that appropriate action may be taken.

2.2 Survey at Vendor’s Shop

Survey requirements for equipment components and packaged units at the vendor’s shop are summarized in relevant sections of applicable ABS Rules/Guides. Each vendor is required to have an effective quality system that is to be verified by the attending Surveyor.

2.3 Structure Fabrication/Erection

A Quality Control Program (QCP) compatible with the type, size and intended service of the CNG carrier is to be developed and submitted to the attending Surveyor for review and agreement. Required hold points on the QCP that is to form the basis for all future ABS surveys at the fabrication yard shall be agreed upon by the attending Surveyor. As a minimum, all of the items enumerated in the following applicable Subsections are to be covered by the QCP. ABS shall assure that all tests and inspections specified in the QCP are satisfactorily carried out by a competent person, and ABS surveys shall be considered to supplement and not replace inspections that should be carried out by the fabricator or operator.

The fabricator is to maintain a system of material traceability to the satisfaction of the attending Surveyor. Data as to place of origin and results of tests for materials shall be retained and are to be readily available to ABS upon request.

Where equipment and components are assembled in blocks or modules, the Surveyor is to inspect the fit-up, piping and electrical connections, and to witness the required tests on the completed assembly in guidance with the QCP and in accordance with the approved plans and Rule/Guide requirements. The progress and suitability of structural fit-up and joining of constructed/fabricated blocks/modules are to be to the satisfaction of the attending Surveyor. All erection joints are to be subjected to visual examination, proven tight, and the extent of nondestructive examination (NDE) carried out is to be to the satisfaction of the attending Surveyor.

2.3.1 Surveys on Hull Structure

2.3.1(a) Quality Control Program. The quality control program for the construction of the hull structure is to include the following items, as appropriate.

- Material quality and traceability
- Steel forming
- Welder qualification and records
Welding procedure specifications and qualifications
- Weld inspection
- Tolerances alignments and compartment testing
- Corrosion control systems
- Tightness and hydrostatic testing procedures
- Nondestructive testing

The items which are to be considered for each of the topics mentioned above are indicated in Sections 17-1/2.3.1(b) through 17-1/2.3.1(i).

2.3.1(b) Material Quality and Traceability. The properties of the material are to be in accordance with this Guide and the ABS Rules for Materials and Welding (Part 2). Manufacturer’s certificates are to be supplied with the material. Verification of the material’s quality is to be done by the Surveyor at the plant of manufacture, in accordance with the ABS Rules for Materials and Welding (Part 2). Alternatively, material manufactured to recognized standards may be accepted in lieu of the above steel requirements, provided the substitution of such materials is approved by ABS. Materials used are to be in accordance with those specified in the approved design and all materials required for classification purposes are to be tested in the presence of a Surveyor. The Constructor is to maintain a material traceability system for all the primary and special application structures.

2.3.1(c) Steel Forming. When forming changes base plate properties beyond acceptable limits, appropriate heat treatments are to be carried out to reestablish required properties. Unless approved otherwise, the acceptable limits of the reestablished properties should meet the minimums specified for the original material before forming. ABS will survey formed members for their compliance with the forming dimensional tolerances required by the design.

2.3.1(d) Welder Qualification and Records. Welders who are to work on the structure are to be qualified in accordance with the welder qualification tests specified in a recognized code or, as applicable, the ABS Rules for Materials and Welding (Part 2) to the satisfaction of the attending Surveyor. Certificates of qualification are to be prepared to record evidence of the qualification of each welder qualified by an approved standard/code, and such certificates are to be available for the use of the Surveyors. In the event that welders have been previously tested in accordance with the requirements of a recognized code, and provided that the period of effectiveness of the previous testing has not lapsed, these welder qualification tests may be accepted.

2.3.1(e) Welding Procedure Specifications and Qualifications. Welding procedures are to be approved in accordance with the ABS Rules for Materials and Welding (Part 2). Welding procedures conforming to the provisions of a recognized code may be accepted at the Surveyor’s discretion. A written description of all procedures previously qualified may be employed in the structure’s construction, provided it is included in the quality control program and made available to the Surveyors. When it is necessary to qualify a welding procedure, this is to be accomplished by employing the methods specified in the recognized code and in the presence of the Surveyor.

2.3.1(f) Weld Inspection. As part of the overall quality control program, a detailed plan for the inspection and testing of welds is to be prepared, and this plan is to include the applicable provisions of the ABS Marine Vessel Rules.

2.3.1(g) Tolerances and Alignments. The overall structural tolerances, forming tolerances and local alignment tolerances are to be commensurate with those considered in developing the structural design. Inspections are to be carried out to ensure that the dimensional tolerance criteria are being met. Particular attention is to be paid to the out-of-roundness of members for which buckling is an anticipated mode of failure. Structural alignment and fit-up prior to welding shall be monitored to ensure consistent production of quality welds. IACS Recommendation No. 47 may be referred to.
2.3.1(h) **Tightness and Hydrostatic Testing Procedures.** Compartments which are designed to be permanently watertight or to be maintained watertight during installation are to be tested in accordance with Section 3-7-1 of the ABS *Marine Vessel Rules* and by a procedure approved by the attending Surveyor. The testing is also to be witnessed by the attending Surveyor.

2.3.1(i) **Nondestructive Testing.** A system of nondestructive testing is to be included in the fabrication specification of the structures. The minimum extent of nondestructive testing shall be in accordance with the ABS *Guide for Nondestructive Inspection of Hull Welds* or recognized design Code. All nondestructive testing records are to be reviewed and approved by the attending Surveyor. Additional nondestructive testing may be requested by the attending Surveyor.

### 2.4 **CNG Containment and Handling Systems**

#### 2.4.1 **CNG Cargo Tank, CNG Piping System Fabrication**

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

#### 2.4.2 **CNG Systems Operations Manual**

The CNG systems' operation/handling manual is to be available onboard to all persons concerned, outlining necessary data for the safe storage and handling of CNG. Description contained in the manual is to include, but not be limited to the following:

1. **Outline features of CNG system such as:**
   - Principal particulars
   - Properties and characteristics of the CNG (range of density and composition)
   - Storage tanks, piping, CNG handling equipment
   - Control system and instrumentation

2. **Safety systems such as:**
   - Fire protection, ventilation, fire detection, fire fighting equipment
   - Personnel protection, safety precautions, equipment
   - Communications

3. **Normal operating procedures or cargo handling guidance such as:**
   - Inverting, gas freeing, loading, discharging, aeration

4. **An envelope of limiting environmental conditions for carrying out safe operations**

5. **Emergency operations such as:**
   - Cargo leakage
   - Jettisoning (if applicable)
   - Accepting CNG from a disabled CNG carrier
   - Lightering at a discharge terminal
2.5 **Process Systems**

Process pressure vessels, refrigerant storage tanks, heat exchangers, piping system components, compressors, pumps and other mechanical equipment and electrical systems, control systems and equipment that are part of a classed process system will be surveyed during fabrication, installation and testing to the same extent that CNG cargo tanks and handling systems are reviewed in accordance with Section 17-1/2.4 above.

2.6 **Piping**

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

2.7 **Electrical**

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

2.8 **Instrumentation**

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

2.9 **Mechanical**

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

2.10 **Surveys During Testing and Trials**

The classification date will be the date on which a Surveyor issues the Interim Classification Certificate for the CNG carrier. Testing and trials of all Rule-required systems is to be verified by the attending Surveyor in accordance with the agreed step-by-step procedures. The Surveyor is to be permitted access to critical/hold points to verify that the procedures are satisfactorily accomplished. The Surveyor is to observe operation under various capacities and conditions.

Sea trials are to be carried out as required by the *Marine Vessel Rules* in accordance with approved procedures and to the satisfaction of the Surveyor.

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

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

2.10.1 **Service Test**

All cargo tanks, thermal protection, any insulation and the cargo-handling equipment are to be tested under service conditions prior to final action with regard to classification. The cargo tanks are to be filled to the normal capacity with cargo at the operating service temperature and service pressure.
The effectiveness of the insulating arrangements (for low temperature CNG) is to be confirmed under operating conditions. If the service tests or subsequent operation are not satisfactory, changes in the insulating arrangements may be required.

For a CNG carrier with substantial process equipment for conditioning of cargo, refer to the ABS Rules for Building and Classing Facilities on Offshore Installations for startup and testing.

2.10.2 Test Agenda

The agenda for the tests required by this Chapter is to be submitted for review. The tests are to be witnessed by a Surveyor and a complete report of the results is to be submitted for consideration prior to final approval of the cargo tank and the adjacent hull structure. In addition, for hydrostatic testing of pressure vessel type cargo tanks, see Section 4-4-1/7.11 of the Marine Vessel Rules.

For cargo tank design using pressure vessel codes or limit state approach, the testing agenda with complete details must be submitted to support the design and high material usage factor.

2.11 Personnel Safety

Personnel safety precautions, which should include checks of operational readiness of all personal protection, fire and gas detection and fire fighting equipment, ESD systems, unobstructed escape routes and establishment of communication procedures, are to be taken during trials and are required to be verified by the attending Surveyor. All such emergency procedures are to be capable of dealing with any contingencies such as fire and other hazards.
CHAPTER 17 Surveys

SECTION 2 Surveys After Construction and Maintenance of Class (2017)

1 General

A survey plan for the cargo containment system shall be developed and submitted for approval. The plan shall identify areas that require examination and testing during special surveys throughout the cargo containment system’s life based upon the system’s design parameters. Cargo containment systems shall be designed, constructed and equipped to provide adequate means of access to areas that need inspection as specified in the survey plan.

2 Survey After Construction

The requirements for Survey after Construction in this Guide refer to the following applicable Chapters of the independent booklet, ABS Rules for Survey After Construction (Part 7):

- CHAPTER 1 Conditions for Survey After Construction
- CHAPTER 2 Survey Intervals
- CHAPTER 3 Hull Surveys
- CHAPTER 4 Drydocking Surveys
- CHAPTER 5 Tailshaft Surveys
- CHAPTER 6 Machinery Surveys
- CHAPTER 7 Boiler Surveys
- CHAPTER 8 Shipboard Automatic and Remote-control Systems
- CHAPTER 9 Survey Requirements for Additional Systems and Services
- APPENDIX
CHAPTER 17 Surveys

SECTION 3 Risk-based Surveys for Maintenance of Class

1 General
The provisions of this Section contain survey requirements specific to the maintenance of classification for CNG carriers for which inspection plans have been developed using risk-based techniques as an equivalent alternative to prescriptive requirements as defined in Section 17-2 of this Guide.

1.1 Applicability
While this Section provides risk-based survey requirements as an alternative for maintenance of Class, the Sections on the classification process contained in this Guide are still applicable. Where no specific references or guidance are given in this Section, the relevant requirements of conventional Rules/Guides remain valid.

1.2 Survey Periods
Because of the diverse design concepts of CNG carriers and the varied contents of inspection plans likely to be developed as part of an Owner’s risk-based approach to classification, it is not considered practicable to establish a firm schedule of survey requirements in this Section for maintenance of class. However, any statutory requirements must be to International Standards, unless modified by the Administration.

2 Requirements for Risk-based Survey

2.1 General
Where the risk-based approach is to be adopted, the Owner’s proposed maintenance and inspection plans, including details of frequency and extent of activities, are to be submitted for review. Where these plans deviate from the conventional survey requirements described in this Guide, the risk assessment methodology is to specifically address these deviations which are not to result in an unacceptable level of safety or integrity of the CNG carrier. In addition to the maintenance and inspection plans noted above, the following documentation is to be submitted to ABS at least six (6) months before the plan is to be put into effect. This documentation is to establish, at a minimum:

i) The basis and methodology employed in the risk-based techniques.

ii) The means by which the technique is used to establish maintenance plans.

iii) The means by which the technique is used to update and modify maintenance and inspection plans.

iv) The means by which the following items are to be controlled:

- Accident and Non-Conformity Reporting.
- Overdue Inspections/Surveys.
- Internal Audits and Management Reviews.
- Control, Storage and Retention of Documents and Data.
- Change Procedures for ABS-approved plans.

2.2 Risk Assessment
Where the risk-based approach is to be adopted on a CNG carrier, the risk assessment on which the inspection and maintenance plan is based is to be specific. If the CNG carrier is to be employed in a
different manner than intended in the original RBI, the risk assessment is to be reviewed and revised as necessary by the Owner and resubmitted to ABS for approval.

3 Surveys

3.1 General

3.1.1 Special Periodical Survey

To credit a Special Periodical Survey based on risk-based inspection techniques, the CNG carrier is to be subject to a Continuous Survey program, whereby the survey of all applicable items is to be carried out on a continuous basis over the five-year Special Periodical Survey cycle. If this program includes a preventative-maintenance/condition-monitoring plan, this plan is to be in accordance with Appendix 7-A-14, “Survey Based on Preventative Maintenance Techniques”, of the ABS Rules for Survey After Construction (Part 7).

3.1.2 Inspection Plan

The inspection plan detailing the timing and extent of activities will be reviewed to establish the scope and content of the Annual and Special Periodical Surveys which are required to be carried out by a Surveyor who will also monitor the Owner’s in-house quality management system required by this Guide. During the service life of the CNG carrier, maintenance and inspection records are to be updated on a continuing basis and be available for reference by the attending Surveyor. The operator is to inform ABS of any changes to the maintenance procedures and their frequencies as may be caused, for example, by changes, additions or deletions to the original equipment.

3.2 Initial Survey

An Initial Survey is to be carried out to confirm that systems and required plans have been properly implemented. The survey is to be carried out a minimum of three (3) months after the date of implementation of the approved plans, but no later than concurrently with the next due Annual Survey.

3.3 Annual Survey

An Annual Survey is to be carried out by a Surveyor within three (3) months before or after each anniversary date of the initial/renewal Classification Survey. The survey is to be carried out in accordance with the approved risk-based inspection plan to confirm the fitness of the CNG carrier for continued operation. Where the inspection plan specifically applies ABS Rules, the applicable items are to be complied with.

3.4 Special Periodical Survey

A Special Periodical Survey of the facilities is to be carried out within five (5) years of the initial Classification Survey and at five-year intervals thereafter. The survey is to include all items in the approved risk-based inspection plan listed under the Annual Survey, confirmation of the completion of the Continuous Survey program, and where the inspection plan specifically applies ABS Rules, the applicable items are to be complied with.

4 Modifications

When modifications to the CNG carrier that may affect classification are to be carried out after the issuance of Classification Certificate, the details of such modifications are to be submitted for review. If ABS determines that the modification will affect classification, the CNG carrier to be modified will be subject to the review, testing and inspection requirements of this Guide. All documentation requirements for review and the design documentation described in Section 17-2/1.3 of this Guide is to be available to the attending Surveyor at the time of the modifications.
5 Damage and Repairs

The requirements stated in Section 17-2/1.2 of this Guide shall apply.