Documentation providing a master hazard register and a framework for quantitative risk assessment

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Contents

Table of Contents

List of Figures

List of Tables

Glossary, abbreviations and acronyms

ABL	Above Base Line
ABS	American Bureau of Shipping (Ship Class Society)
CCTV	Closed-Circuit TV surveillance system
CNG	Compressed Natural Gas
DF	Dual Fuel
ESD	Emergency Shutdown
FSU	Floating Storage Unit
HAZID	Hazard Identification
OCIMF	Oil Companies International Marine Forum
W/H	Wheelhouse

1. Introduction

1.1 Introduction

As part of its HORIZON 2020 initiative European Commission formed a consortium to develop a CNG transportation vessel for gas delivery on medium-short leg routes where offshore pipelines or LNG Ships are un-economic or impracticable.

CNG ship will be fitted with pressure cylinders of composite construction of the CNG transportations. The total quantity of the cylinder arranged on board will ensure the capacity (NG @ 300 bar, 20°C) of abt. 15 x 10^6 Nm^3. The Ship is designed to carry natural gas (min. methane number 70) in the compressed gaseous form @ 300 bar and 20° C temperature.

To ensure the hazards associated with the operation of vessel is adequately identified and mitigated, a Hazard Identification (HAZID) workshop was conducted from 27th February to 28th February 2019. This workshop generated 27 recommendations, which are the basis of the Hazard Register for this design.

This document clarifies the scope of the Hazard Register and provides clarification and a framework for the special studies that need to be conducted in order to fullill the requirements for special studdies towards quantitative risk assessment techniques.

1.2 Scope

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.

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.

In addition to the risk assessments, the novel aspects of the CNG carrier require certain special studies to 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.

2. Design overview

The Ship is designed to carry natural gas (min. methane number 70) in the compressed gaseous form @ 300 bar and 20° C temperature. The Ship will receive the natural gas previously dehydrated and desulfurized by the production facility or CNG FSU. No provision is provided on board the Ship for systems to perform said preliminary treatments of the natural gas.

Basically, it was assumed that the production facility or CNG FSU will supply the gas to the Ship at abt. 240 bar. The Ship is fitted with cargo compressors and relevant systems as necessary to rise the pressure from 240 to 300 bar inside the cylinders to increase the cargo carrying capacity.

Compressors will also be used during Ship unloading operations as scavenging compressors when the differential pressure between gas in the cargo cylinders and receiving shore net is so low to affect the scheduled discharging time.

The CNG ship is divided as follows:

- **Aft ship**: which includes power generators and propulsive systems
- **Mid ship**: which consist of an eight (8) cargo holds, each one divided in two sections by one longitudinal bulkhead, designed to contain the CNG pressure cylinders foreseen for the cargo containment. Loading and unloading cargo station is located on the Deck at 28.000 ABL according to OCIMF rules. The loading and unloading operations will be carried out with ship berthed or with single mooring. Double bottom and double sides in way of cargo holds is provided. These spaces to be used for ballast water and to form a complete segregation of cargo.
- **Fore ship**: which includes accommodation for 30 people and various technical spaces for ship systems and electrical management.

Following section provides brief overview of CNG containment and associated systems. Detailed overview of all ship system is provided in a ship outline specification (Doc# WP5-D5.1-RV0-833-001-A01).

CNG Cargo containment

In the present configuration and size, the Ship is fitted with the following pressure cylinders of composite construction for the CNG transportation:

Cylinder @ 300 bar	Length (m)	External Dia (m)	Quantity (pcs)
Type A	22.5	3.4	256
Type B	20.5	3.4	12
Type C	18.5	3.4	4

The total quantity of the cylinder arranged on board will ensure the capacity (NG @ 300 bar, 20°C) of abt. 15 x 10^6 Nm^3. Cylinders are of the composite type 3, with internal stainless-steel liner wrapped with resins and carbon fibers. Cargo cylinders, tested, approved, certified and installed on board the Ship according with Chapter 5 Cargo Containment of the ABS Rules for CNG Vessels and under ABS survey.

Each cargo hold contains a set number of cargo tanks (each tank is comprised of four pressure cylinders interconnected via common header). Cargo holds are inerted with nitrogen at a positive 50 mbar pressure.

CNG Piping systems

Cargo tanks are connected to loading/unloading manifold via cargo deck piping. All the cargo deck piping is routed via a segregated pipe tunnel that runs above the cargo holds dome, in a central position. Cargo pipe tunnel is also inerted with nitrogen. All the CNG piping is butt-welded without flange connection to prevent any leakage during operation.

CNG loading and unloading operation

Gas will be taken on board via the loading facilities and transferred via the deck piping to the cargo containment system. Compressors will be used to increase the gas pressure from the site delivery pressure to the storage pressure cylinders. Once loading is complete, all the remote-controlled stop valves between deck piping and cargo containment systems will be closed in order to segregate the cargo tanks from each other. The deck piping will remain pressurized after loading operation.

Unloading follows the reverse of the above operations. All tanks valves will be opened simultaneously to start the unloading. Once the tank pressure drops below or equalized the destination pressure, flow will be diverted via compressors to deliver the remaining gas in CNG tanks. A residual gas inside of vessels at the end of the unloading is expected to be abt. 30 bar.

The process facilities are not yet designed, but a concept P&ID is shown in Figure 2.

Cargo compressors and Cargo Control Room

Cargo compressor (2x centrifugal compressor type) with relevant auxiliary services and cargo heat exchangers is provided above Deck at 27,500 ABL. Compressor room is designated as a gas-dangerous area and built, outfitted and installed in the respect of the relevant rules, including the safety, monitoring and alarm appliances.

Cargo Control Room will be located and arranged as per General Arrangement Plan, outfitted and protected as a gas-safe area. Instrumentation shall be, as far as practicable, of indirect reading system to prevent accidental escape of gas in the atmosphere of the Control Room.

Propulsion System

The ship power generation will be performed by four (4) dual fuel engines type Wartsila 8V31DF (4240 kW at 720 RPM each), installed on Deck at 9 000 ABL.

Four GVU (one for each engine) will be installed in Engine Room for engine gas operation mode.

GVU will be connected to loading/unloading gas cargo manifold. Installation of GVU and associated piping will be in accordance to Chapter 15 Section 1 of ABS Rules for CNG Vessels and ABS Guide for Propulsion Systems for LNG Carriers.

Safety and Supervision System

Emergency Shut-down systems: Two emergency shut-down systems are provided: 1) Ship ESD and 2) Cargo ESD. Ship ESD system will shut down ventilation and fuel systems, while the cargo ESD is dedicated to emergency shutdown of the cargo loading/unloading operations. The cargo ESD system will also interfaced with the loading/unloading terminals ESD systems.

Fire detection system:

Fire Detection Plant, comprising a central panel installed in W/H and a number of addressable detectors and manual call points according to the Rules will be installed. The type of detector will be chosen according to the place of installation. The detectors in hazardous areas will be of certified safe (intrinsically safe) type. A dedicated UPS is provided for fire detection system.

Gas detection system:

Natural gas detection system will be installed. The addressable detectors will be located in cargo area, engine room, cargo compressor room and on the inlets of the ventilation system. The central unit located in W/H will collect all the data from the detectors.

CCTV:

A Closed-Circuit TV surveillance system will be installed. The cameras will cover the cargo manifold zones, cargo compressor room and the engine rooms.

Detail information regarding ESD and gas detection system can be found in ESD system philosophy (doc# WP5-D5.3-RV0-833-7-003-A01) and Gas Detection system philosophy (doc# WP5-D5.3-RV0-833-7-004-A01), respectively.

Figure 2-1 and 2-2 provides the general overview of the CNG system.

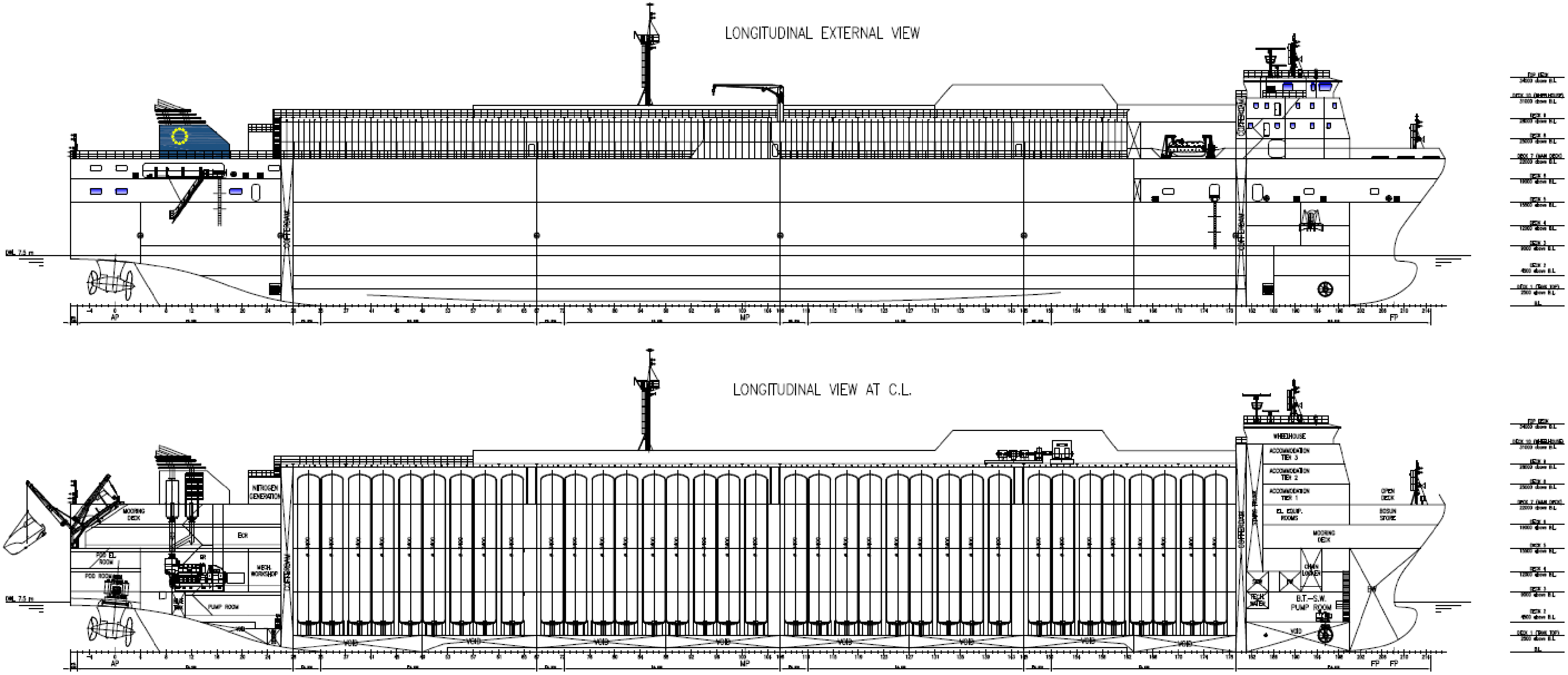

Figure 2-1 General Arrangement – Longitudinal view

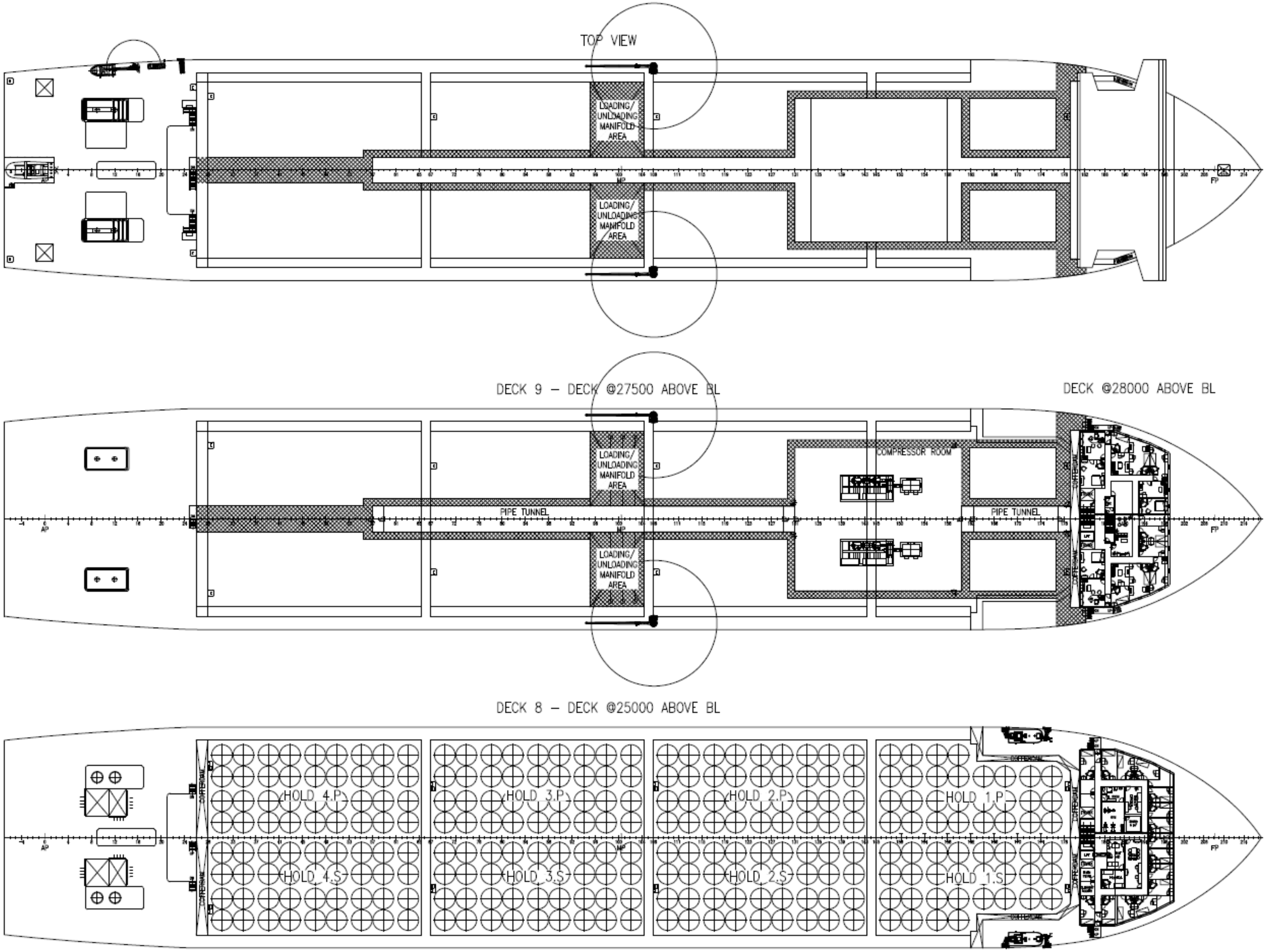
TOP VIEW
LOADING/
UNLOADING
MANIFOLD
AREA
DECK 9 – DECK @27500 ABOVE BL
DECK @28000 ABOVE BL
COMPRESSOR ROOM
PIPE TUNNEL
DECK 8 – DECK @25000 ABOVE BL
HOLD 4.P
HOLD 3.P
HOLD 2.P
HOLD 1.P
HOLD 4.S
HOLD 3.S
HOLD 2.S
HOLD 1.S
AP
FP

Figure 2-2 General Arrangement – Top view

3. Lists of References

The following documents have been used as reference on the present document.

- H2020 EU Funded project GASVESSEL – 723030 – Deliverable No. 8.1 - Safeguards Solutions for the system as identified in the HAZID analysis
- ABS Guidance Notes on Review and Approval of Novel Concepts, 2017 Edition
- ABS Guide For Vessels Intended to Carry Compressed Natural Gases in Bulk, 2018 Edition
- WP5-D5.1-RV0-833-0-002-A04 General arrangement – updated

4. Conclusions

Based on the HAZID analysis, the HAZID team made 27 recommendations as listed in Table 8-1 of the Deliverable No.8.1. References are also made to the HAZID worksheet provided in the same document, where the recommendation was developed, and where a complete description of the scenario can be found.

Table 4-1 below forms the Hazard Register for this design, which addresses the HAZID analysis team's recommendations and which will be used as guidance in order to ensure that the recommendations are incorporated into the design or otherwise resolved early in the next design phase.

It is anticipated that additional hazards may be identified as more details are available during further development of the project phases and accordingly this register should be kept up to date, with items closed out and added, as appropriate.

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 are required. 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.

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.
- Joule-Thompson effect - Of particular interest are all the structures which can be affected by the low temperatures due to this effect (i.e. the Pressure Vessels supports and the hull structures in way of around the cargo containment system and cargo piping at high pressure). This analysis shall support any engineering decision for the steel grade selection in such areas.

Table 4-1 Hazard Register

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
1.	Review ship structural protection against the brittle fracture from low temperature exposure during manifold area leak. Low temperature exposure can lead to long term damage to steel due to brittle fracture. CNG temperature is not expected to be low enough to cause an immediate brittle fracture of structural steel.	Consequences: 2.1.1.1	Navalprogetti	1. A gas dispersion analysis to be perfomred for the cases of gas leak (at high pressures) in the way of the manifolds, when loading/unloading, in order to assess gas ingress to accomodation and /or other manned areas (i.e. engine room or compressor room) 2. Low temperature due to Joule-Thompson effect needs to be assessed
2.	Consider use of quick connect/disconnect coupling for hose connection. Inability to isolate the flow during emergency or leakage scenario can lead to escalation of event.	Consequences: 2.1.1.1	Navalprogetti	
3.	Define flexible hose management and accordingly evaluate venting arrangements of flexible line during emergency scenario to minimize loss of containment.	Consequences: 2.1.1.1	Navalprogetti/Cenergy	Matter already solved with the use of emergency quick disconnection equipment from MIB Italiana SpA

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
4.	Review need for relief valve for the loading manifold. During the workshop team raised a concerned that upstream process upsets can lead to overpressure of manifold piping resulting in loss of containment and fire hazard.	Consequences: 2.2.1.1	Cenergy	
5.	Review class requirement for helicopter operations for emergency evacuation of personnel and provide adequate safeguards to avoid any helicopter accident during evacuation.	Consequences: 2.17.1.1	Navalprogetti	
6.	Review hose connection design to ensure ship movement stresses are accounted in the connection design to avoid damage to hose connection during ship movement. Hose connection damage can lead to loss of containment and fire hazard during loading/unloading	Consequences: 2.28.1.1	Navalprogetti/Cenergy And Esteco for the consequence studies	1. Jet fire analysis for scenarios of fire at the hose connections/ manifold area, during loading/unloading operation to be performed. 2. Thermal radiation effects to also be assessed in the area for the fire scenario described above.
7.	Ensure operating manual considers loading and unloading as a special operation and provides adequate operational safeguards as applicable considering 1) station keeping, 2) fatigue 3) operator training and 4) ship traffic during loading to prevent	Consequences: 2.29.1.1, 2.31.1.1, 2.33.1.1, 2.35.1.1	Navalprogetti	

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
	hose damage. Hose damage can lead to loss of containment and fire hazard during loading/unloading.			
8.	Perform study to analyze low temperature exposure to hold area and pressure profile within cargo hold during cylinder leakage scenario and provide adequate safeguards accordingly.	Consequences: 1.1.1.3	Esteco	1. Low temperature due to Joule-Thompson effect needs to be assessed, especially in way of the cylinders supports, where the probability of a structural failure and gas leak is higher 2. Gas dispersion analysis and pressures distribution within the cargo hold area to be performed
9.	Review gas combustion unit operating philosophy/capacity in regard to 1) release via cylinder rupture disk 2) release via cargo hold rupture disk 3) control venting from leaking cylinders via GCU gas inlet header to ensure GCU is sized adequately to handle anticipated flow rate.	Consequences: 1.1.1.1	Cenergy / ABS	The use of GCU is not found as an acceptable means for Safety Pressure relieving and therefore it has been cancelled.

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
10.	Confirm use of rupture disk in lieu of relief valves and routing to GCU instead to vent mast in terms of Class requirement.	Consequences: 1.1.1.1	Cenergy/Navalprogetti /ABS	
11.	Review cylinder design against external conditions (e.g. extreme weather conditions) in accordance with class requirements and provide adequate safeguards as applicable.	Consequences: 1.18.1.1	CNGV	
12.	Review structural design in terms of class grounding requirement and provide adequate safeguards as applicable.	Consequences: 1.26.1.1	Navalprogetti	
13.	Define survey plan requirements for tanks considering the tank internals/surface and external coating to ensure survey can be performed adequately to identify any fatigue defects occurred during ship operation.	Consequences: 1.30.1.1	CNGV	
14.	Review if gas detection system is required for bilge system. Cargo hold are connected to pump room via bilge system and team raised a concerned that during gas leak in cargo hold there is a potential for gas migration to pump room leading to fire hazard in pump room.	Consequences: 1.45.1.1	Navalprogetti	

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
15.	Review tank inlet valve arrangement to ensure adequate arrangement is provide for isolation of individual cargo tank during emergency scenario.	Consequences: 2.1.1.1	Cenergy / ABS	New arrangement has been proposed by designer, and it is under review by ABS
16.	Review if valve (#32) across remotely controlled valve can be removed. Removal of valve will improve operability of CNG loading and unloading operation.	Consequences: 2.1.1.1	Navalprogetti	
17.	Review rupture disc location to ensure it is in compliance with class requirement. Currently rupture disc is routed to gas combustion unit which may pose a restriction in rupture disc relief path and lead to ineffective pressure relief during overpressure scenario.	Consequences: 2.1.1.1	Navalprogetti/Cenergy/Esteco	The use of CNG is not found as an acceptable means for Safety Pressure relieving and therefore it has been cancelled.
18.	Review if remotely controlled valve (VM2) can be used as an emergency shutdown valve. Concerned was raised during the workshop that remotely controlled valve is currently planned to regulate the flow to cargo tank during loading and unloading operation and may not be able to meet requirements for emergency shutdown valve.	Consequences: 2.1.1.1	Cenergy	New arrangement has been proposed by designer, and it is under review by ABS

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
19.	Review if manual valve (#V36) at cargo tank inlet can be moved in to pipe tunnel. Currently subject valve is located in the cargo hold area and will required entrance into cargo hold area for valve maintenance or to operate the valve. as per the class requirement this valve is supposed to as close as possible to tank. Team wanted to confirm if the design will be able to meet class requirements with valve being moved to pipe tunnel for improved operability efficiency.	Consequences: 2.1.1.1	Cenergy / Navalprogetti	New arrangement has been proposed by designer, and it is under review by ABS
20.	Review need to perform and fire explosion analysis to understand effect on the adjacent area in case of a gas leak in compressor room and provide adequate safeguards as applicable.	Consequences: 3.1.1.1, 3.14.1.1	Esteco	1. Gas dispersion analysis for potential leak scenarios within the cargo compressor room to be performed. Particular attention to be given on flanges and piping connections. 2. Explosion analysis to be perfoprmed for the cargo compressor room. Fragmentation and overpressure effects to be assessed, as applicable
21.	Review emergency shutdown philosophy for the ship in regard to IGC and IGF code and update as required.	Consequences: 3.4.1.1, 3.5.1.1	Navalprogetti	

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
22.	Review compressor inlet separator drain arrangement and ensure it is routed to safe location. If drain valve is left open inadvertently it can lead to gas blow-by resulting in a fire/explosion.	Consequences: 3.6.1.1	Cenergy	
23.	Perform gas dispersion analysis to optimized vent mast location and height to ensure gas release from vent mast will not lead to migration of gas to hazardous zone or accommodation area which can result in a fire hazard.	Consequences: 3.17.1.1	Esteco/Cenergy/Navalprogetti	1. A gas dispersion analysis to be perfomred for the cases of gas release from the vent mast, in order to assess gas ingress to accomodation and /or other manned areas (i.e. engine room or compressor room) 2. Low temperature due to Joule-Thompson effect needs to be assessed 3.Thermal radiation effects to also be assessed in the area for a fire case scenario in way of the mast
24.	Consider providing multiple N2 header such that single failure in the line cannot lead to complete loss of N2 supply to cargo holds. Loss of inert	Consequences: 5.1.1.1	Navalprogetti	

No.	Recommendations	Hazard scenario	Responsibility	Guideline - Status
	atmosphere in a cargo hold can lead to potential fire hazard if ignition source is present during leak.			
25.	Review nitrogen system arrangement for purging operation to ensure cylinders can be effectively and safely made gas free for maintenance purpose. Currently only one inlet port is shown for CNG cylinders and it will be difficult to inert the cylinder completely if separate outlet port is not provided. Ineffective purging can lead to fire hazard.	Consequences: 5.7.1.1	Cenergy/Navalprogetti	
26.	Consider making life raft area open to avoid any gas pockets during gas release scenario. Gas accumulation in life raft can lead to fire hazard and inaccessibility to life raft during evacuation.	Consequences: 7.1.1.1	Navalprogetti	This is to be assessed in association with the gas dispersion analysis performed on the above items
27.	Consider increasing cofferdam till wheel house to protect wheel house from fire incident in compressor room. Also, ensure cofferdam height increase till wheel house is in compliance with class requirement for visibility from wheel house.	Consequences: 7.1.1.1	Navalprogetti	The structure of such wall will have to be assessed based on the explosion analysis for the cargo compressor room as described above