Safety guidelines and a training framework for LNG storage and bunkering at ports

Published Version:
Aneziris, O., Gerbec, M., Koromila, I., Nivolianitou, Z., Pilo, F., Salzano, E. (2021). Safety guidelines and a training framework for LNG storage and bunkering at ports. SAFETY SCIENCE, 138, 1-16 [10.1016/j.ssci.2021.105212].

Availability:
This version is available at: https://hdl.handle.net/11585/845665 since: 2024-03-02

Published:
DOI: http://doi.org/10.1016/j.ssci.2021.105212

SAFETY GUIDELINES AND A TRAINING FRAMEWORK FOR LNG STORAGE AND BUNKERING AT PORTS

Olga Aneziris

Systems Reliability and Industrial Safety Laboratory, National Center for Scientific Research "DEMOKRITOS", Greece. E-mail: olga@ipta.demokritos.gr

Marko Gerbec

Jozef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia. E-mail: marko.gerbec@ijs.si

Ioanna Koromila

Systems Reliability and Industrial Safety Laboratory, National Center for Scientific Research "DEMOKRITOS", Greece. E-mail: ioanna.koromila@gmail.com

Zoe Nivolianitou

Systems Reliability and Industrial Safety Laboratory, National Center for Scientific Research "DEMOKRITOS", Greece. E-mail: zoe@ipta.demokritos.gr

Francesco Pilo

Department of Firefighters, Public Rescue and Civil Defence, Headquarter of Venice, Italy, E-mail: francesco.pilo@vigilfuoco.it

Ernesto Salzano

Department of Civil, Chemical, Environmental, and Materials Engineering, University of Bologna, Italy. E-mail: ernesto.salzano@unibo.it

ABSTRACT

In this paper the main achievements of the project entitled "Sustainability Performance of LNG-based maritime mobility" (SUPER-LNG) financed by the Adriatic Ionian Interreg framework will be outlined. Guidelines for safety reporting, risk assessment, and emergency planning of small scale LNG facilities and bunkering operations at ports were developed. The main elements of these guidelines are presented together with the results of an application to a small LNG facility, consisting of LNG pressurised tanks, LNG trucks, and a loading arm section. In addition, a training programme has been created with the aim to mainly promote safety and to transfer knowledge of the LNG fuel chain to stakeholders, such as port operators, maritime instructors, port authorities, and stakeholders in planning, licensing, and emergency management.

Keywords: LNG safety, ports, bunkering, guidelines, risk assessment, emergency planning, training.

Highlights:

- Review of safety guidelines for LNG storage and bunkering at ports
- Issues in safety and risk assessment for LNG storage and bunkering
- Elements of emergency response planning, at ports with LNG facilities
- A training framework is proposed to promote LNG safety at ports

List of Abbreviations

ADRION	Adriatic Ionian
BLEVE	Boiling Liquid Expanding Vapour Explosion
CE	Centre Event
ECA	Emission Control Area
ESD	Emergency Shutdown
ERP	Emergency Response Planning
HAZOP	Hazard and Operability Analysis
LNG	Liquefied Natural Gas
LHS	Left Hand Side
MAPP	Major Accident Prevention Policy
MLD	Master Logic Diagram
RHS	Right Hand Side
RPT	Rapid Phase Transition
SMS	Safety Management System
SUPER-LNG	SUstainability PERformance of LNG-based maritime mobility

1. Introduction

This paper presents the main results of the project "Sustainability Performance of LNG-based maritime mobility (SUPER-LNG)" financed by the Adriatic Ionian (ADRION) Interreg framework, which addresses safety issues in Liquefied Natural Gas (LNG) installations in the ports located in this region. LNG constitutes an environmentally friendly fuel for ships, since strict emission requirements set by the International Maritime Organisation (IMO), result in the progressive replacement of traditional heavy fuels (IMO, 1997).

IMO has not only set limits for some of the most important pollutants, such as sulphur oxide, nitrogen oxide, ozone-depleting substances, and volatile organic compounds but also dedicated emission control areas (ECAs) with stricter controls for ships emissions. In Northern Europe, which belongs to the ECA areas, a large amount of new built, or even retrofitted, LNG-fuelled ships have been delivered over the last decade. Currently, there are 159 LNG-fuelled ships in service worldwide while 145 new ones have been ordered up to date (Sea/LNG database, DNV-GL). Such an increase together with the further sharp reduction in the sulphur limits for marine fuels, which came into force worldwide on January 1st, 2020 (IMO, 2011), will lead to a great demand for suitable facilities for refuelling ships not only in ECA areas but also in the Adriatic-Ionian one.

Owing to a lack of prior experience in this field in the Adriatic-Ionian area, great effort is required to understand and regulate the safety of LNG installations and bunkering operations at ports. Therefore, the main objectives of the SUPER-LNG project moving on this line are to prepare integrated and harmonized guidelines for the safety assessment of LNG supply systems in the Adriatic-Ionian area, by sharing the relevant experience and the good practices derived from the application of the "Seveso III" Directive (EC, 2012); to set the framework for development and sharing of the technical guidelines addressing the standardization of the technological solutions proposed for LNG supply, with emphasis on safety and security aspects; and to develop a training program for LNG fuel chain stakeholders, port operators, maritime instructors, port authorities, etc.

The main objective of the current paper is to present, the safety aspects for LNG storage and bunkering operations at ports and to respond to the following questions:

- Do existing guidelines cover all the aspects for safe storage and bunkering of LNG at ports?
- What issues should be covered in guidelines for safety reporting and risk assessment?
- Which are the main elements of emergency response guidelines?
- How can a training framework be developed to promote safety of LNG at ports?

The structure of the paper is as follows: section 2 introduces a comprehensive literature review regarding safety guidelines and emergency planning at ports, owing to the transfer and storage of LNG. Section 3 presents the storage and transfer methods of LNG in ports for small and medium scale installations. Section 4 presents the main aspects of the safety reporting guidelines developed within the project SUPER-LNG, by considering guidelines for safety reporting of the major hazards industry, the Seveso III directive, and ISO standards for LNG systems and installations. Section 5 presents the emergency response guidelines developed, based on emergency planning guidelines of European agencies and ports experience. Section 6 presents the training material produced within the project. Finally, in section 7 the conclusions of this paper are presented.

2. Literature review, regulations, and guidelines

The use of LNG as an alternative fuel for ships requires the existence of an appropriate legal framework to ensure safety against human life, environmental protection, and structural integrity, both when bunkering operations are performed and during storage too. In the framework of this project, regulations, existing standards, guidelines, and recommended practices, were collected in the field under consideration, and a systematic search and review were carried out. Aneziris et al. (2020) reviewed regulations, standards, and guidelines for LNG storage and bunkering, while the material was divided into three main categories, namely high-level regulations, standards, and guidelines. High-level regulations are relevant to the definition of the main drivers for the adoption of LNG as an alternative fuel. Technical standards are relevant to LNG storage and bunkering. Class rules are appropriate means for Classification societies to ensure safety and industry guidelines are fundamental in the definition of best practice in LNG bunkering. Risk assessment methods have been used widely used in the LNG sector. Animah and Shafie (2020) reviewed all risk assessment methods applied in the LNG facilities, such as LNG carriers, fuelled ships, plants, terminals, and offshore units. Vanem et al. (2008) applied risk assessment methods to LNG carriers while loading LNG at terminals. Sultana et al. (2019) performed hazard analysis for a ship to ship transfer of LNG, a relatively new method for LNG bunkering. Extensive literature has been produced for consequence assessment of accidental LNG releases on land and water, where various may phenomena may occur, such as pool fires, flash fires, BLEVE, vapour cloud dispersion, vapour cloud explosion, and rapid phase transition, as described by Bubbico and Salzano (2009), Parihar et al. (2011), Sun et al. (2017), Park et al. (2018), Choi et al. (2018), Pio and Salzano (2018, 2019) and Pio et al. (2019). Jeong et al. (2017, 2018) determined the safe exclusion zone for all LNG bunkering methods, therefore assisting emergency response planning in case of LNG accidental release.

In parallel, various guidelines for risk assessment and emergency planning for LNG bunkering operations have been published by individual societies. The International Association of Classification Societies (IACS) has published guidelines on LNG bunkering (IACS, 2016a) and risk assessment for the LNG-fuelled ship, as required by the IGF code (IACS, 2016b). These guidelines provide information on bunkering methods, procedures, and equipment required for LNG bunkering operations, guidance on safety and security zones and use of HAZOP (Hazard and Operability analysis) during bunkering and support for qualitative risk assessment of the fuelled ship. Classification societies have also published several guidelines such as DNV-GL's "Development and operation of liquefied natural gas bunkering facilities" (DNV-GL, 2015). These guidelines present safety systems of bunkering facilities, risk assessment methods, both qualitative and quantitative, for LNG bunkering facilities, and safety management system requirements. Guidance on requirements for simultaneous operations during LNG bunkering operations is also addressed in the risk assessment guidelines. American Bureau of Shipping (ABS) has issued an advisory document providing guidance on technical and operational challenges of LNG-bunkering for both the bunker and the LNG-fuelled ships (ABS, 2017). The latter provides guidance for safety and risk assessment and includes initiating events that can lead to major accidents. The specialised Society for Gas as a Marine Fuel (SGMF) has composed guidance to all parties involved in the bunkering of LNG-fuelled ships (SGMF, 2017). Risk assessment approach, identification of hazard areas, reference to safety and security zones and responsibilities, of involved stakeholders, for LNG bunkering operations, are discussed. Furthermore, all technical requirements and procedures taking place during pre-bunkering and bunkering phases are mentioned. The Society of International Gas Tanker and Terminal Operators (SIGTTO) has published guidelines on various safety issues, including the following: LNG emergency release systems (SIGTTO, 2017a), Emergency Shut Down systems (ESD) arrangements, and linked ship/shore systems for liquefied gas carriers and addendum (SIGTTO, 2017b), LNG ship to ship transfer for petroleum, chemicals and liquefied gases (SIGTTO, 2013), LNG operations in port areas (SIGTTO, 2003) which includes QRA for port areas. European Maritime Safety Agency (EMSA) has issued a guidance on LNG bunkering to port authorities and administrations (EMSA, 2018). This guide includes the regulatory framework for LNG bunkering, bunkering methods, risk and safety aspects for LNG at ports and bunkering, assessment of control zones, and emergency preparedness. Good practices regarding internal and external emergency plans, as well as data related to these plans, are included in EMSA guidelines.

Additionally, emergency planning protocols for LNG facilities at ports are presented in detail by several entities, such as EMSA (2018), IChemE (2007), and DNV-GL (2015). According to these protocols, there are two levels of defence which may mitigate LNG release, should an accidental release of LNG during storage or bunkering occur. The first mitigation level includes measures that contain the release and prevent ignition, while the second level of defence may detect the ignition and extinguish it. Measures of the first level are emergency response and shutdown systems, water curtains, and cryogenic barriers. Measures to prevent ignition and fire are fire protection and suppression systems, fire safety, and firefighting measures for ships and on-site storage tanks. IChemE (2007) proposes that emergency response plans should be prepared for credible serious or major incidents at facilities and proposes strategies for gas cloud, LNG pool, and jet fires and spills. Bureau Veritas (2014) has published guidelines on LNG bunkering including guidelines for emergency situations. It proposes that emergency plans should consider situations such as LNG leakage and spill on the receiving ship, bunkering facility or on the LNG transfer system; gas detection; fire in the bunkering area; unexpected loosening of mooring lines; unexpected moving of the tank or the truck, and unexpected venting on the receiving ship or on the bunkering facility. The LNG Masterplan for Rhine-Main-Danube (2015), which focuses on inland navigation, proposes four different incident response scenarios in case of vapour release from LNG propelled cargo vessel, release of LNG on water and Rapid Phase Transition (RPT), release of LNG on water, RPT and delayed LNG ignition, and collision of LNG propelled cargo vessel with another vessel leading to LNG spill on water and pool fire. For each scenario, a specific list of emergency response actions is provided for the ship crew and the local authorities, fire brigade, and police.

3. LNG at Ports and Bunkering Modes

Figure 1 presents the main elements of the bunkering process at ports, with reference to the so-called “small facilities”, with LNG stored in pressurized tanks 0-4 bar and volume 100 - 3500 m^3. Bunkering takes place by means of a fixed bunkering installation (i.e. a cryogenic pipe and loading arm or flexible hose) from the stationary LNG storage tanks. Such stations are generally supplied by small LNG ships (capacity: 500 to 3,000 m^3) or LNG trucks that bring the LNG from a nearby LNG bunker terminal or from a large LNG import terminal. The main phases of the bunkering process are the following:

(i) delivery of LNG to the port either by trucks or by bunkering vessels
(ii) setting up mooring arrangement, grounding and connecting bunker hoses, inerting, and purging of filling lines
(iii) bunkering of LNG to the fuelled vessels, performed by various means such as truck-to-ship, tank-to-ship, or ship-to-ship (i.e. from a bunkering ship to the LNG fuelled ship)
(iv) stripping, purging, and inerting of filling lines and disconnecting of grounding and bunker hoses.

Bunker quantities of a receiving ship may vary from 50 m^3 for small fishing vessels to 20.000 m^3 for very large ships or oil containers (EMSA, 2018).

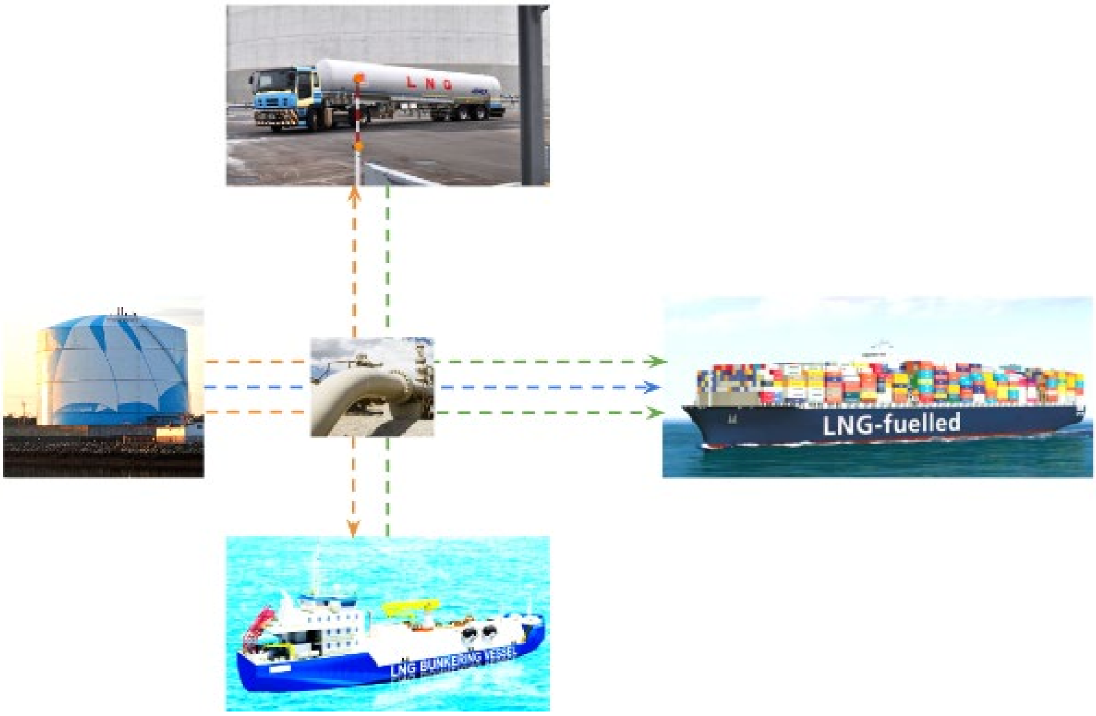

Figure 1. LNG bunkering modes.

4. Guidelines for Safety Reporting

The Guidelines for safety reporting developed within the framework of the SUPER-LNG project are based on the requirements of the Seveso III directive for major hazards, as well as on bunkering standards for LNG such as ISO 18683 and ISO 20519 (ISO 2015a, 2017). The Seveso III directive applies to LNG storage tanks, but not to LNG road transportation activities, where the ADR Agreement (ADR, 2017) is appropriate. Nevertheless, the Seveso III directive has valuable information for safety reporting of LNG trucks, bunker ships, and loading-unloading activities. The three major elements of safety reporting are the following:

- Major Accident Prevention Policy (MAPP)
- Safety Management System (SMS), where the MAPP is demonstrated and implemented by appropriate means and systems

- Risk Assessment for bunkering and storage facilities, outlining the measures taken and demonstrating that all aspects have been taken into account

Quantitative risk assessment can be performed in three major phases. In the first one damage states and their frequency of occurrence are assessed, in the second one consequences owing to the release of flammable LNG are defined and assessed, and in the last one risk is quantified. Therefore, the developed guidelines for safety reporting are separated into five sections and described as follows.

4.1 *Reporting of the Major Accident Prevention Policy*

The Major Accident Prevention Policy (MAPP) is based on Article 8 of the Seveso III Directive. It is formally adopted by the organization's top management and it should be designed with the aim to ensure a high level of protection of human health and the environment. The port should recognize the presence of major accident hazards to the health and safety of humans, assets, and environment that require adequate prevention measures. In addition, it should be proportionate to the major-accident hazards and include the overall port administration aims and principles of action. Top management of the port has a decisive role in the actual performance of the management system and is also responsible for the overall performance of the SMS. It should delegate the technical competencies to lower levels managers and experts, assure adequate resources (e.g. human and financial) for the implementation of the MAPP, and review and act upon the evaluation of its performance. MAPP should include the commitment towards continuously improving the control of major accident hazards, and ensuring a high level of protection. In addition to the evaluation of the performance, the strategical, tactical, and operational safety goals related to the MAPP should be defined and the actual performance should be evaluated against the goals set (activities of monitoring performance and auditing). Finally, the MAPP should be subject to periodic reviews by the top management for the actual progress towards the strategic goals. Thus, the MAPP should serve as a "promise" of the organization against which their activities should be compared by the employees, the general public, and national competent authorities. For that purpose, MAPP is required to be made public to all interested stakeholders, internal or external to the organization, usually published on the web site.

4.2 *Reporting of Safety Management System*

The reporting of the SMS is based on Article 10 and Appendix II of the Seveso III Directive (EC, 2012). The main issues which are addressed are the following:

(i) Organisation and personnel (covers the role and responsibilities of the personnel, safety communication, safety awareness and continuous improvements, personnel training arrangements, and safety involvement of own and contracted personnel).

(ii) Identification and evaluation of major hazards (covers organization's procedure, methods, and tools that are in principle used for the identification of the major accident hazards and evaluation of the related risks for major accidents).

(iii) Operational control (covers best practices for monitoring and control of operations, procedures, and instructions for safe operation and temporary stoppages, alarm management as well as inspection and maintenance)[i].

(iv) Management of change (covers procedures regarding the organizational and technical change proposals collection, evaluation, approval, implementation, and documentation, for their possible safety implications).

(v) Planning for emergencies (covers procedures to identify foreseeable major accident related emergencies and to prepare, test, and review the prepared plans and train the involved own/contracted personnel).

(vi) Monitoring performance (covers topics of: i.) Adoption of the risk tolerability decision criteria/procedures (e.g., quantitative or qualitative, etc.), ii.) Procedures for ongoing assessment of the compliance with the set goals (e.g., using quantitative performance indicators) and iii.) Procedures for reporting of

[i] In addition, Gerbec et al. (2020) strongly suggest to consider at least procedures for permitting and isolation system, shift handover and fatigue management.

near misses and major accidents, their investigation, and measures adopted for the prevention of their repeat occurrence).

(vii) Audit and review (covers procedures for periodic auditing compliance of the operations with the set MAPP and SMS, as well as procedures for reviewing the progress towards set strategic goals of the MAPP and SMS by the top management).

The specification of the issues in Annex II is quite short and as the summary above suggests, organizations usually require more detailed guidelines on MAPP/SMS implementation and application. The guidelines prepared within the SUPER-LNG project aimed to help with illustrative examples in the implementation of SMS details. Table 1 presents an example of Management of Change quantitative performance indicators.

Table 1. Example of possible quantitative performance indicators definitions for the Management of Change element.

Title	Determination of indicator, the formula for the calculation, the frequency of calculation [a]	Unit
Rate of change proposals	N_{CP} = number of change proposals received by the coordinator per annum Scope: each org. unit Frequency: annual Threshold criteria: none (however, the increasing trend might indicate coming overload)	per year
Part of urgent change proposals	N_{ucp} = number of urgent change proposals received by the coordinator per annum $N_{ucp} / N_{CP} \times 100$ Scope: each org. unit Frequency: annual Threshold criteria: <10 % in relation to N_{CP}	%
Part of temporary change proposals	N_{tcp} = number of change proposals where the change as such was planned not to be permanent from the start per annum $N_{tcp} / N_{CP} \times 100$ Scope: each org. unit Frequency: annual Threshold criteria: none	%

Organizations are required to implement SMS within their management system as a specific management aspect, being similar/related, but different from conventional health and safety at work aspect. Implemented SMS is a basis for safety reporting (formal site Safety Report), emergency plans (site internal Emergency Plan), licensing procedure, and inspections by the competent authorities and management's systematic controls over the performance of the technical and organizational safety measures and systems.

4.3.1 *Hazard source identification*

The main objective of this step is to identify the sources of LNG release in the port and the initiating events that can lead to LNG release. The main reporting requirements are the description of the storage and bunkering facilities, the operation modes of the facilities, and the selection of initiating events. Storage tanks, LNG trucks, and or a bunker ship may exist in a port, for loading LNG either to the receiving ship or to the storage tanks. Operation modes in the port may be the following: loading of LNG tanks from a bunker ship, storage of the LNG tanks, loading of the receiving ship either from the LNG tanks, or from a buffer ship or from trucks. The possible events which create a disturbance in the installation and have the potential to lead to the release of LNG are identified and reported. Several approaches may be applied such as the Master Logic Diagrams as presented in Papazoglou et al. (2003), the use of checklists from past accidents in LNG facilities, and the HAZOP method. In order to apply hazard identification methods the following tasks are essential as proposed by Aneziris et al (2014): a) familiarization of the analysts with the design and operations of LNG storage and bunkering b) identification of various operating states of the port facilities and c) division of the LNG port facility into specific areas were the MLD or HAZOP is applied. Figure 2 presents an example of a Master logic diagram applied for the loading arm section, the developed MLD for the loading/unloading pipeline section. There are two major categories of events leading to loss of containment of a pipe break during loading/unloading: those resulting in a structural failure of the containment and those resulting in containment bypassing because of an inadvertent opening of an engineered

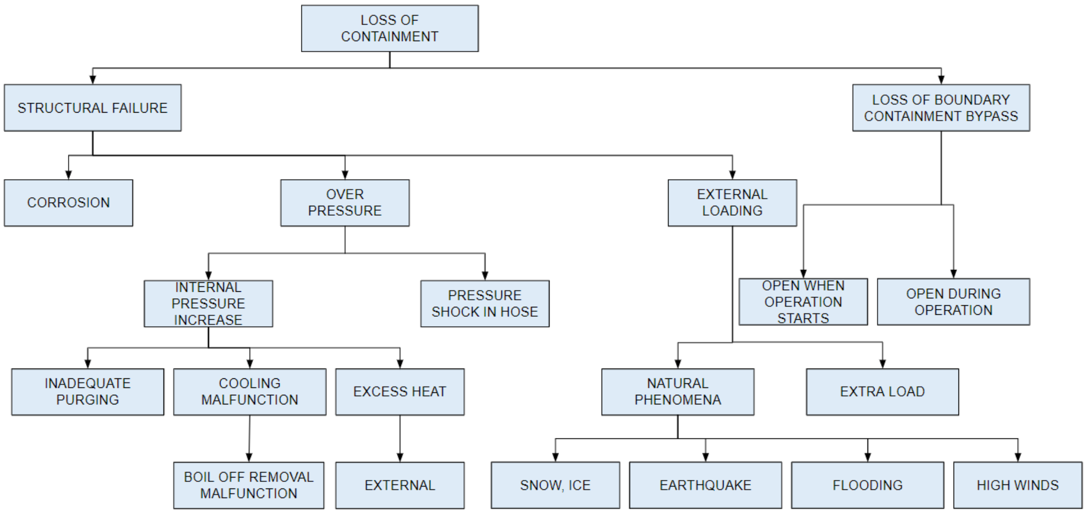

Figure 2. MLD for loading/unloading arm area.

discontinuity in the containment (e.g. valves). Structural failure causes are corrosion, overpressure, or external loading. Overpressure is decomposed in pressure shock and internal pressure increase. Internal pressure increase may be caused by boil-off gas removal malfunction during unloading from ship to tanks or by external excess heat, owing to external fire, or due to inadequate purging of loading arm pipelines after completion of loading. External loading may be achieved in the following ways; a) snow, ice, b) earthquake, c) flooding, d) high winds, and e) extra loads.

Table 2 presents the list of initiating events identified for LNG bunkering installations in the Guidelines for Safety reporting of LNG in port areas developed by Gerbec et al. (2020). Similar lists have been also proposed by ABS (2017), in case of leaks from LNG pumps, hoses, or tanks, inadvertent disconnection of hoses, overfilling/overpressure of fuel tanks, and external impact.

4.3.2 *Safety functions and safety systems*

For each initiating event identified in hazard identification, safety functions, and systems, required to prevent the occurrence of LNG release, are identified and reported. Such safety systems are the following: high-level alarms on LNG tanks to alert operators before tank overfill, ship-to-shore communications to ensure information can be shared between parties involved in bunkering, ESD which protects LNG tanks from overfilling through automatic shutdown on a high level, and pressure safety valves (ABS, 2017). Table 3 presents safety functions and front line systems identified for LNG pressurised tanks. In addition, support systems required for the operation of these frontline systems have been identified such as AC power, DC power, instrument air, cooling water, and water supply.

Table 2. List of initiating events for LNG bunkering installation.

1. Corrosion (tanks, pipelines, loading arms, trucks, hoses, coupling system)
2. Boil-off removal malfunction during loading or storage
3. Excess external heat owing to nearby external fire
4. Rollover in tanks (storage, loading)
5. High level in tanks, trucks
6. High pressure in tanks, pipelines, trucks
7. Pressure shock in pipelines (Inadvertent valve closure during unloading)
8. Inadequate purging or cooling of loading arm, pipelines
9. High temperature, leading to BLEVE of pressurized tank or truck
10. Vibrations (of LNG bunker ship)
11. Earthquake
12. Snow, ice
13. Floods
14. High winds
15. Extra loads; e.g. a) heavy objects drop on hoses, pipelines, loading arms, tanks, trucks, b) vessel collides with equipment, c) truck or vessel leaves with hose still

connected, d) vessel collides with bunker ship in the port, and e) bunker ship runs aground in the port

16. Valve left open before loading/unloading starts
17. Containment bypass during loading (e.g. premature disconnection of loading arms)

Table 3. List of Safety Functions and safety systems for pressurised LNG tanks.

Safety Functions

- Avoid Overpressure owing to temperature rise
- Avoid Overfilling
- Provide Overpressure Protection
- Maintain structural integrity of Pressure Boundary Under Normal pressure conditions
- Avoid Boundary containment by-passing
- Corrosion protection
- Fire protection

Safety Systems

- Boil off removal system
- Thermal insulation of tanks
- Vent (PSV or rupture discs)
- *High Pressure Control System*
  - operation of compressors
  - reduction or termination of loading
  - Emergency Shutdown System (ESD)
  - pressure relief by sending LNG vapours to vent
- *High Level Control System*
  - Manual system
  - Automatic system (Level indicators, High level alarm and control, Emergency Shutdown System)
  - Communication System
  - Constant supervision by Person in Charge
- *Anti-rollover devices*
  - Filling system (procedures for loading LNG in tank and checks for quality control of imported LNG)
  - Recirculation system
  - Monitor boil off
  - Temperature/density monitoring through LNG depth
- Lightning and Earthing protection
- Foundation
- Outer pressurized stressed containment
- Procedures for corrosion protection
- Procedures for Containment bypass protection
- Fire protection system
- Sprinklers

Safety Functions
Bund Area round tank to protect from flooding

Performance requirements (success criteria) imposed on the various frontline systems by each initiating event (e.g. one out of two pressure safety valves) may be also identified and reported.

4.3.3 *Accident sequence determination*

A logic model for the LNG facility is developed in this step. This model includes all initiators of potential accidents and the corresponding response of the installation to these initiating events. Accident sequences are defined in models such as event trees, which contain an initiating event, specific system failures, and human responses. Accident sequences result in plant damage states, which involve the release of LNG. System failures are usually modelled by fault trees, in terms of basic component failures and human errors. Figure 3 presents an Event Tree developed for the initiating event "external fire in jetty during unloading from bunker ship to tank". This model presents the possible response of external fire in the jetty during unloading LNG from the bunker ship to the pressurised tank. It comprises the following events:

a) External fire during unloading from bunker ship to tank.
b) During unloading of LNG from bunker ship to tank, an external fire in the jetty may occur, and increased boil-off removal capacity is required and has to be handled through the safety functions of the plant, due to the high thermal heat flux which is radiated.
c) Manual termination of unloading. In case of external fire, operators both at the plant and at the bunker ship should recognize the fire, communicate this fact among themselves and terminate the unloading operation.
d) Firefighting system. This event describes the availability of the firefighting system of the jetty, which usually consists of several hydrants supplied with water through the firefighting pumps.
e) Emergency shut down in loading arm. This event corresponds to the successful detection of the fire and the closing of the appropriate valves and pumps by the

automatic emergency shutdown system (ESD), which is activated in case of external fire.

f) Pressure safety valves (PSVs). This event models the successful operation of the pressure safety valves in the event of a continuing pressure rise beyond and above the nominal safety valves set points.

This event tree determines six accident sequences. Two of them (#l, #2) constitute successful termination of the incident. Two others (#3, #5) results in the release of LNG from the PSVs, and two of the sequences (#4, #6) lead to pipe rupture and release of LNG.

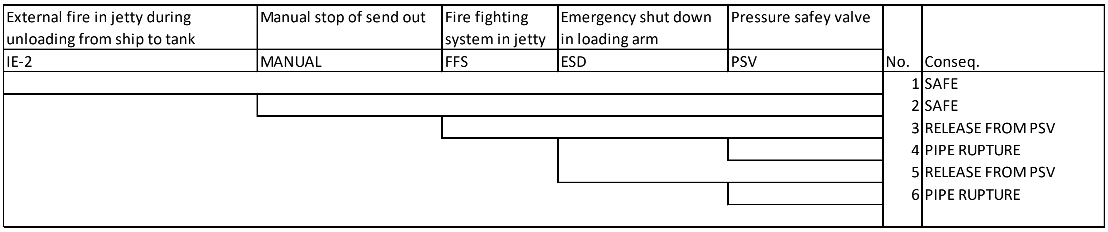

Figure 3. Event Tree for initiating event “external fire at jetty during unloading of LNG from bunker ship to tank”.

4.3.3.1 Bowties for Accident sequence determination

Bowties may also be applied for accident sequence determination, since they are equivalent to Event Trees, as presented by Papazoglou & Ale (2007). Figure 4 presents a general bowtie for an LNG pressurised tank. The Centre Event (CE) of this bowtie represents fire or explosion, owing to a tank break containing LNG. All events to the left of this event represent events aiming at preventing the CE from occurring and the corresponding part of the diagram is called Left Hand Side (LHS). All events to the right of the CE correspond to events aiming at mitigating the consequences of the CE and this part of the model is called Right Hand Side (RHS). The right-hand side (RHS) of this bowtie consists of the following barriers: Fire fighting measures, Collection of release, and Emergency response. The first two barriers affect mitigation of the accident, while Emergency response plans affect the dose humans will receive.

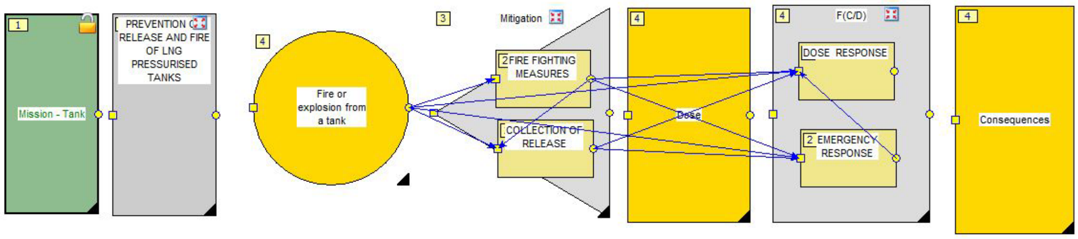

Figure 4. General Bowtie for LNG pressurised tank.

Figure 5 presents the Left-Hand Side of this bowtie in more detail, which consists of the initiating events and their corresponding safety measures of an LNG pressurised tank. These are based on the general ways (or direct "causes") in which either structural failure or bypass of the containment may occur in LNG tanks, as presented by Papazoglou et al. (2003). Initiating events and associated safety systems for an LNG are the following:

a) Corrosion, and Corrosion Protection measures
b) High level and manual or automatic high-level control systems which lead to the emergency shutdown.
c) External fire, manual or automatic high-pressure control systems which lead to emergency shutdown and Pressure Safety Valves
d) Control of extra loads and impact protection
e) Rollover, temperature density, and pressure control leading to Emergency shutdown and Pressure Safety Valves
f) Natural Phenomena and Natural Phenomena Protection
g) Valve left open, and Safeguarding protection
h) In case of release of flammable LNG, fire or explosion may occur only if an ignition source exists. Therefore, ignition prevention measures are essential for preventing fires or explosions.

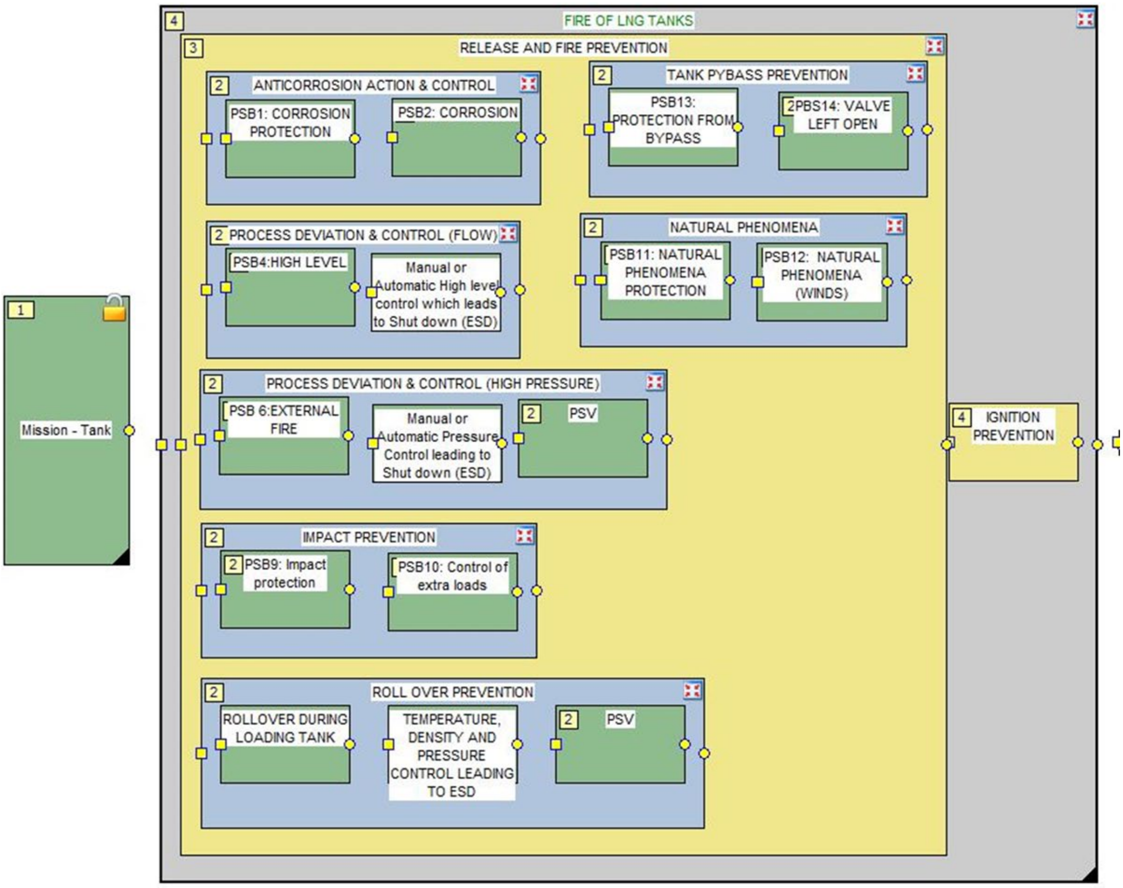

Figure 5. Left Hand Side of the Bowtie for LNG pressurised tank.

4.3.4 *Plant damage state definition*

A plant damage state characterizes the conditions of LNG release. Plant damage states which may be defined in the LNG storage and bunkering facility are the following: LNG tank failure owing to overfilling or overpressure, pipe breaks in various sections of the port, hose rupture or loading arm rupture during LNG transfer, truck overfilling or overpressure and tank or truck BLEVE. Examples of accidental scenarios and plant damage states are also presented in ISO 16901 in the case of LNG import and export facilities (ISO, 2015b).

4.3.5 *Parameter assessment*

Parameters that have to be estimated, in order to quantify the event trees and fault trees are frequencies of the initiating events, (external events, human errors, component failures), component failure rates, and probabilities of human actions. Estimation of parameters is based on generic values which may be provided by NFPA 59A (NFPA, 2019), Offshore and Onshore Reliability Data database (OREDA, 2015), in the Reference Manual BEVI Risk Assessments produced by RIVM (2009) and in British FRED database (UK HSE, 2019).

4.3.6 *Accident sequence and plant damage state quantification*

In this task accident sequences and the plant damage states are quantified. In particular, the Event Trees built in the task “Accident sequence determination” are quantified using the parameter values estimated in the previous task. The results of this task are the frequency of occurrence of each accident sequence and consequently of each plant damage state. In the guidelines developed by Gerbec et al. (2020), the following damage states have been estimated based on the Fault Tree and Event Tree analysis: tank rupture owing to overpressure, tank Rupture owing to overfilling, BLEVE of the tank, a loading arm rupture between LNG bunker ship and tank, while loading tank. The following eight damage states have been quantified based on literature data, presented in Table 4: a) Truck rupture owing to overpressure, b) BLEVE of the truck, c) Pipe rupture (between LNG tanks and pumps), d) Loading arm rupture (between the tank and the fuelled ship), e) Hose rupture piping (between the truck and the fuelled ship), f) Pipe rupture (between tank and truck), g) Hose rupture (between bunker ship and fuelled ship), and h) Tank Rupture of LNG bunker ship. Table 4 presents the frequencies of all plant damage states of a small scale LNG port storage and bunkering facility, as estimated by Gerbec et al. (2020) in the Guidelines.

Table 4. Frequency of plant damage States.

Plant damage state	Frequency (events per year)
LNG FACILITY	
1. Tank Rupture (at port) owing to overpressure	1.55×10^{-5}
2. Overfilling of LNG tank (at port)	1.55×10^{-7}
3. Pipe break between LNG tanks and pumps	1.00×10^{-5}
4. BLEVE of tank (at port)	1.16×10^{-7}
5. Loading arm rupture (between bunker ship and tank)	1.54×10^{-5}
6. Rupture of loading arm during fuelled ship bunkering (tank to fuelled ship)	7.00×10^{-4}
7. Rupture of (un)loading hose during (un)loading of truck (truck to fuelled ship)	4.00×10^{-4}
8. Rupture of pipe (port tank to truck)	1.00×10^{-5}
9. Truck Rupture owing to overpressure	5.00×10^{-7}
10. BLEVE of truck	5.80×10^{-7}
11. Rupture of hose between bunker ship and fuelled ship)	4.00×10^{-4}
12. Tank Rupture of LNG bunker ship	5.00×10^{-6}

4.4 *Reporting for Consequences Assessment of LNG Release*

The second phase of the integrated risk assessment aims at the establishment of the consequences of the released LNG. Two major steps can be distinguished for the assessment of LNG consequences.

4.4.1 *Step 1: Determination of release categories of flammable material*

A release category for a flammable material uniquely determines the type of physical phenomenon that could result in fatalities or injuries. In the case of LNG release, it is established whether a pool fire, or a jet fire or a Rapid Phase Transition (RPT), or Boiling Liquid Expanding Vapour Explosion, (BLEVE) will take place or even a vapour explosion or deflagration will result following atmospheric dispersion of LNG. ISO 16901 presents the sequence of events following LNG release, which depend on the release conditions (ISO, 2015b), and Vanderbroek & Berghmans (2012) present the different scenarios which may occur if LNG is released accidentally from atmospheric or pressurized tanks.

Figure 6 presents the scenarios which may occur, in case of failure of an LNG pressurised tank. If immediate ignition occurs, there will be a fireball-BLEVE (see Figure 6, branch #1), while in case of delayed ignition LNG will vaporize and produce a cloud denser than air spreading according to the weather conditions (wind speed, ambient temperature, class of atmospheric stability, humidity). LNG concentrations depend on the amount of the released LNG and the atmospheric and meteorological conditions. An accident sequence resulting in LNG release to the environment, if precisely determined, would lead to a unique type of release. Such precise knowledge is not always available, however, and in such cases, there is uncertainty about the possible release category following the accident. If the cloud reaches concentrations between upper and lower flammability level (5 - 15% by volume) the mixture can be ignited if contacted by an ignition source and either a flash fire (see Figure 6, branch #2) or an explosion will take place (see Figure 6, branch #3). Finally, if there is no ignition source of the LNG cloud, the release will terminate safely.

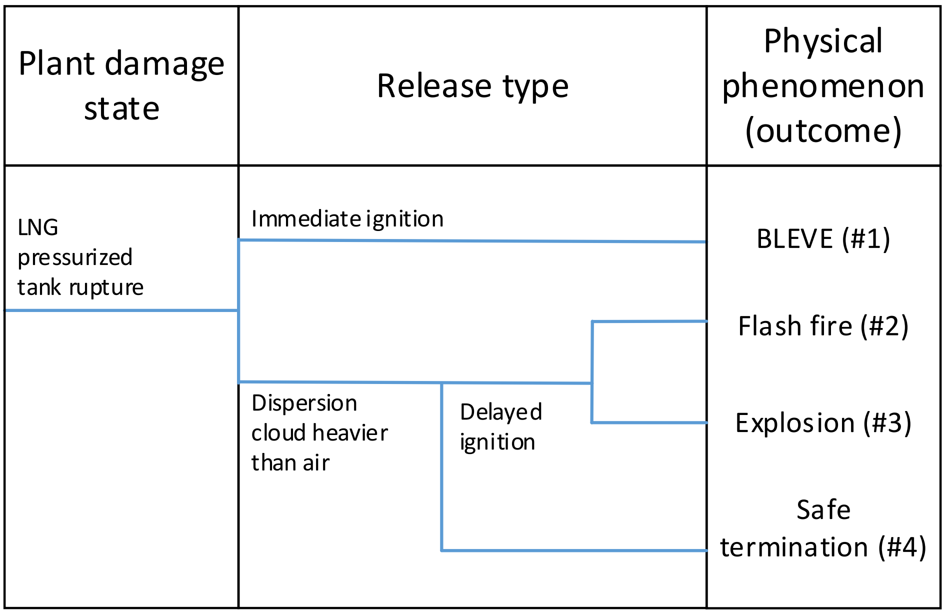

Figure 6. Consequences following the rupture of a pressurised LNG Tank.

4.4.2 *Step 2: Estimation of heat radiation and peak overpressure, dose, and consequence assessment*

In this step, heat radiation or the peak overpressure resulting from LNG for each release category identified in the previous step is assessed. The integrated over the exposure time of an individual to the extreme phenomenon (either radiation or overpressure) generated by LNG release is calculated. This defines the "dose" an individual receives. Appropriate dose/response models receiving as input the dose of heat radiation or overpressure calculate the probability of fatality or injury of the individual receiving the dose, as presented in the Green Book (TNO, 1992).

4.5 *Reporting for Risk Integration*

This last phase leads to the quantification of risk through the integration of the previous results i.e. the combining the frequencies of the various accidents with the corresponding consequences. A risk measure used to quantify risk is individual fatality risk at a location in the form of iso-risk contours. Table 5 presents all the release scenarios which have been considered for the LNG port facility in the Guidelines (Gerbec et al. 2020), together with the distance where conditional risk is equal to 10^{-2}. Total individual risk independent of plant damage state is presented in Figure 7 for the case study LNG bunker storage plant. Total individual risk is equal to 10^{-5}, 10^{-6}, 10^{-7} per year at a distance of 50, 470, 670 meters from the centre of the plant, respectively. These results are valid under various assumptions, regarding weather conditions and distance of ignition, described by Gerbec et al (2020). Accidents with the most serious consequences are: BLEVE of LNG tank (1000 m^3) and rupture of LNG tank followed by delayed ignition, flash fire of the vapours contained in the tank.

Table 5. Distances where conditional risk is equal 1×10^{-2} for LNG storage and bunkering facility.

RELEASE TYPE	Distance in meters
Tank rupture and BLEVE (1000 m^3)	730
Tank rupture and delayed ignition flash fire (1000 m^3)	490
Tank rupture and delayed ignition explosion (1000 m^3)	115
Loading arm rupture (between bunker ship and tank) and jet fire (750 m^3/h)	100
Loading arm rupture (between bunker ship and tank) and delayed ignition -flash fire (750 m^3/h)	175
Loading arm rupture (between bunker ship and tank) and delayed ignition –explosion (750 m^3/h)	115
Rupture of loading arm during fuelled ship bunkering (tank to fuelled ship) and jet fire (250 m^3/h)	55
Rupture of loading arm during fuelled ship bunkering (tank to fuelled ship) and delayed ignition flash fire (250 m^3/h)	165
Rupture of loading arm during fuelled ship bunkering (tank to fuelled ship) and delayed ignition explosion (250 m^3/h)	<50
Rupture of (un)loading hose during (un)loading of truck (truck to fuelled ship) or rupture of pipe (port to tank) and immediate ignition (60 m^3/h)	<25
Rupture of (un)loading hose during (un)loading of truck (truck to fuelled ship) or rupture of pipe (port to tank) and delayed ignition flash fire (60 m^3/h)	35
Rupture of (un)loading hose during (un)loading of truck (truck to fuelled ship) or rupture of pipe (port to tank) and delayed ignition explosion (60 m^3/h)	25
Truck rupture and BLEVE (60 m^3)	185
Truck rupture and delayed ignition flash fire (60 m^3)	235
Truck rupture and delayed ignition explosion (60 m^3)	50

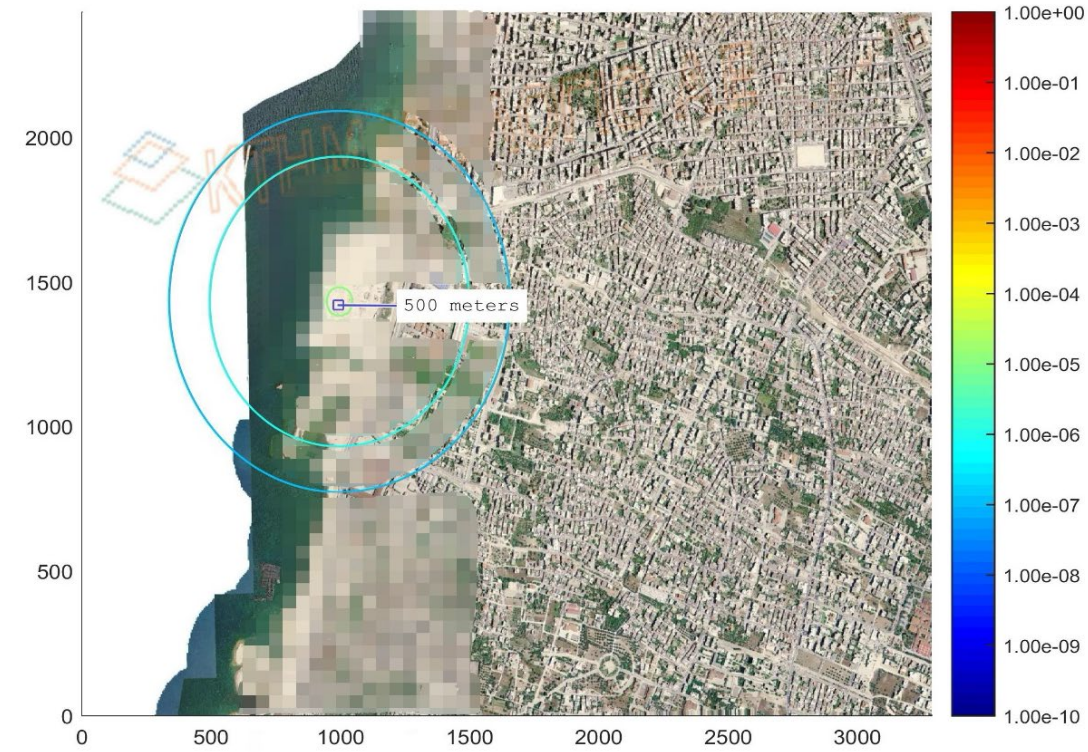

Figure 7. Total unconditional iso-risk contours (10^{-7}, 10^{-6}, 10^{-5} $year^{-1}$) for LNG storage plant at port.

5. Guidelines for Emergency Response planning

An emergency response plan (ERP) is a written set of instructions that describes what workers at the workplace should do in an emergency. The ERP includes protocols to ensure close coordination with emergency response organizations and agencies operating in the area of the analysed asset. The emergency plan should be based on a realistic assessment of hazards associated with the work activity or workplace, and the possible consequences of an emergency occurring as a result of those hazards. External hazards should also be examined in preparing an emergency plan. In developing the plan, consideration should be given to the application of all relevant laws, including public health laws and state or territory disaster plans.

For what concerns the external emergency response plan, i.e. the emergency response addressed to the population and assets located in the surrounding of the LNG installation, few indications can be found either in the open literature or in public repository and normative. Quite clearly, for the specific case of LNG storage at ports, the requirements of the Seveso III Directive must be fulfilled. Hence, all LNG terminals in Europe have produced an emergency plan as, to cite some, LNG Terminal Adriatic (IT), Dunkerque LNG terminal (FR), Świnoujście LNG Terminal (PL), Port of Helsinki (FI). Other similar information can be found for the LNG masterplan for Rhin-Main-Danube and the BP process safety series.

The analysis of the current international standards currently adopted in Europe has shown that the European Maritime Safety Agency (EMSA, 2018) and the International Association of Classification Societies (IACS, 2016a,b) have produced a specific report for bunkering operations, either for internal or for external emergency response. Besides, the Society of International Gas Tanker e Terminal Operators (SIGTTO, 2001; 2004) and the Society for Gas as a Marine Fuel (SGMF, 2017) have produced significant guidelines for contingency plans, for the specific case of LNG. From the public authorities, a guideline can be found as that of the Italian Department of Firefighters (VVF, 2015). According to their experience, accidental scenarios involving LNG should be addressed - in case of an impact on residential areas - by a partial or total evacuation only if the time required for the operations is comparable with the characteristic time for the accidental scenario. Hence, a system of automatic traffic light/ship light must be installed to close roads, maritime lines, and railway. A table-top exercise must be performed once a year; a full-scale exercise every three years. After any exercise, a review of the ERP should be normally performed.

6. Training framework developed within the project

The developed training framework includes specific training material prepared for four courses, namely:

(i) Safety reporting and safety management systems at ports with LNG storage

(ii) Risk assessment methodology for LNG storage and bunkering at ports

(iii) Consequences assessment of accidental scenarios involving LNG and

(iv) Emergency planning for sites storing LNG

The training material was developed by the project partners who carried out also lecturing at three physical training courses and adapted the material to the Moodle© platform[ii]. The training courses targeted the following groups: regional and national public authorities, higher education and research organizations, maritime operators (shipping) and their associations, port operators, visitors\attendees at the maritime industry fairs, and the general public.

The course on "Safety reporting and safety management systems at ports with LNG storage" covered the history of the major accidents, related legislation, criteria, and details of the obligations. Emphasis was on the purpose of the major accident prevention policy (MAPP) and prescribed seven elements of the Safety Management System (SMS), where their purpose, goals, and brief examples of their possible implementation within the organization's management system were given.

The course on “Risk assessment methodology for LNG storage and bunkering at ports” covered the major steps of Quantitative Risk Assessment (QRA,) methods for hazard identification, accident sequence modelling, and estimation of frequencies of damage states and risk indices and risk integration.

The course on “Consequence assessment of accidental scenarios involving LNG” covered the areas of LNG accidental scenarios on water and ground such as dispersion, pool fires, flash fires, jet fires, vapour cloud explosions, and rapid phase transition. Gap analysis and future needs of consequence modelling. Computational Fluid Dynamics (CFD) models is strongly advised for the analysis of LNG vapour dispersion, that is needed also for flash fires and vapour cloud explosion assessment.

The course on “Emergency planning for sites storing LNG” covered the areas of internal emergency planning and external emergency plans. In the case of internal emergency plans, data required according to the Seveso III Directive were presented

[ii] Course login page at: https://lngsafetyandsecurity.moodle.school/login/index.php

as well as mitigation and response measures in case of jet fire, pool fire, and flash fires. The external emergency planning covered the contents of the external plan, organisation required, the most important accidental scenarios, safety distances, information to the public, and the preparation for emergency exercises.

7. Conclusions

In the present paper, the main results of the SUPER-LNG project were presented. Starting with a literature review (scientific paper, international standards, and treaties, industrial guidelines), results include the development of safety reporting guidelines for port LNG facilities, the development of guidelines for emergency planning of LNG facilities at ports, and the creation of a training program for LNG stakeholders, such as port operators, maritime instructors, and port authorities. The training program was also carried out in physical and on-line versions and is freely available to all interested via Moodle™ platform.

Acknowledgments

The authors gratefully acknowledge the financial support of Adriatic-Ionian Program INTERREG V-B Transnational 2014-2020, project #118: SUPER-LNG - "SUstainability PERformance of LNG-based maritime mobility".

References

ABS, 2017. LNG Bunkering: Technical and Operational Advisory. American Bureau of Shipping. Available at: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_LNG_Bunkering_Advisory.pdf

ADR, 2017. ECE/TRANS/257 European Agreement Concerning the International Carriage of Dangerous Goods by Road, United Nations Economic Commission for Europe. Available at: http://www.unece.org/index.php?id=55276

Aneziris, O.N., Papazoglou, I.A., Konstandinidou, Nivolianitou, Z., 2014. Integrated risk assessment for LNG terminals, *J. Loss Prevention in Process Industries*, 28(1), 23-35.

Aneziris, O., I. Koromila, and Z. Nivolianitou, 2020. A systematic literature review on LNG safety at ports. *Safety Science*, 124, 104595. https://doi.org/10.1016/j.ssci.2019.104595

Animah, I. and Shafie, M., 2020. Application of risk analysis in the liquefied natural gas (LNG) sector: An overview, *Journal of Loss Prevention in the Process Industries*, 63, 103980. https://doi.org/10.1016/j.jlp.2019.103980

Bubbico, R., Salzano, E., 2009. Acoustic analysis of blast waves produced by rapid phase transition of LNG released on water, *Safety Science*, 47: 515-521. https://doi.org/10.1016/j.ssci.2008.07.033

Bureau Veritas, 2014. Guidelines on LNG Bunkering, Guidance Note NI 618 DT R00 E. Bureau Veritas.

Choi, B.C., Park, K.H., Doh, D.H., 2018. Impacts of initial temperature and cylindrical obstacles on the dispersing flammable limits of accidental methane releases in an LNG bunkering terminal. *Journal of Hazardous Materials*, 355: 104-110. DOI: 10.1016/j.jhazmat.2018.05.021.

DNV-GL (Det Norske Veritas & Germanischer Lloyd), DNV-GL "LNGi" database. 2016 (https://www.dnvgl.com/services/alternative-fuels-insight-128171).

DNV-GL, 2015. DNVGL-RP-G105: Development and operation of liquefied natural gas bunkering facilities (Recommended practice). Norwegian – Germanischer Lloyd. Available at: https://www.dnvgl.com/oilgas/download/dnvgl-rp-g105-development-and-operation-of-liquefied-natural-gas-bunkering-facilities.html

EC, 2012. Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC. European Commission. Available at: https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=celex:32012L0018

EMSA, 2018. Guidance on LNG Bunkering to Port Authorities and Administrations. European Maritime Safety Agency.

Gerbec M., Aneziris, O., Nivolianitou Z., 2020. *Deliverable 2.3.1: Guidelines for Safety reporting of LNG Infrastructure in port Areas*. Available at: https://superlng.adrioninterreg.eu/library/project-documents

IACS, 2016a. IACS Rec 142: LNG Bunkering Guidelines, 2nd Edition. International Association of Classification Societies and International Association of Classification Societies.

IACS, 2016b. IACS Rec 146: Risk Assessment as required by the IGF code. International Association of Classification Societies and International Association of Classification Societies.

IChemE, 2007. BP Process Safety Series, LNG Fire Protection and Emergency Response. Institution of Chemical Engineers. ISBN: 9780852955765. Check link at https://icheme.myshopify.com/products/lng-fire-protection-and-emergency-response-2nd-edition-2007-printable-pdf-format

IMO, 1997. Resolution MEPC.75(40) Amendments to the Annex of the Protocol of 1978 relating to the International convention for the prevention of pollution from ships, 1973. International Maritime Organisation.

IMO, 2011. Resolution MEPC. 203 (62) Amendments to the Annex of the protocol of 1997 to amend the International Convention for the prevention of pollution from ships, 1973, as modified by the protocol 1978. International Maritime Organisation.

ISO, 2015a. ISO/TS 18683: Guidelines for systems and installations for supply of LNG as fuel to ships. International Organisation for Standardisation.

ISO, 2015b. ISO/TS 16901: Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface. International Organisation for Standardisation.

ISO, 2017. ISO 20519: Ships and marine technology -- Specification for bunkering of liquefied natural gas fuelled vessels. International Organisation for Standardisation.

Jeong, B., B.S. Lee, P. Zhou, and S.M. Ha, 2017. Evaluation of safety exclusion zone for LNG bunkering station on LNG-fuelled ships. *Journal of Marine Engineering and Technology*, 16(3), 121-144. https://doi.org/10.1080/20464177.2017.1295786

Jeong, B., B.S. Lee, P. Zhou, and S.M. Ha, 2018. Determination of safety exclusion zone for LNG bunkering at fuel-supplying point. *Ocean Engineering*, 152, 113-129. https://doi.org/10.1016/j.oceaneng.2018.01.066

LNG Masterplan for Rhine-Main-Danube, 2015. Deliverable 2.4.4 Emergency and incident response study. Retrieved on https://www.prodanube.eu.

NFPA, 2019. NFPA 59A - Standard for the production, storage, and handling of liquefied natural gas (LNG). National Fire Protection Agency. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=59A

OREDA, 2015. Offshore and Onshore Reliability Data, 6th Edition. DNV. Available at: https://www.oreda.com/product/oreda-handbook-2015-6th-edition-volume-i-and-ii-shipping-april-15th

Papazoglou, I.A., and B. Ale., 2007. A logical model for quantification of occupational risk, *Reliability Engineering and System Safety*, 92, 785 - 803. https://doi.org/10.1016/j.ress.2006.04.017

Papazoglou, I.A., and O.N. Aneziris., 2003. Master Logic Diagram. Method for hazard and Initiating event identification in process plants. *Journal of Hazardous Materials,* A97, 11-30. https://doi.org/10.1016/S0304-3894(02)00244-3

Parihar, A., Vergara, C., Clutter, J.K., 2011. Methodology for consequence analysis of LNG releases at deepwater port facilities. *Safety Science*, 49 (5): 686-694. DOI: 10.1016/j.ssci.2011.01.004.

Park, S., Jeong, B., Yoon, J.Y., Paik, J.K., 2018. A study on factors affecting the safety zone in ship-to-ship LNG bunkering. *Ships and Offshore Structures*, 13: 312-321. DOI: 10.1080/17445302.2018.1461055.

Pio, G., Carboni, M., Iannaccone, T., Cozzani, V., Salzano, E. 2019. Numerical simulation of small-scale pool fires of LNG. *Journal of Loss Prevention in the Process Industries*, 61: 82-88. DOI: 10.1016/j.jlp.2019.06.002.

Pio, G., Salzano, E., 2018. Flammability parameters of liquified natural gas, *Journal of Loss Prevention in the Process Industries*, 56: 424-429. https://doi.org/10.1016/j.jlp.2018.10.002.

Pio, G., Salzano, E. 2019. The effect of ultra-low temperature on the flammability limits of a methane/ air/ diluent mixtures. *Journal of Hazardous Materials*, 362: 224-229. DOI: 10.1016/j.jhazmat.2018.09.018.

RIVM, 2009. Reference Manual Bevi Risk Assessments. National Institute of Public Health and the Environment (the Netherlands). Available at: https://www.rivm.nl/documenten/reference-manual-bevi-risk-assessments-version-32 .

SGMF, 2017. Bunkering of Ships with LNG - Competency and Assessment Guidelines version 2.0. The Society for Gas as a Marine Fuel. ISBN: 978-0-9933164-5-6

SIGTTO, 2001. A Guide to Contingency Planning for Marine Terminals Handling Liquefied Gases in Bulk, 2nd Edition, Witherby Publishing Group, UK.

SIGTTO, 2003. LNG operations in port areas - essential best practices for the industry. The Society of International Gas Tanker and Terminal Operator.

SIGTTO, 2004. Liquefied Gas Fire Hazard Management, 1st Ed., Witherby Publishing Group, UK.

SIGTTO, 2013. LNG ship to ship transfer guide for petroleum, chemicals and liquefied gases. The Society of International Gas Tanker and Terminal Operator.

SIGTTO, 2017a. LNG Emergency Release Systems. Recommendations, Guidelines and Best Practice. The Society of International Gas Tanker and Terminal Operator.

SIGTTO, 2017b. ESD arrangements & linked ship/shore systems for liquefied gas carriers & addendum. The Society of International Gas Tanker and Terminal Operator.

Sultana, S., Okoh P., Haugen S., Vinnem, E., 2019. Hazard analysis: Application of STPA to ship-to-ship transfer of LNG, *Journal of Loss Prevention in the Process Industries*, 241-252. https://doi.org/10.1016/j.jlp.2019.04.005

Sun, B., Guo, K., Pareek, V.K., 2017. Hazardous consequence dynamic simulation of LNG spill on water for ship-to-ship bunkering. *Process Safety and Environmental Protection*, 107: 402-413. DOI: 10.1016/j.psep.2017.02.024.

SUstainability PERformance of LNG-based (SUPER-LNG) project, financed by Adriatic-Ionian Programme INTERREG V-B Transnational 2014-2020, https://superlng.adrioninterreg.eu/

TNO, 1992. Methods for determination of possible damage to people and objects resulting from releases of hazardous materials : CPR 16E (Green Book), Voorburg. ISBN 9789053070529.

UK HSE, 2019. *UK HSE failure rate and event data for use within risk assessments* - FRED (02.02.2019). Available at: http://www.hse.gov.uk/landuseplanning/failure-rates.pdf

Vandebroek, L., Berghmans, J., 2012. Safety Aspects of the use of LNG for Marine Propulsion. Procedia Engineering, 45, 21-26. https://doi.org/10.1016/j.proeng.2012.08.114

Vanem, E., Pedro Antão, P., Østvik I., de Comas, F., 2008. Analysing the risk of LNG carrier operations. *Reliability Engineering & System Safety*, 93, 1328-1344. https://doi.org/10.1016/j.ress.2007.07.007

VVF, 2015. Circolare 18 maggio 2015, prot. n. 5870 Ministero dell'Interno, Dip. VV.F- Guida tecnica ed atti di indirizzo per la redazione dei progetti di prevenzione incendi relativi ad impianti di distribuzione di tipo L-GNL, L-GNC e L-GNC/GNL per autotrazione. Retrieved on: http://www.vigilfuoco.it/sitiVVF/ascolipiceno/downloadFile.aspx?s=85&f=47706)