Open type ferry safety systems design for using LNG fuel

D.-N. Pagonis[1*], G. Livanos[1], G. Theotokatos[2], S.Peppa[1] N. Themelis[3]

1. Department of Naval Architecture, Technological Educational Institute of Athens, Greece
2. Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, UK
3. Hellenic Register of Shipping, Greece

[*]**Corresponding author Email:** D.N.Pagonis@teiath.gr

Abstract

This feasibility study investigates the viability of employing Liquefied Natural Gas (LNG) fuel to an open type Ro-Ro passenger ferry and the potential challenges imposed with regard to the vessel safety systems. The study proposes appropriate methodology for converting the existing ship to run on LNG fuel and discusses all the necessary modifications to the ship's safety systems; furthermore, the ship's evacuation analysis is investigated accordingly. The basic requirements that the ship already complies with are initially reported for each safety system while the additional restrictions that need to be taken into consideration for employing LNG fuel are analysed; appropriate actions are proposed. Furthermore, a Hazard Identification Study (HAZID) is also carried out. Overall, the technical feasibility of the investigated scenario is clearly demonstrated; minimal modifications to the ship's safety systems in order to comply with the imposed safety rules are required for the specific type of ship.

Keywords

LNG fuel; Fuel conversion; Ship safety systems; LNG regulations; Open-type ferry; Design study;

1. Introduction

The use of liquefied natural gas (LNG) as fuel for propulsion of commercial ships can lead to both significant reduction of the ship engines exhaust gas emissions (CO2, NOx, SOx, PM) [IMO (2009)] and lower operational cost due to the substantial lower price of LNG (compared to the Diesel fuels); thus, LNG fuel is expected to dominate the shipping industry as the most likely alternative fuel for many newbuild and existing vessels. The idea of employing LNG as ship fuel is not new since it has been employed for many years on gas carriers with boilers (in the case of steam turbine propulsion), four-stroke diesel mechanical propulsion or diesel electric propulsion [Curt B (2004)]. In recent years though, the LNG infrastructure has been developed to the extent that a number of LNG-fuelled ferries have already been built (Word Ports Climate Initiative, http://www.lngbunkering.org/lng/vessels/ferries); for example "Viking Grace" -the first LNG-fuelled passenger ship in the world, is operating at the line Turku - Aland Islands (Finland) - Stockholm (Sweden) carrying 2800 passengers on board since 2013. Thus, based on the obtained experience, LNG fuel is now established as a clean and reliable fuel for propulsion and auxiliary power generation. Apart from the obvious scenario of building a new LNG fuelled ship though, a significant amount of currently operating vessels could be suitable for appropriate conversion to employ LNG fuel since retrofit solutions are becoming economically viable and worth considering [Aronietis R et al. (2014)]. Hence, retrofitting of an existing ship into LNG is of high interest for the shipping industry from economical and environmental point of view.

In this paper, we have performed a detailed study of converting an open type Ro-Ro passenger ferry to employ LNG fuel -with respect to its safety systems; the investigation involves the analysis of all the necessary modifications and the proposal for appropriate actions. In particular, the additional requirements for the ship safety systems to run on LNG are considered and the necessary modifications are determined; the study is based on the regulations required at national and international level for the operation of ships with LNG fuel (HRS rules http://www.hrs.gr, DNV GL rules https://www.dnvgl.com). It should be noted that to the knowledge of the authors there are no available studies investigating the retrofitting of an existing Ro-Ro passenger ferry with regard to the vessel safety systems.

The modifications under evaluation cover all ship's safety systems and are divided into four main categories including Fire Safety systems, Ventilation system, Fire and Gas detecting safety measures and Evacuation of the ship. Furthermore, a quantitative Hazard Identification Study (HAZID) has been performed based on an expert's panel for an open type ferry.

2. Methodology

As already mentioned the present study evaluates the technical feasibility of retrofitting a typical existing open type Ro-Ro passenger ferry in order to operate on liquefied natural gas (LNG). The particulars of the vessel are presented in the table below (Table 1). We should note that the selection of the specific type of vessel is mainly based on the wide usage of similarly designed vessels operating on domestic coastal routes throughout the Greek territory, and especially close to urban areas; thus, employing LNG as fuel for the particular type of vessel is of great interest and importance.

Vessel particulars	
Length	102.5 m
Breadth	19.4 m
Depth	4.1 m
Draft	2.65 m
Gross Tonnage	2110 ton
Speed	16 knots
Power output	4205 kW
Auxiliaries	415 kW
Passengers	1100
Cars	252

Table 1Vessel's particulars

The study was focused on the analysis of the following:

- Fire Safety systems: modifications on the ship safety systems required for the storage and use of liquefied natural gas as fuel for ships, taking into consideration the additional requirements for the ship safety systems and the regulations required at national and international level for the operation of ships with fuel LNG. In particular, the required alterations to Fire insulation, Fire pumps (number and capacity), Fire line, Water spray systems (Sprinkler/Drencher) and Fixed/Portable fire extinguishing systems (CO_2, etc) are investigated.
- Ventilation system: the topology of the existing system (air inlets/outlets etc), the capacity of the installed fans, the capacity and the location of the additional fans required for the LNG fuel line are examined.
- Fire and Gas detecting safety measures: the addition of an appropriate gas detection system is analysed and proposed including the system's type, sensor's topology and the appropriate interfacing to the ship's LNG fuel supply automation system.
- Evacuation plan: the number and topology of lifesaving appliances (i.e. number of life jackets, number and location of life rafts etc.) and the evacuation analysis are reconsidered taking into account a potential gas leakage or fire at the LNG tanks.

- Hazard Identification Study (HAZID): an identification of main hazards and evaluation of the severity and the probability of each hazard has been investigated with the participation of local maritime experts and research scientists.

2.1 Modification of the Fire safety systems

As a result of several fire casualties onboard, the fire safety regulations for ships have been improved considerably. The increased need for requirements for fire safety aboard ships was the basis for the development of the current rules and regulations [Regulation 2, 2.1 SOLAS (1974) as amended]. According to previous study concerning the LNG fuel feeding system of the particular ship, two storage tanks are necessary [Theotokatos G et al. (2015)]. The required LNG tanks are located at an appropriate superstructure on top of Platform Deck – as shown at Fig. 2.

In the following sections the fire safety systems of the specific ship will be investigated in order to determine the feasibility of employing LNG as fuel with respect to fire safety and the potential necessary modifications that have to be performed. In particular the following are analysed for the particular case study: Fire insulation, Fire pumps (number and capacity), Fire line, Water spray systems and Fixed/Portable fire extinguishing systems.

2.1.1 Fire insulation

According to SOLAS regulations, ship spare parts are classified with respect to fire insulation in three categories: "A", "B" and "C" Class Division [Regulations 2, 3, 4, 10 SOLAS (1974)]. The ship is always divided into main vertical zones. Main vertical zones are those sections into which the hull, superstructure and deckhouses are divided by "A" class divisions, the mean length and width of which on any deck does not typically exceed 40 m [Regulation 3, 32 of SOLAS (1974)].

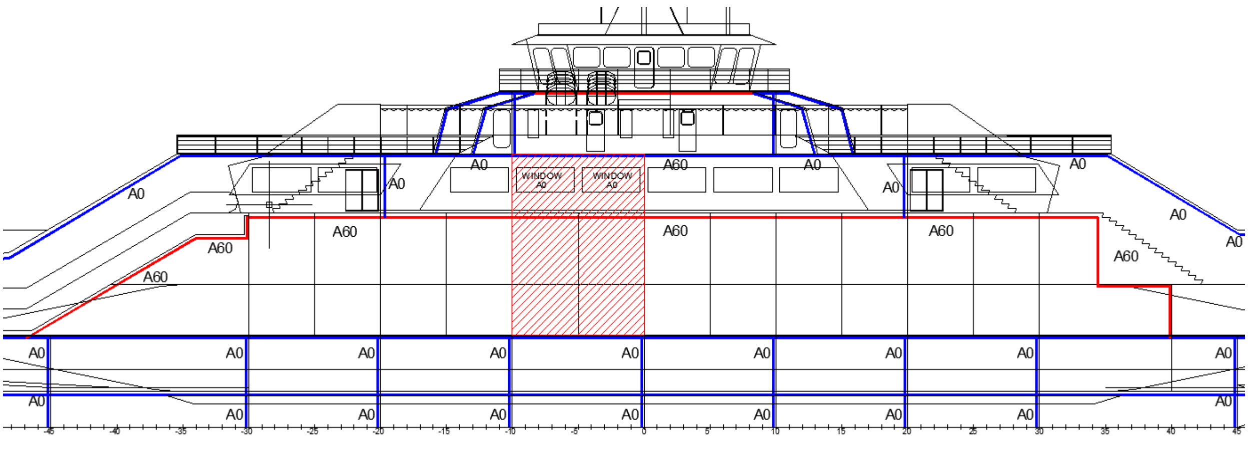

Fig. 1 Side view of the ship's existing fire insulation

Most of the fire insulation employed on the vessel is of Class A-60 standard (see Fig.1). In particular, the floor of the accommodation deck and certain areas of the Sun Deck are shielded with Class A-15 insulation. The area of the emergency generator and the rest of accommodation spaces are shielded with Class A-60 insulation. The sides of the ship from the main deck to the ceiling of the accommodation space are shielded with Class A-60 insulation whilst the windows at the accommodation deck are of Class A-0.

Application of necessary modifications, with respect to Fire insulation, is required in order the vessel to comply with additional requirements (see A1 in Appendix) presented when LNG fuel is used. In particular the following modifications should be considered:

- The docking station and the superstructure where the LNG tanks are located should be shielded with Class A-60 insulation (the boundaries surrounding the LNG tanks are already shielded with class A-60 insulation, as shown at Fig. 2).
- The windows of the accommodation space facing the LNG tanks should be removed and replaced by appropriate Class A-60 standard insulation sheet.
- The bridge windows facing the LNG tanks should be replaced by windows of Class A-0 standard.
- The side of the stairways facing tanks on Accomodation Deck should be shielded with Class A-60 insulation.

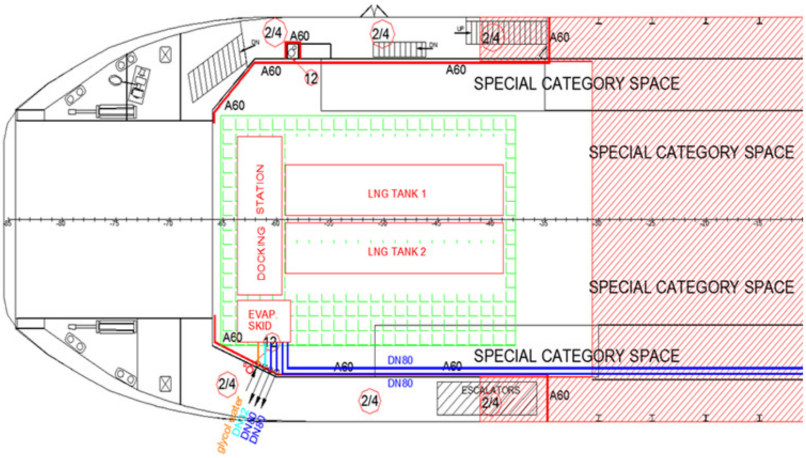

Fig. 2 Insulation at Platform Deck and at the boundaries of superstructure where the LNG tanks are located

2.1.2 Fixed Fire extinguishing systems

According to HRS rules concerning fixed fire extinguishing types by Mizithras P et al. (2015), every ship shall be equipped with sufficient means to suppress and swiftly extinguish a fire in the space of origin. Usually, the most common fire extinguishing mean is the main fire water supply system, consisted of hydrants and hoses. Beside this, various fixed fire extinguishing systems can be installed on the ship for that purpose, regarding the potential fire growth in protected spaces. In addition, some fixed fire extinguishing appliances can be used, which are usually one of the following types:

- Fixed gas fire extinguishing system
- Fixed expansion foam fire extinguishing system
- Fixed pressure water spraying fire extinguishing system

The ship is equipped with appropriate Fire Sprinkler / Drencher system according to Resolution A.123 (V) of International Maritime Organization (2012) and CO_2 system according to Chapter 2-II, Part A, R.5.1 of Council Directive 98/18/EC (1998). The main characteristics of each system are presented below. It must be noted that only the key aspects of each system are presented since there is no need to re-evaluate the already approved by the class and flag authorities.

The Sprinkler system consists mainly of a pump with nominal characteristics of 90 m^3/h and 5 m head (the required capacity is 84 m^3/h) and a sprinkler tank with a volume of 2800 Lt. The Sprinkler tank together with the Sprinkler pump is located beside the After Engine room. There are two Sprinkler stations onboard; their specifications are presented in Table 2.

Sprinkler station	Deck	Area (m^2)	Head (m)
1	Accommodation Deck	1012.26	120
2	Wheel house Deck, Sun Deck	169	21

Table 2 Sprinkler system's specifications

The Drencher system consists of three Drencher pumps with nominal characteristics of 140 m^3/h and 30 m head while the required capacity for the two largest Drencher zones onboard is equal to 269.5 m^3/h. The

Drencher pumps are located in the After Engine room. There are four main Drencher zones onboard; their specifications are presented in Table 3.

Drencher Zone	Area (m^2) Height < 2m	Area (m^2) Height > 2m	Deck
ZONE 1	346.5	-	Lower Deck
ZONE 2	346.5	-	Lower Deck
ZONE 3(A)	213.6	-	Main Deck
ZONE 3(B)	163.4	185.436	Platform Deck
TOTAL ZONE 3	377	184.436	
ZONE 4(A)	213.6	-	Main Deck
ZONE 4(B)	163.4	185,436	Platform Deck
TOTAL ZONE 4	377	184.436	

Table 3 Drencher system's specifications

The ship fixed fire extinguishing system consists of five main CO_2 cylinders located in the CO_2 room at the fore side of the Platform Deck next to the stores room. The necessary CO_2 capacity is directly proportional to the volume of each engine room according to Chapter 2-II, Part A, R.5.2 of Council Directive 98/18/EC (1998). For a total engine room volume of 288 m^3 the required quantity of CO_2 is calculated equal to 206 Kg. Therefore the quantity of five 45 Kg each CO_2 cylinder installed in each engine room is considered sufficient.

Taking into consideration the available additional rules concerning the use of LNG as fuel [HRS rules, Mizithras P et al. (2015), GL Guidelines for the use of gas as fuel for ships, Germanischer Lloyd (2010)], it can be concluded that the existing fixed fire extinguishing systems of the ship (i.e. Sprinkler/ Drencher and CO_2 systems) are sufficient. This is because both the engine rooms of the ship are considered of Inherently Safe type (all gas fuel piping is of double wall type) and there is no bunkering station on board. Thus, no alteration is necessary at the specific systems. We should note though that a fixed water spray line for the LNG fuel tanks is necessary to be installed (see section A2 of Appendix) as presented in the next section.

Water spray system for Gas storage tanks

In the specific case study, the required water spray system for cooling and fire prevention of the exposed parts of gas storage tanks is incorporated into the cassette type LNG tanks. The necessary potential modifications with respect to the ship's fire pumps (i.e. number/capacity) should be determined in order to provide the additional water supply along with the necessary modifications at the ship's fire line.
According to the international safety rules imposed by R4 of Council Directive 98/18/EC (1998) every ship shall be provided with appropriate fire pumps, fire mains, hydrants, hoses and nozzles. Ships certified to carry more than 500 passengers, (ship case) should have at least ***three*** fire pumps, one of which may be a main engine driven pump.
Although there is no additional requirements concerning the number of fire pumps when LNG is employed as fuel, calculations are necessary to verify that the capacity of the existing fire pumps is sufficient to deliver the additional supply for the water spraying system at the LNG tanks. The ship already has ***four GS/Fire pumps*** installed (two at each engine room); each pump nominal characteristics are 37.5 m^3/h and 40 m head.

At first, the appropriate dimensions of the bilge line (internal diameter of main line and branch suction lines) are calculated in order to determine the minimum required bilge pump capacity. The required fixed fire extinguishing capacity, Q_{FFE} is then obtained since it is proportional to the particular figure. Thus, we can determine if the capacity of the fire pumps already fitted on board, $Q_{installed}$ is sufficient to cover both systems (fixed fire extinguishing, Q_{FFE} and LNG water spraying, Q_{LNG_WS} i.e. $Q_{installed} \geq Q_{FFE} + Q_{LNG\_WS}$).
According R21 of Council Directive 98/18/EC (1998) and HRS rules, Part5, Chapter 9, 5.2 of Hellenic Register of Shipping (2015) the internal diameters of the main bilge line and the branch bilge suction are calculated equal to $101.5\ mm$ and $56.3\ mm$ respectively. As a result the following are derived:

- All the internal diameters of the main bilge lines should be at minimum 102 mm.
- All the internal diameters of the branch bilge suctions should be at minimum 57 mm.

Taking into account that the total number of passengers of the ship is more than 500 and the number of bilge pumps should be at least *three*, according R21 of Council Directive 98/18/EC (1998).
The minimum bilge pump capacity is calculated equal to $59.23\, m^3/h$ according to HRS rules, Part 5, Chapter 9, 6.3 of Hellenic Register of Shipping (2015).
It should be noted that the ship has four bilge pumps installed, two of them located in each engine room, with nominal characteristics 70 m^3/ h and 30 m head.

The maximum capacity of the fire pumps installed on the ship is calculated below in order to determine potential alterations to the existing pumping system. The diameter of the ship fire line shall be sufficient for the effective distribution of the maximum required discharge from the fire pumps. Each of the required fire pumps (other than any emergency pump required) shall have a capacity not less than 80% of the total required capacity divided by the minimum number of required fire pumps, but in any case not less than *25 m^3/h* according to CHAPTER II-2, R4, 2 of Council Directive 98/18/EC (1998).
The calculated minimum capacity for each pump according to the above rules is equal to $\mathbf{29.61\frac{m^3}{h}}$ -higher than the required for the particular ship type. Note that according to the corresponding regulations, for the specific ship type, ***three*** fire pumps are required as a minimum; in the particular ship though ***four*** fire pumps are already installed. The calculated capacity both for bilge and fire pumps are presented in Table 4. Note that the calculated capacity of the fire pump is significantly lower than the installed fire pumping capacity.

	Installed	Calculated	Difference
Fire pump	37.5 m^3/h	29.61 m^3/h	~ 8 m^3/h
Bilge pump	70 m^3/h	59.23 m^3/h	~ 10 m^3/h

Table 4: Installed and calculated capacities of fire and bilge pumps

As mentioned previously, the LNG water spray system should have an application rate of 10 Lt/min/m^2 for horizontal projected surfaces; the total surface of the area, occupied by the two LNG tanks is equal to 59.5 m^2. Thus, the additional flow rate necessary to cover the requirements for cooling the LNG tanks in an emergency situation is calculated equal to $\mathbf{35.7m^3/h}$.
Note that the specific figure is ***comparable*** to the minimum required capacity for each of the fire pump onboard; furthermore, the total pumping capacity required in order to fulfill both requirements (i.e. LNG water spray system, Q_{LNG_WS} plus the minimum fixed fire extinguishing capacity for the particular ship type, Q_{FFE}) is equal to 29.61 + 35.7 m^3/h = ***65.32 m^3/h***, which is almost twice the capacity of each of the fire pump.
As noticed above, the ship is equipped with an additional fire pump; therefore, one possible solution is to dedicate this pump to the LNG water spray system; thus there would be three fire pumps -to comply with class requirement and one pump dedicated to the LNG water spray system. However, in order for this scenario to be feasible the total *hydraulic loss* (taking into account the existing fire line and also the LNG water spray system line) *should be less than 40 m* (head of each fire pump); in the following section, this is verified.

Calculation of hydraulic loss for the existing fire line

The hydraulic loss for the existing fire line is calculated in order to determine if the necessary supply rate can be provided by a single fire pump. Note that the path for each branch of the fire line (for the horizontal hydraulic loss calculations) is considered the longest one at each deck (a typical path is presented in Fig. 3).
The hydraulic loss, $\boldsymbol{H_{Loss}}$ in meters, of each of the line braches is calculated by the following equation considering the friction loss and the fitting loss (elbows, valves, etc):

$$\boldsymbol{H_{Loss}} = \left[\lambda\left(\frac{L_p}{d_{in}}\right) + \zeta\right]\left(\frac{W^2}{2g}\right) \tag{1}$$

where λ = friction factor
L_p = the length of the fire line branch
d_{in} = the inner diameter of the pipe
ζ = the additional resistance of the fittings along the considered branch

W = the velocity of the fluid
g=9.81 m/sec^2.

The friction factor, λ can be easily obtained by Moody chart as a function of the Reynolds number, R_e and the relative roughness, ε/d_{in} of the pipe for laminar or turbulent flow. For the surface roughness, ε of the piping material a representative value of 0.15 for galvanized iron roughness is employed.

The head loss of the fire line branches on the Lower Deck, Main Deck, Platform Deck, Accommodation and Sun Deck are presented in Table 5 together with the total hydraulic loss which is equal to **20.56 m**.

The elevation corresponding to the length of vertical piping is equal to 13.4 m. Furthermore, the minimum water jet height at the last nozzle (at the Sun Deck) is considered equal to 2.1 m (requirement imposed by Chapter II, R4 of Council Directive 98/18/EC (1998)). Thus the minimum head increase of each pump is equal to 36.06 m which is less than *40 m* (head of each pump installed on board).

Location	d_{out}(mm)	s(mm)	d_{in}(mm)	ε/d_{in}	$R_e \cdot 10^5$	λ	L_p (m)	ζ	W(m/s)	$\mathbf{H_{Loss}}$**(m)**
Lower-Deck	88.9	4.5	80.9	0.0019	1.2	0.025	20.3	12.3	2.08	**3.72**
Main-Deck	76.1	3.6	68.9	0.0022	1.36	0.0255	4.06	3	2.77	**1.74**
Platform Deck	76.1	3.6	68.9	0.0022	1.36	0.0255	48.14	5.1	2.77	**8.8**
Accomodation Deck			53.1	0.0033	1.5	0.026	5.22	3.3	3.98	**4.66**
Sun Deck			53.1	0.0028	1.55	0.026	1.74	1.2	3.98	**1.64**
									Total	**20.56**

Table 5 Head loss calculation for the existing fire line

<u>Calculation of hydraulic loss for the LNG water spray line</u>

To calculate the hydraulic loss for the water spray system due to the LNG implementation, it is assumed that the path line for the water spray system will be identical to the fire main line until the Platform Deck where the line is connected to the LNG tanks water spraying system (as shown at Fig. 4). The corresponding head loss for the water spray line for the Platform Deck is presented in Table 6.

Location	d_{out}(mm)	s(mm)	d_{in}(mm)	ε/d_{in}	$R_e \cdot 10^5$	λ	L_p (m)	ζ	W(m/s)	$\mathbf{H_{Loss}}$**(m)**
Platform Deck	76.1	3.6	68.9	0.0022	1.36	0.0255	19.14	3.0	2.77	**3.88**

Table 6 Head loss calculation for the water spray line at Platform Deck

The total hydraulic loss for the particular line is the sum of the losses on Lower Deck, the Main Deck (decks underneath –as shown at Table 5) and the loss calculated in Table 6. Thus, the total head loss is equal to **9.34 m.**

The elevation corresponding to the length of vertical piping is equal to **14.5 m**. Thus the minimum head increase of the pump dedicated to the LNG water spraying line should be equal to **23.84 m** which is less than *than 40 m* (head of each pump installed on board**)**. As a result, the head of one fire pump is considered sufficient.

As it can been seen from the above calculations the proposed alteration on the vessel fire line is feasible. Note that a connection to the ship fire line through a screw-down non-return valve should be provided in order to comply with the additional requirements for fixed fire extinguishing system, when LNG is used as fuel.

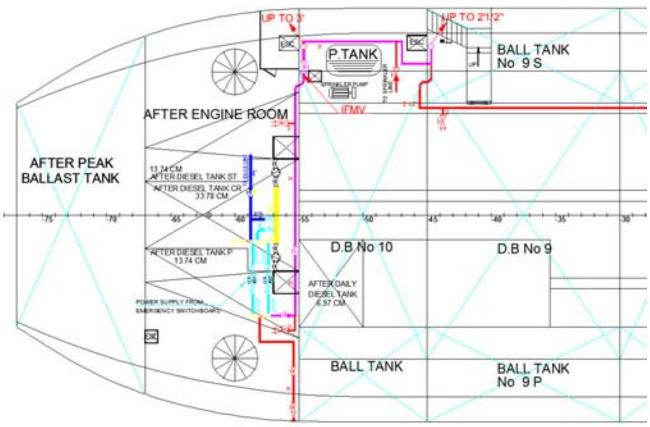

Fig. 3 Lower Deck: Path line of the fire system (see line in magenta color)

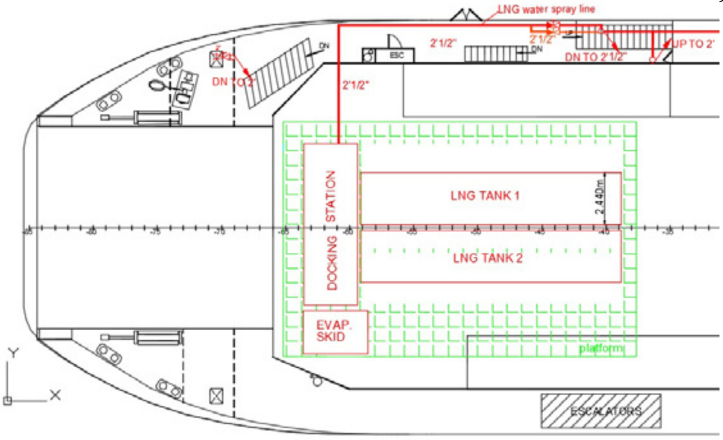

Fig. 4 Platform Deck: Path line of the water spray system to the LNG tanks (see line in red color)

2.1.3 Portable Fire extinguishers

Apart from the installed fixed fire extinguishing systems, the ship shall be provided with portable fire extinguishers according to Chapter 2-II, Part A, R.6 5.1-5.6 of Council Directive 98/18/EC (1998). According to GL Guidelines for the use of gas as fuel and HRS rules concerning preventive measures, fire extinction by Mizithras P et al. (2015), ***one*** portable dry powder fire extinguisher of at least ***5 kg*** capacity should be located near the *bunkering* station. We should note that the above requirement is the only additional requirement concerning portable fire extinguishers when LNG is employed as fuel.

According to the ship Fire Control Plan, there are 57 portable fire extinguishers onboard described as follows:

- 20 air-foam fire extinguishers of 10 Lt capacity
- 31 dry powder fire extinguishers of 6 kg capacity and 2 dry powder fire extinguishers of 12 kg capacity
- 4 CO_2 fire extinguishers

The above fire extinguishers are located at the ship decks as shown in Table 7 and 8.

Extinguisher type	Portable fire extinguishers (Lower Deck - Deck 1)			
	After Engine Room	**Fore Engine Room**	**Machinery Spaces**	**Garage (693m^2)**
Dry powder fire extinguisher of 12 kg	1	1	-	-
Dry powder fire extinguisher of 6 kg	1	1	2	-
Air-foam fire extinguisher	1	1	-	4

Table 7 Lower Deck: Portable fire extinguishers

Extinguisher type	Portable fire extinguishers (Decks 2 -6) Main Deck (Deck 2)	Platform Deck (Deck 3)	Lounge Deck (Deck 4)	Sun Deck (Deck 5)	Wheel House Deck (Deck 6)
CO_2	-	-	-	1	1
Dry powder fire extinguisher of 6 kg	16	2	7	2	-
Air-foam fire extinguisher	8 (10 Lt)	4	-	-	-

Table 8 Decks 2 to 6: Portable fire extinguishers

There is no available bunkering station onboard the ship but there is a docking station located on top of the superstructure (since the two LNG tanks are of cassette type). Therefore, two additional dry powder extinguishers should be added at the specific area. In more detail, ***two dry powder*** fire extinguishers of ***6 kg*** should be added near the docking station as an additional safety measure as shown at Fig. 5.

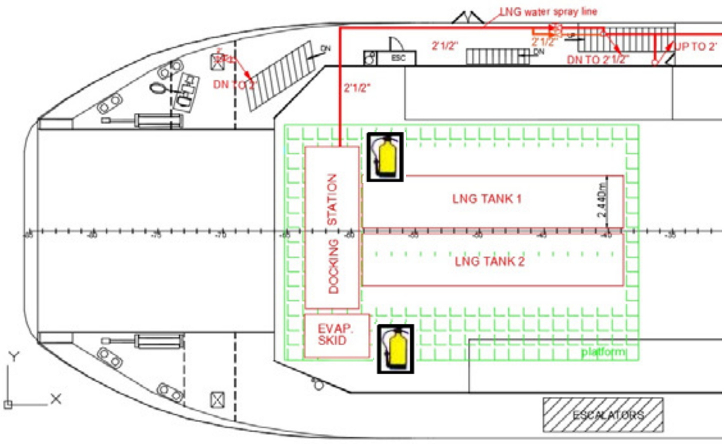

Fig. 5 Superstructure on top of which the two cassette type LNG tanks will be located

2.2 Modification of the Ventilation System

In the current section, the ship initial ventilation system will be examined in order to detect any potential modifications to comply with the additional rules when LNG is employed as fuel. The basic HRS's requirements for ship's ventilation system, are found in the technical report of Mizithras P et al. (2015) - section concerning ventilation system provisions. Taking into consideration the additional requirements (see A3 in Appendix) for employing LNG as fuel, the potential modifications will be determined and appropriate action will be proposed accordingly. Potential modifications/alterations are mainly focused on the system topology (i.e. air inlets/outlets etc), the capacity of the existing fans to supply with air the engine rooms and the installation of additional fans to preserve the air changes inside the fuel-gas piping systems.

It can be safely assumed that the existing ship ventilation system complies with its class/flag requirements. Furthermore, running on LNG, the adequacy of the existing ventilation system to provide with the required air changes the two engine rooms should be examined.

<u>Air changes calculation in machinery spaces:</u>
The following calculation for the machinery spaces are according to ship's ventilation plan:
Machinery space "A":

- The capacity of the ventilation system of the machinery space is: 29,000 m^3/h
- The required air supply for the main engines is: 12,384 m^3/h
- The required air supply for the generators is: 1,104 m^3/h

The remaining capacity of air supply in the machinery space is equal to 15,512 m^3/h.
For a machinery space volume equal to 286.32 m^3, the air changes are calculated equal to ***54.18 air changes/hour***.
Machinery space "B":

- The capacity of the ventilation system of the machinery space is: 29,000 m^3/h
- The required air supply for the main engines is: 12,384 m^3/h
- There are no generators at this machinery space

The remaining capacity of air supply in the machinery space is equal to 16,616 m^3/h.
The air changes in Machinery space B are easily calculated equal to ***58.03 air changes/hour.***
We should note that according to the vessel's approved ventilation plan, both machinery spaces are equipped with one appropriate fan. The ventilation ducts come out from the main deck, underneath the lateral ramps.

<u>Ventilation system for the Machinery spaces</u>
According to previous study concerning the LNG fuel feeding system of the particular ship, all LNG fuel supply lines are of double wall type and both machinery spaces are considered as Inherently Safe type [Theotokatos G et al. (2015)]. Thus, the already installed ventilation system concerning the machinery spaces does not require any change in principle. It should be noted though that there will be an extra load to the installed system due to the necessary air changes inside the double wall fuel supply lines; thus, the system's adequacy with regard to the necessary air supply in the machinery spaces should be investigated.

<u>Ventilation system of the Double wall fuel supply lines</u>
According to the above requirements, a separate ventilation system should be installed on board for the ventilation of the double wall fuel lines. We should note that the system outlets should be located in open air, away from any ignition sources while its capacity shall be at least 30 air changes per hour. Since the four gas valve units (GVUs) are located inside the machinery rooms [Theotokatos G et al. (2015)] they are considered part of the double wall fuel line (Fig. 6); thus, the ventilation capacity for these units should also be equal to at least 30 air changes per hour.

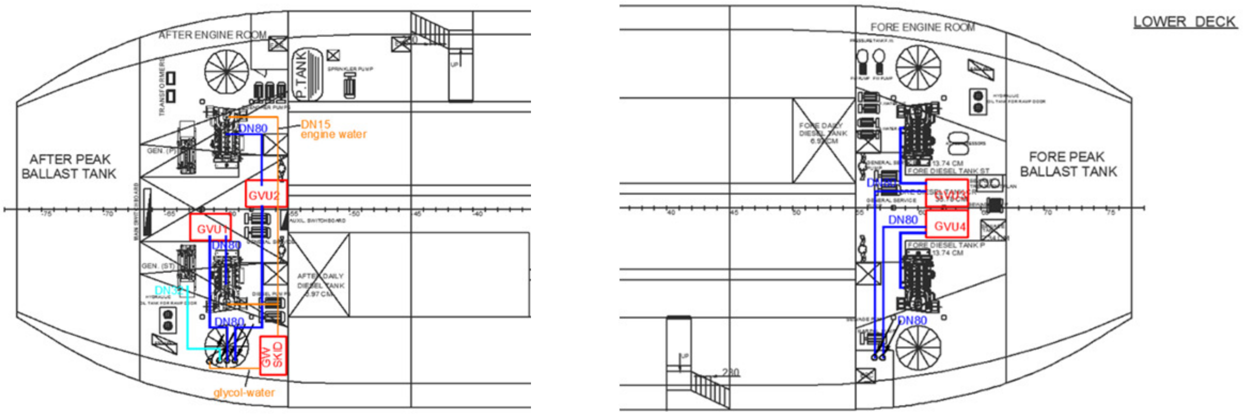

Fig. 6 Double wall fuel line topology inside each machinery room- 4 GVUs are present

The air suction for the ventilation of double wall piping system, will be located inside each machinery room at the point where the fuel supply pipe terminates at each engine; as the gas valve unit is considered part of the double duct in the engine room, the air enters through the gap of the double wall pipe towards the GVU (see Fig. 7).
In order to fulfill the above mentioned safety requirements, two appropriate ventilation fans of the same rated power should be installed on top of the superstructure of the LNG storage tanks (as shown at Fig. 8). At the specific location, they are placed more than 1.5 m away from the boundaries of any hazardous area and they are far away from the air outlets of the existing ventilation system of the machinery spaces. Each ventilation

fan should provide the total necessary air supply for the ventilation of the entire double wall piping (serving both machinery spaces).
It should be noted that the fans should not be powered by a common circuit from the main switchboard. Furthermore, it is proposed (although not required) one of the fans to be powered by the emergency power supply; thus, once there is a loss of main power onboard, there is sufficient ventilation provided from the remaining fan in operation.

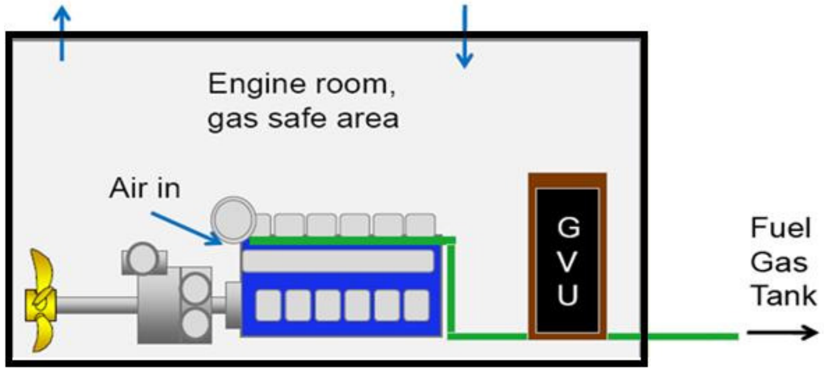

Fig. 7 Air inlet of double wall piping ventilation located at each engine [Jacobs P (2012)].

The ventilation system should always be in operation when gas fuel is in the double wall pipes and it should start and stop before gas is fed into the pipes. Accordingly, the gas will be fed into the inner pipe after the stabilization of the air changes in the double wall pipe (otherwise, for safety reasons the main gas valve will shut down). Complying with the class requirements, the materials, the construction process, the strength of the pipes and ducts of the ventilation system should be resistant to explosions and expansions of the ducts in case of duct breakdown.

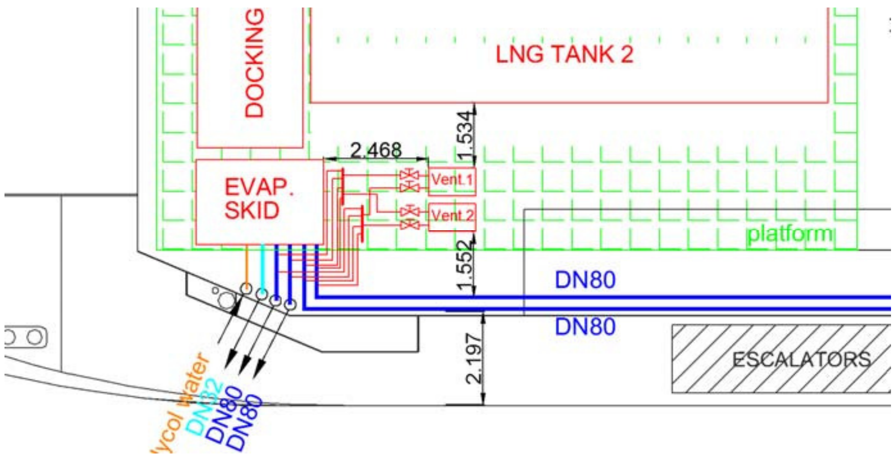

Fig. 8 Installation of the two dual wall piping ventilation fans (Vent.1&2) on top of the superstructure where the LNG storage tanks are located-the necessary safety distance requirements are fulfilled.

<u>Calculation of the necessary air supply for the ventilation of the double wall fuel line</u>
The calculations for the air supply required for the ventilation of the gap inside the double wall pipes is summarised in Table 9.

	Engine Room A'	**Engine Room B'**

	to GVU_1	to GVU_2	to GVU_3	to GVU_4	Units
Diameter-NG pipe (d_{inner})	80	80	80	80	mm
Wall thickness	10	10	10	10	mm
Interbarrier distance	30	30	30	30	mm
Diameter-outer pipe (d_{outer})	120	120	120	120	mm
Pipeline length (L)	24	24	96	96	m
Interbarrier area	4945.5	4945.5	4945.5	4945.5	mm^2
Interbarrier volume	0.1187	0.1187	0.1187	0.1187	m^3
Air supply (Q_{line})	**3.56**	**3.56**	**14.26**	**14.26**	**m^3/h**

Table 9 Air supply calculation concerning the dual wall fuel lines

Note that the air supply required for the ventilation of the gas valve units-GVUs (there are two GVUs at each engine room) shall be added to the above values.
Typical dimensions of a GVU are 2.3 x 1.9 x 1.2 m^3 given in technical report of Pagonis D.- Dimitrellou S. (2014), which correspond to a volume of approximately 5.3 m^3.
By considering 30 air changes per hour, the necessary air supply for each GVU is equal to **159 m^3/h**; table 10 presents the required total air supply for the two engine rooms.

	Engine Room A'	Engine Room B'	units
Dual pipe supply	2 x 3.56	2 x 14.26	m^3/h
GVU supply	2 x 159	2 x 159	m^3/h
Total air supply	**325.12**	**346.52**	m^3/h

Table 10 Total air supply needed for both engine rooms

Thus, the minimum total air supply for each ventilation fan is equal to Q_{min} = **672 m^3/h**.

<u>Adequacy of the existing ventilation system for the machinery spaces</u>
Although the additional air supply required for the new ventilation system of the LNG fuel line is relatively small, it should be verified that the existing engine room ventilation system is sufficient, as the inlets of the new ventilation network will be located inside each machinery space.
Machinery space "A":

- The initial remaining capacity of air supply to the machinery space taking into consideration the engines and gen-sets air consumption is equal to 15,512 m^3/h (see previous section -Existing ventilation system in machinery spaces)
- The air supply required for the ventilation of the dual pipe and GVUs is equal to 325.12 m^3/h
- The volume of the machinery space is 286.32 m^3

Thus, the new value for the air changes is equal to: (15,512-286.32) m^3/h / 286.32 m^3 = 53.04 > 30, which is *sufficient*.
Machinery space "B":

- The initial remaining capacity of air supply to the machinery space taking into consideration the engines' air consumption is equal to 16,616 m^3/h (see previous section - Existing ventilation system in ship's machinery spaces)
- The required air supply for the ventilation of the dual pipe and GVUs is equal to 346.52 m^3/h
- The volume of the machinery space is 286.32 m^3

Thus, the new value for the air changes is equal to: (16,612-346.52) m^3/h / 286.32 m^3 = 56.82 > 30, which is *sufficient*. Therefore, we can safely conclude that the capacity of the existing ventilation system of the machinery space is sufficient.

2.3 Modification of the Fire and Gas detecting safety measures

In this section, the existing ship safety measures concerning fire and gas detection, will be examined in order to detect any necessary modifications to comply with the additional rules when LNG is employed as fuel. Taking into consideration that the ship already complies with its class requirements concerning safety measures the necessary modifications to fulfill the additional requirements (see A4 in Appendix) when LNG fuel is employed will be determined and appropriate action will be proposed accordingly. The main modification/alteration in the specific section is focused on the installation of appropriate gas detection system to cover particular areas of the ship.

The ship fire detection system is in compliance with the requirements in CHAPTER II-2-R13 of Council Directive 98/18/EC (1998) [Mizithras P et al. (2015)]. The ship is equipped with a stand-alone fire detection system which currently incorporates 40 smoke detectors and 4 heat detectors; in detail the location of the detectors is as follows:

- 4 heat detectors are located at the engine rooms (Lower Deck)
- 7 smoke detectors at the Lower Deck
- 2 smoke detectors at the Main Deck
- 16 smoke detectors at the Lounge Deck
- 15 smoke detectors at the Sun Deck

According to the additional requirements concerning detecting safety measures when LNG is employed as fuel, the necessary alterations are focused on the topology of the existing fire system, the application of heat detectors instead of smoke detectors and the installation of gas detectors at certain areas of the ship. In particular:

<u>Lower Deck</u>

At the Lower Deck four heat detectors are already installed at the engine rooms (2 in each engine room). According to the additional requirements that should be employed, each engine room is considered an enclosed space containing gas piping whilst each gas valve unit is considered part of the double duct in the engine room. Thus, it is proposed the installation of *eight gas detectors* in total, four at each engine room (as shown at Fig. 9) -two for the engine room space and two for each GVU.

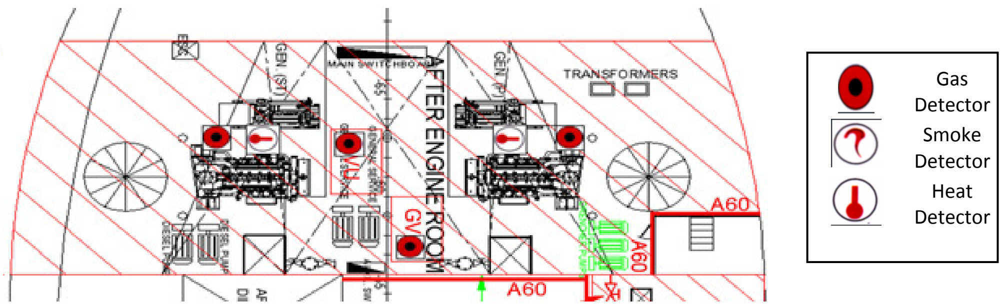

Fig. 9 Aft engine room

Lower closed garage

At lower closed garage there are seven smoke detectors already installed. There is no need to install any heat or gas detectors as no pipelines or equipment of natural gas exist at the particular area.

Main Deck

At Main Deck (Deck 2) there are four smoke detectors already installed to cover the four Embarkation areas. The number of existing smoke detectors cannot be considered sufficient for fast fire detection because of the rapid gas diffusion in the area and the reduced smoke production when natural gas is burnt. Furthermore, at least one detector shall be installed in a space which accommodates passengers. Therefore, the replacement of all smoke detectors by *heat detectors* and the addition of one gas detector at each of the four embarkation areas (i.e. *four gas detectors* in total) is proposed.

Note that a gas detector should be fitted as well at each enclosed space containing gas piping, thus *a heat detector* and *a natural gas detector* are proposed to be installed at the two enclosed areas of the main deck where the gas fuel lines enters to each engine room i.e. *two heat detectors and two gas detectors* in total. At the Garage area no detector device is required as the garage is an open area and there is natural ventilation.

Platform Deck

At Platform Deck (Deck 3) there are available two embarkation areas as well. Correspondingly, it is proposed *a heat detector* and *a gas detector* to be installed at both areas.

The ventilation inlet for the After engine room is located at a distance less than 6 m from the LNG tanks. Note that the two areas are not in the same deck (the superstructure is not at the Platform Deck level) and there is a height difference of 2.62 m; thus, the total distance between the two points of interest is 5.4 m. According to the regulations *a gas detector* should be installed at the specific inlet in order to detect a gas leak.

Alike, the ventilation inlet for the Fore engine room is set near the double wall fuel supply lines for the specific engine room; therefore *an additional gas detector* should be installed at the specific inlet.

Lounge Deck

The Lounge Deck (Deck 4) is already equipped with appropriate smoke detectors. Although there are no gas pipelines passing through the Deck, gas detectors should be installed due to the relative additional regulations concerning the safety of the passengers. In particular, at least one detector should be installed at each space where passengers are accommodated. Thus, it is proposed to install *eleven gas detectors* on the Lounge main area (in accordance to the maximum spacing of detectors already employed for the existing smoke detectors) and additionally *four gas detectors* for the four separate rest-room areas at the deck i.e. *fifteen gas detectors* in total (Fig. 10).

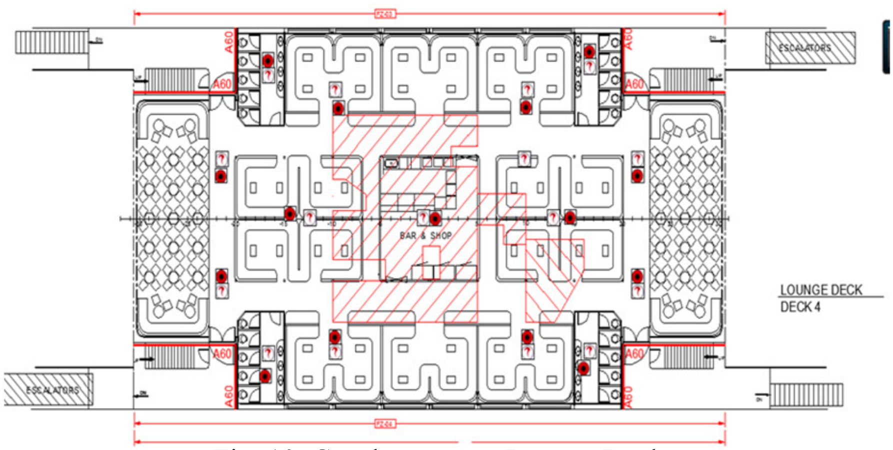

Fig. 10 Gas detectors at Lounge Deck

Sun Deck-Wheel House Deck

At Sun Deck (Deck 5) & Wheel House Deck (Deck 6) as in the case of the Lounge Deck gas detectors should be installed for the safety of the passengers at each separate area; note that the areas where only the crew is present /accommodated have been fitted with appropriate gas detectors as well. This is proposed taking into consideration the additional requirement for the positioning of gas detectors in areas where personnel may be present. Therefore, *nine gas detectors* for the nine separate areas on Sun Deck (Fig. 11) and *one gas detector* for the Wheel House Deck should be installed.

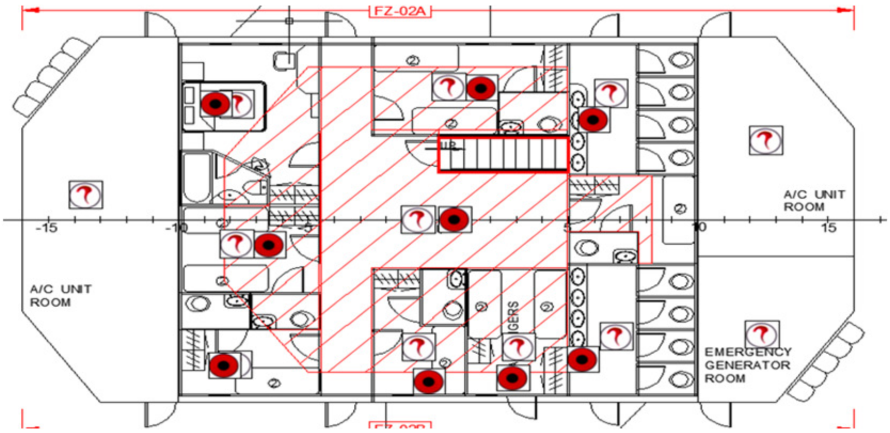

Fig. 11 Gas detectors at Sun Deck

Superstructure where the LNG storage tanks will be located

In addition to the above, *a gas detector* should also be installed at the superstructure where the storage tanks will be located. More specifically, the detector should be placed near the evaporator skid at the ventilation outlet of the double wall fuel lines ventilation in order to detect any possible gas leak.

Existing fire detection system aboard

The vessel existing fire detection system is a stand-alone AUTRONICA system of type BX-10M ('M' stands for Marine type as described in Installation and Commissioning Handbook of Fire Alarm Control Panel BX-10, Autronica Fire and Security AS (2015). The BX-10M model can support up to four independent zones (loops). The system fulfills all appropriate regulations concerning the ship category (emergency back-up power supply in the main unit, etc.) while it is approved by Det Norske Veritas (DNV), Lloyd's Register of Shipping (LR) and the American Bureau of Shipping (ABS).

According to the system technical specifications, each detector zone may include up to 32 detectors or manual call-points. Automatic detectors and manual call points may be combined in the same zone whilst disabling a zone is not deactivating the manual call-points in the zone. Furthermore, automatic detectors can include both smoke detectors and heat detectors. Although detailed technical specifications can be found in the system handbook, a brief introduction to system automation interface is necessary in order to initially evaluate the system's compatibility to the necessary new safety equipment that will be installed onboard, such as an appropriate gas detection system and to the LNG pack interface.

Alarm control signals of the system

The control panel has two sounder outputs, which are activated in parallel when an alarm is given. The outputs give a 24V DC pulsing voltage on alarm and are monitored for breaks and short circuiting. Maximum load per circuit is 0.63A.

Fire detection control signals of the system

There is one control output signal for each detector zone (loop), one output signal common for all four zones and furthermore one signal for the disabled zones. All signals are supplied as transistor controls (open collectors).

Common Alarm Output (BMA) & Common Fault Output (BMF) control signals

The available common alarm output can be used for alarm transfer to an external fire alarm receiving station (LNG Pack interface in the specific case). The output consists of a non-monitored potential free relay output,

plus a break and short circuit monitored power output. The specific output is activated at alarm from any zone and is active until the system has been reset.
The available common fault output is used for fault transfer to an external fire alarm receiving station. The output consists of non monitored potential free relay output, plus a break and short-circuit monitored power output.

Compatibility investigation of system automation interface with LNG fuel supply interface
As already analysed in the design study of ship piping systems and machinery for LNG fuel by Theotokatos G et al. (2015), it is proposed that the ship LNG fuel supply will be provided by appropriate cassette type tanks. Consequently, the compatibility of the existing fire detection system to the LNG supply system should be considered. In order to make an initial but a realistic investigation it is assumed that a typical commercial solution for a cassette type tank will be installed on board for LNG storage; that is the LNGPac™ system of Wärtsilä presented by Bui Y (2015).

Process Control Automation
The operation of the LNGPac™ is largely automated and controlled by a PLC-based control system. The central unit of the control system is the PLC cabinet near the tank connection space, which is located in an environmentally controlled space. All operating procedures / sequences, alarm procedures are part of an appropriate software developed by Wärtsilä.
The PLC cabinet consists of three independent PLCs: one for process control and two for safety valves controlled by solenoids which are placed in safe area near the tank docking station, Yang B (2014).
The fire detection and the gas detection system of the ship should be able to be connected directly to the two Safety Programmable Logic Circuits (PLC) that are incorporated in the LNGPac™ control unit. This should not be a problematic task since the existing fire detection unit on board provides sufficient control signals-relay outputs for fire detection. Similarly, potentially installed fire detectors inside the LNGPac™ system can be connected to an appropriate fire zone of the existing system.

Installation of a typical Gas Detection System
According to class rules, the existing ship does not incorporate a gas detection system. Therefore, a new system should be installed for the gas leakage detection according to the topology previously proposed incorporating a total number of forty four gas detection sensors.
Two typical (commercially available) stand-alone gas detection systems -which one could consider for the particular study, are Martek type MM2000 and Autronica type OGS 2.1 systems respectively; for details see MM2000TM datasheet by Martek Marine Ltd (2015) and Type OGS 2.1 datasheet of fixed gas detection system by Autronica Fire and Security AS (2015a).
Both systems fulfill all appropriate IMO regulations and classification societies' rules and regulations. The Lowest Explosion Limit detection range (LEL) for both systems is adjustable (0-100%).
Regarding system compatibility with the LNGPac™ automation and control interface, both systems have output control signals (of relay type) for power failure and common system failure, in addition to a common alarm control signal (relay type as well) for gas detection, as standard features; therefore, they can be easily incorporated to the LNG fuel supply unit.

2.4 Evacuation analysis of the ship

This section analyses the evacuation from the existing passenger ship according to present maritime safety regulations. Evacuations analysis is based on a set of five evacuation scenarios and can be related to actual accident scenarios, covering major hazards as gas leakage and fire.
At first the evacuation plan of the existing ship is assessed to determine any potential modifications to be carried out in order the vessel to comply with the imposed rules when LNG is employed as fuel. Although there are no additional requirements concerning the number of lifesaving appliances (i.e. number of life jackets, number of life rafts etc) for the particular case-study, as reported by Mizithras P et al. (2015), a brief analysis of the already existing and fulfilled regulations concerning Life Saving Appliances (Chapter III of the Annex to the 1974 Solas Convention, as amended, adopted by Council Directive 98/18/EC (1998)) will follow in the next section; taking into consideration specific provisions when LNG fuel is employed [Mizithras P et al. (2015)], possible modifications/alterations will be pointed out.

The vessel is classed as class ‘C’ ship in compliance with the Council Directive 98/18/EC (1998). According to the approved Passenger Ship Safety Certificate, she can carry onboard up to:

i) 604 persons in summer (592 passengers + 12 crew) and

ii) 548 persons in winter (536 passengers + 12 crew)

The number of crew onboard is considered equal to twelve according to the existing ship safety plan. Table 11 summarizes the mandatory rescue equipment for the particular ship’s category and number of passengers (i.e. “C” class with more than 250 passengers) -note that N stands for total number of people onboard and is considered equal to 604 which is the maximum number of persons onboard during summer operation.

According to Table 11, the number of survival crafts onboard should be equal to 755 (a safety margin of 25% is taken into account). Thirty one inflatable life rafts, each with a capacity of twenty five persons are required (755/25 = *31 inflatable life rafts).*

At this point, it should be noted that although there are no additional requirements concerning the number of lifesaving appliances (i.e. number of life jackets, number of life rafts etc) with respect to the already existing and fulfilled regulations [Mizithras P et al (2015)], for the case of survival crafts and rescue boats, attention should be paid to their specific location. For this reason, in the following two sections, the main and already fulfilled requirements -concerning the survival crafts of the vessel are presented, whilst the necessary provisions about the location of crafts/rescue boats on a gas fuel ship are included.

Rescue Equipment	
Rescue boats	1
Survival crafts	1.25 N
Lifebuoys	8
Life jackets	1.05 N
Child lifejackets	0.1 N
Distress flares	12
Radar transponders	1
Line-throwing appliances	1
Two-way VHF radiotelephone apparatus	3

Table 11 Necessary rescue equipment according to Council Directive 98/18/EC (1998) for the particular ship category and number of passengers N (‘C’ class with more than 250 passengers)

With respect to the arrangement and stowage of the crafts onboard the ship complies with the requirements for ro-ro passenger ships according to Chapter III of the Annex to the 1974 Solas Convention, as amended, adopted by Council Directive 98/18/EC (1998).

In accordance to requirements for evacuation in Mizithras P et al. (2015) each survival craft or rescue boat has to be located as follows:

- *As far as* practicable forward of the *propeller* of the ship.
- *Away from any tank* containing explosive or hazardous cargoes.
- *Equally distributed on each side* of the ship.
- Taking into account the liquefied natural gas *storage tanks arrangement.*

Furthermore, all the arrangements for installing the required natural gas storage and supply systems shall not reduce the amount or limit the use of life-rafts and of fast rescue boats which are required for the evacuation of the ship.

The existing ship is supplied with twenty four life rafts on wheel house and nine life rafts on the Lounge Deck level, equally distributed –as far as practicable, on both sides of the ship. Furthermore, there is no Davit-launched type life rafts -all are of throw-overboard launching type.

Note that the total number of life rafts is equal to thirty-three (according to the ship’s approved plans), which is sufficient considering the above calculated minimum required number of thirty one, to comply with the imposed rules.

According to the above requirements concerning the arrangement and stowage of the crafts onboard the ship, the survival crafts have to be located as far as practicable forward of the propeller of the ship, equally distributed on each side of the ship and away from any tank containing explosive or hazardous cargoes. Taking into account that the superstructure where the fuel tanks will be located is near the four crafts at the AFT side of the ship, the specific crafts should be reallocated accordingly. The proposed new location of these crafts is shown in Fig. 12. In more detail, three crafts should be moved to the FOR side of the ship at the same location where a single life raft is already placed; the remaining craft can be moved to the wheel house deck. In this way, there is no life craft near the fuel tanks and their distribution on both sides of the ship is practically equal. Note that the above proposal is feasible since the crafts are not of Davit-launched type.

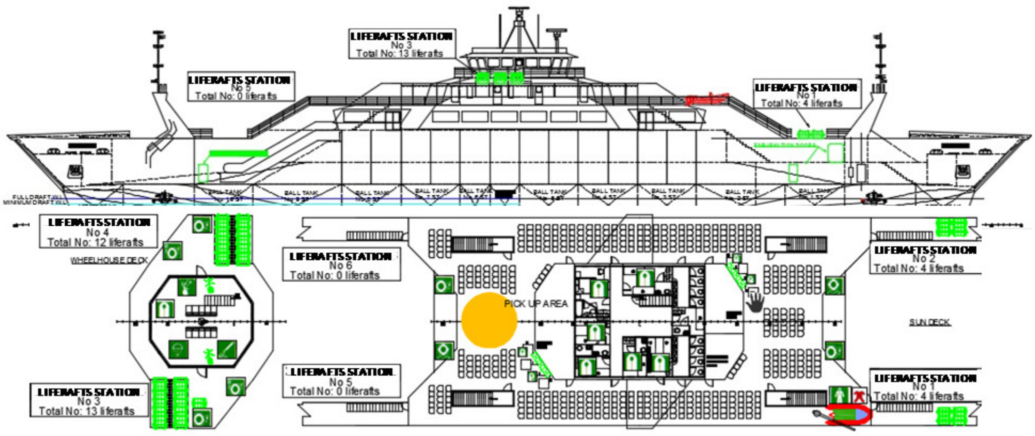

Fig. 12 Necessary reallocation of life rafts. Four crafts are reallocated from the AFT side (Lounge Deck level) to the FOR side of the ship and to the Wheel house deck in order not to be close to the LNG tanks

2.4.1 Modification to the Evacuation Plan

With respect to the survival crafts, muster stations, embarkation stations and launching arrangements the ship complies with the requirements for Life Saving Appliances in Chapter III of the Annex to the 1974 Solas Convention, as amended, adopted by Council Directive 98/18/EC (1998). According to the additional provisions about gas fuelled ship evacuation plan in Mizithras P et al. (2015) additional requirements (see A5 in Appendix) should be taken into consideration.

With respect to the additional requirements when LNG is used as fuel, a necessary alteration on the ship evacuation plan arises concerning the helicopter pick up area (as shown at Fig. 13). In more detail, although the specific area is not adjacent the LNG fuel tanks, it is proposed to be reallocated from the AFT side of the ship at the Sun deck to the FOR side of the ship at the same deck (as shown at Fig. 13). In this way, at the event of an emergency situation (for any reason) the passengers or the crew will be waiting as far as possible, away from the location of the LNG tanks/equipment.

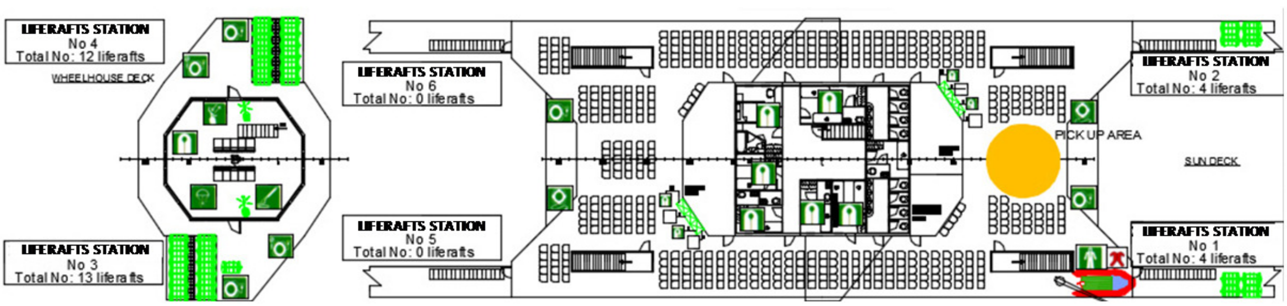

Fig. 13 Sun Deck: Reallocation of the helicopter pick up area

2.4.2 Evacuation scenarios

In this section, the evacuation analysis is investigated in order to evaluate the existing evacuation plan and identify possible alterations that should be performed when LNG is employed as fuel; such alterations could be the maximum number of passengers onboard during night operation, evacuation paths, etc. The analysis is based on the appropriate Guidelines for evacuation for new and existing passenger ships that apply for the particular vessel type adopted by the MSC.1/Circ.1238 of International Maritime Organization (2007).
It should be noted that the presence of the LNG tanks is taken into consideration for the required calculations for the estimation of the total evacuation time, T_{total} in all the evacuation scenarios considered for the current study. Furthermore, the worst case of considering an additional number of passengers assembled at the Sun Deck is also evaluated. The five case scenarios considered are described as follows:

- *Scenario 1: No fire/leakage at the area of the LNG tanks - Summer day operation.*
- *Scenario 2: No fire/leakage at the area of the LNG tanks – Summer, operation at night.*
- *Scenario 3: Fire/leakage at the area of the LNG tanks – Summer day operation.*
- *Scenario 4: Fire/leakage at the area of the LNG tanks – Summer, operation at night.*
- *Scenario 5: Fire/leakage at the area of the LNG tanks – Summer, operation at night assuming additional number of passengers located at the Sun Deck.*

Note that summer operation is assumed in all the scenarios since it involves the maximum number of passengers accommodated on board, according to the vessel approved safety certificate (Open type Ferry).
The parameters and the methodology involved in the analysis of each case scenario are based on the Guidelines for evacuation for new and existing passenger ships of MSC.1/Circ.1238//30 of IMO (2007) which can be summarized as follows:

- *Clear width (Wc)* - Clear width is measured off the handrail (m) for corridors and stairways and the actual passage width of a door in its fully open position.
- *Initial density of persons (d)* - The initial density of persons in an escape route is the number of persons (*p*) divided by the available escape route area pertinent to the space where the persons are originally located and expressed in (p/m^2).
- *Specific flow of persons* (F_s) - Specific flow (p/(m s)) is the number of escaping persons past a point in the escape route per unit time per unit of clear width *W*c of the route involved. Values of F_S are given in Table 11 as a function of initial density.
- *Speed of persons (S)* - The speed (m/s) of persons along the escape route depends on the specific flow of persons and on the type of escape facility. People speed values are given in Table 12.
- *Calculated flow of persons* (F_c) - The calculated flow of persons (p/s) is the predicted number of persons passing a particular point in an escape route per unit time. It is obtained from the equation:

$$\boldsymbol{F_c = F_s \cdot W_c} \qquad (2)$$

Furthermore:

- *Flow time* (t_F) - Flow time (s) is the total time needed for N persons to move past a point in the evacuation path, calculated as:

$$\boldsymbol{t_F = N / F_c} \qquad (3)$$

  where *N* is the number of persons
- *Stairway travel time* (t_{stair}) – Travel time (s) to traverse a stairway in order to reach the assembly station.
- *Deck travel time* (t_{deck}) - Travel time (s) to move from the farthest point of the escape route of a deck to the corresponding stairway.
- *Assembly travel time* ($t_{assembly}$) – Travel time (s) to move from the end of the stairway to the entrance of the assigned assembly station.
- *Travel time (T)* - Travel time expressed in seconds, calculated as:

$$\boldsymbol{T = (\gamma+\delta)\, t_I} \qquad (4)$$

where: γ is a correction factor to be taken equal to 2 for day operating scenarios and 1.3 for night operating scenarios
δ is the counter flow correction factor to be taken equal to 0.3,
t_I is the sum of travel times (t_{stair}, t_{deck} & $t_{assembly}$) expressed in seconds in ideal conditions

The calculation of *total time* required for evacuation, T_{total} defined in Guidelines for evacuation analysis for new and existing passenger ships in MSC.1/Circ.1238//30 of International Maritime Organization (2007) is expressed as follows:

$$T_{total} = 1.25\ (A + T) + 2/3\ (E + L) \leq n \qquad (5)$$

where: n = 60 for ro-ro passenger ships,
A is the awareness time and should be 5 min for the day time scenarios,
E and L are the embarkation and launching time respectively,

The embarkation and launching time should be calculated separately based upon results of full scale trials on similar ships and evacuation systems or data provided by the manufacturers. For cases where neither of the two above methods apply though, it should be assumed equal to 30 min.

Scenario 1: No fire/leakage at the area of the LNG tanks – Summer, day operation

According to class approved ship evacuation plan, during summer operation, the following distribution of people is considered on board: 284 people located at the Sun Deck plus 536 people at the saloons.

To evacuate the ship, there are four available evacuation paths (at areas A, B, C and D respectively, as shown in Fig. 14) in order to reach the Assembly Stations at the Lounge Deck. Thus, 71 people are assumed to be directed to each evacuation path.

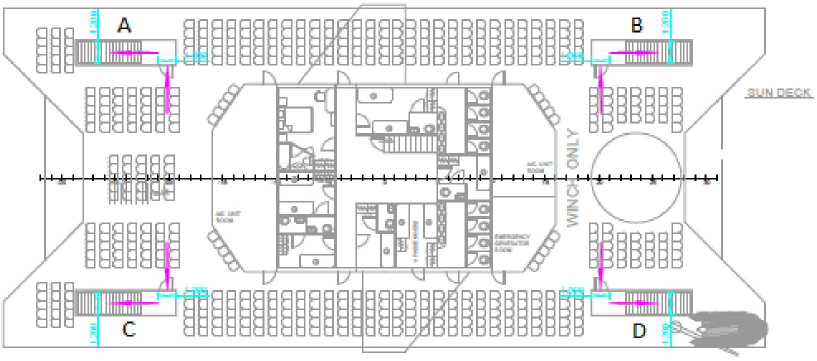

Fig. 14 Sun Deck: Four evacuation paths towards the stairways A, B, C, D are available

Type of facility	Initial density d (p/m²)	Specific flow Fs (p/(m s))	Initial speed of persons S (m/s)
Corridors	0	0	1.2
	0.5	0.65	1.2
	1.9	1.30	0.67
	3.2	0.65	0.20
	≥ 3.5	0.32	0.10

Table 11 Specific flow of persons, F_s and initial speed, S depending on the initial density, d

As a first the deck travel time t_{deck} is calculated assuming a minimum speed of persons S equal to 0.67 m/s according to Table 12 (Corridor type of facility) for all four escape routes on the Sun Deck. We consider the remotest point of the deck towards the nearest stairway. Table 13 summarizes the results; note that the distance from the farthest point of the escape route of the deck to the corresponding stairway has been extracted from the approved plans of the vessel. The value considered is the maximum one (areas A & C).

Type of facility	Specific flow Fs (p/(m s))	Speed of persons S (m/s)
Stairs (down)	0	1.0
	0.54	1.0
	1.1	0.55
Stairs (up)	0	0.8
	0.43	0.8
	0.88	0.44
Corridors	0	1.2
	0.65	1.2

	1.3	0.67

Table 12 Speed of persons, S depending on the specific flow, F_s and the type of facility to escape

Sun Deck area	Length (m)	Speed(m/s)	t_{deck} (s)	Comments
A	14.59	0.67	***21.78***	Value considered
B	12.19	0.67	18.19	
C	14.59	0.67	***21.78***	
D	12.19	0.67	18.19	

Table 13 Deck travel time, t_{deck} for the A,B, C, D areas on the Sun Deck

The calculation of the stairway travel time, t_{stairs}, (time needed to descent down the stairs to the lower deck) follows. A minimum speed of persons S equal to 0.55 m/s is assumed according to Table 12 (Stairs –type of facility) for all four escape routes; the corresponding results are summarized in Table 14.

Stairways	Length (m)	Speed (m/s)	t_{stairs} (s)	Comments
A	3.8	0.55	6.91	Same travel time applies for all cases
B	3.8	0.55	6.91	
C	3.8	0.55	6.91	
D	3.8	0.55	6.91	

Table 14 Stairway travel time t_{stairs} for the four stairways

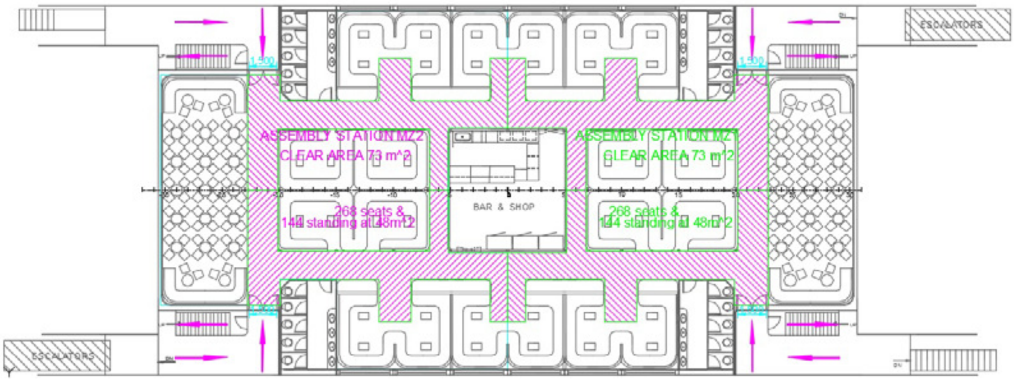

Fig. 15 Lounge Deck: Assembly travel paths: Four paths are present from the end of each stairway to the entrance of the assigned Assembly station

To estimate the assembly travel time time $t_{assembly}$ we should calculate the travel time to move from the end of each stairway at the Lounge Deck to the entrance of the assigned Assembly station at the same deck (as shown at Fig. 15). A minimum speed of persons S equal to 0.67 m/s is assumed according to Table 12 (Corridor type of facility) for all four routes on Lounge Deck; the corresponding results are summarized in Table 15.

Assembly Path	Length (m)	Speed (m/s)	$t_{assembly}$ (s)	Comments
A	8.92	0.67	13.31	Same travel time applies for all cases
B	8.92	0.67	13.31	

C	8.92	0.67	13.31
D	8.92	0.67	13.31

Table 15 Lounge Deck: Assembly travel time $t_{assembly}$ for A, B, C, D paths

In this evacuation scenario the following calculations of flow time are considered: a) using the stairways (from the Sun Deck to the Lounge Deck) and b) using the corridors (entering the Assembly stations at the Lounge Deck). It should be noted that the value for clear width (W_c) is extracted from the approved ship plans whilst the value for the specific flow, F_s depends on the assumed initial density of people which is considered maximum (worst case). Thus, for a density of 3.5 P/m^2 -both for the stairs and the corridors, the corresponding value for the specific flow, F_s is equal to 0.32 P/(m s) -see Table 11. Furthermore, 71 persons (N) are considered to be directed to each evacuation path (i.e. to pass through each staircase and corridor) as mentioned previously. The obtained results are summarized in Table 16.

Type of facility	F_S (P/(m s))	W_C (m)	$F_C = F_S \cdot W_C$ (P/s)	$t_F = N/F_C$ (s)	Comments
Stairways	0.32	1.2	0.384	**184.90**	Value considered
Corridors	0.32	1.3	0.416	170.67	

Table 16 Scenario 1: Calculation of Flow time, F_c for the stairways and the corridors for each of the four evacuation paths available

As we can see from Table 16, the larger flow time t_f is equal to 184.90 s and this is the value considered for the calculation of the sum of travel times (t_{stair}, t_{deck} & $t_{assembly}$) that is equal to 226.89 s.
We can now calculate the travel time T from equation (4), which is equal to 8.70 min. From equation (5) the total evacuation time, T_{total} for the first case scenario is calculated equal to ***37.13 min.*** We can safely conclude that the result is acceptable (≤ 60 min).

Scenario 2: No fire/leakage at the area of the LNG tanks – Summer, operation at night
With this case scenario, we consider different values for the correction factor (γ) and the awareness time (A). Apart from the appropriate change in these parameters, the analysis is exactly the same as the previous one. Therefore, following the same procedure and assumptions as in the first case scenario we obtained the time to travel and flow time for Scenario 2, as shown in Table 17.

Travel time	(s)
Deck travel time (t_{deck})	21.78
Stairway travel time (t_{stairs})	6.91
Assembly travel time ($t_{assembly}$)	13.31
Flow time (t_F)	184.90
Sum of travel times (t_i)	226.89

Table 17 Scenario 2: Values of Deck/Stair/Assembly travel time and flow time

Consequently for the specific scenario we can use equation (4) and (5) to calculate the travel time T= 8.7 min and the total evacuation time, T_{total}=***43.38 min,*** respectively**.** We can safely conclude that the result is acceptable (≤ 60 min) in the Scenario 2 as well.

Scenario 3: Fire/Leakage at the area of the LNG tanks – Summer, day operation
To define the third evacuation scenario, a fire/leakage at the LNG fuel tanks is assumed causing possible obstructions or unavailability of some evacuation paths. In particular 284 passengers located at the Sun Deck *should only be directed to areas B and D* at the FORE side of the vessel (as shown at Fig. 11) since areas A and C at the AFT side of the ship are obstructed due to the fire/leakage at fuel tanks.
Apart from the restriction of the evacuation paths, we should also take into account the increased distance from the farthest point of the escape route of the Sun Deck to the corresponding stairway for the calculation of the deck travel time t_{deck}. A minimum speed for the passengers, S equal to 0.67 m/s is considered

(according to Table 12) as in the previous scenarios for both escape routes; the travel time results of third scenario are summarized in Table 18.

Sun Deck area	Length (m)	Speed(m/s)	t_{deck} (s)	Comments
B	36.52	0.67	***54.51***	Same travel time applies for all cases
D	36.52	0.67	54.51	

Table 18 Scenario 3: Deck travel time t_{deck} - only B and D areas are considered

It should be noted that the Stairway travel time, (t_{deck}) and the Assembly travel time, ($t_{assembly}$) are not affected due to the restriction on the evacuation paths and have the same values as in the previous scenarios; therefore their values are equal to 6.91 s and 13.31 s respectively.

As mentioned above, we use equations (2) and (3) to calculate the flow of persons F_c and flow time t_F respectively. In the specific scenario, 142 persons (2x71) should be considered to be directed to each evacuation path (i.e. to pass through each staircase and corridor) since only two paths are available. Note that the values for clear width, Wc and specific flow, F_s are not affected and are the same as in the previous scenarios. The obtained results for Flow time calculations are summarized in Table 19.

Type of facility	F_S (P/(m s))	W_C (m)	$F_C = F_S \cdot W_C$ (P/s)	$t_F = N/F_C$ (s)	Comments
Stairways	0.32	1.2	0.384	**369.80**	Value considered
Corridors	0.32	1.3	0.416	341.35	

Table 19 Scenario 3: Calculation of Flow time, F_c for the stairways and the corridors – only two evacuation paths are available

As we can see from Table 19, the higher flow time t_f is equal to 369.80 sec and this is the value considered for the calculation of the sum of travel times $t_{stairs} + t_{deck} + t_{assembly} + t_F = 444.53$ s. We calculate the travel time T from equation (4) equal to 17.04 min. From equation (5) the total evacuation time, T_{total} for the Scenario 3 is calculated equal to ***47.55 min.*** We can safely conclude that the result is also acceptable (≤ 60 min).

<u>Scenario 4: Fire/Leakage at the area of the LNG tanks – Summer, operation at night</u>

For the fourth scenario a Fire or Leakage at the area of the LNG tanks is considered for the night case. The day and night case differ in the awareness time (A) parameter; for the night case, the analysis is exactly the same as the one previously presented (Scenario 3).Thus, following the same procedure and assumptions as in the third scenario we obtained the travel times and flow time in Table 20.

Travel time	(s)
Deck travel time (t_{deck})	54.51
Stairway travel time (t_{stairs})	6.91
Assembly travel time ($t_{assembly}$)	13.31
Flow time (t_F)	369.80
Sum of travel times (t_i)	444.53

Table 20 Scenario 4: Values of Deck/Stair/Assembly travel time and flow time

As in the above scenarios, we calculate the travel time T from equation (4) equal to 17.04 min. The total evacuation time, T_{total} for Scenario 4 is calculated from equation (5) equal to ***53.80 min.*** We can safely conclude that the result is acceptable (≤ 60 min) in this case also.

Scenario 5: Fire/Leakage at the area of the LNG tanks – Summer, operation at night assuming additional number of passengers located at the Sun Deck

To further evaluate the safety of the vessel evacuation in case of an emergency, a "worst case" scenario is analysed; a fire/leakage at the fuel tanks area during night operation at summer is considered whilst an additional number of passengers is located at the Sun Deck.

In more detail, it is considered that the passengers assumed at the previous scenario (i.e. 284 in total) are sitting on the available seats while additional passengers are present as well, occupying the available free space on the specific deck.

The free space on the deck - estimated from the available plan, is equal to approximately 28 m^2; thus, taking into consideration a maximum density of people of 3.2 p/m^2, we can calculate the number of additional passengers as $28\ m^2 \cdot 3.5\ p/m^2 = 98$ persons. Thus, a total number of ***382 persons*** is assumed to be located at the sun Deck.

In order to calculate the Deck, Stairway and Assembly travel time the analysis is exactly the same as the one previously presented assuming a leakage or a fire at the fuel tanks at night (see Scenario 4). Thus, the results for the travel times are presented in Table 21.

Travel time	(s)
Deck travel time (t_{deck})	54.51
Stairway travel time (t_{stairs})	6.91
Assembly travel time ($t_{assembly}$)	13.31

Table 21 Scenario 5: Values for Deck/Stair and Assembly travel time

In order to estimate the flow time though, we consider a total of 382 persons located at Sun Deck; the corresponding calculations are presented in Table 22.

Type of facility	F_S (P/(m s))	W_C (m)	$F_C = F_S \cdot W_C$ (P/s)	$t_F = N/F_C$ (s)	Comments
Stairways	0.32	1.2	0.384	**497.40**	Value considered
Corridors	0.32	1.3	0.416	459.13	

Table 22 Scenario 5: Calculation of Flow time, F_c for the stairways and the corridors – only two evacuation paths are available

Similarly to the previous cases, the sum of travel times is equal to 572.13 s. From equation (4) we can calculate the total travel time equal to 21.93 min. The total evacuation time, for the specific scenario is calculated from equation (5) equal to ***59.91 min.***

The total calculated evacuation time for the five different case scenarios analysed in our study is presented in Table 23. As it is easily observed the necessary time for evacuation increases when a fire or a leakage at the LNG fuel tanks is considered since there is a restriction on the available evacuation paths –i.e. the two paths located at the AFT side of the ship are not employed. Nevertheless, no significant alteration at the evacuation plan (apart from the reallocation of the helicopter pick-up area) is necessary since in all cases considered (even in the worst case –Scenario 5) the total time for evacuation is still acceptable (i.e. ≤ 60 min).

Evacuation Scenarios analysed	**Total evacuation time (min)**	
	Day	***Night***
No fire/leakage at the area of the LNG tanks	37.13	43.38
Fire/Leakage at the area of the LNG tanks	47.55	53.80
Fire/Leakage at the area of the LNG tanks – Additional number of passengers present at Sun Deck	-	59.91

Table 23 Total evacuation time calculated for all the evacuation scenarios analysed

2.5 HAZID Analysis for LNG fuelled ship operation

To identify hazards related to LNG-fuelled open type ferry operation and evaluate the severity and the probability of each hazard, a Hazard Identification Study (HAZID) was carried out with the participation of a panel of local experts. The synthesis of the participants of the panel is covering a large range of the related stakeholders; universities, a class society, a research center, a transmission system operator and a port authority; in total 14 participants were involved. The particular study covered all aspects of the proper transfer and maintenance of natural gas aboard, as well as the ones related to ship's normal operation during navigation or in port operation.

In general, a HAZID study is a method of risk assessment and in fact, it is the first step of the Formal Safety Assessment (FSA) procedure according to IMO's MSC./Circ. 1023 (IMO 2002). It uses a systematic process to identify hazards in order to plan, prepare, avoid or even reduce their impact. In order to perform the specific analysis there are several steps that must be completed. At first, each hazard or threat must be identified, followed by the clarification of the relevant cause. Once this has been achieved, the consequences of the related accident are determined and the existing safeguards and barriers are evaluated regarding their efficiency. As a final step, proper measures referred to as Risk Control Options that will further reduce the risk generated by the potential circumstances, are applied.

The framework applied for the specific HAZID study is summarized as follows:

1. Identification of hazards related with the operational aspects of a diesel-LNG fueled open type ferry.
2. Identification of the relevant causes, the consequences and proposal of appropriate risk control options (RCO) for each hazard identified previously.
3. Evaluation of the severity and the probability of each hazard.
4. Ranking of the hazards in terms of risk.

Consequently, as a first step of the study the basic risk categories associated with each of the hazards were defined by the members of the team; the following risk categories were considered:

1. Bunkering (61 hazards)
2. Evacuation (7 hazards)
3. Power Supply Systems (4 hazards)
4. Ferry Loading/Unloading (4 hazards)
5. Sailing/In port Operations (15 hazards)
6. LNG Storage System (11 hazards)
7. LNG Distribution System (13 hazards)

It should be mentioned that hazards covering various types of bunkering -such as truck-to-ship, ship-to-ship, portable tanks etc, were taken into consideration; in total 115 hazards were identified.

According to IMO (2002), the risk of each hazard can be defined by multiplying its probability to occur with the resulting consequences due to its occurrence:

$$\text{Risk} = \text{Probability} \times \text{Consequence} \tag{6}$$

Note that as it is proposed by IMO (2002), the risk can be measured effectively in a logarithmic scale, so equation (6) can be reformed to equations (7) and (8) respectively:

$$\log(\text{Risk}) = \log(\text{Probability}) + \log(\text{Consequence}) \tag{7}$$

$$\text{RI} = \text{FI} + \text{SI} \tag{8}$$

where FI and SI correspond to the frequency and severity index respectively. The corresponding values of FI and SI can be obtained from Table 24, which cover a typical range of frequencies (from very remote to very frequent events) and severity of consequences (from negligible to catastrophic ones). These values are provided by IMO (2002).

Each participant of the panel of experts assigned an index for frequency and for severity to each identified hazard. Taking into consideration all the possible combinations, a typical risk matrix was obtained in which the risk value ranges from 2 to 13.

According to IMO (2002) the objectivity of the specific procedure is quantified and evaluated by calculating the concordance coefficient which is deduced as follows:

$$W = \frac{12\sum_{i=1}^{i=I}\left[\sum_{j=1}^{j=J} xi_j - 0.5J\left(I+1\right)\right]^2}{J^2(I^3 - I)} \tag{9}$$

where:

J : Total number of experts participating in the hazards ranking

I : Total number of accident scenarios which were evaluated

$x_{i,j}$: Rank of each scenario 'i' by expert 'j'.

FI	Frequency	Definition	F (per ship year)
1	Extremely Remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships	10^{-5}
2	Very Remote	Likely to occur once per year in a fleet of 10000 ships	10^{-4}
3	Remote	Likely to occur once per year in a fleet of 1000 ships	10^{-3}
4	Little Probable	Likely to occur once per year in a fleet of 100 ships, i.e. likely to occur in the total life of a ship's life	10^{-2}
5	Reasonably Probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during a ship's life	10^{-1}
6	Probable	Likely to occur once per year on one ship	1
7	Frequent	Likely to occur once per month on one ship	10
8	Very Frequent	Likely to happen once or twice a week	100

SI	Severity	Effects on Human Safety	Effects on Ship Safety	Equivalent fatalities
1	Negligible	Single or minor injuries	Equipment failure	10^{-3}
2	Minor	Single or major injuries	Local equipment damage	10^{-2}
3	Significant	Multiple or severe injuries	Non-severe ship damage (e.g. Port stay required)	10^{-1}
4	Critical	Single fatality or multiple severe injuries	Severe damage (e.g. Yard repair)	1
5	Catastrophic	Multiple fatalities	Total loss	10

Table 24 Frequency, Severity Index and criteria

Depending on the calculated value of the concordance coefficient, the agreement on the ranking of hazards can be characterized as "poor" ($0<W<0.5$), "medium" ($0.5<W<0.7$) and "good" ($0.7<W<1$). For the specific study, the obtained value (W) was equal to 0.86; therefore the ranking of hazards is considered to be solid. Table 25 presents the top 5 ranked hazards; the information presented in each line of this table, corresponds to a particular hazard (same procedure was followed for all identified 115 hazards). The overall results for each one of the 115 hazards identified during the workshop could be found in Pirounakis et al (2015). As mentioned previously, each hazard is assigned to a basic risk category while the possible causes and consequences as well as possible risk control options (RCO) are considered. Each RCO refers to Human Safety (S), Environmental (E), Costs and Finance (C), Ship Safety and Technology (T). Additionally, the mean values of FI and SI were calculated by the assigned values of the participants.

The main hazards considered by the panel of experts are the following:

- Asphyxiation which may be caused in case of released natural gas in confined space or presence of natural gas in a space with lack of breathing apparatus.

- Falling objects due to rough weather conditions in case that objects are not properly tightened on board.
- Lack of sufficient coordination and control during evacuation or, in case of existing ship's retrofitting, not sufficient updating of the existing evacuation arrangements on board. Main severe consequence of this hazard is the entrapment of a crew member of passenger on the vessel.
- Fire or explosion in any part of the ship and in particular in accommodation spaces and garage.
- Long term lay-up of the ship on the shore which may cause a pressure build up in the tank if the tank still contains natural gas in liquefied form.
- Maintenance errors or manufacturing defects of the installed equipment (e.g. piping, hose connection, insulation, instrumentation).
- Errors during control or operation of the gas equipment or during bunkering operation.
- Collision or grounding of the ship or even heavy ship movements due to weather may have impact to the gas equipment.
- Human error during car loading/uploading operation.

The obtained risk matrix grouped by the basic risk categories are presented in Fig.16. As we can observe, all hazards were characterized as below probable in terms of their frequency occurrence, whereas their severity ranges from minor to catastrophic effect. In Fig. 17 the risk ranking of hazards is presented by attributing a risk characterization to the risk index (from low to extreme risk). The majority of hazards lie in the medium risk level; for those that are characterized as "high risk", the respective RCO should be applied in order to fall into the medium risk level at least. Finally, we carried out a statistical analysis based on the risk values of each hazard (115 in total) by considering the basic risk category each hazard belongs. Therefore each category could obtain a mean value (obtained from the risk index value of each hazard) and the respective standard deviation. Table 26 presents the results per category in terms of the ranking of their mean values. The corresponding standard deviation for each category is also presented. Hazards during evacuation appear to be the most critical ones, followed by sailing and in port operations.

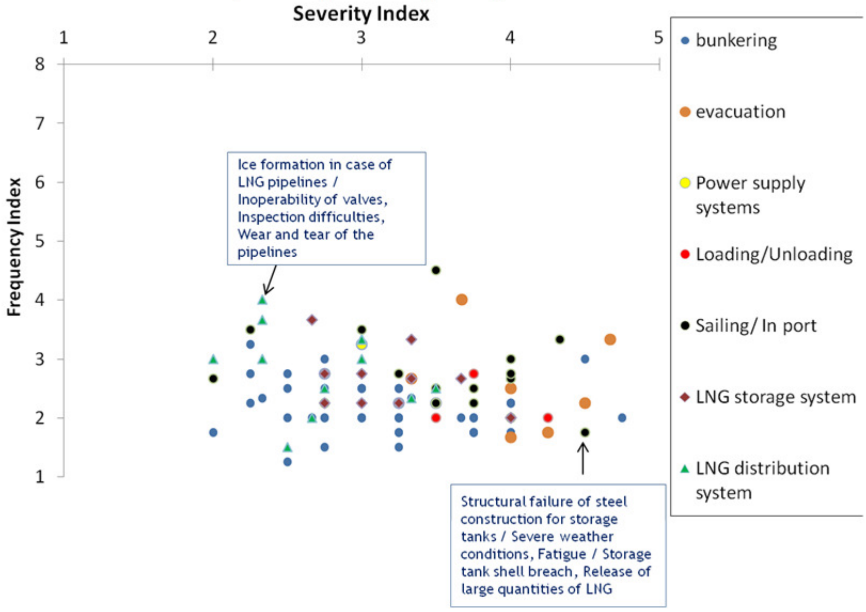

Fig. 16 Obtained values in risk matrix

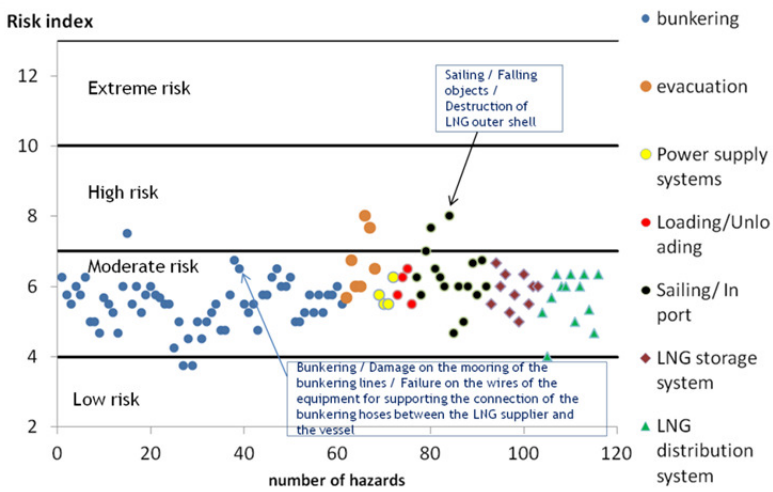

Fig. 17 Ranking of hazards based on their Risk Index

Rank position	Hazard index	Hazards List	Cause	Consequence	RCO	Category	Analysis FI	Analysis SI	Analysis SUM
1	2.5	Asphyxiation	-Released natural gas in confined space - Lack of breathing apparatus	- Loss of consciousness - Death	-Installation of gas detectors - Provision of breathing apparatus	S, C,T	3.33	4.67	8.00
2	6.10	Falling objects	Rough weather conditions	Destruction of LNG tank outer shell	Lashing of objects	S,T	4.50	3.50	8.00
3	2.6	Lack of sufficient coordination and control during evacuation	Human incompetence	- Extended evacuation time - More injuries - More fatalities	- ISM - Fire control plan -Emergency preparedness, - SOLAS	S,T	4.00	3.67	7.67
4	5.12	Fire / Explosion in machinery spaces	Fuel and oil leakages in the machinery room due to technical failure	- Damage of LNG system - Release of LNG - Loss of maneuverability - Loss of power - Injury of crew members	- Installation of detectors - Fire mitigation systems - Structural fire integrity - Shielding of pipes and LNG pipes - Testing and maintenance of ESD system or correct application of the inherently gas safe system	S, T, E	3.33	4.33	7.67
5	1.22	Gas dispersion cloud	Large release of LNG during bunkering	Possible fire, asphyxiation.	Hazardous zones establishment.	S, E	3.00	4.50	7.50

Table 25 Top 5 ranked hazards

rank	Risk category	Mean RI	st. dev RI
1	Evacuation	6.67	0.89
2	Sailing/In port Operations	6.27	0.85
3	Ferry Loading/Unloading	6.00	0.46
4	LNG Storage system	5.85	0.50
5	Power Supply Systems	5.75	0.35
6	LNG Distribution System	5.63	0.74
7	Bunkering	5.48	0.67

Table 26 Ranking of basic risk categories based on mean attained Risk Index.

3. Results

Fire safety systems

Most of the existing ship fire insulation is of Class A-60 standard, although in certain areas of the ship it is not required by the corresponding class regulations. To comply with the class requirements when LNG fuel is employed modifications to fire insulation of the vessel involve: the insulation of the docking station and the superstructure where the LNG tanks are located with Class A-60 standard, the replacement of the windows of the accommodation space facing the LNG tanks with Class A-60 type insulation sheet, replacement of bridge windows facing the LNG tanks by windows of Class A-0 standard, Class A-60 type insulation for the side of the stairways facing tanks.

The vessel is already equipped with appropriate fixed fire extinguishing systems, i.e. Sprinkler / Drencher systems and CO_2 system; no alteration is necessary for the specific systems since both engine rooms are considered of Inherently Safe type and no bunkering station is installed aboard ship. Furthermore, the fixed fire extinguishing system should be equipped with an appropriate water spraying system for cooling and fire prevention of the exposed parts of the LNG storage tanks which are located above deck. The additional water supply (with respect to the already installed ship's fire pumps) along with all the necessary modifications at the ship existing fire line have been investigated. As the ship is already equipped with an additional fire pump with respect to the minimum required for its class it is proposed to dedicate one pump to the LNG water spray system.

Fire detection system

The necessary modifications are focused on the topology of the existing fire system, the usage of heat detectors instead of smoke detectors and the installation of gas detectors at certain areas of the ship. Furthermore, an initial compatibility investigation of the existing fire detection system and its automation interface with regard to the LNG fuel supply interface was carried out by assuming that a typical commercial solution for a cassette type tank is to be installed on board for LNG storage; the existing fire detection unit on board provides sufficient control signals-relay outputs for fire detection while the potentially installed fire detectors inside the LNGPac™ system can be connected to an appropriate fire zone of the existing system.

The installation of an appropriate gas detection system has been proposed including details of commercially available system as the system's type, the employed sensor's topology and the appropriate interface to the LNG fuel supply automation system.

Ventilation system

The analysis mainly involved the investigation of the system's current topology and the calculation of the necessary additional capacity of air supply into the machinery spaces, taking into account the type of the machinery room, the minimum required air changes inside the dual pipe LNG fuel lines and the necessary additional equipment; the existing ventilating system of the engine rooms is sufficient. Additionally, a separate ventilation system should be installed on board dedicated for the ventilation of the double wall fuel line, i.e. two ventilation fans of the same rated power are proposed to be installed on top of the superstructure of the LNG storage tanks.

Evacuation analysis

Five different evacuation scenarios involving ship summer operation-during day and night, have been analysed and presented in order to point out possible alterations to the evacuation plan of the ship. It is found that the necessary evacuation time increases when fire/leakage at the LNG fuel tanks is considered due to restriction on the available evacuation paths during night operation as expected. There is no need for significant alteration at ship's evacuation plan since the evacuation time is still acceptable according to the imposed rules.

HAZID Analysis

A HAZID study was carried out in order to identify the main hazards related to LNG-fuelled open type ferry operation and evaluate the severity and the probability of each hazard. The majority of hazards lie in the "medium risk level" while the identified hazards during evacuation appear to be the most critical ones, followed by sailing and in port operations related hazards.

4. Conclusions

In this paper the conversion of an open type Ro-Ro passenger ferry with regard to its safety systems for the implementation of LNG fuel has been presented. The basic requirements that the ship already complies with are reported along with the additional requirements imposed by national and international classification societies for LNG fuelled ships; all the necessary modifications that have to be considered for each safety system are investigated. Furthermore, an appropriate evacuation analysis is performed along with a HAZID study in order to identify the main operational hazards, taking into consideration the usage of LNG fuel. The main conclusions of the study for the particular type of ship can be summarized as follows:

- No major modifications of ship's initial fire and safety systems are required in order to conform to safety regulations for LNG fuel; a separate water spray line for the LNG tanks should be installed.
- The installation of an appropriate gas detection system should be performed.
- The installation of a separate ventilation system dedicated for the ventilation of the double wall fuel line should be performed.
- No significant alteration at the evacuation plan is necessary since in all the appropriate scenarios considered the total time for evacuation is still acceptable.
- The most critical hazards according to the performed safety assessment of the converted diesel-LNG dual fuel ship where related to evacuation, sailing and in port operations.

From the outcome of this investigation it can be concluded that the required modifications to the ship's safety systems in order to employ Liquefied Natural Gas (LNG) as fuel are viable. Although the type of our vessel covers a wide range of similar cases, the specific results should not be generalized for every case due to the potential differences in the initial design of each vessel.

Acknowledgements

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Appendix: Additional requirements for fire safety systems

A1. Fire insulation

The following additional requirements should be fulfilled when LNG is employed as fuel regarding ship Fire insulation:

- Tanks or tank batteries located above deck should be shielded with class A-60 insulation towards accommodation, service spaces, cargo spaces and machinery spaces, including also auxiliary apparatus, machines, cables and the superstructure needed (in this case the docking station) according to GL Guidelines for the use of Gas as Fuel for ships, Fire Safety 3.2, Germanischer Lloyd (2010).

- Any boundary of accommodation spaces till the height of the bridge windows and any boundary of the machinery and cargo spaces that is facing gas fuel tanks on the open deck, shall require A-60 fire integrity too according to HRS rules concerning Preventive measures, Fire protection divisions by Mizithras P. et al. (2015).
- Bridge windows shall be designed according to Class A-0, capable to withstand if the fire loads coming from the outer side of the space according to HRS rules concerning preventive measures, and fire protection divisions [Mizithras P et al. (2015)].

A2. Fixed fire extinguishing systems

The following additional requirements should be fulfilled though when LNG is employed as fuel regarding the provision of a fixed water spray system at the location of the tanks [HRS rules concerning Safety means for LNG powered ships, Preventive measures, Fire extinction by Mizithras P et al. (2015), GL Guidelines for the Use of Gas as Fuel for Ships, Fire Safety 3.3.2.2 by Germanischer Lloyd (2010)]:

- A water spraying system should be fitted for cooling and fire prevention of the exposed parts of gas storage tanks located above deck. The system should be designed to cover all areas as specified above with an application rate of *10 Lt/min/m^2* for horizontal projected surfaces and *4 l/min/m^2* for vertical surfaces. The capacity of the water spray pump should be sufficient to deliver the required amount of water to the hydraulically most demanding area.
- A connection to the ship's fire main through a screw-down non-return valve should be provided. For the purpose of isolating damaged sections, stop valves should be fitted at least every 40 m or the system may be divided into two or more sections with control valves located in a safe and readily accessible position not likely to be cut-off in case of fire. Remote start of pumps supplying the water spray system and remote operation of any normally closed valves to the system should be located in a readily accessible position which is not likely to be cut off in case of fire in the areas protected.

A3. Ventilation systems

According to GL Guidelines for the Use of Gas as Fuel for Ships [GL (2010)] and section 2.10 concerning ventilation system in Mizithras P et al. (2015) the main additional requirements regarding the ship ventilation system when LNG is employed as fuel are the following:

- Any ducting used for the ventilation of hazardous spaces should be *separate* from that used for the ventilation of non-hazardous spaces. The ventilation should function at all environmental conditions the ship will be operating in.
- Any loss of the required ventilating capacity should give an audible and visual *alarm* at a permanently manned location.
- The ventilation system for machinery spaces containing gas fuelled engines should be *independent* of all other ventilation systems.
- *Air inlets* for hazardous enclosed spaces should be taken from areas which, in the absence of the considered inlet, would be non-hazardous. Air inlets for non-hazardous enclosed spaces should be taken from non-hazardous areas *at least 1.5 m away* from the boundaries of any hazardous area.
- *Air outlets* from non-hazardous spaces should be located outside hazardous areas. Air outlets from hazardous enclosed spaces should be located in an open area which, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.

Furthermore, in section concerning ventilation system-double wall pipeline by Mizithras P et al. (2015) the following basic requirements should be fulfilled:

- The capacity of the ventilation for a pipe duct or piping shall be *at least 30 air changes per hour*. The capacity may be reduced below this value if a flow velocity of minimum 3 m/s is ensured. The velocity of flow shall be calculated for the duct, when fuel pipes, instrumentation lines and other components have already been installed on it.
- If the gas valve unit (GVU) room is considered part of the double duct in the engine room, the ventilation capacity of this unit will be *at least 30 air changes per hour*. For this reason, the number

and power of the ventilation fans which will be used should be such that if one fan or a group of fans with common circuit from the main switchboard are out of service, *the capacity of the remaining fans shall not be less than 100% of the total required power*.

A4. Fire and gas detecting safety measures

According to the necessary detecting measures and gas detection in technical report of Mizithras P et al. (2015) the additional requirements when LNG is used as fuel are focused on the replacement of smoke detectors by heat detectors and the installation of gas leakage detectors at specific areas of the ship. In more detail, the specific requirements can be summarized as follows:

- Smoke detectors on their own cannot be considered sufficient for rapid fire detection because of the fast gas diffusion in the spaces and the reduced smoke production when natural gas is burnt. So, heat detectors shall be included in the fire detection system design, which will detect any abnormal increase of the temperature or heat release in the atmosphere.
- The enclosed spaces containing gas piping or other gas equipment without ducting to the outer environment shall be equipped with gas detectors.
- The location of gas detectors shall consider areas where personnel may be present or where leaks and spills could occur during gas transferring procedures and storage. In addition, possible flow direction of leaking gas and elevations depending on relative density of air and any potential gas leakage shall be taken under consideration.
- Each duct around gas piping shall be equipped with gas detectors.
- The gas valve unit room is considered as a part of the double duct in the engine room, so a gas detection system shall be installed there too.
- At least one detector shall be installed in a space which accommodates passengers, at the highest part of the space or at the point where accumulation of gas is expected, for the safety of the passengers.
- Gas detectors may be installed to each ventilation inlet of accommodation and machinery spaces if equipment containing natural gas is located within 6 m from these ventilation inlets, to each ventilation inlet located in areas which surround spaces containing natural gas equipment at a distance of 1.5 m and to each ventilation outlet from enclosed hazardous spaces when the outlet of this ventilation duct is located in a gas safe area.
- An audible and visual alarm will be transmitted to the navigation bridge or/and to a continuously manned room if a fire has been detected in the tank room or in the machinery space.
- Gas detectors may be installed to each ventilation inlet of accommodation and machinery spaces if equipment containing natural gas is located within 6 m from these ventilation inlets, to each ventilation inlet located in areas which surround spaces containing natural gas equipment at a distance of 1.5 m and to each ventilation outlet from enclosed hazardous spaces when the outlet of this ventilation duct is located in a gas safe area.

A5. Provisions for the evacuation of a gas fuelled ship

According to the additional provisions about gas fuelled ship evacuation plan in Mizithras P et al. (2015) the following additional requirements should be taken into consideration for the evacuation plan of a gas fuelled ship:

- The evacuation paths and the assembly points of the ship shall not be located above or adjacent to gas storage tanks or close to any venting or ventilation outlet which may be used for the abduction of gas.
- Each escape path shall not pass close to any equipment component or piping system containing natural gas.
- Radius of evacuation and expulsion on ship shall depend on the size of the incident on ship. In case of a pipe or valve leakage, the radius will be short, removing the passenger from that part of the ship. On the other hand, if a leakage occurs at ship storage tank then the evacuation radius on the ship may be expanded to the entire ship, depending of course to the size of the tank and to the size of the crack on it.
- For any reason, at an emergency situation, the passengers or the crew shall not pass or wait near equipment containing natural gas in vapour and especially in liquefied form.

- All the arrangements that shall be done on the ship for installing the required systems for the storage and supply of natural gas shall not reduce the amount or limit the use of the life-rafts and of the fast rescue boats which are required for the evacuation of the ship.

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