Requirements for

Liquefied Hydrogen Carriers

ABS

October 2023

REQUIREMENTS FOR

LIQUEFIED HYDROGEN CARRIERS
OCTOBER 2023

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

ABS Plaza
1701 City Plaza Drive
Spring, TX 77389 USA

Foreword

There is an increased commitment from the International Maritime Organization (IMO) to reduce Green House Gas (GHG) emissions from shipping through the use of gases or low-flashpoint fuels such as hydrogen, ammonia, methane, methanol, or their e-fuel variants produced from non-fossil fuel sources. These fuels are expected to become more widely adopted by the marine industry as a substitute for conventional residual or distillate marine fuels. In response to the IMO GHG reduction targets, the marine industry has increased its interest in the use and transport of hydrogen due to its properties as a zero-emission fuel and the ability to produce hydrogen from renewable and sustainable sources. This document addresses the carriage of liquefied hydrogen in bulk.

The ABS criteria to be applied to liquefied gas carriers are detailed in Part 5C, Chapter 8 of the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)*, which incorporates the IMO Resolution MSC.370(93) *Amendments to the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code).

Currently, the IGC Code does not include detailed prescriptive requirements for the carriage of liquefied hydrogen. Because hydrogen is not a product gas covered in Chapter 19 of the IGC Code, a Tripartite Agreement between the Administration and the port Administrations is required as per 1.1.6.1 of the IGC Code. This Agreement is to be based on a provisional assessment and denotes the preliminary suitable conditions of carriage based on the principles of the Code.

Additionally, IMO Resolution MSC.420(97), *Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk*, adopted on 25 November 2016, provides minimum recommendations for the carriage of liquefied hydrogen in bulk.

Accordingly, this document has been developed to further support the carriage of liquefied hydrogen on vessels, and incorporates the provisions denoted in the aforementioned IMO Resolution MSC.420(97) .

Where these Requirements are proposed to be used for compliance with the IGC Code and MSC.420(97), such application is subject to approval by the vessel's Flag Administration prior to issuance of relevant statutory certificates.

The applicable edition of the *Marine Vessel Rules* is to be used in conjunction with this document.

This document becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this document is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

REQUIREMENTS FOR

LIQUEFIED HYDROGEN CARRIERS

CONTENTS

SECTION 1
General

1 Introduction

International regulations pertaining to ships engaged in the safe carriage of liquefied gases in bulk are covered by IMO Resolution MSC.370(93) *Amendments to the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code). The IGC Code has been incorporated along with ABS requirements into Part 5C, Chapter 8 of the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)*.

Hydrogen is not included among the list of products with specified minimum requirements in Chapter 19 of the IGC Code. Instead, hydrogen is subject to the requirements of paragraph 1.1.6.1 of the IGC Code:

Where it is proposed to carry products that may be considered to come within the scope of this Code that are not at present designated in chapter 19, the Administration and the port Administrations involved in such carriage shall establish a Tripartite Agreement based on a provisional assessment and lay down preliminary suitable conditions of carriage based on the principles of the Code.

The IMO also adopted Resolution MSC.420(97) *Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk* on 25 November 2016. The *Interim Recommendations* contain provisional recommendations for the carriage of liquefied hydrogen which are intended to lay the groundwork for future minimum or special requirements for the carriage of liquefied hydrogen, as per the process outlined in Paragraph 5 of the preamble of the IGC Code. The *Interim Recommendations* were developed with the assumption that liquefied hydrogen carriers will not be used to carry other cargos, and thus the recommendations are not applicable to vessels engaged in such practices.

2 Scope

These Requirements are based on the special requirements provided by IMO Resolution MSC.420(97) *Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk*.

These Requirements are to be applied to both new construction and existing vessel conversions, regardless of size, engaged in the carriage of liquefied hydrogen in bulk.

The Requirements contained herein provide Classification criteria for the arrangements, construction, installation and survey of machinery, equipment and systems for vessels engaged in the carriage of liquefied hydrogen in order to minimize risks to the vessel, crew and environment.

These Requirements specify the unique requirements applicable to vessels carrying liquefied hydrogen, and are always to be used in association with the IGC Code, as incorporated in Part 5C, Chapter 8 of the *Marine Vessel Rules*, and with other relevant Sections of the *Marine Vessel Rules*. Vessels intended to carry liquefied hydrogen as cargo are to comply with Part 5C, Chapter 8 of the *Marine Vessel Rules* in its entirety, except as modified herein. The goals and functional requirements in the cross-referenced Rules and Regulations are also to be applied.

Liquefied gas tank barges intending to carry liquefied hydrogen cargo will be specially considered on a case-by-case basis. Refer to the ABS *Rules for Building and Classing Steel Barges* for more information.

Vessels intending to use hydrogen cargo as fuel will also be specially considered on a case-by-case basis. Refer to the ABS *Requirements for Hydrogen Fueled Vessels* for more information.

3 Classification

In accordance with 1-1-3/3 of the ABS *Rules for Conditions of Classification*, the mandatory notation **Liquefied Hydrogen Carrier** is to be assigned to a liquefied gas carriers designed to carry liquefied hydrogen and built to the requirements of this document and other relevant sections of the *Marine Vessel Rules*. See 5C-8-1/1 of the *Marine Vessel Rules* for more information on other ABS notations for vessels built in accordance with the IGC Code.

4 Certification

ABS design review, survey, testing, and the issuance of reports or certificates constitute the certification of machinery, materials, equipment and systems. Refer to Section 4-1-1 of the *Marine Vessel Rules* for more information. Requirements for certification are to take into consideration the specific properties of hydrogen, as described in Section 1/7 of this document.

Commentary:

Because the temperature of liquefied hydrogen is -253°C, the cargo containment system, auxiliary systems and piping may operate at conditions outside of standard certification parameters and may require additional provisions for certification.

End of Commentary

5 Flag Administration Approval

Where these Requirements are considered to be used to comply with the IGC Code, such application is subject to approval by the vessel's Flag Administration prior to issuance of relevant statutory certificates.

6 Definitions and Abbreviations

For the purpose of this document, the definitions provided in 5C-8-1/2 of the *Marine Vessel Rules* are to be applied here.

7 Properties of Hydrogen

7.1

For the purpose of this document, the properties of hydrogen cargo are defined by Table 3 of the *Interim Recommendations* or a recognized standard such as ISO/TR 15916. Alternative definitions for hydrogen properties are to be submitted to and reviewed by ABS for approval.

Commentary:

Hydrogen exhibits a number of unique characteristics that must be considered. It has a wide range of flammability limits, its flames are difficult to see, and its higher flame velocity may lead to a detonation and resulting shockwave rather than deflagration. Hydrogen also has a high rate of permeation into surrounding materials due to its small molecular size, which can lead to the weakening of the surrounding structure in a phenomenon known as hydrogen embrittlement.

End of Commentary

7.2

In the same format used in Section 5C-8-19 of the *Marine Vessel Rules* for respective cargoes, 1/Table 1 below describes the general requirements to be applied to liquefied hydrogen carriers as defined in Table 2 of the *Interim Recommendations*. Column 'i' denotes special requirements, which are addressed in the contents of this document.

TABLE 1
General Requirements for liquefied hydrogen carriers

a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
Product Name		Ship Type	Independent Tank type C required	Control of vapour space within cargo tanks	Vapour detection	Gauging		Special Requirements
Hydrogen		2G	-	-	F	C		

8 Plans and Data to be Submitted

The following plans, data and specifications are to be submitted in addition to any applicable plans and data as listed in Part 1, Part 4, and Part 5C, Chapter 8 of the *Marine Vessel Rules*:

8.1 Ship Arrangement and Systems

Documentation covering the ship arrangements and systems including but not limited to the following are to be submitted, as applicable:

i) Risk assessment plan and associated risk assessment report(s) as referenced by Section 2/2 of these Requirements

ii) General arrangement of vessel

iii) Cargo containment system arrangements

iv) Cargo piping system arrangements, including complete pipe stress analysis

v) Cargo loading and offloading station arrangements

vi) Hazardous area classification plan, including the gas dispersion study which informed the classification of hazardous areas

vii) Cargo operations and maintenance manuals (for reference only)

viii) Emergency response plan, including mitigation techniques for hydrogen release from the cargo containment system

ix) Description of the control, monitoring and safety systems, including alarm and shutdown monitoring and cause and effect diagram

8.2 Cargo Containment

For Section 4 of these Requirements, plans and specifications covering the cargo containment system listed below are to be submitted, including but not limited to the following, as applicable:

i) General arrangement plans of the vessel showing the position of the cargo containment system and details of manholes and other openings in cargo tanks

ii) Plans of the hull structure in way of the cargo tanks, including the installation of attachments, accessories, internal reinforcements, saddles for support and tie-down devices

iii) Plans of the structure of the cargo containment system, including the installation of attachments, supports and attachment of accessories

For independent cargo tanks, the standard or Code adopted and utilized for the construction and design is to be identified. Detailed construction drawings together with design calculations for the pressure boundary, tank support arrangement and analysis for the load distribution. Anti-collision arrangements, chocking arrangement and other applicable design calculations are to be provided

iv) Distribution of the specification, grades and types of steel proposed for the structures of the hull and of the cargo containment system, including attachments, valves, accessories, and other components, together with the calculation of the temperatures on all of the structures which can be affected by the low temperatures of the cargo. Material suitability for hydrogen applications, including vulnerability to hydrogen embrittlement for the design temperature and pressure, is to be included.

v) Design loads and structural analyses for the cargo storage tank(s) together with complete stress analysis, as applicable, of the hull and cargo containment system including sloshing analysis

vi) Specifications and plans of the insulation system and calculations of the heat balance

vii) Procedures and calculations of the cooling down and loading operations, including loading limit curve

viii) Details of all cargo and vapor handling equipment

ix) Details of loading and unloading systems, venting systems, and gas-freeing systems, as well as a schematic diagram of the remote-controlled valve system

x) Details and installation of all systems used to manage boil-off hydrogen gas.

xi) Details and installation of the safety valves and relevant calculations of their relieving capacity, including back pressure

xii) Details and installation of the various monitoring and control systems, including the devices for measuring the level in the tanks and the temperatures in the containment system

xiii) Schematic diagram of the ventilation system indicating the vent pipe sizes and location of the openings

xiv) Cargo tank pressure accumulation calculation for all cargo pressure tanks

xv) Schematic diagram of the refrigeration system together with the calculations concerning the refrigerating capacity

xvi) Details of the electrical equipment installed in the cargo containment area and of the electrical bonding of the cargo tanks and piping

xvii) Diagram of inert-gas system or hold-space environmental-control system

xviii) Diagram of gas and leak detection systems, including detection level thresholds, sequence of operations, and any interlocks.

xix) Schematic-wiring diagrams

xx) Details of fire extinguishing systems

xxi) Welding procedures, stress relieving and non-destructive testing plans

xxii) Construction details of any submerged cargo pumps including materials specifications

xxiii) Testing procedures during sea/gas trials

xxiv) Inspection/survey plan for the liquefied cargo containment system

SECTION 2

Risk Assessment, Novel Concepts and Equivalents

1 Goal

The goal of this Section is to outline the necessary assessments of risks which are to be carried out in order to eliminate or mitigate any adverse effects to the vessel, persons on board, and the environment.

2 Risk Assessment

2.1

A risk assessment is to be conducted to address the risks arising from the storage, transport, and transfer of liquefied hydrogen that could affect persons on board, the environment, the structural strength or the integrity of the ship. Consideration is to be given to the hazards associated with the physical layout, operation and maintenance of the vessel, following any reasonably foreseeable failure. In particular, the risks to the crew and the environment from fire or explosion caused by hydrogen gas are to be considered. The risk assessment plan is to be developed and submitted to ABS for review and approval prior to conducting the risk assessment, as detailed in 2/2.4.

2.2

Risks are to be analyzed using acceptable and recognized risk analysis techniques. Loss of function, component damage, fire, explosion, and electric shock are to be considered as a minimum. The analysis is to seek to minimize or eliminate risks wherever possible. Risks which cannot be eliminated are to be mitigated as necessary (to an acceptable level of safety). Details of risks, and the means by which they are mitigated, are to be documented by report and submitted for review.

Commentary:

See the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries* for further guidance on risk assessment. IEC/ISO 31010:2009 *Risk Management – Risk Assessment Techniques* and SAE ARP 5580-2001 *Recommended failure modes and effects analysis (FMEA) practices for non-automobile applications* also provide guidance on risk management.

End of Commentary

2.3

The risk assessment is to specifically consider, but is not limited to, the criteria referenced in 5C-8-1 of the *Marine Vessel Rules* and the following:

i) Hazards associated with the properties of liquefied and gaseous hydrogen (Section 1)

ii) The design of air-locks for spaces required to be entered during normal operations (Section 3) *iii)* Protection of the cargo containment system, cargo manifold, cargo machinery space, and piping system, with consideration given to the effects of mechanical damage and of cryogens that may form as condensation on surfaces due to low temperature (Section 3)

iv) Arrangements of the cargo loading and offloading system, pipe routing and single failure or leakage scenarios, especially when bow/stern arrangements are being considered (Section 3)

v) Arrangements, suitability, and overall effectiveness of the cargo containment system (Section 4)

vi) Where pressure vessels are considered for the cargo containment system, the risk of a boiling liquid expanding vapor explosion (BLEVE) and any methods of control proposed to maintain cargo temperature and pressure are to be analyzed (Section 4)

vii) Where vacuum insulation is used in the cargo piping or cargo containment system design, the risk of leakage on either side of the vacuum layer is to be considered. Causes and consequences of loss of vacuum on the cargo containment system, supporting structure, and any adjacent hull structure are also to be considered. When considering a failure resulting in loss of vacuum, such as failure of a vacuum pump, the magnitude of the heat flux and its effect on the cargo containment system and surrounding structure is to also be considered. (Section 4)

viii) Causes and consequences of cargo release, including permeation into and through materials, and safeguards implemented in the cargo containment and cargo piping systems to mitigate cargo release. (Section 4)

ix) The possibility of impurities being present or being introduced to the hydrogen cargo and the arrangement of cargo filtration systems. (Section 5)

x) When employed as a method of control, the design and arrangement of the reliquefaction system and its incorporation into the cargo containment system (Section 7)

xi) When employed as a method of control, the design and arrangement of the Gas Combustion Unit (GCU) and its incorporation into the cargo containment system (Section 7)

xii) Pressure relief scenarios outlined in 5C-8-8/4.1 of the *Marine Vessel Rules*, as well as the location of release for pressure release valves (Section 8)

xiii) Suitability of electrical installations for their purpose, when being proposed for use in the cargo area and cargo machinery spaces (Section 10)

xiv) The risk of hydrogen fire and firefighting philosophy, taking into account the fire extinguishing system, isolation capabilities of cargo piping, cargo tanks, and cargo equipment (Section 11)

xv) Arrangement of any fixed and portable fire extinguishing systems, including quantity of carbon dioxide for protected spaces or arrangement of other extinguishing agents, and their suitability for fighting hydrogen fires (Section 11)

xvi) The number and locations of fixed hydrogen flame detectors, as well as their lower detection limits and alarm thresholds (Section 11)

xvii) The possibility of detonation or deflagration in spaces with higher density of cargo piping and equipment or in spaces with higher risk of hydrogen release, such as the cargo machinery room, pipe racks, cargo manifold, etc. (Section 11)

xviii) Verify the arrangements of the ventilation system for safe operation, specifically how blockages, clogs, back pressure and other phenomenon associated with ventilation systems are addressed (Section 12)

xix) Potential sources of release, flow rates and likelihoods of hydrogen release, as well as the need for additional quantitative analysis such as a gas dispersion analysis, or a HAZID/HAZOP for the ventilation system, vent mast locations, and other related items (Section 12)

xx) Arrangements of the gas detection systems, ventilation inlets/outlets, and closing arrangements of accommodation spaces, machinery spaces, service spaces and control stations (Section 13) *xxi)* Potential and risk of crew exposure to gaseous hydrogen, liquid hydrogen, and any other cryogenic or hazardous chemicals on board (Section 14)

2.4

The risk assessment plan developed and submitted to ABS for review is to contain, but is not limited to:

i) Description of proposed function

ii) Quantitative and/or Qualitative risk assessment method(s) to be used and description of the method(s)

iii) Scope and objectives of the assessment

iv) A list of all standards being applied

v) Subject matter experts / participants / risk analysts, including their background and area of expertise

vi) Proposed risk acceptance criteria and a risk ranking matrix

vii) Risk register which includes ranks for each risk, and relevant risk control and management measures. The risk register is to be maintained throughout the life of the vessel. Any modifications to risk control and management measures are to be submitted to ABS.

Further guidance on submitting a risk assessment plan can be found in the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*.

3 Novel Concepts and New Technology Qualification

3.1

Some new technologies may be so unconventional compared to existing designs that the requirements contained in ABS Rules/Guides or industry standards are not directly applicable to them. The ABS *Guidance Notes on Qualifying New Technologies* can be used to qualify these new technologies by confirming their ability to perform their intended functions in accordance with defined performance and safety requirements.

3.2

The ABS *Guidance Notes on Review and Approval of Novel Concepts* offers a methodology for requesting classification of a novel concept. These Guidance Notes describe the process and responsibilities for ABS review of proposed novel concepts from the project concept phase through maintenance of classification while in service. The approval is dependent on consideration being given, through engineering evaluations and risk assessments, to the novel features to determine if the concept provides acceptable levels of safety in line with current offshore and marine industry practice. The primary focus of novel concept classification is on safety even though the qualification of individual new technologies may have additional functional requirements as requested by the client (e.g., reliability).

3.3

Further guidance on Novel Concepts and New Technology Qualification can be found in the ABS *Guidance Notes on Review and Approval of Novel Concepts* and the ABS *Guidance Notes on Qualifying New Technologies*.

4 Equivalents

4.1

Arrangements, procedures, equipment, components, and systems for which these Requirements or associated references are applicable may incorporate equivalent arrangements or comply with alternative recognized standards in lieu of these Requirements. Acceptance of these equivalent arrangements or alternative recognized standards is subject to determination by ABS that they are no less effective than these Requirements and acceptance of the same by the flag administration as described in 5C-8-1/3, Equivalents, of the *Marine Vessel Rules*.

4.2

Where deemed necessary, requirements may be imposed by ABS in addition to those contained in the alternative arrangements or recognized standards so that the intent of these Requirements is met. In all cases, the arrangement, procedure, equipment, component or system is subject to design review, survey during construction, testing, and trials as applicable by ABS for purposes of verification of its compliance with the equivalent arrangements or alternative recognized standards. The verification process is to be equivalent to that outlined in these Requirements. See also 4-1-1/1.7 and 5C-8-1/3 of the *Marine Vessel Rules*. The arrangement, procedure, equipment, component or system and its incorporation into the vessel is also to be analyzed in a risk assessment as described in Section 2/2 of this document.

SECTION 3 Ship Arrangements

1 Goal

The goal of this section is to provide guidance for the location, space arrangement, and mechanical protection of cargo containment and handling systems to minimize the consequences of any minor hull damage or release of cargo that might occur, and to provide safe access for operation and inspection.

2 Functional Requirements

2.1

The cargo containment system and cargo piping are to be arranged to minimize the risk of hydrogen release.

2.2

Cargo tanks, piping, and equipment are to be arranged such that a fire will not lead to an unacceptable loss of containment, loss of power, or render equipment in other compartments inoperable.

2.3

The cargo containment system and its components are to be arranged such that they are protected against mechanical damage, such as dropped or falling objects.

2.4

The cargo containment system is to be arranged such that the damaging effects of cryogenic fluid from spills, leaks or other releases are minimized.

2.5

The cargo piping system is to be arranged to minimize the number of enclosed and confined spaces where hydrogen gas could accumulate if released.

3 General

3.1

In cases where arrangements are made for bow and stern loading and unloading, pipe routing and single failure or leakage scenarios and their consequences are subject to ABS technical assessment and approval during the risk assessment in Section 2.

3.2

Pipes containing hydrogen are not to be directed outside of the cargo area, in particular through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.

4 Cargo Machinery Spaces

4.1

The cargo machinery space is to be arranged such that a release of hydrogen gas does not result in the buildup of hydrogen creating an unsafe atmosphere. Enclosed spaces are to be designed to limit the accumulation of hydrogen gas insofar as practicable.

4.2

Spaces where a gas combustion unit (GCU) or other hydrogen-consuming device is operated are to be considered Category A Machinery Spaces.

5 Air-locks

5.1

The design of the air-locks for spaces required to be entered during normal operations is to be evaluated during the risk assessment in Section 2.

SECTION 4
Cargo Containment

1 Goal

The goal of this section is to provide for the safe containment of cargo under all design and operating conditions while considering the nature of the liquefied hydrogen.

2 Functional Requirements

2.1

The functional requirements listed in 5C-8-4/3 of the *Marine Vessel Rules* are to be applied to cargo containment systems for liquefied hydrogen cargo.

2.2

The cargo containment system is to be safeguarded against mechanical damage.

3 General

3.1

Where applicable to the selected cargo containment system, the requirements of the ABS *Guide for Building and Classing Liquefied Gas Carriers with Independent Tanks* and the ABS *Guidance Notes on Strength Assessment of Independent Type C Tanks* are also to be considered. The requirements of Part 5C, Chapter 12 of the *Marine Vessel Rules* are to be considered where a membrane type cargo containment system is employed.

3.2

The suitability of the proposed cargo containment system and the overall effectiveness of the design are to be evaluated as a part of the risk assessment in Section 2.

3.3

The cargo containment system is to be resistant to hydrogen embrittlement at the design temperatures and pressures. Refer to Section 6 of this document for material requirements of systems intended for use with hydrogen.

3.4

Exposed surfaces in the cargo containment system are not to reach temperatures at or below -183° C, where oxygen can condense and form a potentially hazardous atmosphere.

3.5

Safeguards to prevent the deterioration of insulation capability as a result of leakage, mechanical damage, or other failures are to be incorporated into the cargo containment system design as far as practicable.

4 Vacuum Insulation

4.1

Where vacuum insulation is employed in the cargo containment system, the risk assessment in Section 2 is to consider the causes and consequences of loss of vacuum on the cargo containment system, supporting structure, and any adjacent hull structure. When considering failures resulting in loss of vacuum, such as failure of a vacuum pump, the magnitude of the heat flux and its effect on the cargo containment system and surrounding structure is to also be considered.

4.2

Where vacuum insulation is employed in the cargo containment system, the insulation's performance is to be evaluated through calculations. This evaluation is to consider the normal range or upper limit of the cold vacuum pressure of the system, and the loss of vacuum is to be defined with respect to this value.

4.3

Aging deterioration of vacuum insulation is to be mitigated as far as practicable, and scenarios such as vacuum decay from seals and valve leaks as well as outgassing from materials inside the vacuum space are to be considered in the design of the system. Aging deterioration of vacuum insulation is to be evaluated and tested using means and methods subject to ABS technical assessment and approval.

5 Thermal Insulation

5.1

The outermost layer of the thermal insulation system is to be sealed to prevent the ingress of any air which may condense within the insulation.

SECTION 5

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

1 Goals

The goal of this section is to provide for the safe handling of hydrogen, under all operating conditions, to minimize the risk to the ship, crew and to the environment.

2 Functional Requirements

2.1

Piping and pressure vessel design criteria and methodology are to limit the risk of single failures causing unsafe conditions.

2.2

Where cargo piping passes through enclosed or confined spaces, the design of the piping system is to mitigate the risk of hydrogen release.

2.3

Means and arrangements are to be provided to prevent impurities from damaging the equipment and system.

2.4

The cargo piping system is to be designed to protect the system and its components from excessive stresses due to the expansion and contraction of the material that may occur due to temperature fluctuations.

2.5

Exposed surfaces not a part of the cargo piping system are to be safeguarded against damage from contact with cryogenic fluids.

2.6

The cargo piping system is to be designed to minimize the number of points where release may occur (e.g., flanges, seals, valves, or other fittings).

2.7

The cargo piping system is to be fabricated such that the connections between components minimize the risk of hydrogen leaks occurring.

3 General

3.1

Exposed surfaces in the cargo piping system are not to reach temperatures at or below -183° C, where oxygen can condense and form a hazardous atmosphere.

3.2

Where exposed surfaces cannot be prevented from reaching -183° C, drip trays or other protective measures are to be provided to collect and facilitate the evaporation of cryogenic liquids.

3.3

Hydrogen piping passing through enclosed or confined spaces within the cargo area with potential sources of release, such as valves, flanges, or seals are to be:

i) Double-walled, or

ii) The spaces are to be equipped with mechanical ventilation and hydrogen gas detectors which activate the alarm at not more than 25% LFL and shut isolation valves at not more than 50% LFL, or

iii) The spaces are to be maintained in an inert condition.

3.4

Double-walled piping containing liquefied hydrogen is to be safeguarded against the formation of cryogenic liquids in the annular space.

3.5

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

3.6

Where employed, thermal insulation is to be sealed to prevent the ingress of any air which may condense within the insulation.

4 Arrangements for Cargo Piping Outside the Cargo Area

4.1

For vessels intending to use hydrogen cargo as fuel, including in a GCU where thermal oxidation is employed as a method of control, the gas fuel system is to be evaluated by a risk assessment and the requirements of 5C-8-16 of the *Marine Vessel Rules* and the ABS *Requirements for Hydrogen Fueled Vessels* are to be applied.

5 Cargo Transfer Arrangements

5.1

Where a vessel is fitted with a cargo sampling system, the system is to not unsafely vent hydrogen gas to the atmosphere.

5.2

Filters, purifiers or separators are to be provided for the removal of condensates, if expected, from the cargo piping system.

Commentary:

Impurities in the cargo piping system can form from air or inert gas that is not purged from the system before liquefied hydrogen is introduced. In the presence of liquid hydrogen, air and inert gas can solidify and cause blockages in piping or machinery.

End of Commentary

6 Piping Fabrication and Joining Details

6.1

Cargo piping between the cargo tank and the shut-off valve is to be designed using fatigue/fracture analysis, with an adequate safety margin and provisions for continuous condition monitoring.

6.2

The cargo piping system, and any other piping containing hydrogen during normal operations, is to be joined by full-penetration butt-welded connections, with the exception of valves, flanges, and other joints that are essential for the function of the piping system or required for maintenance and survey purposes.

6.3

Screw couplings are not to be used for joining pipes in hydrogen piping systems except for instrumentation lines which can be isolated from the main line.

6.4

Where flange connections are present, they are to comply with a recognized standard (e.g., AIAA G-095 5.4, ASME B31.12) or an alternative standard determined to be acceptable for liquefied hydrogen service for the flange type, manufacture, and test.

6.5

Valves used in the cargo piping system are not to trap liquid hydrogen when closed, as trapped liquid hydrogen can expand when warmed and damage the valve.

SECTION 6

Materials of Construction, Manufacture, Workmanship and Testing

1 Goal

The goal of this section is to identify the required properties, testing standards and stability of metallic and non-metallic materials and fabrication processes used in the construction of cargo containment and piping systems to for their selected functions.

2 Functional Requirements

2.1

Materials that may be directly exposed to hydrogen during normal operations are to meet the design requirements appropriate for the application, operating conditions, and environment.

Commentary:

Hydrogen embrittlement is a phenomenon that results in a significant reduction in material tensile strength, ductility, and fracture toughness. The initiation and severity of hydrogen embrittlement depends upon the interaction of materials used, the mechanical loading, and environmental variables. This deterioration in properties leads to accelerated fatigue crack growth and consequently shorter equipment life. Furthermore, if not properly accounted for, material degradation due to hydrogen can result in catastrophic unpredicted failure. Hydrogen permeation occurs when ionic hydrogen passes through otherwise solid metals, polymers or other materials and reforms on the other side. This process is dependent on the structure of the material and the temperature and pressure of the hydrogen. Information regarding material compatibility with hydrogen environments and effects of material exposure to hydrogen can be found in various industry references, such as ANSI/AIAA G-095A-2017 *Guide to Safety of Hydrogen and Hydrogen Systems*, ASME B31.12 *Hydrogen Piping and Pipelines*, and NASA/TM-2016-218602 *Hydrogen Embrittlement*.

End of Commentary

2.2

Materials exposed to conditions where high oxygen concentrations may occur are to be resistant to the detrimental effects of increased oxygen concentrations, as described in 5C-8-17/17 of the *Marine Vessel Rules* discussing requirements for nitrogen.

2.3

Material handling and construction techniques are to minimize the introduction of hydrogen into materials that are susceptible to hydrogen embrittlement.

2.4

Materials used for insulation of the cargo piping and cargo containment systema are to be noncombustible.

3 General

3.1

Materials for cargo containment, process piping, pressure vessels, and other systems exposed to hydrogen are to be in accordance with recognized standards (e.g., ANSI/AIAA G-095A-2017 *Guide to Safety of Hydrogen and Hydrogen Systems*, ASME B31.12 *Hydrogen Piping and Pipelines*) applicable for hydrogen service at design temperatures and pressures. For materials with minimum design temperatures below -165°C, their properties are to be agreed upon based on recognized and approved standards.

3.2

Test procedures are to be based on recognized standards deemed acceptable by ABS for application to liquefied hydrogen systems (e.g., ASME B31-12, *Hydrogen Piping and Pipelines*).

3.3

For cargo tanks, cargo piping, and other equipment, tightness testing is to be conducted using helium, a mixture of 95% nitrogen and 5% hydrogen, or any other gas composition demonstrated to be effective as a testing medium.

3.4

For materials intended for use as insulation, tests are to be carried out with a medium to cover the full range of temperatures expected during normal operations to verify suitability for use.

SECTION 7

Cargo Pressure and Temperature Control

1 Goal

The goal of this section is to provide requirements for maintaining cargo tank pressure and temperature within design limits of the containment system.

2 Functional Requirements

2.1

Means are to be provided for maintaining cargo tank pressures and temperature within the design limits of the cargo containment system.

2.2

Means are to be provided for the handling of any boil-off gas that may form in the cargo containment system.

3 Methods of Control

3.1

For a method of control selected to maintain the cargo tank pressure and temperature, the specific properties of liquid hydrogen are to be considered in its design.

3.2

Where a reliquefaction system is employed as a method of control, its overall design and incorporation into the cargo containment system are to be reviewed and its level of safety is to be verified in the risk assessment in Section 2.

3.3

The requirements detailed in 5C-8-7/3 of the *Marine Vessel Rules* are to be applied insofar as practicable to the reliquefaction system. The reliquefaction system is to meet the requirements in Section 2 of this document are to be followed and an equivalent level of safety is to be demonstrated.

3.4

The requirements detailed in 5C-8-7/4 of the *Marine Vessel Rules* are to be applied insofar as practicable to the GCU and associated systems, excluding the provision in 5C-8-7/4.1 of the *Marine Vessel Rules* limiting thermal oxidation to LNG cargos only.

Where a gas combustion unit (GCU) is employed as a method of control, its overall design and incorporation into the cargo containment system are to be reviewed and its level of safety is to be verified in the risk assessment in Section 2, considering the ABS *Requirements for Hydrogen Fueled Vessels* and 5C-8-16/9. The requirements in Section 2 of this document are to be followed and an equivalent level of safety is to be demonstrated.

SECTION 8

Vent Systems for Cargo Containment

1 Goal

The goal of this section is to provide requirements for the proper pressurization of the cargo containment system.

2 Functional Requirements

2.1

Means are to be provided to safeguard the cargo containment system from overpressure or underpressure beyond its design capability.

2.2

Means are to be provided to safeguard hold spaces and interbarrier spaces from overpressure or underpressure beyond their design capabilities.

2.3

The vent system is to be provided with means to prevent the introduction of moisture, which can freeze and block the vent or piping when exposed to liquid hydrogen.

3 General

3.1

The risk assessment in Section 2 is to consider the pressure relief scenarios outlined in 5C-8-8/4.1 of the *Marine Vessel Rules*. The location of release is also to be considered.

3.2

Cargo vent systems are to be designed and installed in accordance with a recognized standard such as CGA G 5.5 *Standard for Hydrogen Vent Systems* or NFPA 2 20 *Hydrogen Technologies Code*.

3.3

The properties of hydrogen are to be considered when performing pressure relief valve tests for type approval, especially for cryogenic and valve seat tightness testing. Testing is to confirm the function of the valve at cryogenic temperatures and the absence of leaks, as well as the suitability of all hydrogen-wetted materials within the valve components.

3.4

Pressure relief valves and related piping or equipment are to be designed such that any buildup of ice or moisture that may occur as a result of low air temperatures condensing air will not reduce their effectiveness or ability to be operated.

SECTION 9

Cargo Containment System Atmosphere Control

1 Goal

The goal of this section is to establish requirements for monitoring containment system integrity and provide for the maintenance of a safe atmosphere within the system and hold spaces.

2 Functional Requirements

2.1

Measures are to be provided to prevent the formation of a flammable or explosive gas mixture within the cargo containment system, hold spaces and interbarrier spaces.

2.2

Where temperatures in cargo hold spaces are low enough for cryogenic liquid formation to occur, means of protection against the effects of cryogenic liquids are to be provided.

3 Atmosphere Control Within Hold Spaces

3.1

The method of atmosphere control within hold spaces is to prevent the formation of any flammable gas mixture.

3.2

The provisions of 5C-8-9/2-3 of the *Marine Vessel Rules* are further restricted. Dry air may not be used as an alternative to inert gas.

3.3

Where atmospheric control measures within hold spaces cannot prevent the formation of cryogenic liquids, drip trays are to be installed to collect and facilitate the evaporation of any cryogens that may form in hold spaces in order to prevent damage to the underlying structure. Drip trays are to be constructed using materials suitable for the low temperatures of cryogenic fluids.

4 Inerting and Inert Gas Production on Board

4.1

The provisions of 5C-8-9/5.1 of the *Marine Vessel Rules* are modified due to the low limiting oxygen concentration of hydrogen. The oxygen content of inert gas is at no time to be greater than 2% by volume.

4.2

At no point is any inert gas to be exposed to conditions where it could cause blockages or damage to the integrity of the cargo containment system or hold spaces.

Commentary:

Because nitrogen gas condenses at -196 C, nitrogen is not suitable for use as a blanketing, purging, or inerting gas for systems which contain liquefied hydrogen or hydrogen gas below -196 C.

End of Commentary

SECTION **10**

Electrical Installations

1 Goal

The goal of this section is to provide for electrical installations that minimize the risk of fire and explosion in the presence of a flammable atmosphere.

2 Functional Requirements

2.1

Electrical installations are to be arranged to minimize the risk of sparks or other ignition sources in hazardous areas.

3 General

3.1

The risk assessment in Section 2 is to include a HAZID/HAZOP where potential sources of release, flow rates and likelihoods of hydrogen release are identified. The resulting data is to be fed into a quantitative gas dispersion study to establish the hazardous zones.

3.2

For compliance with 5C-8-10/2.5 of the *Marine Vessel Rules*, hazardous area zones are also to be evaluated and established according to International Electrical Commission 60079 Series of Explosive Atmosphere Standards, specifically, 60079-10-1:2020 Classification of Areas – Explosive gas atmospheres and 60079-10-1 Annex H – (Informative) Hydrogen. T1.

3.3

Electrical installations are to be in accordance with 4-8-4/27 of the *Marine Vessel Rules*, as applicable to hydrogen.

3.4

Electrical equipment in hazardous areas is to meet ISO/IEC 60079-20 group IIC class T1 requirements.

SECTION 11
Fire Protection and Extinction

1 Goals

The goal of this section is to provide requirements for fire protection, detection and fighting for all system components related to the storage and transfer of hydrogen cargo.

2 Functional Requirements

2.1

Fire detection, protection and extinction measures appropriate to the hazards of hydrogen concerned are to be provided.

2.2

The fire detection, protection and extinction systems are to cover all areas where the presence of hydrogen is possible

2.3

The fire protection and extinction systems are to be arranged such that explosive atmospheres will not form due to the fire extinguishing process.

3 Fire Extinction, Fire Detection and Alarm Systems

3.1

The ability of fire extinguishing systems to extinguish hydrogen fires is to be verified by the risk assessment in Section 2.

Commentary:

Unless the supply of hydrogen is cut off, there is a risk of re-ignition or detonation of unconsumed hydrogen. As a result, water spray systems can be used to cool adjacent structures and equipment, but are not recommended as the primary means of fighting hydrogen fires.

End of Commentary

3.2

Where a carbon dioxide fire extinguishing system is employed, the amount of carbon dioxide.

3.3

Flame detectors used in the fire detection system are to detect hydrogen flames and be designed in accordance with a recognized standard (e.g., NFPA 2, EN54-10, IEC 60092-504, or another equivalent standard).

3.4

Fixed hydrogen flame detectors are to be arranged at any locations where a risk of hydrogen fire exists, and the number and locations of hydrogen flame detectors are to be verified by the risk assessment in Section 2.

Commentary:

Hydrogen flames are typically pale blue in color and may not be visible in daylight. Hydrogen fires also give off less radiant heat than most hydrocarbon fires. These characteristics can make it difficult to detect hydrogen fires.

End of Commentary

SECTION 12
Artificial Ventilation in the Cargo Area

1 Goal

The goal of this section is to provide for proper arrangement of ventilation of enclosed spaces and compartments in the cargo area to control the accumulation of hydrogen and other hazardous gases.

2 Functional Requirements

2.1

The ventilation system is to prevent the formation of a hazardous atmosphere in enclosed or confined spaces.

2.2

The design of the ventilation system is to consider the buoyant nature of hydrogen gas, such that no hydrogen accumulates in the cargo area.

Commentary:

Hydrogen leaks are affected by buoyant and diffusive forces, which differ based on the nature of the leak and environmental conditions at the leak site. While gaseous hydrogen is generally lighter than air, low temperature (cryogenic) hydrogen may be denser than air and can react with the surrounding atmosphere. Releases of hydrogen may also form heavier-than-air vapors.

End of Commentary

2.3

The effectiveness of the ventilation system is to not be reduced by the effects of condensation or ice buildup on its components.

2.4

The cargo area ventilation system is to provide for the safe discharge of hydrogen gas or gas mixtures.

3 General

3.1

Ventilation systems are to be designed such that any buildup of condensation or ice within the system that may occur as a result of low air temperatures will not reduce the overall effectiveness of the ventilation system.

3.2

The cargo area ventilation system is to be independent of other shipboard ventilation systems.

3.3

In enclosed spaces where the exteriors of cargo pipes, cargo manifolds, or other exposed surfaces can reach temperatures below -183°C, mechanical ventilation is to be provided to prevent the buildup of an enriched oxygen environment.

4 Spaces Required to be Entered During Normal Cargo Handling Operations

4.1

The ventilation system for enclosed spaces that are required to be entered during normal operations is to be evaluated during the risk assessment in Section 2.

4.2

The provisions in 5C-8-12/1.8 of the *Marine Vessel Rules* are replaced by the following requirement: Where forced ventilation is required for an enclosed space, the full required ventilation capacity for each space is to be available after failure of any single fan, or group of fans with a common circuit from the main switchboard or emergency switchboard.

SECTION 13

Instrumentation and Automation Systems

1 Goal

The goal of this section is to provide for the arrangement of control, monitoring and safety instrumentation and automated systems that support and enhance the safe operation of liquefied hydrogen carriers as addressed in the other Sections of these Requirements.

2 Functional Requirements

2.1

Cargo monitoring systems are to be arranged such that no release of cargo occurs during measurement activities or when not in use.

2.2

Monitoring and safety systems are to be arranged such that the ESD system is not activated due to the false alarm of any single detector or sensor.

2.3

The gas detection system is to detect any leaks of hydrogen from cargo piping or the cargo containment system.

3 General

3.1

Cargo monitoring systems such as tank level gauging, pressure monitoring and gas detection system are to be indirect, closed or closed-loop type.

4 Gas Detection

4.1

The number and locations of hydrogen gas detectors as provided by 5C-8-13/6.12 of the *Marine Vessel Rules* are to be considered and confirmed during the risk assessment in Section 2.

4.2

Hydrogen is to be treated as flammable cargo for the purposes of 5C-8-13/6.3 of the *Marine Vessel Rules*. Hydrogen detectors are to be installed in enclosed spaces where hydrogen gas may accumulate, such as at high points in a room or areas of a room with lower air flow from the ventilation system.

4.3

With consideration for the lower flammability level of hydrogen the requirement in 5C-8-13/6.15 of the *Marine Vessel Rules* has been modified. Gas detectors are to alarm at 1% hydrogen by volume, or 25% of the LFL.

SECTION 14
Personnel Protection

1 Goal

The goal of this section is to provide additional requirements for the protection of any personnel on the vessel from harm during normal operations or emergencies involving hydrogen.

2 Functional Requirements

2.1

Suitable protective equipment is to be provided to mitigate risk of harm in both routine and emergency scenarios.

3 Personnel Protection

3.1

A portable hydrogen detector and anti-static clothing is to be made available for all crew members working in the cargo area.

3.2

Explosion-proof lamps and any other electronic equipment provided to personnel is to meet ISO/IEC 60079-20 group IIC class T1 requirements.

3.3

Protective clothing and other PPE are to be selected with consideration for the risk of contact with cryogenic liquids.

SECTION 15
Surveys and Maintenance of Class

1 General

1.1

The manufacture, testing, inspection and documentation is to be in accordance with requirements of 5C-8-1 and any other applicable sections of the *Marine Vessel Rules*, and 7-3-2/1.13.8, 7-3-2/3, 7-3-2/5, 7-6-2/1, 7-6-2/3 of the ABS *Rules for Survey After Construction (Part 7)*.

1.2

For cargo tanks, cargo piping, and other equipment, tightness testing is to be conducted using helium, a mixture of 95% nitrogen and 5% hydrogen, or any other gas composition demonstrated to be effective as a testing medium.

2 Surveys During Construction

For survey during construction of various equipment and systems, the survey is to include applicable sections of 5C-8, 4-1-1/Tables 3 through 6 of the *Marine Vessel Rules* and the ABS *Rules for Survey After Construction (Part 7).*

3 Surveys After Construction

3.1 Annual Hull Survey

For annual hull surveys, the survey is to include applicable sections of 7-3-2/1.13.8 of the ABS *Rules for Survey After Construction (Part 7).*

3.2 Annual Machinery Survey

For annual machinery surveys, the survey is to include applicable sections of 7-6-2/1.5 of the ABS *Rules for Survey After Construction (Part 7).*

3.3 Intermediate Hull Surveys:

For intermediate surveys, the survey is to include applicable sections of 7-3-2/3.11.2 & 3 of the ABS *Rules for Survey After Construction (Part 7).*

3.4 Special Periodical Surveys-Hull:

For special surveys, the survey is to include applicable sections of 7-3-2/5.11 of the ABS *Rules for Survey After Construction (Part 7).*

3.5 Special Periodical Surveys-Machinery:

For special surveys, the survey is to include applicable sections of 7-6-2/3.3.3 of the ABS *Rules for Survey After Construction (Part 7)*.