



SUPER-LNG



DELIVERABLE T2.1.1: HARMONIZING BEST PRACTICES FOR SAFETY ASSESSMENT AND REFERENCE TECHNICAL STANDARDS



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ABBREVIATIONS/DEFINITIONS

ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways.
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road.
BS	Bunkering Ship
CDI	Chemical Distribution Institute
Directive 2008/68/EC	On the inland transport of dangerous goods
Directive 2014/94/EU	On the deployment of alternative fuels infrastructure.
EN 12065	Installations and equipment for liquefied natural gas (LNG) - Emulsifying tests for the production of medium and high expansion foam and powders for the extinguishing of liquefied natural gas fires.
EN 12066	Installations and equipment for liquefied natural gas (LNG) – Tests on insulating coatings of liquefied natural gas containment basins.
EN 12308	Installations and equipment for liquefied natural gas – Tests of suitability for the use of gaskets for flanged fittings in LNG pipes.
EN 13645	Installations and equipment for liquefied natural gas – Design of onshore installations with a storage capacity between 5T and 200T.
EN 1473	Installations and equipment for liquefied natural gas (LNG) – Design of ground installations.
EN 1474-2	Installations and equipment for liquefied natural gas - Design and testing of marine transfer equipment - Part 2: Design and testing of transfer hoses.
EN 1474-3	Installations and equipment for liquefied natural gas - Design and testing of maritime transfer equipment – Part 3: Offshore transfer systems.
EN 1532	Installations and equipment for liquefied natural gas - Earth-ship interface.
EN 16348	Gas infrastructure - Safety management system (SMS) for gas transport infrastructure and pipeline integrity management system (PIMS) for gas transport pipelines Functional requirements.
EU Ports Regulation 2017/352	Establishing a framework for the provision of port services and common rules on the financial transparency of ports.
FS	LNG-fueled ship
HSE	Health and Safety Executive
IACS	The International Association of Classification Societies
IACS REC 142	LNG bunkering guidelines
IACS REC 146	Risk assessment as required by the IGF Code
ICS	International Chamber of Shipping
IGC Code	Code for the Construction Equipment of Ships Carrying Liquefied Gases in Bulk
IGF Code	Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
IMO	International Maritime Organisation
ISO 12614:2014	Road vehicles -- Liquefied natural gas (LNG) fuel system components.
ISO 12617:2017	Road vehicles -- Liquefied natural gas (LNG) refuelling connector -- 3,1 MPa connector.
ISO 12991:2016	Liquefied natural gas (LNG) -- Tanks for on-board storage as a fuel for automotive vehicles.
ISO 16903:2015	Petroleum and natural gas industries -- Characteristics of LNG, influencing the design, and material selection.
ISO 16904	Petroleum and natural gas industries -- Design and testing of LNG marine transfer arms for conventional onshore terminals.
ISO 16924:2016	Natural gas fuelling stations -- LNG stations for fuelling vehicles.
ISO 18132:2011	Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels -- General requirements for automatic tank gauges.
ISO 19970:2017	Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels -- Metering of gas as fuel on LNG carriers during cargo transfer operations.
ISO 20088-1:2016	Determination of the resistance to cryogenic spillage of insulation materials.



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ISO 20519:2017	Ships and marine technology -- Specification for bunkering of liquefied natural gas fuelled vessels.
ISO 28460:2010	Petroleum and natural gas industries -- Installation and equipment for liquefied natural gas -- Ship-to-shore interface and port operations.
ISO/TR 17177:2015	Petroleum and natural gas industries -- Guidelines for the marine interfaces of hybrid LNG terminals.
ISO/TS 16901:2015	Guidance on performing a risk assessment in the design of onshore LNG installations including the ship/shore interface.
ISO/TS 18683:2015	Guidelines for systems and installations for the supply of LNG as fuel to ships.
ISPS Code	International Ship and Port Facility Security Code
NFPA 52	Vehicular natural gas fuel systems code.
NFPA 59A	The standard for the production, storage, and handling of liquefied natural gas (LNG).
OCIMF	The Oil Companies International Marine Forum
Seveso III Directive	EU Directive (2012/18/EU) on the control of major-accident hazards involving dangerous substances.
SGMF	The Society for Gas as a Marine Fuel
SIGTTO	The Society of International Gas Tanker and Terminal Operators
SOLAS	Safety Of Life At Sea
STCW	Standards of Training, Certification, and Watch-keeping for Seafarers



SUMMARY

This report presents the gap analysis and the results of the discussion among partners for what concerns the harmonization of best practices for safety assessment and for the choice of reference technical standards for the use of Liquefied Natural Gas (LNG) in harbor of the Adriatic and Ionian coasts, starting from the scientific and technological achievement reported in the deliverable of WP1: Report on International regulations and technical standards for LNG in maritime activities.

The document defines the advancement and the procedures for the safety and security of LNG for each of the three main countries involved in the project: Greece, which includes the port of Piraeus and the port of Patras; Slovenia, which includes the port of Koper; and Italy, which includes the port of the Apulia-based south Mediterranean maritime system, which includes the harbor of Bari, Brindisi and other ports as Barletta and Manfredonia.



INTRODUCTION

From a regulative perspective, LNG projects can be divided into two parts: the maritime side which is usually regulated by a national authority, and the land side of the project, usually covered by a local authority (e.g., national Maritime Authorities and affected municipalities or rescue services). Road transports are regulated by the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) applicable from 1 January 2019 (United Nations Economic Commission for Europe (UNECE), 2018).

The international (global or regional) regulatory frame is composed of four essential levels plus a possible fifth level that can be added (port regulations can specify local regulatory environment for LNG Bunkering):

1. High-level regulations (EU directives, IMO regulations)
2. Standards (ISO, CEN)
3. Class rules
4. Industry guidelines and guidance notes
5. Local port regulations

The necessary regulative permit process can start once the terminal layout has been decided. For the onshore installation, building and environmental permits are required, in addition to compliance with Directive 2014/94/EU on the deployment of alternative fuels infrastructure (European Commission, 2014), Seveso III directive (Directive 2012/18/EU) (European Commission, 2012b) and other European directives as implemented by member states' laws. It is important to note that the Seveso III directive does not apply to the transport of dangerous substances and directly related intermediate temporary storage outside the establishments covered by the scope of the Directive. Loading and unloading of dangerous goods and the related safety aspects are in principle governed by the *Accord européen relatif au transport international des marchandises Dangereuses par Route* (ADR). This is an international treaty on transport signed by the European countries but not limited only to Europe. The truck-to-ship bunkering scenario is not a typical unloading situation, but rather a process-operation that is not covered in transport instrument requirements. The truck may affect the assessment of the location in which it is parked, and it may also be relevant whether or not the tractor is uncoupled from the container during the fuelling. Typically, the competent authorities also apply time limits (e.g., 24h) above which 'intermediate temporary storage' can no longer be claimed. This particular situation may be subject to a case by case assessment by the bunker facility operator and port authorities & administrations, in cooperation with the competent authorities.

The environmental permit process follows the requirements set by the environmental impact assessment (EIA) directive (Directive 2011/92/EU) (European Commission, 2012a). Together with Seveso III, the EIA Directive is a relevant instrument for LNG bunkering projects, especially for the permitting processes. As LNG bunkering projects fall under Annex II of the EIA Directive and Member States may have introduced different thresholds or criteria for this type of projects, it is essential to verify the applicable national legislation. It is the responsibility of each Member State to identify the thresholds and criteria for LNG storage capacity above which the provisions of the EIA Directive apply. Whether an LNG project, with local small-scale storage, would be subject to an EIA should be a result of a determination in accordance with national legislation transposing Art. 4(2)-(6) of the EIA Directive.



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For the maritime side, all installations where LNG is used as fuel, the IMO IGF Code (International Maritime Organization (IMO), 2015) is applicable, whether for LNG carriers, the IGC Code applies (International Maritime Organization (IMO), 2016).

Following standard concepts for the risk analysis, the following sections are based on hazard identification and consequences assessment procedures.



1. RISK MANAGEMENT RECOMMENDATIONS FOR LNG BUNKERING OPERATIONS:

The analysis of the available documents allowed to identify the typical hazards usually relevant for LNG plants. Management of emerging risk linked to both offshore and onshore LNG terminals were addressed within the iNTeg-Risk research project, carried out under the 7th Framework Program (EU grant number CP-IP-21345-2). As a result of this study, a specific guideline was issued (“Blue Book”), collecting methods and new techniques for the safety assessment of LNG terminals, in addition to a review of state-of-the-art consequence assessment models specifically related to LNG hazards (Cozzani *et al.*, 2011). Considering technical standards literature, the reference types of hazards to be evaluated during hazard assessment are provided in the form of lists. This analysis represents a minimum requirement of the technical standard, whereas some freedom is granted on the hazard identification techniques to be used. The ISO/TS 16901:2015 standard specifies types of accident scenarios to be considered for LNG import/export terminals. The specifics of the given accident scenarios (e.g., release size and associated base frequencies) are however not provided. There is a need for a complete and detailed definition of credible accident scenarios that can occur during the operation of Small-Scale LNG installations and activities. The CEN standard 1473:2007 propose a subdivision of hazards for LNG plants in two classes, depending on the origin of the threat: i) hazards of internal origin, arising from both LNG and non-LNG related process operations and loss of containment; and ii) hazards of external origin, arising from outside the plant.

The hazards of internal origin can be further distinguished in hazards related to loss of containment of LNG or natural gas and hazards which are not specific to natural gas.

The hazard related to loss of containment of LNG and natural gas depends on the hazardous properties of these materials and the process conditions. LNG and natural gas are flammable materials and may be present in the plant at low temperatures and/or high pressure. The standard ISO 16903:2015 identifies the main hazards related to LNG which result from the physical and chemical properties, cryogenic temperatures, dispersion characteristics, and flammability characteristics:

- Cryogenic damage – metal embrittlement, cracking, structural failure;
- Cryogenic injuries – frost burns;
- Asphyxiation – if air oxygen is replaced, methane asphyxiation may occur;
- Reduced visibility due to un-ignited vapor clouds;
- Thermal radiation from various fire scenarios:
 - delayed or immediate ignition of vapor clouds (flash fire), slow fire front;
 - delayed or immediate ignition of a vapor-air mixture (fireball), rapid burn;
 - LNG pool fires;
 - flame jets from leaks in pipes, hoses, tanks or pressure vessels
- Rapid phase transition, RPT;
- Vapour cloud explosion (in confined spaces and enriched with other hydrocarbons);
- Boiling liquid expanding explosions (BLEVE);
- Rollover in LNG storage tanks;
- Pipe burst – violent expansion of trapped LNG from a quiescent liquid in piping.

Internal hazards which are not specific to LNG are related to the presence of other hazardous



materials and equipment in the plant. Qualitatively, they do not differ from the analogous hazards commonly found in process and chemical industries. For example, the (non-exhaustive) lists of external hazards contained in EN 1473:2007 includes dangerous situations arising from:

- LPG and heavier hydrocarbon storage;
- simultaneous loadings on multi-product jetty;
- poor communication between ship and shore;
- traffic within the plant both during construction and operation;
- leakage of other hazardous substances, in particular, flammable refrigerant;
- missiles originating from an explosion;
- pressurized and steam raising equipment;
- fired heaters and boilers;
- rotating machinery;
- utilities, catalysts, and chemicals (fuel oil, lubricating oils, methanol, etc.);
- pollutants found in the feed gas of liquefaction plants;
- electrical installations;
- harbor installations associated with the LNG plant;
- security issues (e.g., intrusion, sabotage);
- accidents during construction and maintenance;
- escalation of accidents.

Considering the hazard of external origin, hazards typical of chemical & process plants are generally considered beside hazards related to specific features of interest for LNG terminals (e.g., exposure to sea conditions, presence of floating vessels, be potential aims for terrorist attacks, etc.). This leads to a quite extensive list of hazards that varies in the application according to specific cases. The minimum requirements for on-shore plants, described in EN 1473:2007, include the analyses of the hazards caused by:

- LNG carriers approaching the berth at excessive speed or angle;
- the possibility of collision with the jetty and/or LNG carrier at berth by heavy displacement vessels passing the berth;
- the impact of projectiles and consequences of collision (ship, truck, plane, etc.);
- natural events (lightning, flooding, earthquakes, tidal bores, icebergs, tsunamis, strong winds, etc.);
- ignition by high energy radio waves;
- proximity of airport and/or flight-paths;
- a “domino effect” resulting from fires and/or explosions at adjacent premises;
- flammable, toxic or asphyxiant drifting gas clouds;
- permanent sources of ignition, such as high voltage power lines (corona effect);
- the proximity of the site to any external uncontrolled sources of ignition.

The external causes related to security issues have received significant interest in the last years. Though, the assessment practice in the safety reports is different and differs case by case. A widely recognized reference document that treats the floating units (either carriers of floating terminals) is the SAND2004 6258 report issued by Sandia National Laboratories (Hightower *et al.*, 2004). Besides the damages to the ship due to accidental events (e.g. collisions, grounding, ramming), the report considered four main categories of intentional damage events:



1. Ramming: it could occur between an LNG unit and a fixed object or between a boat (any size) and an LNG unit.
2. Triggered Explosion: these events assume pre-placed explosives, either on the ship or in a fixed location (e.g., mine).
3. Insider Takeover or Hijacking: the control of a ship or the sabotage of a plant section by unauthorized/malicious people can lead to several undesirable events (e.g., ram intentionally an LNG vessel into a critical infrastructure element, breach, and spill of an LNG cargo tank through use of explosives or by overriding offloading system safety interlocks to discharge LNG intentionally onto the ship, onto unloading terminal equipment, or onto the water). A ship hijacking may require coordinated efforts by insiders or others.
4. External Terrorist Actions: they could come from several paths, including the attack of the LNG ship with a wide range of munitions or bulk explosives (U.S.S. Cole-type attack, attacks with munitions such as rocket-propelled grenades, attacks by missiles, attacks by planes, etc.).

1.1 HAZARD IDENTIFICATION TECHNIQUES

In case of a loss of containment a potential hazard to people and property may occur. As well known, the comprehensive identification of potential hazardous scenarios is critical. Common loss of containment accidents, based on historical data, can be sorted by relevance, intended as likelihood of occurrence. A consolidated list of hazards (from historical accidents and site specific HAZID/HAZOP studies) should be considered.

As demanded by standards ISO/TS 18683:2015 and ISO 20519:2017, the current industry practice is to perform an HAZID for LNG activities, especially in case of particular circumstances, when the risks are not fully known, such as simultaneous operations (SIMOPS), or in case of non-standard LNG bunkering scenarios, as described in ISO/TS 18683:2015. Some authorities also request an HAZID to be carried out as part of the permitting process, even though this usually is not explicitly mandated in legislation.

The purpose of the HAZID review is to identify hazards using a risk matrix. The HAZID shall also identify risk-reducing measures for all hazards representing medium or high risks. The HAZID should consider accidental spills and identify technical and operational safeguards. The HAZID shall also determine maximum credible release scenarios as a basis for the determination of the safety zones as required by ISO 20519:2017.

An HAZOP is a structured and systematic examination which can be referred to a complex planned, an existing process, or an operation, and it identifies and evaluates problems that may represent risks to personnel or equipment. The intention of performing an HAZOP, in the specific context of LNG Bunkering, is to review the design to pick up design and engineering issues that may otherwise not have been found. The HAZOP technique is qualitative and aims to identify potential hazards and operability problems. Structure and direction are given to the review process by applying standardized guide-word prompt to the review of each node. Guidance for conducting a HAZOP for LNG bunkering operations is detailed in the Annex of IACS Rec.142 (International Association of Classification Societies (IACS), 2016).



1.2 CONSEQUENCE EVALUATION

Modeling tools for the consequence evaluation of the major LNG-related accidents are described shortly in this section. A review of source term and consequence models can be found in the cited literature (see WP1 del for more details).

Published research on LNG spills includes reviews by Prince (Prince, 1983), Thyer (Thyer, 2003), Luketa-Hanlin (Luketa-Hanlin, 2006), ABS Consulting (ABS consulting, 2004) and Hightower et al. (Hightower *et al.*, 2004) which consider data on spills of LNG and other cryogenics on land and water. In the 1970s, spills of LNG onto water were investigated by the US Bureau of Mines (Burgess, Biordi and Murphy, 1972), Esso (G.F. Feldbauer *et al.*, 1972) and Shell (Boyle and Kneebone, 1973). Reid and co-workers at MIT examined spills of LNG onto a range of dike floor materials (e.g., Drake, Jeje and Reid, 1975; Reid and Wang, 1978; Valencia-Chavez and Reid, 1979). Other work on LNG spills on solid surfaces is the one made by Moorhouse (Moorhouse and Pritchard, 1982).

The loss of containment of LNG can result in a wide range of situations, depending on storage and local ambient conditions. Possible source terms are liquid jets, two-phase jets, evaporating pools, sub-sea releases. A review of the important physical processes which determine the development of the source and how these processes can be parameterized is presented below.

A typical loss of containment may be due to a process equipment failure, involving piping or storage tanks. An LNG release that occurs in a storage facilities or during a bunkering operations could be determined by a huge number of different events, such as:

- Overfilling of the bunkering tank;
- Rollover;
- Bunker barge collision with another ship;
- Ship grounding or striking;
- Overpressure;
- Terrorist attack;
- Sabotage by insider;
- TPI (third party interference);
- Corrosion;
- Operations or unloading accident (e.g., failure of transfer system);
- Harsh natural phenomena (earthquake, tsunami, etc.);
- Airplane collision;

A fundamental step of the consequence assessment is the quantification of the amount released during the loss of containment event. Releases can be categorized based on their physical state (i.e., liquid, vapor or two-phase release) and duration (instantaneous, continuous or semi-continuous). The amount of hazardous substance released may vary substantially depending on the liquid level, size and location of rupture, operation and emergency shutdown conditions, double containment and in general on primary and secondary safety measures. Release rate calculations should take into consideration all possible controlling mechanisms involved in the heat and mass transfer processes.



LNG can be stored at its atmospheric boiling point (approximately -162 °C) or in pressurized tanks, equipped with a pressure relief valve, at higher temperature. Most spill scenarios occur at atmospheric pressure, and the amount of liquid released is determined by the static liquid head above the release point. In case of releases from pressurized vessels or piping, a jet fire could occur, and in case of a catastrophic failure of the containment vessel, a BLEVE could result.

After any spill event, the LNG immediately vaporizes, forming a white condensation cloud of cold vapors. If the spill takes place upon water, the LNG can start to mix with the water and due to the high value of the water heat capacity and a huge temperature difference an RPT event may occur. Spills on calm water can become similar in behavior to spills on land, because of ice formation, which may decrease the evaporation rate over time. The vaporization rate is a crucial parameter for the consequence evaluation because it influences the distance at which the lower flammability limit (LFL) is reached and the burning rate of pool fires.

In case of leakage from small holes in tank or pipe, the liquid outflow rate can be predicted by Bernoulli's theorem, otherwise, in case of flash within the pipe, through a Homogeneous Equilibrium Model (HEM), based on the resolution of the combined balance equations and stoichiometric relationships. In the absence of models that consider the actual structure of the tank and physics of cryogenic release, the orifice model is commonly adopted:

$$Q = C_D \pi \rho_L R^2 \sqrt{2gH}$$

where Q is the liquid volumetric outflow, C_D the efflux coefficient, ρ_L the liquid density, R the equivalent hole radius, g the gravity acceleration and H the hydrostatic head. This model, ignoring the presence of additional barriers existing in storage tanks or vessels (all with double hull) and phenomena such as reducing pressure in the tank as a result of leakage, in many situations overestimates the flow discharged.

The typical events that can follow the spillage of LNG on ground or water surfaces, which are explained in more detail underneath, are:

- 1.2.1 Pool spreading and evaporation
- 1.2.2 Flash fire
- 1.2.3 Jet fire
- 1.2.4 Pool fire
- 1.2.5 Rapid phase transition

1.2.1 Pool spreading and evaporation

Following the spillage of LNG on ground or water surfaces, a liquid pool could be formed. Subsequently an LNG evaporation occurs until the balance among the LNG release rate, gravitational spread, surface tension effects, heat transfer, and gas boil-off is reached. In case that the pool is confined to a bund, or to enclosures between the offloading shore and the LNG ship or between two LNG ships during ship-to-ship bunkering, the pool surface is limited. If the liquid pool is unconfined, it can spread and evaporate depending on the liquid and ambient conditions and on the release surface kind, hence the surface area of the pool will be time-dependent.



In case of a release of a significant amount of LNG the dimensions of the resulting are dependent on the surface characteristics. Initially, the pool have a limited radius on ambient but as long as the heat is transferred from the various heat sources to the pool, the spread and vaporization rate can vary. Following indications of the Yellow Book by TNO, (Van Den Bosh and Weterings, 2005) the heat transfer mechanism involving an LNG pool are:

- Heat conduction from the surface beneath,
- Convection from air,
- Solar and long-wave radiation heat flux.

In the analyzed literature, most of the experiments concerning LNG spreading on the water were conducted before 2007. Those experiments were on small scales, and application of such experiments results to large-scale applications are known to have the main technical uncertainties in terms of the dynamics of the front of the spreading pool and the heat-transfer rate (Luketa-Hanlin, 2006). It is important to note that current understanding of LNG spills over water is conservative, where an average value of vaporization rate is used although it is a transient parameter that can change with time. Models involving an average vaporization rate lack in experimental validation in the analyses that have a direct influence on the exclusion zones (Gopaldaswami *et al.*, 2014).

1.2.2 Flash Fire

A flash fire is the non-explosive combustion of a flammable vapor cloud resulting from a release of LNG into the open air. A dispersed cloud of methane and any other hydrocarbons present can be ignited anywhere where the concentration is between the respective flammability limits. Ignition is typically located at the edge of the cloud, but if it occurs in the middle, and if the cloud is narrow, it has been observed that the combustion front is almost flat, like a vertical wall moving both backs toward and away from the source. Once ignited, the cloud will expand upon combustion, like explosions, typically by a volume factor of around 8 (Woodward and Pitblado, 2010) and will “flash back” across all its flammable mass and will burn at the UFL boundary until all hydrocarbons are burned. Eventually, the fire will reach to the source and may ignite, causing a pool fire or a jet fire, depending on the characteristics (duration, momentum, etc.) of the emission considered. Combustion velocities measured in laboratory-scale tests are usually in laminar flow conditions. Lees (Mannan, 2005) reports that, in general, laminar burning velocities for saturated hydrocarbons range from a few cm/s near the flammability limits to about 45 cm/s near the average stoichiometric concentration. Methane has a reported maximum laminar flame velocity under laboratory conditions of 36 cm/s. In the presence of congestion or confinement, flame speeds can accelerate due to turbulence generated by obstacles, reaching velocities in the range of a few m/s up to 10.

Since the whole process involved in a flash fire is transient and quite fast, flame duration and intensity for most flammable clouds are insufficient to cause a significant thermal radiation hazard outside the flame envelope; hence a flash fire hazard exists to people within the flame.

1.2.3 Vapour cloud explosion

A vapor cloud explosion (VCE) refers to combustion of a large cloud of fuel-air mixture in open atmosphere. There are two types of VCEs: deflagrations and detonations. Detonations occur at supersonic to sonic speed relative to the unburned fuel and with shock wave generation. In order to have a vapor cloud detonation, a strong source of ignition is required. Moreover, detonations normally occur with highly reactive materials such as acetylene, hydrogen, and ethylene. Methane and LNG mixtures are considered of low to medium reactivity and do not



detonate (Woodward and Pitblado, 2010). Hence only deflagrations are of concern. Flame speeds and overpressure resulting from deflagrations are determined not only by fuel-air mixture composition but also by congestion, confinement, and fuel reactivity, which produce the flame acceleration

Medium and large-scale experiments performed by igniting stoichiometric concentrations of completely unconfined gas developed only low flame speeds with no flame acceleration and only minor overpressures (Harris and Wickens, 1989). It is recognized that a deflagration develops only when the LNG vapors are either partially confined or are within a highly congested region where flame speeds are accelerated by flowing around numerous obstacles (Bjerketvedt, Bakke and van Wingerden, 1997). However, in the Buncefield accident report, it is concluded that a vapor cloud passing over a dense line of trees might have resulted in rapid flame acceleration that can cause a VCE which may also transition to a detonation (Steel Construction Institute, 2009). The few large-scale experimental tests with LNG reported in the literature (e.g. China Lake, Maplin Sands, and Coyote tests) resulted in all cases in very low flame speeds, hence in the negligible generation of blast waves capable of significant damages. A series of large-scale vapor cloud explosions in a congested region were conducted by Lowesmith (Lowesmith, Hankinson and Johnson, 2011) using methane/hydrogen mixtures in order to determine factors that could lead to continued flame acceleration through the congested region. Methane VCE tests explored the effects of initial flame speeds entering the congested region, showing that a higher initial speed resulted in higher peak overpressures and that a limiting flame speed was achieved.

1.2.4 Jet fire

A leak from a pressurized pipeline or the base of a large tank may lead initially to jetting of the liquid. For the case of an unobstructed jet, a significant fraction of the LNG may vaporize in the air before the liquid rains out and forms a pool, as shown in tests undertaken by Advantica (Cleaver, Johnson, and Ho, 2007) and Shell (Kneebone and Prew, 1974). Jet fires can impinge upon buildings and process equipment and act, literally, like a blowtorch. They generate very high heat fluxes and can burn through most objects given enough exposure time. However, the reach of jet fires is minimal, especially for liquid jets, typically less than 50 m. The nature of the jet and hence the amount of vaporization from the jet will depend upon the ambient temperature, the pressure, and temperature of the LNG, the initial velocity of the liquid, the orifice size and shape, the fluid trajectory, atomization of the liquid spray and the entrainment rate of fresh air. For small-scale LNG terminals in the proximity of ports installations, the jet-fire hazard is more significant in units where LNG flows at relatively high pressure (for example transfer equipment); thus, a higher momentum jet may be formed after an accidental release. Radiation from the jet is the critical aspect to be modelled for consequence estimation of this kind of fire scenario. The jet fire model is either a point source model or a solid flame model. Three levels of detail can be distinguished, with increasing precision, but also resources and computational costs:

- Empirical correlations
- Integral models
- Distributed parameters models (CFD-based models)

1.2.5 Pool Fire

Releases of LNG from process equipment lead to pools formation. When an LNG spill is ignited on a horizontal, solid surface in open areas, within enclosures, or on sea surfaces, a pool fire



takes place. LNG pool fires pose the greatest hazard to people and structures from loss of containment incidents. The largest LNG pool fires are expected to be from LNG impoundment sumps or diked areas around an LNG storage tank or from an unconfined spill from a tank of an LNG carrier at sea (Woodward and Pitblado, 2010). Once a pool forms, its size is limited by the evaporation (before ignition) and evaporation and combustion (after ignition). For LNG releases over water, the shape and size can be affected by environmental conditions, such as wind, waves, and currents. For continuous release, the pool will spread until the burn rate matches the rate of addition from the spill. The main hazard related to pool fires comes from the significant amount of thermal radiation generated, which is influenced by different parameters such as the geometry of the flame and the location of the target body with respect to the fire. Physical aspects such as emission characteristics of the fire, smoke blanketing, and radiation atmospheric absorption will also have a significant influence over fire consequences. Pool fires are buoyancy-driven, phenomena influenced by large turbulent eddies that control the air entrainment. The characteristic of fire results in an "intermittent" fire, whose shape is readily affected by variations in local wind speed and air turbulence.

1.2.6 Rapid Phase Transition

In case of an LNG release on water, a rapid phase transition (RPT) can occur. This is a very rapid physical phase transformation of LNG liquid to methane vapor when in contact with sea water.

RPT does not involve any combustion and cannot be characterized as a detonation even at near distances, due to low energy. Hence, the pressure pulse created by small pockets of LNG that evaporates instantaneously when superheated (by mixing in water) decay as any other pressure pulse.

The hazard potential of rapid phase transitions can be severe but is highly localized within or in the immediate vicinity of the spill area. It does not depend on ignition but can be potentially damaging weak structures on the ship or more in general atmospheric equipment, because of domino effects induced by the pressure wave propagating from the evaporation surface, whereas it is unlikely that large structural elements of a ship would be damaged. Furthermore, the damage from RPT explosion could be limited by good design of the LNG vessel.

1.3 RISK ASSESSMENT

Risk assessment of LNG terminals is carried out following conventional quantitative risk assessment (QRA) steps as for all the other Seveso installations in European countries. Various techniques, methodologies, guidelines, and tools used for the general analysis of the risks of activities with hazardous substances were identified. These are commonly used to determine external safety distances between major hazard industrial facilities (or activities) and surrounding land-uses (e.g. vulnerable objects such as residential areas).

A bunkering operations risk assessment should be undertaken in accordance with ISO/TS 18683. This technical specification is specific to the supply of LNG as fuel to ships and refers to recognized standards that provide detailed guidance on the use and application of risk assessment. The objectives of the bunkering operations risk assessment are to demonstrate that risks to people and the environment have been eliminated where possible, and if not, mitigated as necessary, and to provide insight and information to help set the required safety zone and security zone around the bunkering operation.



In order to meet these objectives, as a minimum, the bunkering operations risk assessment should cover the following operations:

- Preparations before and on ship's arrival, approach and mooring
- Preparation, testing, and connection of equipment
- LNG transfer and boil-off gas (BOG) management
- Completion of bunker transfer and disconnection of equipment
- Simultaneous operations (SIMOPS)

Following the indication of ISO/TS 18683, the risk assessment shall be carried out in agreement with recognized standards, such as ISO 31010, ISO 17776 and ISO 16901. Moreover, the risk analysis shall be carried out with a team ensuring an objective and independent assessment.

As required by ISO/TS 18683 a qualitative risk assessment needs to be carried out as a minimum requirement for bunkering installations complying with the defined standard bunkering scenarios as described in ISO/TS 18683 (i.e., TTS, PTS or STS). In case of any deviation from the standard bunkering scenarios as defined by the ISO standard, the qualitative risk assessment shall be supplemented by a detailed assessment of the deviations as agreed with the regulator. This is achieved by means of a quantitative risk analysis (QRA) in order to demonstrate that the overall acceptance criteria are met and that implemented safeguards compensate for not meeting all requirements.

The requirement for a QRA (in addition to a Qualitative Risk Analysis - QualRA) is normally determined by the Administration or Port Authority based on the conclusions and outcomes of the QualRA.

A QRA is recommended when:

- a. Bunkering is not of a standard type (PTS, TTS or STS, in simple standard configuration, as defined in ISO/TS 18683);
- b. Design, arrangements, and operations differ from the guidance given in ISO/TS 18683 or IACS Rec.142;
- c. Simultaneous Operations (SIMOPS) are planned to take place along with LNG bunkering.
- d. Automation elements are introduced to significantly reduce human intervention in operations (linked to system analysis)
- e. A reduction in a Safety Zone is intended, based on consequence/ probabilistic data for the specific LNG bunkering location
- f. Whenever a numerical calculation of Risk is required for verification of any given Risk Criteria.

For assessing LNG operations, the QRA shall consider all possible bunkering configurations reflecting the variety of ships to be bunkered. Furthermore, the qualitative risk assessment shall, as a minimum, comprise the following elements:

- SCOPE: Definition of study basis and familiarization with the design and planned operation of the bunkering facility
- Hazard Identification: This activity is divided into two main parts, a higher level HAZID, included in the context of a QualRA, followed by a more detailed HAZOP. The aim of



this task is to identify risk-reducing measures for all hazards representing medium or high risks. The HAZID/HAZOP should consider accidental spills and identify technical and operational safeguards. Maximum credible release scenarios are identified to provide a basis for the determination of the safety zones;

- CRITICAL HAZARDS for Modelling and Risk Analysis
- SAFETY ZONE: Determination of safety zones in accordance with guidance given in annex B of ISO/TS 18683 or ISO standard 20519.
- REPORT: Study assumptions, methodologies, operational safety measures, and key findings shall be reported. The QRA report shall be submitted to authorities as part of the permitting documentation.

1.4 QRA METHODOLOGY

A quantitative risk assessment is a well-known and widely accepted methodology to quantify safety risks. It is a risk-based approach: a combination of the consequences derived from a range of possible accidents and the likelihood of the accidents defines the risk, which can be represented as individual or societal to express the results of QRA. LUP criteria are based on specific acceptability criteria with respect to the calculated risk. A QRA can give insight into the risks to human life or property of certain activity by calculating the potentially hazardous effects of a variety of scenarios as well as considering the probability of occurrence of these scenarios.

Objectives of a QRA study are:

- Quantify the level of safety risks (to people or property) associated with the operation of a plant or activity with hazardous materials,
- Demonstrate that the levels of risks are in compliance with risk acceptance criteria as agreed with authorities.
- Evaluate and select safeguards and risk-reducing measures, if needed.

A typical QRA follows a five steps methodology, which are explained in more detail underneath:

- 1.4.1 Hazard Identification
- 1.4.2 Consequence Modelling
- 1.4.3 Frequency Estimation
- 1.4.4 Risk Assessment
- 1.4.5 Risk Management

1.4.1 Hazard identification

The first phase of risk assessment consists in analyzing the installation to identify potential accident initiators, assess the response of the plant to these initiators and establish end damage states of the plant resulting in the release of a dangerous substance in the environment.

As requested by ISO/TS 18683 standard, the HAZID shall as a minimum consider the following hazardous events:

- 1) LNG releases:
 - a. failure of QC/DC or ERC equipment;
 - b. hose or loading arm failure due to:



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- i. design flaws;
 - ii. excessive loads due to dropped objects or collision and impacts from ships or trucks;
 - c. ships mooring failure;
 - d. pressure surge in transfer lines;
 - e. releases from piping systems;
 - f. incorrectly planned or performed maintenance;
 - g. incorrect operational procedures including:
 - i. cooling down;
 - ii. connection;
 - h. over-filling and over-pressurization of ships bunker tanks (e.g. by flashing, incorrect bunker rate or bunkering procedure);
 - i. over-pressure of transfer systems caused by thermal expansion or vaporization of trapped LNG;
 - j. possible rollover in bunker tanks caused by loading LNG of different densities.
- 2) Ignition sources:
- a. electrical hazards;
 - b. other ignition sources;
 - c. activities inside the safety zone;
 - d. gas dispersion beyond the safety zone.
- 3) Release of nitrogen, asphyxiation.

The hazardous effects that should be considered include:

- 1) Fire hazards:
- a. structural failure and escalation due to high temperatures;
 - b. injuries to personnel;
 - c. damage to equipment;
 - d. ignition of secondary fires;
 - e. potential BLEVE of pressurized fuel tank subjected to a fire.
- 2) Possible vapor cloud deflagration/flash fires:
- a. damage to equipment and escalation;
 - b. injury to personnel;
 - c. damage to fire-fighting equipment and safeguards.
- 3) Cryogenic hazards:
- a. structural failures incl. brittle fracture of the steel structure exposed to LNG spills;
 - b. frostbite or asphyxiation from liquid or cold vapor spills;
 - c. possible rapid phase transition caused by LNG spilled into the water.

1.4.2 Consequence modelling

This step is needed in order to evaluate the resulting effects in case of accidents occur, and their impact on people and property. Ignited flammable releases can result in different consequences such as jet, pool, or flash fire, fireball or vapor cloud explosions depending on the type of scenario and time and place of ignition. The consequence assessment shall be carried out using recognized consequence modelling tools that can determine the resulting effects and their impact on personnel, equipment, and structures. These tools are generally validated by experimental test data appropriate for the size and conditions of the hazard to be evaluated.



Reference is made to paragraph 1.2 for more information regarding leading consequence and risk assessment tools and their suitability to quantify consequences or risks of potential accidents occurring in LNG installations or during activities.

1.4.3 Failure frequencies

The frequency at which hazardous events or scenarios may happen can be estimated following various common techniques such as:

- Historical analysis of incidental data
- Fault tree analysis
- Event tree analysis

There are currently no LNG-specific failure frequencies due to the lack of available incident data. Specific accident sequences (the event trees) are defined starting from an initiating event, considering specific system failures or successes and their timing, and human responses. Accident sequences result in plant damage states, which involve the release of the hazardous substance. Fault tree analysis allows for the quantification of the system failure probabilities and accident sequence frequencies. System failures are modeled in terms of fundamental component failures and human errors to identify their primary causes.

In order to retrieve basic component failure frequencies, DNV-GL suggests the use of data from the Hydrocarbon Release Database (HCRD) by the UK HSE (Health and Safety Executive, no date), which are based on historical data from oil platforms in the North Sea and are representative for equipment used in those installations. The data forms the basis for onshore and offshore QRA's which, in the absence of LNG-specific data, is also used in QRAs for LNG installations. There is currently no statistically sound basis for modifying the source failure data from the HCRD (or any other dataset for that matter) to account for onshore and cryogenic or LNG specific applications.

1.4.4 Risk assessment acceptance criteria

The calculated risks arising from hazardous scenarios need to meet acceptance criteria defined in agreement with regulatory requirements or provided by the plant owner or local authorities. General insights and specific definition for the acceptance criteria can be found in several normative, standards and known textbook and papers (Paté-Cornell M.E., 1994) (TNO, 2018) (Salzano *et al.*, 2013) (Iervolino *et al.*, 2019).

Individual risk is defined for any given location around the installation as the probability of fatality (or the probability of receiving a dangerous dose) per year, for an individual located continuously at the given location, as a result of an accident at the installation. This criterion ensures that no individual is exposed to an unacceptably high level of risk.

Societal risk is defined as the cumulative probability, $F(N)$, that N or more persons will receive the pre-defined level of undesired consequences (fatality or receiving a dangerous dose) as a result of an accident in the installation of concern. This kind of metric expresses the aversion of society to an increased number of casualties in an accident.

Examples of recommended or possible risk criteria applicable to both QualRA and QRA are listed in ISO/TS 18683 Annex-A, here reported in Table 1. Risk acceptance criteria for quantitative risk assessment of risk to personnel are normally expressed as annual individual risk (AIR) for the different groups of personnel exposed to the risk.



Table 1: Risk acceptance criteria from Annex A of ISO/TS 18683.

Risk target	Acceptance criteria	Comment
First-party personnel	$IR < 10^{-5}$ ev./year	Applies to crew and bunkering personnel
Second-party personnel	$IR < 5 \cdot 10^{-6}$ ev./year	Port personnel
Third-party personnel	$IR/\text{year} < 10^{-6}$ ev./year	General public without involvement in the activity

1.4.5 Risk management

In case the calculated risks are beyond the acceptance criteria used, risk reduction measures may be necessary to make the risks acceptable. Investigation of risk mitigation measures and their impact on the calculated risk can also be performed to demonstrate that the residual risk is As Low as Reasonably Practical (ALARP). For a risk to be ALARP it must be possible to demonstrate the disproportion between any further risk reduction measure cost and the benefit gained (*ALARP 'at a glance' UK HSE web page, 2019*).



2. GAPS IN THE GREEK REGULATORY FRAMEWORK

Greece, as a country, has a long history in maritime activity with strong presence till today; therefore, there is a pressing need to be in line with IMO's recent requirements and follow the prevailing trends that require reduced ship emissions. Within this context, significant efforts have been made by the Greek administration for the use of LNG (an environmentally friendly resource) as a fuel on board ships. The culmination of these efforts is the current discussion for a new Greek law that will frame LNG bunkering in major Greek ports. This new Greek law is expected to appear in the coming months and it will include the entire regulatory framework for the implementation of safe bunkering of LNG-fuelled vessels. This Regulation will be applied in all LNG bunkering procedures in the Greek ports, (namely, on shore, on more and at open sea) irrespectively of the flag of the ship. However, despite this upcoming law, Greece has introduced most of the international and European regulations into the country legislation body, as required by the Greek participation to European and International bodies. In the following sections, a more detailed analysis is made of the current Greek Statutory system regarding the safety of LNG as a marine fuel, with reference to the implementation of specific EC Directives and International Standards, together with Guidelines of Major Institutions and Best Practices recommended by LNG handing practitioners in the Greek Legal system.

2.1 INTERNATIONAL REGULATIONS

It is commonplace to mention that IMO is the most competent and internationally accepted legislative body for the issuing of international regulations regarding the shipping industry with worldwide implementation. Greece, being a member of IMO since 1948 has taken all necessary actions to comply with all IMO's rules and regulations by issuing the following laws or Presidential Decrees.

Greek law 126/1987: All ships (i.e., FS and BS) entering the Greek waters should be under the SOLAS requirements.

Greek law 1314/1983 (2/A): All ships (i.e., FS and BS) entering the Greek waters should be under the STCW code requirements.

Presidential Decree 126/1987: Ships carrying LNG as cargo (i.e., BS) should be under the IGC code requirements.

Presidential Decree 90/2016: Ships using LNG as fuel (i.e., FS) should be under the IGF code requirements.

Greek law 3622/2007: All Greek ports should be under the ISPS code requirements.

2.2 EUROPEAN REGULATIONS

In addition, as a member of the European Union, Greece is obliged to follow European legislation. As a result of this, the following Ministerial Decisions and Laws have been issued in order to implement an equivalent number of EU/EC Directives in the Greek legislative body:

Greek Ministerial Decision 172058/2016 (ΦΕΚ 354/Β/17.2.2016): All critical infrastructures, including the LNG ports, should comply with the Seveso III directive (i.e., Directive 2012/18/EU).



Greek Ministerial Decision Γ5/22039/2825/2017: All trucks carrying dangerous goods by Greek roads should comply with the European agreement ADR (in line with the Directive 2008/68/EC).

Greek Law 4439/2016: All LNG ports should comply with the Directive 2014/94/EU which is about the development of alternative fuels infrastructure.

Greek Ministerial Decision Γ5/22039/2825: All trucks and ships (i.e., BS) carrying dangerous goods by Greek roads should comply with the Directive 2008/68/EC.

However, no decision has been taken on Regulation 2017/352 which concerns the establishment of a framework for the provision of port services and standard rules on the financial transparency of ports. It is worth mentioning that, as Greece does not possess “navigable” rivers having, thus, no inland waterways, the European agreement “ADN” on the International Carriage of Dangerous Goods by Inland Waterways does not apply in Greece.

2.3 STANDARDS

The knowledge and use of various International (ISO) and European (CEN) standards is very extended in Greece, also owing to the extend international trading of goods in and out of the county; however, there is no formal requirement to implement these standards, nor is there any official request for their advisory use. Nonetheless, some ISO standards, namely ISO 16901, 18683, 20519 and 28460, are fundamental since they focus on safe LNG bunkering procedures; therefore, Greece could adopt them at an advisory level. It is worth mentioning that in the upcoming law for LNG bunkering explicit reference is made for the advisory use of ISO standards 20519 and 28460.

Additionally, there are some CEN standards that are also important owing to their application to LNG bunkering procedures, namely EN 1474-2 and EN 1474-3, together with standards concerning the installation and storage of LNG, i.e. EN 1473, EN 13645, and NFPA 59A, that could also be recommended through a Greek law at an advisory level.

2.4 GUIDELINES

Up to now, there is no formal requirement in Greece for the application of any guidelines in the use of LNG as a marine fuel. Nevertheless, there is the provision for a number of important guidelines to be included in the new LNG bunkering Law, namely the following:

- The Ship to Ship Transfer Guide for Petroleum, Chemicals and Liquefied Gases, first edition, 2013 (CDI, ICS, OCIMF, and SIGTTO)
- The Tanker safety guide (Liquefied gas) (ICS)
- The Rec. No 142 for LNG bunkering guidelines (IACS)
- The Gas as marine fuel safety guidelines – bunkering (SGMF)
- The Mooring Equipment Guidelines (OCIMF)
- The Recommendations for manifolds for refrigerated Liquefied Natural Gas Carriers (LNG) (SIGTTO)
- The LNG Transfer Arms and Manifold Draining, Purging and Disconnection Procedure (SIGTTO).



3. GAPS IN THE SLOVENIAN REGULATORY FRAMEWORK

Slovenia inherited the SOLAS and STCW international conventions from the former Socialist Federative Republic of Yugoslavia (SFRY) being the member of IMO, however, Slovenia became IMO member in 1993. Thus, international treaties are part of the national legislation. IMO codes are implemented in a so-called "silent way" if they do not interfere too much with the legislation. On the other side, some parts of the STCW convention are implemented by Act on 2006 amendments to the international convention on standards of training, certification and watch keeping for seafarers, 1978, as amended (OG RS No. 108/2012) and Decree on seafarer certification (OG RS No. 85/2014). The ECE/ADN/36 is not implemented due to the fact that there are no inland waterways.

While the national maritime legislation does not mention LNG as energy source/fuel, it is mentioned in some other legislation. The Energy Act (OG RS No. 17/2014 and 81/2015) mentions superficially the term LNG, LNG terminal, its storage, redistribution (as LNG) and regasification (as natural gas (NG)) in relation to the roles and duties of the operating organizations involved either in NG or LNG distribution networks. However, the mentioned Energy Act does not go into any technical details, nor defines/points to any specific LNG related regulations or standards.

3.1 INTERNATIONAL REGULATIONS

Slovenia has implemented several international treaties, codes, and directives related to maritime activities. The web site of the Ministry of infrastructure, Slovenian Maritime Administration (http://www.mzi.gov.si/en/legislation_and_documents) provides a list of all acts, regulations, rules and IMO resolutions. Of these, the first is the Maritime Code (OG RS No. 62/16 and 41/17) which implements about 20 related EU Directives. The above-mentioned documents do not mention explicitly the LNG, reflecting the fact that there is currently no maritime LNG related infrastructure in Slovenia.

3.2 EUROPEAN REGULATIONS

The EU directives are duly implemented into the national legislation. Generally, if there are no available national regulations, EU legislation, the available international standards (e.g., ISO), then the standards or codes are used from other countries (e.g., NFPA from the US) for specific projects and licensing procedures.

3.3 STANDARDS AND GUIDELINES

The use of various international (e.g., ISO) and European (CEN) standards is a common practice in Slovenia as the national economy is tightly bound with the other EU countries. In that respect and the fact there is an increasing number of (for example) ISO standards adopted in the field of LNG infrastructure and technology, it can be reasonably anticipated that the national regulations will likely refer to the available standards and other guidelines.



4. GAPS IN THE ITALIAN REGULATORY FRAMEWORK

In Italy, the application of the Seveso Directive for the Venice LNG Project in 2018 has produced a Safety Report and a Safety Report Evaluation.

- EN 1473 and NFPA 59 A are the most complete guidelines for the tank and terminal layout.
- NFPA 59 A is the first guideline for the tank and terminal LNG, while EN1473 is the basic reference for development and design in Europe. There are some differences between the two guidelines, in particular for the stand-off distances from LNG storage and about mitigation systems (water curtain foam and powder).
- In EN1473 to NFPA 59A, there are some indications about safety and internal distances for tanks. These distances are significantly different from risks assessment results.
- Internal distances in EN 1473 and NFPA 59 A are of the same order, comparable to one tank diameter. On the other hand, with the risk assessment criteria commonly adopted by the RdS (Seveso) a random rupture of liquid pipe in the upper part of the tank gives results larger than deterministic normative, with distances up to 200 m or more with radiation threshold value of 7 kW/m².
- In general, the use of risks assessment technique is more conservative than the deterministic evaluation for safety distances.
- Guidelines for vehicle-ship bunkering are not considered in national and international regulations UNLESS ISO 20519. Define guideline for vehicle-ship bunkering should be useful.
- Define a priority list for standards and guideline may be a necessity

With respect to the gap analysis presented in the WP1 deliverable, some modifications referring to the Italian regulation guidelines are reported in Table 1.



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Table 1: Some modifications (red color) suggested by Italian partners on the general fundamental regulation framework applied to LNG –fueled ships Regulation- Standard as per WP1.

Regulation-Guideline	Shore-Portside	Ship Side	Bunkering Interface	Training	Risk Assessment
Seveso Directive 2012/18/EU	Terminal	No	Yes	Yes	Yes
ISO 16903	Terminal ship Truck-vehicle tank	Ship	Yes	Yes	No
ISO 18683	No	No	Yes	Yes	Yes
ISO 20088-1	Terminal Ship Tank	Ship	Yes	No	No
EN1473	Tank	No	No	Yes	Yes
EN 1474-2	No	No	Yes	Yes	No
EN 1474-3	No	No	Yes	Yes	No
NFPA 59A	Terminal	No	No	No	Yes



5. CONCLUSIONS

The most significant regulations and guidelines, the specificity of each country involved in the project and the scientific and technological background of the participants, including personnel from other harbour systems, based in the associate partners (Albania, Montenegro, Ravenna industrial association) have been assessed.

It has been evidenced the difficulties in the harmonization of national and international approach to the LNG marine system. At this aim, the need for the future development of Super-LNG it has also been clarified, for what concerns the training and the definition of guidelines of WP2 on safety reports and emergency procedures.

It has been assessed that in general, the use of risks assessment technique is more conservative than the deterministic evaluation for safety distances. Furthermore, since guidelines for vehicle-ship bunkering are not considered in national and international regulations UNLESS ISO 20519 it will be useful to define guideline for vehicle-ship bunkering. Moreover, define a priority list for standards and guideline may be a necessity.



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