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THREATS AND RISKS DURING TRANSPORTATION OF LNG ON EUROPEAN INLAND WATERWAYS

Summary. This paper describes guidelines and recommendations for emergencies and incidents on inland waterways. It also provides a review of existing knowledge of an LNG incident that occurred along the European inland waterway corridors. The article also reports on the latest progress in incident guidelines and describes the tools for port authorities to control credible scenarios produced by human or technical failures. This paper aims to analyse the risks that occur during transportation of liquefied natural gas. The possible strategies for the elimination of LNG spills and accidents are also discussed.

1. INTRODUCTION

The use of natural gas as a fuel has increased over the past few years. To move this fuel across oceans, natural gas must be converted into liquefied form. Liquefied Natural Gas (LNG) is a mixture of the several hydrocarbons with a very high proportion of methane (more than 91%). Like methane, LNG is odourless, colourless, nontoxic and noncorrosive. [1] [3] The liquefaction process is as follows: natural gas (NG) is at first extremely supercooled; thus, it is converted into a liquid. This procedure reduces its volume by more than 600 times – as shown in Fig. 2; when liquefied, natural gas (NG) that could fill a beach ball becomes LNG that can fit inside a ping-pong ball.

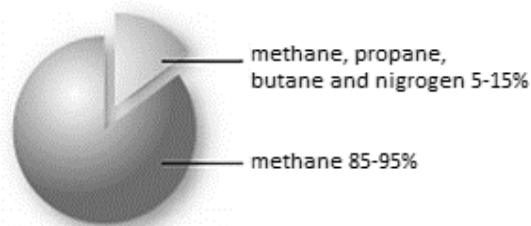


Fig. 1. LNG consists mostly of methane [1]

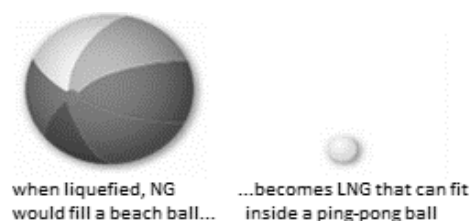


Fig. 2. Liquefaction process [1]

LNG is used for propulsion systems on LNG carriers and is also used as fuel for inland waterway ships. For maritime navigation, LNG is different from the marine diesel oil (MDO). This contrast must be well understood when LNG has to be used for vessel propulsion:

- LNG has to be stored at a very low temperature (circa -162°C) [2] [4];
- Any skin contact will cause burn injuries – LNG is a continuously boiling liquid;
- Any contact with steel will cause brittle fractures;
- During a cargo transshipment, excessive boil-off gas is generated (and must be managed);
- It is a highly flammable substance.

Despite the many dangerous properties of LNG, it is obvious that LNG is a clean fuel and its use has many advantages in minimisation of pollution on inland waterways. Table 1 shows the emissions saving with LNG propulsion systems in contrast with MDO engines.

Table 1

The difference in minimisations of air emissions between LNG and diesel fuel [5]

No.	Characteristics	MDO engine	LNG engine
1	Thermal efficiency	38%	50%
2	CO ₂ emissions	NO	25 – 30%
3	NO _x emissions	NO	85%
4	SO _x emissions	NO	100 %
5	Particle emission reduction	NO	100%

2. BUILDING AND OPERATION OF LNG CARRIERS AND LNG-FUELLED SHIPS

There are approximately 370 LNG carriers in operation, of which 60 LNG carriers are equipped as dual-fuel. The number of LNG-fuelled vessels in the global fleet is still limited. Recent data from DNV GL (Det Norske Veritas) report an operational fleet of 47 LNG-fuelled vessels, with another 85 confirmed for delivery by the end of 2022, which represents a doubling of the fleet [13, 14].

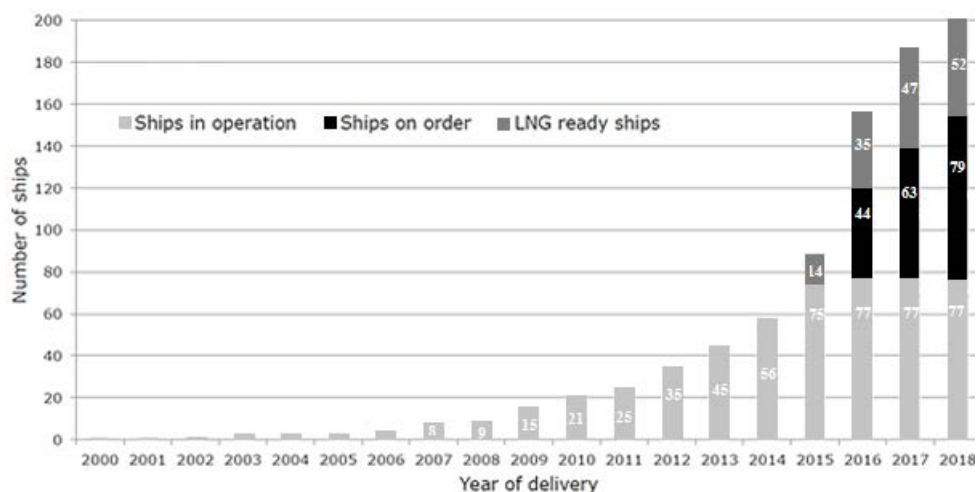


Fig. 3. LNG ship fuel projects [13]

The majority of the confirmed LNG-fueled ships worldwide operate in Norway. The European Union has established a role for LNG in its transport strategy for 2020 and is promoting the development of liquefied natural gas facilities through subsidies, what provides a financial incentive for use of such vessels.

3. LEGAL ENVIRONMENT

To date, there is no legislation for LNG-fuelled inland vessels; thus, all pilots are operating on special licenses. In 2015, LNG-fuelled vessels did not exist on the Danube river. In 2015, a pilot programme was conducted in Romania - rebuilding of inland tug to an LNG-fueled vessel.

Thus, the transportation of LNG on inland waterways (as a dangerous good) must be performed in accordance with the ADN agreement (European Agreement on the International Carriage of Dangerous Goods by Inland Waterways). According to the classification of dangerous goods defined in the ADN agreement, liquid natural gas is categorized as Class 2 – flammable gases. The ADN

agreement is obligatory for transportation of dangerous goods on every European inland waterway. ADN established an international agreement AND-R, which regulates the transportation of dangerous goods on the Rhine river and ADN-D for the Danube River.

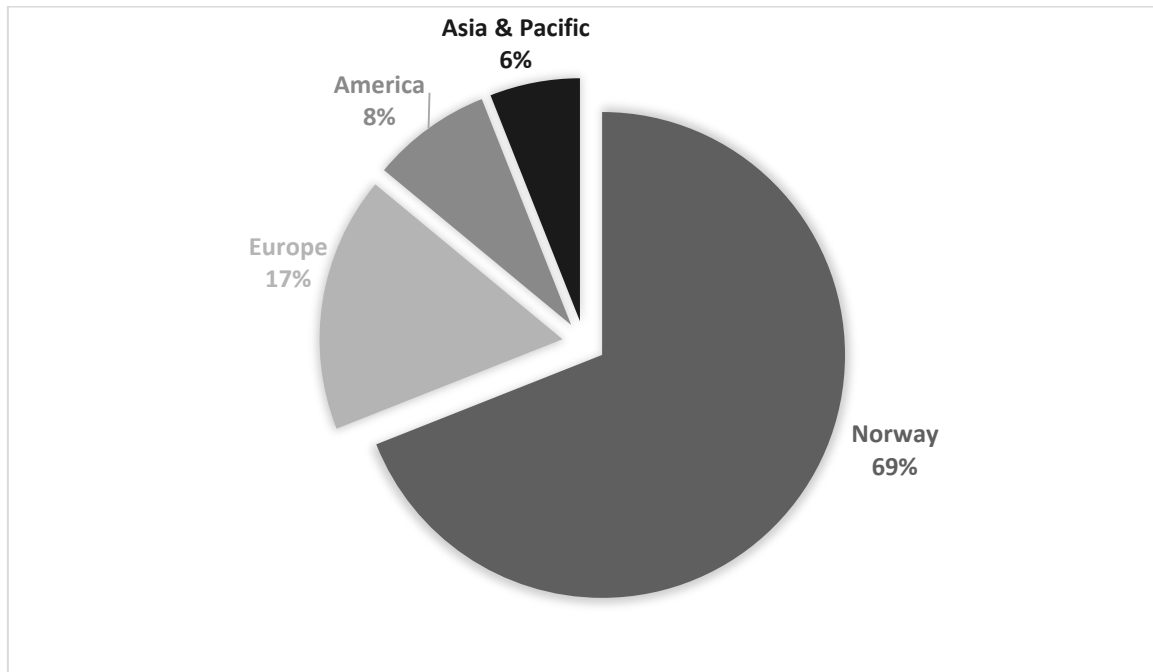


Fig. 4. Area of operation of LNG-fuelled vessels¹ [13]

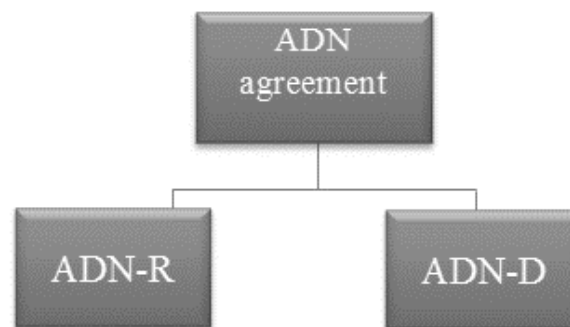


Fig. 5. Divisions of ADN agreement

4. POTENTIAL RISKS

Possible hazards resulting from the spillage of large quantities of LNG (intentional or accidental) can be caused by many factors. The key determinants include the human impact, the conditions of the fairway and into ports, storage, fixture and stowage of goods and also the technical conditions of the vessel. [12] Fig. 4 presents an overview of possible scenarios that involve the release of LNG and consequences.

There are many possible threats during the manipulation or transportation of LNG. In this part, we will precisely describe threats in the inland navigation. Collision incidents can lead to the deformation of the LNG containment and the release of LNG can occur. The effects of these incidents can adversely affect health, life, property and the environment. The following are the most common incidents where there is a heightened risk of loss of containment:

- Collision with another vessel
- Collision with jetties

¹ Excluding inland barges and LNG carriers.

- Collision with bridges
- Grounding of the ship

4.1. Collision with another vessel

The collision of vessels resulting in a breach of the LNG tank can result in the release of liquid into the separation section (between the tank and the ship's hull). A large breach can result in a direct release into the water.

The spill floating on the water will be warm, causing increased evaporation of the LNG [4]. The expansion of the spill across the water is caused by the river flow and the wind.

4.2. Collision with jetties

A collision with the quayside usually occurs during the manoeuvring, but because of the low speed during the manoeuvring, the probability of LNG release is very low. The more likely scenario is an incident when the LNG vessel on a berth is struck by another vessel.

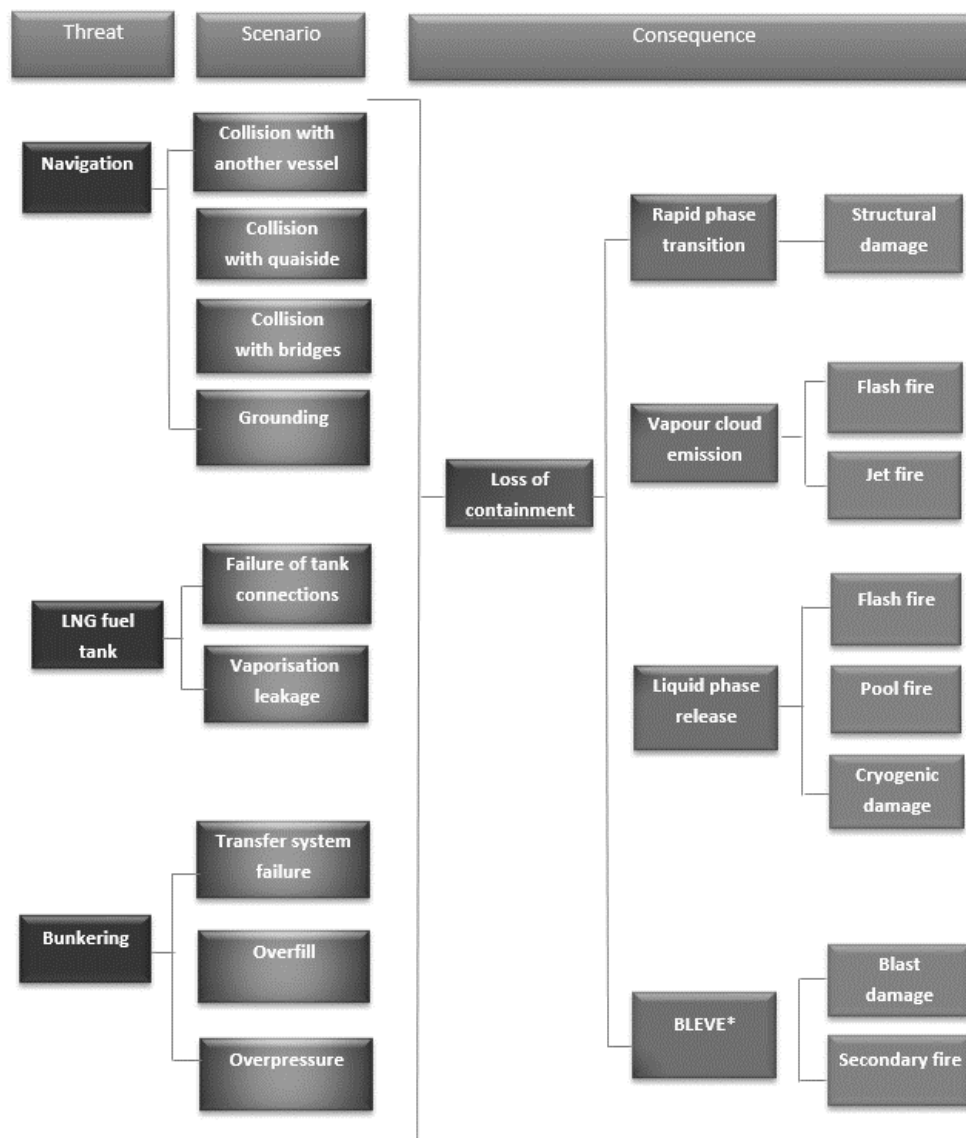


Fig. 6. Overview of possible scenarios involving the release of LNG and consequences

4.3. Collision with bridges

The storage tanks of LNG located on the deck are not protected against the damage from the outside; thus, it is realistic to expect damage to the tank. This can lead to the release of LNG or gas vapour. Incidents of collision of vessels with a bridge are quite common. Fig. 5 shows an example of damage after a collision on the Elbe River (Germany).



Fig. 7. Collision with the bridge on Elbe river [4]

4.4. Grounding

When a ship is powered by LNG, there is a need for storage of LNG fuel on board. In the case of grounding, the tank will not be damaged if the LNG fuel tank is placed on the deck. If the LNG fuel tank is located below deck, there may be a small risk of damage to the tank (in case of grounding, the impact on the hull of the ship is more than 0.8 m) [4]. If the LNG fuel tank is damaged, the LNG leaks and comes into contact with the water. This can lead to a gas or a vapour cloud, which can quickly develop on the water surface.

5. RISK ASSESSMENT

The data available for LNG carriers show that manoeuvres of the LNG carriers in the harbours and berths are critical and often accompanied by a high degree of uncertainty. The Class society and the flag state authority must approve the LNG risk assessment.

There are two main studies dealing with the issue of risk assessment of LNG carriers. *HAZID* is the core of the qualitative risk assessment. The HAZID should be carried out as a review of the possible hazardous events that can occur based on previous accident experiences. A well-planned and comprehensive HAZID is a critical and important basis for the risk-assessment process. A comprehensive HAZID is an important basis of the risk-assessment process. The HAZID technique involves the following:

- Workshop meeting with a multi-disciplinary team, which uses a special brainstorming technique based on a checklist of potential threats.
- Means of identifying, describing and assessing threats and hazards at the earliest stage of development.
- Rapid identification and description of processes.

- Then, the HAZID produces a list of hazards, ranked according to the consequences, and also recommendations for risk-reducing measures and an action plan. [14]

FMEA (Failure Mode and Effect Analysis) is a systematic analysis method for the identification of possible failures of technical systems or components for the detection of failure consequences and for the classification of failures. The main aim of an FMEA is to search for hidden failures and their prevention. The FMEA method is described by many technical standards (IEC Standard 60812, DIN 25448, US Military Standard MIL-STD-1692,). For the assessment of the FMEA, the ranking of the results is performed and a criticality matrix is used. In the matrix, the failures are detected and shown according to the severity and the probability of occurrence [13, 14].

6. THREATS OF LNG RELEASE AND POSSIBLE SOLUTIONS

In this chapter the situations that can occur in the case of LNG spills into the water are characterised. The possible scenarios, the means to deal with the negative consequences of the vapour release and the various types of fires and explosions that may occur are also identified. Therefore, the use of conventional probabilistic risk-assessment methods is acceptable. The risks associated with emergency incidents are determined by combining the occurrence and possible consequences to produce a risk ranking. The quantification of risks includes two parameters:

- Probability of emergency incident,
- Severity of consequence.

6.1. Vapour release

A vapour release from an atmospheric tank can result in spill (pool) formation. The speed of release depends on the volume of vapour released. Release from elevated pressures or temperature tanks results in two phases of release:

- 17% presents a pressure release
- the remaining 83% forms a pool [4].

A vapour cloud must not migrate into confined space, inside the vessel or in buildings because an ignition of the vapour cloud can create a confined vapour cloud explosion and cause secondary fires.

The following preventive measures can be used to avoid injury to persons:

- If the vapour cloud is likely to enter inland vessel or buildings, the first priority is to remove every vessel near from the danger zone or evacuate all persons.
- The residents or employees in the buildings along the waterway must be evacuated.
- Any sources of ignition must be isolated or removed [4].

The vapour from the LNG pool can be covered by high-expansion finished foam on the surface of the LNG pool. With correct application, the concentration of vapour above the pool can be reduced by circa 50% [6].

6.2. Pool fires

In the case of direct igniting of the vapour above the LNG spill (pool), the LNG burns off at various speeds. This depends on whether the pool is on the water or on land.

LNG pool fires cannot be extinguished on water; thus, the emergencies must be dealt with as follows:

- Prevent escalation – fire protection systems can prevent further escalation. The first fire would have already gone out before the first responders arrive. In the case of smaller LNG pool fires, the emergency response services should focus on cooling the remaining LNG tanks and ship's construction.
- Contain the fire.
- Control the fire.

Burning time on water will be very quick – if the pool is extremely large, the duration of burning will be very short. In the case of small LNG pool fires, the emergency response services should focus on cooling the remaining LNG tanks and the construction of ships. The cooling should be performed using an up-wind approach (for example, from a firefighting vessel with water sprays directed towards the length of the vessel) [9]. Fig. 7 shows the strategies of firefighting.

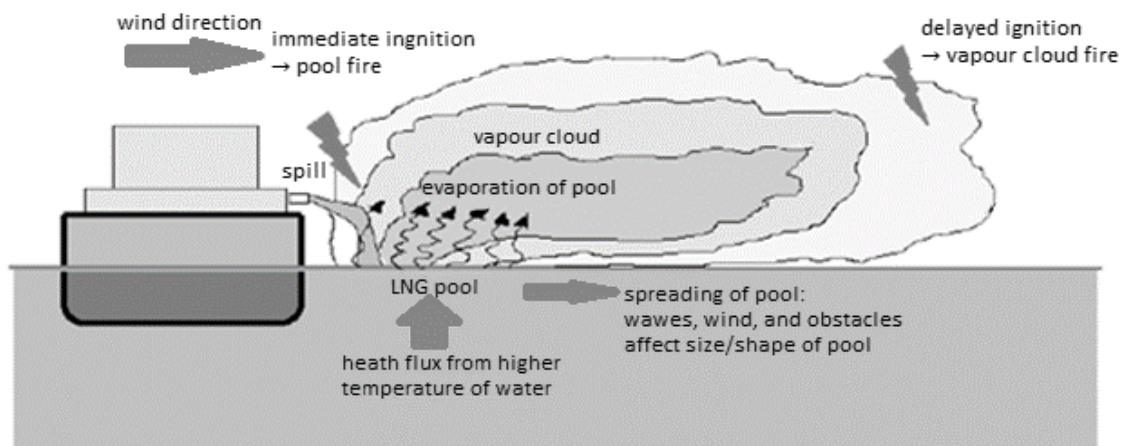


Fig. 8. Possible fire scenarios when LNG is spilled on water [4]

A confined LNG pool fire occurs when the product cannot flow away and burns in a contained space. For fires in a small surface area ($<10 \text{ m}^2$), dry chemical powder should be used to extinguish the fire. Extinction with foam is not available in the case of greater fires (more than $<10 \text{ m}^2$), even though high ex foam can reduce the intensity of the fire, but need periodically “top up” of foam to be effectual [10].

6.3. Flash and jet fire

Flash fire can occur when vapours drift in a downwind direction to a source of ignition or directly ignite. A jet fire may occur when a pressurized gas or fluid is released and forms a vapour cloud that can ignite. A jet fire has a powerful effect on equipment such as tanks or pipes that are not effectively isolated. Unprotected steel will fail very quickly because single hull LNG pressure tanks are sensitive to jet fires – failure of the containment can cause a rapid release of vaporising substances and a fire ball [4].

For a gas fire, there are two main steps:

- Stop the flow of the LNG gas by an Emergency shutdown.
- Protect all other tanks, pipes and ship construction and cool them with water-spray systems. It is recommended to use a thermal imaging camera to analyse whether the cooling effect has been achieved [4].

6.4. Boiling Liquid Expanding Vapour Explosion (BLEVE)

BLEVE can occur when the LNG tank fails at increased pressure usually due to flame trespass (jet fire) or mechanical impact on the containment. The subsequent decrease in pressure and ignition of the large vapour release cause a Boiling Liquid Expanding Vapour Explosion (BLEVE), usually recognised as a fire ball.

The normal mechanism for BLEVE is a pressure vessel containing pressurised liquefied gas (pressurised LNG tank) subjected to external fire trespass or catastrophic failure due to other causes. Isolation of a pressurised tank contributes towards reducing the risk of escalation from the impacting

fire. Physical barriers can prevent direct fire trespass and mechanical impact. For example, if the LNG fuel tank is situated below deck, the ship's hull will act as a physical barrier [11].

6.5. Rapid phase transition

In the event of spillage of LNG on the water, an accident called rapid phase transition (RPT) can occur. The RPT is a physical explosion that results because of the effect of uncontrollable boiling of cryogenic LNG through contact with water, whose temperature is high (12-17°C – depending on the mixing intensity [4]). We also found that RPT can occur when very hot gas is imported to a pipe that contains LNG.

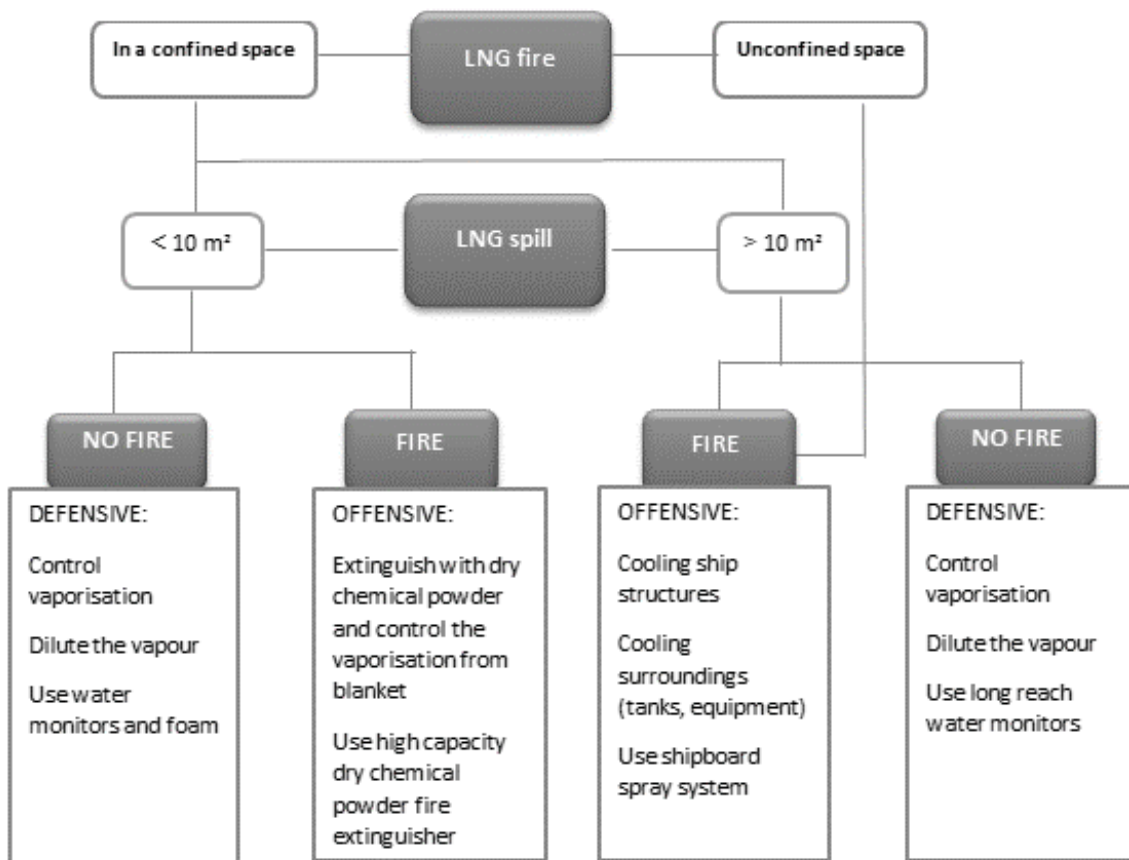


Fig. 9. Firefighting strategies

7. CONCLUSION

The demand for LNG is increasing worldwide because it is an environment-friendly clean energy. In Europe and North America, new environmental regulations require reduction of local emissions. LNG is almost free from sulphur and particulates can help them to meet requirements. Liquefied natural gas has the potential to be used for cargo ships, ferries, barges and tugs. At present, it is used as a fuel for vessels on inland waterways, for example on the Rhine and Danube River or for ferries in Norway.

LNG is classified by the ADN agreement as dangerous cargo. Because of this, it is necessary to perform a safety assessment, identify the risks of a possible spillage of LNG and to design measures for the prevention and mitigation of the effects in case of an accident. For this purpose, this paper

reports on the potential risks arising from the transportation of LNG by inland waterways and provides a variety of solutions and scenarios in the case of emergencies. Compliance with safety standards and recommendations will ensure safe transport and eliminate threats to health, life, the environment and property.

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