

RECOMMENDED PRACTICE

DNVGL-RP-G105

Edition October 2015

Development and operation of liquefied natural gas bunkering facilities

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FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.

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CHANGES – CURRENT

General

This document supersedes DNVGL-RP-0006, January 2014.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

On 12 September 2013, DNV and GL merged to form DNV GL Group. On 25 November 2013 Det Norske Veritas AS became the 100% shareholder of Germanischer Lloyd SE, the parent company of the GL Group, and on 27 November 2013 Det Norske Veritas AS, company registration number 945 748 931, changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS”, “Det Norske Veritas”, “DNV”, “GL”, “Germanischer Lloyd SE”, “GL Group” or any other legal entity name or trading name presently owned by the DNV GL Group shall therefore also be considered a reference to “DNV GL AS”.

Main changes

- New structure and naming of all sections.
- Additional scope covering inland shipping, bunkering between different IMO-type tanks and other different bunkering configurations (e.g. cassette bunkering).
- Updated according to ISO/TS 18683, ISO 16901, ISO DIS 20519, ISO 6976:2005, ISO 6578:1991 and SGMF gas a marine fuel safety guidelines.
- New sections on quality and quantity metering (Sec.7, App.E and App.F).
- Update of the guidelines for risk assessments, including safety zone, security zone and execution and handling of SIMOPS (App.D).
- Update of all DNV GL rules references.

Editorial corrections

In addition to the above stated main changes, editorial corrections may have been made.

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SECTION 1 INTRODUCTION

1.1 Objective

Liquefied natural gas (LNG) has proved to be a viable option as a fuel for ships. Key differences from traditional marine fuels include its low flashpoint and cryogenic temperature, but also importantly the fact that the supply of LNG as bunker fuel is not yet widespread or routine. Hence, it is essential to understand the different risks involved in operations using LNG as opposed to other conventional fuels.

The objective of this recommended practice (RP) is to establish the guidelines required to protect the safety of people, property and the environment when developing and operating LNG bunker facilities. Furthermore, this document is intended to increase the overall understanding of the risks associated with LNG bunkering and demonstrate how to best manage the associated risks.

1.2 Purpose of this recommended practice

The purpose of this RP is to provide guidance to the industry on development, organizational, technical, functional and operational issues in order to ensure global compatibility and secure a high level of safety, integrity and reliability for LNG bunkering facilities.

The functional requirements provided in this RP shall be in line with, but elaborate on, ISO/TS 18683 *Guideline for systems and installations for supply of LNG as fuel to ships* /1/.

1.3 Scope and limitations of this recommended practice

Figure 1-1 shows the typical project lifecycle process of an LNG bunkering facility. The scope of this RP stretches across the activities, from the strategy phase through to the operation of an LNG bunkering facility.



Figure 1-1 Lifecycle process of an LNG bunkering facility project

The main topics covered by this RP are as follows:

- Development of LNG bunkering facilities (Sec.4)
- Risk assessments for LNG bunkering facilities (Sec.4 and Sec.6 and App.D)
- Safety management system (SMS) requirements (Sec.5)
- Operation of LNG bunkering facilities (Sec.6)
- Determination of the quantity and properties of the supplied LNG (Sec.7)

Figure 1-2 illustrates the different types of bunkering operations covered by the scope. The bunkering scenarios directly covered by this RP are: terminal-to-ship, truck-to-ship and ship-to-ship transfers. The practices presented may, with special considerations, also be used for other bunkering scenarios, like the use of portable tanks referred to as “cassette bunkering”. The RP is applicable to vessels covered by the IMO regulations as well as inland shipping.

Regarding simultaneous operations on land and sea (e.g. cargo handling, passenger operations, ship traffic close to the bunkering location, etc.), the RP addresses the risk management requirements and discusses the methodologies available.

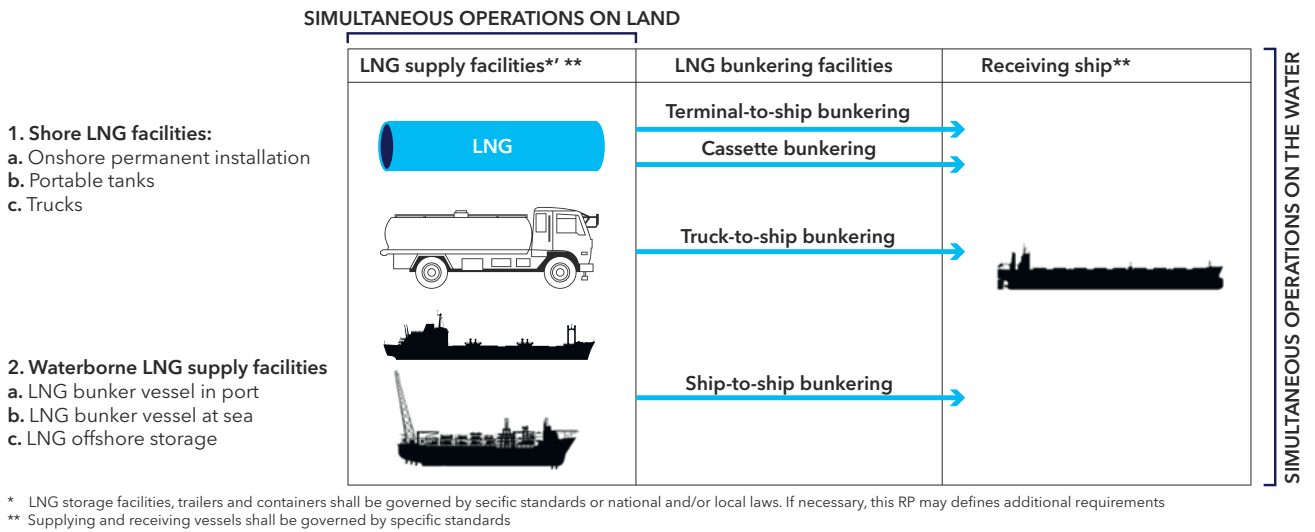


Figure 1-2 Scope of this Recommended Practice (DNVGL-RP-G105:2015)

The following are excluded from the scope of this RP:

- Installations, arrangements and operations on the receiving vessel other than those related to LNG bunkering.
- The development of intermediate storage facilities and any activity upstream from intermediate storage, in the value chain.
- The recycling or dismantling of an LNG bunkering facility at the end of its lifecycle.

SECTION 2 APPLICATION

2.1 Use and users of this recommended practice

This RP applies to all the organizations involved in the LNG bunkering. In general, at least three organizations are involved:

- The organization supplying the LNG to the receiving vessel (bunker operator).
- The organization managing the receiving vessel (ship manager).
- The organization providing the regulatory regime (port and/or national authority).

The operator of the terminal where the bunkering takes place may also be involved in the LNG bunkering, depending on local conditions. The terminal operator is mainly involved in the integration of the facility's safety management systems.

2.2 Regulatory requirements

In the context of this RP, regulatory requirements are defined in or derived from legislative instruments relevant to LNG bunkering operations, such as:

- Internationally binding conventions/directives.
- Federal/national legislation.
- Federal/national/state/regional/local regulations.
- Terms and conditions of licences and permits.

Regulatory requirements represent the minimum obligations the LNG bunkering operations should meet. The operator of the bunkering facility (in agreement with other stakeholders) may decide to build and operate to meet higher standards with regard to safety, reliability or environmental protection.

In the case of any conflict between regulatory requirements and this RP, the former shall prevail.

2.3 Relationship with other specifications, guidelines and standards

Design specifications, guidelines and standards covering systems, components, equipment and materials are referred to in this RP where relevant and documented in [Sec.8](#). The paragraphs below and references in this RP provide a collection of the most relevant documents for developing LNG bunkering facilities.

ISO/TS 18683, *Guidelines for systems and installations for supply of LNG as fuel to ships /1/*, is a technical specification that provides guidance on the planning, design and operation of LNG bunkering facilities along with applicable industry standards for system design to ensure a high level of safety, integrity and reliability.

ISO/TS 16901, *Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface /6/*, provides recommendations for risk assessments of the planning, design and operation of LNG facilities onshore and at the shoreline using risk-based methods and standards.

ISO DIS 20519, *Ships and marine technology - Vessel - LNG bunkering standard*, is a draft standard initiated by IMO and sets requirements for LNG bunkering systems and equipment that are not covered by the IGC Code.

For determination of calorific value and density of the supplied LNG, references are made to the methodologies provided in ISO 6976:2005 and ISO 6578:1991.

The IGC Code, *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, was adopted by IMO resolution MSC.5(48) and has been mandatory under SOLAS chapter VII since 1986-07-01. The code applies to all ships carrying liquefied gases having a vapour pressure exceeding 2.8 bar absolute at a temperature of 37.8°C.

The IGF Code, *International Code of Safety for Ships using Gases or other Low-flashpoint Fuels*, is mandatory for ships fuelled by gases or other low-flashpoint fuels. It was adopted in June 2015, along with amendments to make it mandatory under the International Convention for the Safety of Life at Sea (SOLAS).

The SGMF safety guidelines for the bunkering of gas as a marine fuel aim to give the different parties involved a common understanding of the LNG bunkering operations through recommended procedures, checklists and technical and organizational guidance.

2.4 Assumptions

This RP assumes that bunker vessels are designed and built according to the IGC Code and applicable Class Rules. Technical design requirements for the LNG fuel transfer equipment on bunker vessels are outlined in the DNV GL rules for gas bunker vessels. A ship complying with these rules will obtain a gas bunker notation /14/.

Receiving ships shall be designed and built according to the IGF Code /1/ and applicable Class Rules and/or equivalent codes for inland shipping. It is assumed that inland vessels that are not covered by IMO will also be designed in accordance with local and equivalent regulations.

Onshore installations and road tankers are assumed to meet national regulations or regulations equivalent to EN 1473 /18/ or NFPA 59A /19/.

2.5 Appendices

The appendices provide reference material that can be used in the development, design and operation of LNG bunkering facilities:

[App.A](#) provides information on general risk management frameworks. This should assist the developer in applying a consistent risk management process for the development, design and operation of LNG bunkering facilities.

[App.B](#) describes the properties and typical hazards of LNG.

[App.C](#) states the functional requirements outlined in ISO/TS 18683 /1/.

[App.D](#) provides recommended practices for risk assessments of LNG bunkering facilities.

[App.E](#) gives an overview of the variations in LNG characteristics worldwide.

[App.F](#) provides a calculation method for determining the LNG energy content.

SECTION 3 DEFINITIONS

3.1 Terms and definitions

Table 3-1 Terms and definitions

<i>Term</i>	<i>Definition</i>
boiling liquid expanding vapour explosion (BLEVE)	sudden release of the content of a vessel containing a pressurised flammable liquid followed by a fireball
bunkering facility	in the context of this document, this is the ship/facility interface where LNG bunkering is intended to take place or is taking place The term may be used for any of the bunker scenarios terminal-to-ship, truck-to-ship or ship-to-ship.
bunkering	the process of transferring fuel to a ship In the context of this document, bunkering relates to the transfer of LNG from a supply installation to a receiving vessel. The supplied LNG has the sole purpose of being used as a fuel.
cassette bunkering	bunkering of LNG by mobile LNG tanks/containers that are lifted onto the receiving vessel and connected to the fuel system on board
consequence	outcome of an event
drip-free coupling	A coupling that automatically closes at both separation points of the joints when it is disconnected. A drip-free coupling avoids any spill of liquid or vapour or limits it to a minimum. Another term that may be used is "dry-disconnect".
dry break-away coupling	coupling which separates at a predetermined section at a set breaking load and in which each separated section contains a self-closing shut-off valve which seals automatically When activated, a dry break-away coupling avoids any spill of liquid or vapour or limits it to a minimum. A dry break-away coupling shall provide two functionalities: A separation function that is triggered in sufficient time before reaching the load limit on the bunker connection to separate the line between the supply side and the receiving vessel. A closing function to close the line at both separation points to prevent the spill of liquid or vapour.
E&P industry	the upstream oil and gas sector is also commonly known as the exploration and production (E&P) sector
emergency shutdown (ESD)	method that safely and effectively stops the transfer of natural gas and vapour between supply facilities and the receiving vessel
emergency release system (ERS)	system that allows a quick disconnection of the supply side from the receiving vessel in an emergency
hazard	potential source of harm
hazard identification	brainstorming exercise using checklists where a project's potential hazards are identified and gathered in a risk register for follow-up in the project
hazard and operability study	systematic approach by an interdisciplinary team to identify hazards and operability problems occurring as a result of deviations from the intended range of process conditions
hazardous area	area in which a flammable gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of apparatus
impact assessment	assessment of how consequences (fires, explosions, etc.) affect people, assets, the environment, etc.
inerting	placing tanks, piping and machinery in a non-flammable atmosphere by displacing oxygen
integrated automation system	automation system that monitors and automates the bunkering sequences and integrates the systems on the supply side and receiving ship

Table 3-1 Terms and definitions (Continued)

<i>Term</i>	<i>Definition</i>
location-specific individual risk	the Location-Specific Individual Risk (LSIR) is the risk of death for a hypothetical individual who is present at a particular location continuously all year (i.e. 24 hours a day, 7 days per week) without wearing personal protective equipment
mitigation	limitation of any negative consequence of a particular event
probability	extent to which an event is likely to occur
protective measure	means used to reduce risk
purging	placing tanks, piping and machinery in a natural gas atmosphere by displacing inert gas
quick connect/disconnect coupling (QCDC coupling)	a coupling that can be manually connected and disconnected. Bolted flange connections are not QCDC couplings
rapid phase transition	rapid physical phase transformation of LNG liquid to methane vapour mainly due to submersion in water
receiving vessel	a vessel that is receiving LNG as fuel
risk	effect of uncertainty on objectives In a safety context, the combination of the probability of harm occurring and the severity of that harm.
risk analysis	systematic use of information to identify sources and estimate the risk
risk assessment	overall process of risk analysis and risk evaluation
risk contour	two-dimensional representation of risk (i.e. IR) on a map
risk criteria	terms of reference by which the significance of risk is assessed
risk evaluation	procedure based on the risk analysis to determine whether the tolerable risk level has been achieved
risk management	coordinated activities to direct and control an organization with regard to risk
risk management system	set of elements of an organization's management system concerned with managing risk
risk matrix	matrix portraying risk as the product of probability and consequence, used as the basis for risk assessment
safety	absence of an unacceptable risk
safety integrity level	a discrete level for specifying the safety integrity requirements of the safety functions to be allocated to the safety-related systems (IEC 61508-4)
safety zone	the area around the bunkering station where only dedicated and essential personnel and activities are allowed during bunkering
security zone	the area around the bunkering facility and vessel where ship traffic and other activities are monitored (and controlled) to mitigate harmful effects
simultaneous operations (SIMOPS)	simultaneous operations running in parallel to the bunker process, either on land, on the water or on the vessels involved
societal risk	the annual frequency of a particular number of fatalities occurring concurrently as a result of accidents
stakeholder	any individual, group or organization that can affect, be affected by, or perceive itself to be affected by, a risk
supply side	any truck, barge, vessel, container, permanent installation or other that is supplying LNG as fuel to a receiving vessel
terminal	if not otherwise stated, the cargo terminal or jetty where bunkering operations occur and the receiving vessel is berthed
tolerable risk	risk which is accepted in a given context based on DNV GL current values
Topping up	final sequence of the LNG transfer to ensure the correct filling level in the receiving tank
water curtain	sprinkler arrangement to protect steel surfaces from direct contact with LNG

3.2 Abbreviations

Table 3-2 Abbreviations

<i>Abbreviation</i>	<i>Description</i>
AIR	average individual risk
ALARP	as low as reasonably practical
BLEVE	boiling liquid expanding vapour explosion
BOG	boil-off gas
ERC	emergency release coupling
ERP	emergency response procedures
ERS	emergency release system
ESD	emergency shutdown
ESDV	emergency shutdown valve
FAR	fatal accident rate
FMEA	failure mode and effects analysis
F-N	frequency number curve, measure for societal risk
FR	functional requirement
GIIGNL	The International Group of Liquefied Natural Gas Importers
HAZID	hazard identification study
HAZOP	hazard and operability study
HCRD	hydrocarbon release database
HFO	heavy fuel oil
HSE	health, safety and environment
HVAC	heating, ventilation, air conditioning
IAPH	International Association of Ports and Harbours
IAS	integrated automation system
IMO	International Maritime Organization
IR	individual risk
ISGOTT	International Safety Guide for Oil Tankers and Terminals
ISIR	individual-specific individual risk
ISO	International Organization for Standardization
ISPS	International Ship and Port Facility Security
LNG	liquefied natural gas (<i>Note: LNG is defined in EN 1160 /16/</i>)
LFL	lower flammable limit
LOC	loss of containment
LSIR	location specific individual risk
LUP	land-use planning
MGO	marine gas oil
MOC	management of change
NG	natural gas
PIC	person in charge
PKI	propane knock index
PPE	personal protective equipment
QCDC	quick connect/disconnect coupling
QRA	quantitative risk analysis
RP	DNV GL recommended practice
RPT	rapid phase transition
SGMF	society of gas as marine fuel
SIGTTO	Society of International Gas Tanker and Terminal Operators
SIL	safety integrity level
SIMOPS	simultaneous operations
SMM	safety management manual

Table 3-2 Abbreviations (Continued)

<i>Abbreviation</i>	<i>Description</i>
SMS	safety management system
SOLAS	International Convention for the Safety of Life at Sea
STCW	standards of training, certification and watchkeeping
STS	ship to ship (bunkering)
SWIFT	structured what if technique
UFL	upper flammable limit
VCE	vapour cloud explosion

3.3 Verbal forms

For verification of compliance with this RP, the following definitions of the verbal forms, shall, should and may are to be applied:

Table 3-3 Verbal forms

<i>Term</i>	<i>Definition</i>
shall	verbal form used to indicate requirements strictly to be followed in order to conform to this document
should	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required
may	verbal form used to indicate course of action permissible within the limits of the document

SECTION 4 DEVELOPMENT OF LIQUEFIED NATURAL GAS BUNKERING FACILITIES

The development and operation of LNG bunkering facilities requires due attention to safety and the use of risk assessment techniques (/1/, /3/, /5/ and /6/) in order to evaluate safeguards and demonstrate compliance with regulatory targets.

This section contains guidance on technical requirements for the planning, design and development of LNG bunkering facilities in accordance with ISO/TS 18683 /1/.

4.1 Establishing the business case

The first step in the development process is to outline the business case. Based on this, the process of identifying and developing the design basis may be instigated. The business case should address, but not be limited to the:

- Target market (geography, location, capacity) and LNG supply options.
- Identification of stakeholders.
- Regulatory requirements.

This forms a basis for outlining the relevant bunkering configuration options (truck-to-ship, ship-to-ship or terminal-to-ship) and identifying potential locations and battery limits.

The next steps will include assessing the feasibility of the potential locations with respect to regulatory and stakeholder requirements. This may require a risk assessment (e.g. a HAZID) to map potential hazards and identify potential showstoppers.

4.2 Stakeholder involvement

The involvement of different stakeholders in the process of developing an LNG bunkering facility may vary and is highly dependent on local conditions. The stakeholders' involvement throughout the project shall be addressed in the overall project plan. Different roles and responsibilities are described in the sections below.

4.2.1 Port or national authority

The port or national authority should determine the overall responsibility for the bunkering operations and an accreditation scheme for LNG bunker operators in the ports under its authority. The authority may decide if additional requirements other than those from IMO, Class, ISO, etc. /1/ shall be imposed.

The port or national authority should specify the following:

- Regulatory scheme.
- Risk acceptance criteria.
- Acceptability of the location of bunkering facilities.
- Permit to build on a given location issued at the end of the feasibility phase.
- Acceptability of using portable bunkering facilities.
- Restrictions on bunkering operations such as simultaneous bunkering and loading, unloading, passenger presence, embarking, disembarking and portable-tank loading.
- Overall contingency plans and arrangements.
- Traffic control/restrictions.
- Permit to operate issued at the end of commissioning.

4.2.2 Bunkering facility developer/operator

In the planning and development phase, the developer of the bunkering facility will be responsible for the following:

- Defining the business case.
- Developing the concept and bunker scenario.

- Conducting risk assessments and establishing risk acceptance criteria that reflect the companies' risk acceptance (if these are more stringent than applicable legislation).
- Conducting the necessary analyses in agreement with the authorities.
- Achieving the relevant permits for installing and operating the bunkering facility.
- The detailed design of the bunkering systems.
- The quality assurance of the design, engineering, procurement, fabrication, construction, installation and commissioning.

4.2.3 Receiving ship

The involvement of the operator/owner of the receiving ship is generally limited at this stage, but it may become involved with the bunkering facility operator to ensure compatibility and engagement in the operational phase, depending on the commercial contract.

It should also inform the authority or bunkering facility operator if the following are relevant:

- Simultaneous operations during bunkering.
- One or more of the requirements listed in this document will not be met.

4.3 Risk assessments for developing liquefied natural gas bunkering facilities

A risk assessment shall be carried out as part of the planning of LNG bunkering facilities to demonstrate safety in accordance with local or other governing regulations and authority practices.

The type of risk assessment required for a project is dictated by the bunkering scenario selected for the specific site. Roughly speaking, the bunkering scenarios are categorised as standard and non-standard /1/.

A standard bunkering scenario is defined as follows:

- No deviations from the functional and operational requirements specified in [Sec.4](#) and [Sec.5 /1/](#).
- Design of components and systems is according to recognized standards.
- No simultaneous operations requiring a dedicated risk assessment.

A non-standard scenario is one that has any deviations from the above criteria /1/.

For the standard scenarios, a qualitative risk assessment supplemented by a consequence assessment will normally be sufficient, depending on the requirements set by the local authorities.

If the above is not documented to be satisfactory, a detailed QRA shall be carried out to demonstrate the efficiency of safeguards and barriers and compliance with the respective authority requirements. In some cases, the authorities may require a specific quantitative risk assessment regardless of the bunkering scenario.

Detailed information and recommendations on different risk assessment methodologies and acceptance criteria, including the calculation of safety distances and determination of security zones, are provided in [App.D](#).

4.4 Layers of defence

To ensure that the LNG bunkering is planned, designed and operated in a safe manner, a bow-tie model shall be used as part of the risk management development process. This serves as a technique to assess if adequate barriers are in place to mitigate different unplanned hazardous scenarios. The bow-tie model applied in this RP corresponds to logic presented in ISO/TS 18683 /1/.

The bow-tie model describes the course of events related to a major accidental hazard and the barriers in place to prevent a potential escalation. The barriers can be both operational and technical. The core philosophy behind the bow-tie model is to ensure a correlation between the risks related to major accident hazards for a specific site and the ability of the barriers in place to prevent, contain and mitigate the consequential events.

The barriers identified in the bow-tie model are broken down into three layers of defence at different stages along the course of events. Each layer includes a set of functional and operational requirements that shall be evaluated and implemented to safeguard the LNG bunkering operations.

The three layers of defence are defined as follows:

- The 1st layer of defence: the functional requirements within the 1st layer of defence shall ensure operations, systems and components aiming at the prevention of accidental release of LNG or natural gas, /1/. Table C-1 items F1 through F13 determine the functional requirements of the 1st layer of defence.
- The 2nd layer of defence: the functional requirements from Table C-1 items F14 through F22 serve as the 2nd layer of defence in terms of controlling hazardous situations in the event that a release occurs and thereby preventing/minimising the harmful effects /1/.
- The 3rd layer of defence: the functional requirements set forth in Table C-1 items F23 and F24 on emergency preparedness serve as the 3rd layer of defence in terms of establishing emergency preparedness procedures and plans to minimise consequences and harmful effects in situations that are not contained by the second layer of defence /1/.

Figure 4-1 illustrates the bow-tie model indicating the three layers of defence as described above. The major accidental hazard or initiating/top event represents a “release of LNG or NG” scenario. This top event may have different causes and the consequences shall be prevented, contained or, in the worst scenario, minimised to the extent possible by the protective barriers in the 1st, 2nd or 3rd layers of defence.



Figure 4-1 The three layers of defence illustrated in the bow-tie diagram /1/

4.5 Functional requirements for the design of liquefied natural gas bunkering facilities

The following sections describe the functional requirements related to the development process for an LNG bunkering facility. The recommendations provided are based on the functional requirements listed in Table C-1 /1/.

The functional requirements serve as barriers along the three layers of defence (see [4.4]) with the overall purpose of mitigating potential risk to people, assets and the environment.

4.5.1 Equipment standards

Equipment standards are listed in Tables 1 and 2 in ISO/TS 18683 /1/. Hardware and systems shall be designed to allow for a full range of operations within the defined operational limitations and design criteria.

Temperature and pressure ranges in the system shall reflect the use of both natural gas and nitrogen in liquid and gaseous phases. The material selection for the cryogenic equipment shall be based on the lowest possible temperature scenario achievable (e.g. during blowdown).

It is emphasised that standards and requirements for equipment and components stated in the ISO/TS 18683 /1/ guideline shall be adhered to and not replaced by operational procedures. Exceptions shall be documented in a risk assessment.

4.5.2 Bunker hose(s)

The bunker hoses shall be designed for cryogenic liquids, de-pressurisation, inerting and gas freeing according to Tables 1 and 2 of ISO/TS 18683/1/.

To determine the correct hose length, the vessel's relative freeboard changes and movements shall be taken into consideration. The limiting parameter for the hose dimension is the flow velocity. The industry practice is for the flow velocity not to exceed 10 m/s.

The hoses shall be handled with caution both when not in use and during bunkering operations. It is important to keep the hoses sheltered during transportation and to provide proper support when lifting to avoid damage. Each hose section shall have a seal which is sufficient to avoid any moisture or other contaminants from entering the hose.

4.5.3 Loading arms and hose-handling equipment

Proper means shall be in place to ensure the safe handling of the bunker hose(s) and related equipment during connection and transfer operations. If loading arms or other hose-handling equipment (e.g. cranes) are used, their design shall be in accordance with the applicable standards given in Tables 1 and 2 of ISO /TS 18683 /1/.

4.5.4 Connectors

The connectors will be exposed to frequent large temperature variations that may impose excessive loads on couplings, joints and seals. Hence, due attention should be given to the design and selection of the connector system to ensure high integrity and reliability for the purpose of minimising the leakage frequency.

Connectors shall be designed to sustain the design loads from the weight of equipment, thermal gradients and internal and external pressure loads without exceeding the connector design resistance. All connectors shall be certified according to the standards given in Tables 1 and 2 of ISO/TS 18683 /1/.

The connectors shall be of a drip-free, quick connect/disconnect (QCDC) type. Unless other arrangements are made in advance, the supply facility should provide the male portion of the coupling to the receiving vessel.

4.5.5 Systems for inerting and purging

The systems and procedures for purging before and after transfer shall be defined by the designer of the system. It shall be demonstrated during commissioning and after repair or conversions that the procedure will ensure satisfactorily low levels of:

- Oxygen, H₂O and CO₂ (prior to transfer to prevent a flammable atmosphere, hydrate formation and corrosion in the transfer lines).
- Methane/natural gas (post transfer; a methane volume concentration of below 2% is considered satisfactory).

Nitrogen is commonly used as gas for inerting. It may be supplied by batteries on board the vessel or on the quay, or by similar arrangements such as nitrogen generators.

The inerting and purging systems shall be designed to minimise emissions of natural gas to the environment during normal operations.

4.5.6 Trapped liquefied natural gas and liquid locks

Trapped LNG can cause excessive pressure due to heat transfer from its surroundings. The system shall be designed to avoid trapped LNG by means of proper pressure relief arrangements and expansion loops (if necessary).

The release of natural gas into the atmosphere as a result of trapped LNG shall be avoided as far as reasonably practicable.

4.5.7 Vent mast

Vent masts are required for overpressure prevention and the blowdown of the transfer system. There shall be a vent mast located on both the supply and receiving facility for quick gas relief in case of an emergency or system failure.

The vent mast(s) shall be dimensioned according to the maximum credible capacity scenario. Evacuation routes, the presence of people/personnel during normal operations and nearby equipment need to be considered when establishing the layout and location of the vent masts.

For a receiving vessel, the arrangements shall be according to IGF Code /9/. The arrangements for a shore-based facility or trucks shall be according to local regulations (e.g. risk-based). For a bunker vessel, the vent mast arrangement shall be according to the IGC code /8/, DNV GL Gas Bunker Vessel notation /14/ or other local regulations.

4.5.8 Draining systems for transfer lines

The transfer lines shall be designed to accommodate the drainage of liquid residuals post transfer without any release of methane to the atmosphere.

4.5.9 Safety zone and ignition source control

A safety zone is required to be established around the bunkering station/facilities to ensure that only essential personnel and activities are allowed in the area. This is to control the exposure to flammable gas in case of an accidental release of LNG or natural gas during bunkering. The way in which to determine a safety zone is described in [App.D](#).

The safety zone will normally be inside the security zone and encompass hazardous areas defined by IEC 60079-10-1 /13/ or other relevant regulations. All permanent equipment inside the hazardous area shall be rated and comply with ignition prevention requirements.

Only tools, equipment and communication devices that are rated according to the area classification shall be used within the defined safety zone. Their design shall be according to Tables 1 and 2 of ISO/TS 18683 /1/.

Operational procedures and checklists shall be developed and address the proper use of hardware and equipment within the defined safety zone.

4.5.10 Emergency shutdown system

The emergency shutdown (ESD) philosophy shall be developed during the design phase. The terminology is recommended to be in accordance with SIGTTO /11/. The SIGTTO ESD definitions are given below:

- *ESD-1 emergency shutdown stage 1* – shuts down the LNG transfer operation in a quick controlled manner by closing the shutdown valves and stopping the transfer pumps and other relevant equipment in ship and shore systems. Activation of ESD-1 shall set off visual and audible alarms.
- *ESD-2 emergency shutdown stage 2* – shuts down the transfer operation (ESD-1) and uncouples the bunker hose/loading arms after closure of both the ERS isolation valves.

The primary function of the ESD system is to stop liquid and vapour transfer and eliminate potential ignition sources in the event of a hazardous scenario in order to regain control of the situation. The ESD system shall bring the LNG transfer system to a safe condition. If a QRA is necessary, the ESD safeguards shall be evaluated in the QRA. General requirements for the ESD system are as follows:

- Manual activation shall be available.
- ESD /12/ shall be activated by the following events, but not limited to:
 - fire detection
 - manual activation from the receiving or supply side
 - excessive relative movement between the receiving and supply side
 - power failure
 - loss of communication

- high level alarms in the tank(s)
- abnormal pressure in the transfer system
- low temperature at the bottom of the drip tray
- it shall be possible to stop the operation from either the receiving or supply side's control panel at any time during the process.

Different ESD configurations are available. Most importantly, it shall be documented that the ESD configuration selected will contain any release and prevent uncontrolled escalation as far as reasonably practicable. This shall be addressed in a risk assessment /7/. The different configurations for an ESD set-up are /11/:

- *Linked ESD system* – transmits ESD signals from ship to shore or vice versa via a compatible system. Various technologies have been adopted, such as pneumatic, electric, fibre-optic and radio telemetry, but vessels trading worldwide may need more than one for compatibility reasons.
- *Unlinked ESD system* – a system that independently initiates a shutdown on the receiving vessel or on the supply side. A shutdown on the other side is then activated by manual communication.
- *Pendant ESD system* – a hand-held portable device provided either by the receiving vessel to the supply side or by the supply side to the receiving vessel for manual activation of the ESD system by the other party in the absence of a compatible, linked ESD system.

It is recommended that a linked ESD system is provided together with vocal (or sign) communication in order to minimise the response time and ensure the quick and safe shutdown of the bunkering operations (ESD-1).

4.5.11 Emergency release system

An emergency release system (ERS) shall be installed and interconnected to the ESD system via a link. In SIGTTO, ERS is referred to as ESD-2. The ERS shall enable disconnection through separation of the connected systems in order to safely isolate the receiving vessel from the supply side. The design shall provide a system for recording and tracking the calculated force or bending moment to ensure separation before the hose or loading arm is placed under stress. Both automatic activation and manual activation from a remote location shall be made available.

The ERS shall consist of an Emergency Release Coupling (ERC) with two interlocked isolation valves, one upstream and one downstream of the ERC. Upon activation, the valves shall close the line on both sides of the separation point to minimise potential LNG leakage upon activation.

If a pendant or unlinked ESD system is selected, measures shall be in place to demonstrate that ESD-1 is activated on both the receiving and supply sides before ESD-2 is activated. This shall be addressed in the risk assessment to prevent pressure surge and potential damage to the transfer system.

As an alternative to ERS, a separate dry break-away coupling (passive system) upstream of the drip-free QCDC coupling may be installed. This will be mechanically activated upon drift-off only. If a combined dry break-away drip-free QCDC coupling is used, a separate ERS is not required.

4.5.12 Prevention against electrostatic and galvanic ignition

There are two cases of electrostatic or galvanic ignition which require proper means of protection:

- Low voltage and high current comprise the most common case. This is a galvanic cell situation between the supplier and receiver where the sea water functions as an electrolyte. The high currents and low difference in potential (less than 1 volt) can result in an incendiary arc.
- High voltage and low current are caused by static charging which, if discharged, can cause sparks that are sufficient to ignite a cloud of natural gas.

In order to provide protection against arcing during the bunkering operation, the hose connector(s) or loading arms shall be fitted with insulated flanges as detailed in SIGTTO /11/, ISGOTT /10/ and ISO/TS 18683 /1/.

The connector flange shall be fitted so that the seaward side of the hose or arm is electrically continuous to

the vessel and the pipelines are earthed to shore on the inshore end of the pipe. As an alternative to insulating flanges, a single length of electrically discontinuous hose can be used in each hose string. For more detailed design specifications, see Tables 1 and 2 in ISO/TS 18683 /1/.

4.5.13 Leakage detection

Gas detection equipment shall be installed where gas may accumulate and on the ventilation inlets. A gas dispersion analysis or physical smoke test shall be used to determine the best possible arrangement. The number and location of gas detectors in each space and for the different parts of the bunkering system shall be considered, taking size, layout and ventilation into account. The gas detectors shall be connected to the control and ESD systems.

An audible and visible alarm shall be activated before the vapour concentration reaches 20% of the lower flammable limit.

Leakage detection on the receiving vessel shall be according to IGF Code /9/, while on the shore side it shall be according to the national authority's requirements and on a bunker vessel it shall follow IGC /8/ specifications.

4.5.14 Cryogenic spill protection

Cryogenic protection shall be provided for the relevant assets where there is a potential for damage to structures upon exposure to an LNG spill.

Spill protection (e.g. drip trays) shall be installed on the receiving vessel according to the IGF Code /9/. The IGC Code /8/ shall by default be used for bunker vessels. Further requirements are also provided in the DNV GL Gas Bunker Vessel notation /14/. Spill protection for onshore assets shall be according to local regulations or addressed in the risk assessment.

In general, requirements relating to the cryogenic protection of assets include, but are not limited to:

- The surrounding structures shall not be exposed to unacceptable cooling in the case of a leakage of liquid gas.
- Drip trays shall be fitted below liquid gas bunkering connections and where leakage may occur.
- The drip trays shall be of appropriate material, such as stainless steel or aluminium.
- The drip trays shall be dimensioned according to the maximum amount of spill rate, drain capacity and possible spray effects.
- The arrangement should be drained to sea, protecting the deck, hull, jetty, pier or other related equipment.
- The sufficient clearance for connection/disconnection and safe access to couplings with regard to the height of the presentation flange and vertical clearance from the drip tray needs to be ensured in the design.
- Cryogenic protection for the shore side potentially exposed to LNG shall be evaluated.
- Protection for other vessels alongside the receiving ship shall be considered, e.g. supply barges.


An alternative protective measure for cryogenic run-off or spray onto the hull's side plating is the use of a temporary water curtain. For the LNG transfer rates in a bunkering scenario, a flow rate of 0.5-1.0 m³/h per metre water curtain is recommended. The applicability shall be evaluated taking cold weather conditions and the potential for ice build-up into account.

4.5.15 Fire protection and suppression

The type and capacity of the fire protection and suppression systems installed in bunker stations depend on the location of the bunkering activity, volume of the transferred LNG, transfer rate and size of the ship(s). The primary function of a fire protection system is to maintain the safety of personnel. Secondary considerations are to minimize loss and damage to assets.

The specific fire protection requirements shall be according to:

- IGF Code /9/ and applicable class rules (e.g. DNV GL Rules for Classification of Gas Fuelled Ships /7/) for the receiving ship.

- 
- The IGC Code /8/ and applicable class rules (e.g. DNV GL Rules for Classification of Liquefied Gas Tankers /15/ and DNV GL Gas Bunker Vessel notation /14/) for a bunker vessel.
 - Local regulations (e.g. issued by port authorities) for fixed shore-based installations.

SECTION 5 SAFETY MANAGEMENT SYSTEM

According to ISO/TS 18683 /1/, bunkering operations shall be developed and conducted under the control of a recognised safety management system (SMS). This chapter contains recommended practices that may be used by the parties involved in LNG bunkering for developing and implementing an adequate safety management system. More specifically, this RP identifies the “common ground” for the different stakeholders involved to ensure the interfaces are dealt with properly.

Generally, the SMS will be implemented as part of the involved organizations' operational procedures.

The first section provides background information regarding the common safety management system principles and safety management systems in general. The second section addresses and discusses the recommendations specific to the SMS of parties involved in LNG bunkering operations.

5.1 Purpose of a safety management system

The overall purpose of an SMS is to ensure that the organization achieves its business objectives in a safe manner. The efficient control of an organization's risks can only be achieved through a process that brings together three critical dimensions:

- A technical component including applied tools and equipment.
- A human component of front line people with their skills, training and motivation.
- An organizational component consisting of procedures and methods defining the relationship between tasks.

Typically, the SMS is translated into a safety management manual (SMM), the key instrument for communicating the organization's approach to safety management. The SMM documents all aspects of safety management, including the safety policy, organization, procedures, checklists and individual safety responsibilities. An overview of the typical document levels is shown in [Figure 5-1](#).

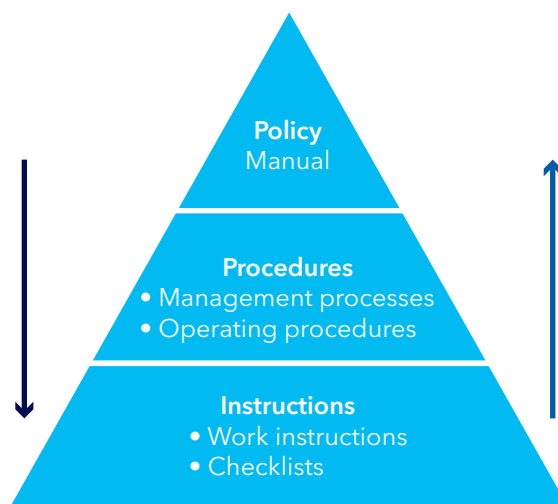


Figure 5-1 Typical levels of documents in an SMS

An SMM shall include, but not be limited to:

- Safety policy and objectives.
- Safety accountabilities and responsibilities.
- Document control and procedures.
- Hazard identification and risk management system schemes.
- Safety performance measurement and monitoring.
- Incident investigation and reporting.

- Emergency response planning.
- Management of change (including organizational changes with regard to safety responsibilities).
- Safety communication, training and promotion.

5.2 Safety management systems for liquefied natural gas bunkering operations

This recommended practice is applicable to the safety management systems of all parties involved in the design, construction, commissioning or execution of a bunkering operation. Specific topics for the SMS which should be considered by parties involved in LNG bunkering are mentioned in the following sections.

5.2.1 Safety management systems compatibility

The interfaces between the different SMSs of the various parties involved in the LNG bunkering are illustrated in [Figure 5-2](#).

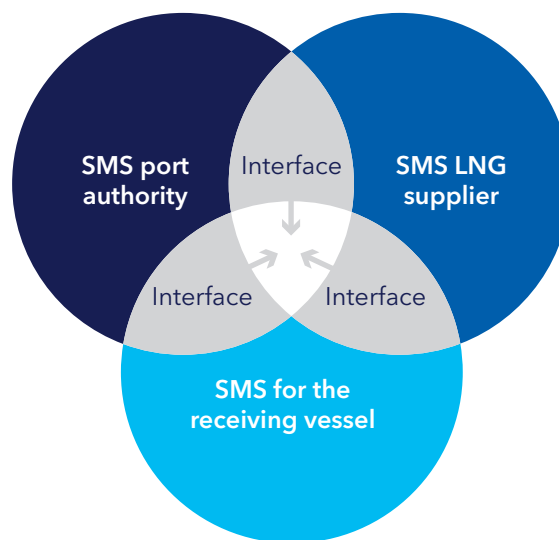


Figure 5-2 Interfaces between SMSs

Since LNG bunkering directly involves two main parties, i.e. the supplier and receiving ship, the compatibility of their safety management systems is crucial. This step is part of the compatibility check between the supplier and receiving ship. The compatibility of the safety management systems shall be demonstrated as follows:

- *Between two vessels:* both vessels shall make their documents of compliance and safety management certificates available. If the languages used are not compatible, the text shall include an English translation or a translation to any other language agreed on by both parties.
- *Between a shore-side bunkering facility and a ship:* the bunkering facility shall make an explanatory document available to the masters of visiting ships advising them of the bunkering facility's expectations regarding the safe conduct of operations and ensuring that the ship's crew understand these expectations. It is recommended that this is done through the completion and signing off of a ship/shore safety checklist.
- *Between a truck and a ship:* the dedicated locations where the bunkering takes place shall make an explanatory document available to the supplying company and to visiting ships advising them of the location's expectations regarding the safe conduct of operations and ensuring that the truck operator and ship's crew and officers understand these expectations. It is recommended that this is done through the completion and signing off of a ship/truck safety checklist. This compatibility check shall be signed off by both parties prior to the operation.

5.2.2 Safety policy and objectives

The Safety Policy outlines in writing the methods and processes that the organization will apply to achieve the desired safety profile. It shall declare the principles and philosophies that lay the foundation for the organization's safety culture and be communicated to all staff throughout the organization.

In preparing a safety policy, senior management shall consult with the key staff members in charge of LNG bunkering operations. Consultation shall ensure that the safety policy and stated objectives are relevant to all staff and generate a sense of shared responsibility for the safety culture in the organization.

Since the safety policy of an organization states its safety principles and philosophy, it is important that the safety policies of the different parties involved in LNG bunkering are aligned with each other.

The SMS shall support the implementation and maintenance of the three layers of defence described in [4.4] Figure 5-3 illustrates the link between the main parts of an SMS and the layers of defence.

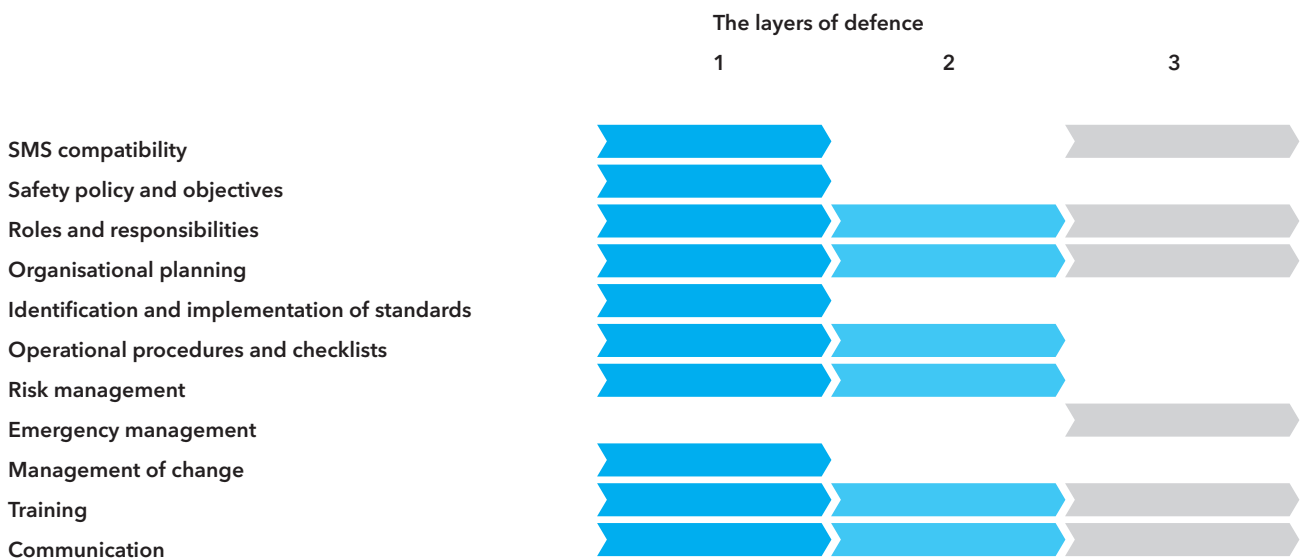


Figure 5-3 Relationship between the SMS and layers of defence

5.2.3 Organizational planning

To ensure safe operations, the organization shall plan its activities, including respective duties, during the LNG bunkering operation.

ISO/TS 18683 /1/ requires an organizational plan to be prepared and implemented in operational plans and reflected in qualification requirements. The plan shall describe, but not be limited to the:

- organization
- roles and responsibilities of the crew and officers of the receiving vessel and bunkering personnel
- communication lines and language.

5.2.4 Maintenance system

All systems and components related to LNG bunkering shall be maintained and tested according to, at a minimum, vendor recommendations in order to maintain their integrity. To achieve this, the SMS shall contain a maintenance system describing the maintenance regime for each asset in the asset register (the asset register is a list of all the equipment to be maintained, including design parameters, safe operating limits and calibration data). Inspection routines and procedures for the testing and replacement of equipment shall be integrated in the maintenance system.

5.2.5 Identification and implementation of standards

The design of bunkering facilities shall be in accordance with recognised standards. To achieve this objective, the SMS shall be able to:

- Identify and document applicable regulatory requirements.
- Identify, address and document emerging regulatory issues.
- Identify and document relevant industry codes and standards.
- Identify, track, assess and document changes in the regulatory regime, industry codes and applicable standards.

5.2.6 Document control

In order to ensure that everyone in the organization is supplied with the correct information that is necessary for the role he/she has in the LNG bunkering operations, document control procedures are part of the SMS. Hence, the SMS shall have procedures in place to ensure that:

- Revisions are communicated to all staff concerned and modifications are identified.
- Related internal documents and procedures are updated accordingly.
- Obsolete/invalidated versions are clearly marked accordingly.
- Modified versions are clearly marked, changes are identified and a current version number is incorporated.
- Document changes are recorded and kept for traceability purposes.

Operating procedures shall be established and documented for all bunkering operations. Operations Manuals that contain the procedures shall be developed and integrated into the SMSs for all parties involved in the bunkering operations.

5.2.7 Risk management

As an integrated part of the SMS, a formal risk management process shall be developed and maintained to ensure that analysis (in terms of the likelihood and severity of a consequence), assessment (in terms of tolerability) and control (in terms of mitigation of risks to an acceptable level) are performed.

Additionally, the management levels that have the authority to make decisions regarding the tolerability of safety risks for LNG bunkering shall be specified.

5.2.7.1 The risk management process

The risk management process and procedures shall be consistent with ISO 31000 /3/ (see [App.A](#)) or an equivalent process and take appropriate account of specific considerations for LNG bunkering activities.

An illustration of the risk management process and how it shall be undertaken is presented in [Figure 5-4](#). The following sections describe the different steps embedded in the risk management process.

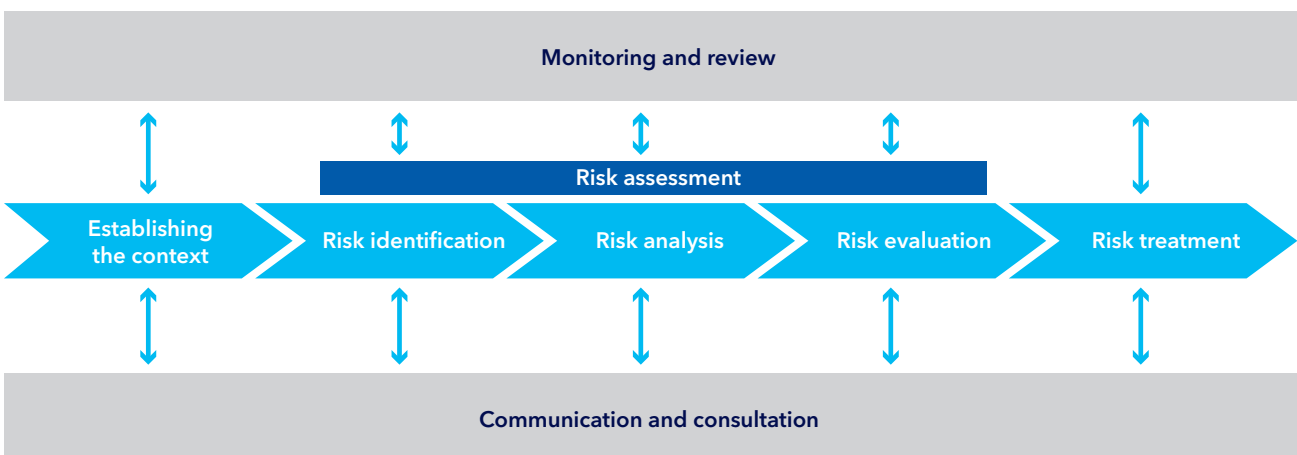


Figure 5-4 ISO 31000 Risk management process

5.2.7.2 Stakeholder identification

LNG bunkering stakeholders typically include, but are not limited to, the following:

- supplying party
- receiving party
- terminal operator
- port authority
- representative of the municipality
- other parties involved in simultaneous operations and activities

There shall be effective internal and external communication and consultation with relevant stakeholders to ensure that the full risk picture is identified and assessed.

5.2.7.3 Establishing the context

Establishing the context is the input interface from the SMS to Risk Management.

The objective of this step is to set the scope and criteria for the risk management process. The context may include parameters related to both the internal context (circumstances within the organization that may influence the process) and external context (circumstances outside the organization that may influence the process).

5.2.7.4 Risk assessment

Risk assessment is the overall process of risk identification, risk analysis and risk evaluation. Risk assessment provides an understanding of risks, their causes, consequences and their probabilities. These aspects can be illustrated by the bow-tie model for LNG bunkering operations. Risk assessments for LNG bunkering procedures are detailed in [App.D](#).

5.2.7.5 Monitoring and review

The identification of hazards and evaluation of risks shall be undertaken to reflect the situation in a particular phase of the lifecycle (e.g. construction activities, start-up of operations, decommissioning). Hazard identification and risk assessment activities shall be reviewed and may need to be updated if significant new issues are identified or there is any significant change to the installation or operation.

The range of conditions for which the hazard identification and risk assessment are valid shall be documented. The criteria triggering the need for re-evaluation shall be defined and documented.

Monitoring and review are the output interface from Risk Management to the SMS.

5.2.8 Emergency management

In spite of all technical and operational safeguards and measures, the possibility of an emergency situation shall always be taken into account. Hence, emergency response planning is an important part of the SMS. The emergency management cycle is illustrated in [Figure 5-5](#).



Figure 5-5 Emergency management cycle

The upper steps of the cycle, prevention-mitigation and preparedness, are safeguarded through continuous risk management and emergency preparedness. In the case of an emergency, a response is required through emergency procedures and a contingency plan. In general, effective action aims at:

- rescuing casualties
- safeguarding and evacuating others
- minimizing damage to property and the environment
- preventing escalation and bringing the incident under control.

Effective action shall be enabled through developing practical and location- and/or situation-specific emergency procedures and exercises.

5.2.8.1 Contingency plan

The contingency plan shall set out the responsibilities, roles and actions of the various organizations and personnel involved in the LNG bunkering operation, and thus make maximum use of the resources (expertise, knowledge, equipment, etc.) of the parties that are directly involved.

The contingency plan shall also include checklists and contact details which shall be regularly reviewed and tested. Copies of the plan shall be communicated to all parties involved in the bunkering operations, including the planned emergency response team, and be part of the training programme.

A contingency plan shall contain, but not be limited to:

- Facility contact details and telephone numbers of key operating, safety and security personnel (local medical facility, fire department, facility supervisors/responsible, port security, police, etc.).
- The contact details of persons appointed to be responsible and in charge of operations.
- Procedures for handling personal injuries (frost burns, suffocation, etc.).
- Procedures for guiding third parties and evacuation routes.
- If the system is approved for passengers on board during the bunkering operations, the handling and safe evacuation of passengers shall be included.
- A detailed list of areas where people – including people not involved in the bunkering – may be located during the LNG bunkering.

5.2.8.2 Emergency procedures

Site- and operation-specific emergency procedures shall be developed and form part of the contingency plan. The emergency procedures shall reflect the risk assessment's mitigating actions. Regular testing of emergency equipment, training and drills to ensure emergency preparedness are imperative and shall be repeated on a regular basis.

The emergency procedures shall include, but not be limited to:

- A description of the emergency lighting and emergency power systems.
- A description of the ESD systems.
- First aid procedures and, if there are first aid stations, the location of each station.
- Emergency LNG fuel transfer system shutdown procedures.
- Procedures addressing natural gas leakage.
- Procedures addressing fire in or in the vicinity of the location where LNG is being transferred.
- Procedures for evacuation.
- The location of mustering areas.
- Information on alerting, communication with and the location of the local fire brigade, hospital and police.
- Procedures for the operation and location of active fire-fighting equipment.

5.2.9 Management of change

Management of change (MOC) should be a formal process that identifies external and internal change that may affect established cultures, processes and services. It utilises the organization's existing risk management process to identify potential hazards in order to establish whether there are any adverse

effects on safety. Change can introduce new hazards that could impact the appropriateness and effectiveness of any existing risk mitigation.

With regard to MOC related to bunkering operations, the same points as for any other operations are valid. Organizational changes with regard to safety responsibilities should be assessed in detail in order to ensure safe operations at all times.

5.2.10 Training

All personnel working with LNG bunkering are to be trained and authorized for working with cryogenic and flammable liquids. In general, all staff should receive training as appropriate for their safety responsibilities in order to be competent to perform their duties. Besides the initial training, the continuous maintenance of competence by means of refresher training is a key issue. Training should include human and organizational factors.

Training requirements for personnel involved in LNG bunkering are regulated according to IGF Code /9/, STCW, ISO/TS 18683 /1/ and industry codes e.g. SIGTTO /11/. Shore personnel shall be trained according to national applicable standards.

The DNV GL Standard, *Competence related to the On Board Use of LNG as Fuel* /4/, stipulates the training and competence requirements for crew on LNG-fuelled vessels. This standard includes a detailed overview of the IMO competence requirements related to the different types of operation.

Records of crew training shall be maintained and stored.

SECTION 6 OPERATION OF LIQUEFIED NATURAL GAS BUNKERING FACILITIES

A high level of safety, integrity and reliability in the operation of LNG bunkering facilities shall be safeguarded and given high priority by all parties involved. This section contains guidance on the operation of LNG bunkering facilities in accordance with ISO/TS 18683 /1/.

6.1 Stakeholder involvement

The following chapters detail the responsibilities of the port or other national authorities, operator and receiver of LNG in the operations phase.

6.1.1 Port or national authorities

Port or national authorities will have an active role in reviewing documentation from the developer and issuing the final permit to operate at the end of the commissioning phase. A permit to bunker may be issued in the operation phase, if required.

In cases where deviations from agreed procedures are necessary, authorities and LNG suppliers may request to be involved.

6.1.2 Bunkering facility operator/developer

The bunkering facility operator shall be responsible for the operation of the bunkering facility, including, but not limited to, the following:

- Planning the operation.
- Planning and conducting training for personnel before the first delivery of LNG at the selected facility including, but not limited to, personnel involved in the LNG bunkering and personnel from authorities and emergency response services.
- Ensuring the compatibility of the interface between the receiving and supply sides.
- Operating the facility in line with plans and procedures.
- Plans and procedures reflecting the status of the facility.
- The technical condition of the equipment in daily operations.
- The LNG supplier shall be responsible for determining the LNG quantity and quality delivered.

6.1.3 Receiving ship

The operator of the receiving vessel is responsible for maintaining the vessel according to IMO regulations, Class rules and the Flag State's regulatory requirements.

The operator of the receiving vessel shall as a minimum:

- Ensure compatibility with the bunkering facility.
- Ensure that all functional requirements listed in this document are met.
- Ensure appropriate competence management and that the crew is trained according to appropriate standards.
- Inform the bunkering facility operator in advance in order to allow the supplier to make necessary preparations including, but not limited to, informing the port authority.
- Attend pre-bunkering meetings to ensure compatibility and familiarization with local conditions.
- Initiate the stopping sequence for the LNG transfer.

6.2 Risk assessments for the operation of liquefied natural gas bunkering facilities

In general, the required risk assessments shall be carried out in a facility's development phase, and additional risk assessments will only be required if:

- The study basis deviates from the scenario assessed in the risk assessment forming the basis for the permit from the authorities:
 - due to different receiving ships;
 - due to modifications to operating procedures;
 - due to the introduction of simultaneous operations;
 - and/or due to modifications to bunkering equipment.
- Required by authorities or other stakeholders.

Guidance on risk assessment methodology and acceptance criteria is provided in Appendix D.

6.3 Roles and responsibilities

Each organization involved in LNG bunkering shall clearly define the safety roles, responsibilities and accountabilities for LNG bunkering throughout the organization. This shall include the direct accountability for safety on the part of the person in charge and senior management. The safety responsibilities and expected behaviours of personnel categories that are involved in LNG bunkering shall be defined (e.g. in job or functional descriptions). Normally, a person in charge (PIC) is nominated and is responsible for supervising the bunkering operations in accordance with the defined bunkering procedures.

A key point in the entire LNG bunkering process is the alignment of the different parties regarding the roles and responsibilities during bunkering operations. The operations manual, as described in [Sec.5](#), shall include an organizational plan describing the responsibilities of personnel for the bunkering operations. The organizational plan shall describe how communication and checklists for the supply side and receiving vessel are to be established and updated.

Roles that shall be considered, at a minimum, are listed below:

- person in charge (PIC)
- master/CE of the receiving vessel
- master/CE of the bunker vessel
- LNG truck operator
- terminal operators/facility supervisors
- personnel on watch in the transfer area
- security guards
- local fire brigade.

The responsibility for and control of the operations shall be defined within the following requirements:

- Supply side:
 - responsibility for the condition of the connected system
 - responsibility for communication, operating rules and approval from the authority.
- Receiving side:
 - overall responsibility for the operations.
- Both sides are responsible for their own checklists and operations.
- Both sides are equally responsible for mutual checklists.
- Both sides have the right to terminate the operations at any time.
- Both sides are responsible for safe emergency response.

Clear responsibilities shall be defined for emergency situations and the accountability of the PIC shall be clearly documented and communicated. In general, the overall responsibility for the receiving vessel lies with the master or chief engineer. The overall responsibility for the supply side lies with the truck driver, bunker terminal operator or bunker vessel operator.

6.4 Operating procedures and checklists

Operating procedures shall be developed and documented in the SMS (see [Sec.5](#)) in the form of operations manuals and checklists as required in [Table C-1 /1/](#). A risk assessment shall be conducted in order to address potentially hazardous situations and identify preventive measures. The risk assessment and inputs to the methodology are described in [App.D](#).

A site-specific operations manual and checklists shall be developed by the designer and approved by the authorities (if mandatory). Examples of checklists for ship-to-ship, truck-to-ship and terminal-to-ship operations are provided in ISO/TS 18683 /1/ and by IAPH.

It is essential that both procedures and checklists reflect all the specific issues for the bunkering facility and operations including, but not limited to:

- The bunkering scenario (truck-to-ship, shore-to-ship, ship-to-ship).
- The operational limitations for the transfer operation.
- Any specific requirement stipulated by the authorities as part of the permit.
- In the case of SIMOPS (e.g. embarking/disembarking of passengers, cargo/goods handling, parallel bunkering, etc.), all the safeguards that have been taken into account in the QRA.
- The safety zone and specific requirements that may influence or limit adjacent activities.
- The organization of the bunkering operations, including responsibilities, accountability and control of personnel involved.
- Required communication and agreements between the supplier and receiver prior to, during and after the bunkering.
- ESD systems, controls and arrangements (manual, automatic or pendant).
- Transfer equipment (single or multiple liquid connections, hoses/loading arms, connectors, vapour return (if installed), including specific requirements for the connection sequence.
- Operational instructions in agreement with vendor data including:
 - connection of systems
 - testing of systems
 - inerting/purging of the transfer lines before LNG transfer.
 - start-up and stop procedures.
 - transfer procedures
 - draining and inerting/purging of the transfer lines post LNG transfer.
- Generic examples of checklists are given in ISO/TS 18683 /1/ and by IAPH. The IAPH checklists can be downloaded from the IAPH website.

The use of checklists and procedures shall be given due attention to ensure that ticking all the boxes does not end up as a formality. Hazardous scenarios and consequences that can potentially arise due to crew/officers and operators neglecting procedures shall be addressed in the risk assessment and risk mitigating measures shall be identified. It is the responsibility of the operator, in agreement with the authorities, to establish a practice to prevent this issue. In principle, this control can be carried out by:

- Witnessing by a representative of the authorities.
- Witnessing by a surveyor from a third party.
- Witnessing by the assigned responsible person for the bunkering operations, e.g. the PIC. It needs to be clearly defined that this is one of the PIC's responsibilities and that he/she is authorised for this role.

6.5 Functional requirements for operating liquefied natural gas bunkering facilities

The operation of the LNG bunkering facility shall be carried out in compliance with the operational plan for the facility and checklists. The functional and operational requirements in this section are outlined in accordance with ISO/TS 18683 /1/ and provide guidance on how to prevent, contain, control and mitigate potential operational risks along the different layers of defence explained in [4.4].

6.5.1 Compatibility of the bunkering systems

Checklists for the compatibility of the bunkering system shall be developed as part of the detailed design for use prior to instigating bunkering operations.

The checklists shall include, but not be limited to:

- Verified compatibility of connecting equipment and couplings.
- Initial checks with regard to the physical and signal compatibility of the ESD system, to be performed prior to the bunkering operations. If a linked ESD system is used, the compatibility of the receiver and supplier side shall be checked and confirmed in advance of any operations (see [4.5.10]).
- The language for communication shall be agreed upon between all parties involved prior to any operation.
- Equipment for communication shall be checked for compatibility and tested prior to operation start-up.
- Mooring arrangements between the receiving vessel and supply side should be checked for compatibility with regard to loads, geometry and operational envelope prior to commencing bunker operations.
- The compatibility of hazardous zoning and ventilation, including the location of vent masts and safety valves, shall be checked (for information on safety zones and security zones, see App.D. This applies to both permanent and temporary activities and installations. In the case of STS bunkering, if the bunker vessel is classified according to the IGC code /8/, an exception for hazardous zoning needs to be documented according to the equivalence principle.
- The maximum allowable working pressure, transfer pressure range and BOG control and handling shall be checked for compatibility.

6.5.2 Communication during liquefied natural gas bunkering operations

Clear communication between different parties during normal operations and emergency situations is one of the factors necessary to ensure safe operations. Therefore, clear communication rules have to be agreed on between the different parties before starting any activity. Responsibilities shall be defined as per [6.3].

Continuous communication between the receiving vessel and supplier during bunkering operations is of major importance. Therefore, communication protocols should address:

- Appropriate redundancy of communication equipment.
- Restricted use of non-EX-proof communication equipment.
- Protocol to handle communication failure during approach or pre-bunkering preparations.
- Protocol to suspend all operations in progress immediately if communication failure should occur during bunkering operations.
- Protocol to resume operations after secure communications have been restored and after having received formal clearance by the port authorities.

6.5.3 Pre-bunkering operations

A number of elements shall be addressed as part of the pre-bunkering operations and shall be confirmed in a checklist. This shall comprise, but not be limited to:

- The organization of and communication for the LNG bunkering operations.
- The liquid level and tank pressure for the receiving vessel shall be checked and noted in the bunker documentation. The receiving vessel's maximum tank filling levels, transfer rate and amount shall also be documented, signed and delivered to the operator responsible for the LNG supply.

- Special recommendations and requirements with regard to SIMOPS (e.g. embarking/disembarking passengers, cargo handling, parallel bunkering, etc.) as identified in the risk assessment shall be considered and implemented (see [App.D](#)).
- Personal protective equipment shall be available and in compliance with the requirements stated in [\[6.5.4\]](#)
- Personnel involved in the bunkering process shall be provided with suitable, intrinsically safe tools and communication equipment in compliance with SOLAS.
- Continuous monitoring and control of ship traffic and other activities shall be provided within the security zone (as defined in the risk assessment).
- Safe mooring shall be prepared by the deck officers in accordance with good seamanship and professional judgement by the deck officers. Note that for STS bunkering, the bunker vessel shall be able to disconnect and move away quickly. This can be ensured by quick-release hooks, magnet-/ vacuum-based mooring and/or an axe available on deck. For STS bunkering when ships are moving, refer to SIGTTO guidelines [/11/](#).
- The weather forecast shall be checked with respect to the acceptable operational envelope as defined in the risk assessment. Weather limitations will typically include wind, visibility, waves, current, tide and ice.
- Spill protection systems shall be checked.
- Gas detectors shall be installed as per [\[4.5.13\]](#) and tested.
- All crew that need to access rooms or spaces in the safety zone shall be informed of the bunkering operations.
- Adequate lighting shall be ensured for the bunkering operations, illuminating all working areas on both the supply side and receiving vessel along the transfer line.
- The pressure of the nitrogen supply shall be noted prior to the bunkering operations.
- Fire equipment onshore and on board the vessel shall be checked and ready to use.
- The emergency plan (see [\[5.2.8\]](#)) shall be communicated to all relevant parties.
- An agreement stating the transfer rate and quantity of LNG shall be signed by and distributed between the receiving and supply sides prior to bunkering (see [\[6.5.15\]](#) and [Sec.7](#)).

Completion of the checklists shall be communicated and signed before the transfer operation can initiate.

6.5.4 Personal protective equipment

It shall be ensured that personal protective equipment (PPE) is available and used by all personnel involved in the direct handling of cryogenic equipment during the operations. All personnel shall receive the proper training in the use of PPE.

PPE shall include, but not be limited to:

- A fire- and cryogenic-retardant overall.
- Splash goggles/face shield or equivalent.
- Insulated/cryogenic gloves.
- Protective footwear such as steel-toed boots.
- Suitable head protection such as hard hats.

6.5.5 Implementation and enforcement of the safety zone

The safety zone shall be clearly marked and access control shall be implemented prior to instigating any bunkering operations.

The safe handling of equipment, system response and operations inside the safety zone shall be reflected in the system-specific checklists and operating and emergency procedures. All relevant systems located inside the safety zone shall be designed according to Tables 1 and 2 of ISO/TS 18683 [/1/](#). Operational procedures and checklists shall address the proper use of hardware and equipment within the defined safety zone.

The safety zone, as defined in [App.D](#), shall include the following operational and technical restrictions:

- Only personnel that are essential for the bunkering operations and have received appropriate training shall be present in the safety zone during bunkering.

- All equipment used within the safety zone shall be rated according to relevant standards.
- The use of electrical equipment that is not required for the bunkering operations within the safety zone shall be eliminated.
- The safety zone shall be adequately marked by fences, warnings signs or other physical barriers to prohibit the entry of unauthorized personnel.
- Access to the bunkering station/area during bunkering operations shall be restricted to trained and authorized personnel.
- No maintenance or other work inside the safety zone shall be performed during bunkering.
- Passenger operations, including the embarking and disembarking of passengers, adjacent to the safety zone during the bunkering operations require a QRA. See [App.D](#) for details.
- SIMOPS, such as the loading and unloading of cargo, provisions and other goods, passing traffic on nearby waterways, or activities on the terminal adjacent to the safety zone during the bunkering operations, shall be addressed in a QRA. See [App.D](#) for details.
- Ventilation requirements in the area shall be described in the approved operational procedures.
- The safety zone shall be secured against mechanical impact that may cause damage to the operators, bunkering system and equipment.

6.5.6 Connection and testing of the emergency shutdown system

The ESD system shall be connected and tested to ensure the intended functionality (e.g. warm ESD test) before the LNG transfer starts.

6.5.7 Connection and testing of the transfer system

The following equipment shall be checked upon connection of the transfer system:

- transfer line(s)/loading arms
- manifolds
- couplings.

The vapour return, if fitted, shall be connected before the LNG liquid arms/hoses are connected in order to balance the pressure between the two tanks.

The electrical insulation shall be checked and it shall be confirmed that there is no metallic contact between the supply and receiving sides.

The connected system, including the bunker hose(s), shall be pressure tested prior to the bunkering operations. This can be done using Nitrogen, thus combining the inerting and testing processes.

6.5.8 Inerting/purging operations before transfer

The inerting/purging operations shall be carried out as specified in the operational plan and their completion is to be confirmed in checklists.

The purpose of inerting before transferring LNG is to remove any humidity, CO₂ and oxygen from the system in order to prevent hydrates and corrosion and mitigate fire hazards in the transfer lines. Hydrates may block the transfer lines or damage sensors, seals and valve seats.

6.5.9 Transfer operations

The transfer operations shall be continuously monitored and special attention shall be given to the following elements, among others:

- potential LNG leakage from the transfer lines, manifolds and couplings
- the pressure and temperature in the transfer system and cargo tanks
- the LNG tank level
- the LNG transfer rate
- the mooring conditions
- the bending radius of the bunker hose shall be monitored to stay within its design specifications.

The pressure in the receiving tank shall be controlled during bunkering according to the atmospheric or pressurized tank-type design.

Vapour return lines may be connected in order to control the pressure in the receiving tank or reduce the bunkering time. The supply facility is normally responsible for the vapour return. Bunkering to or between atmospheric tanks requires a vapour return. For pressurised (IMO type C) tanks, the pressure may be controlled by sequentially filling LNG from the bottom and spraying on top of the receiving tank, eliminating the need for a vapour return.

6.5.10 Leakage detection during transfer

The operators on both sides shall monitor the bunkering operations and respond to leakage detection according to procedures.

The operation shall be terminated (ESD-1) in the case of confirmed gas detection and not be resumed until it is safe to proceed. Confirmed gas detection will normally require a voting system with signals from several gas detectors or manual/operator confirmation. The ESD-1 shall ensure the closing of necessary valves, including the cargo pump, and shall give audible and visible signals. For transfer systems with unlinked or pendant ESD, manual detection is acceptable.

Portable gas detectors for the personnel directly involved in handling equipment shall be available and used. They shall be capable of measuring 0-100% of the lower flammable limit for natural gas.

6.5.11 Topping up and transfer stop

The receiving ship shall give the signal to ramp-down and stop the transfer operations when the LNG level in the tank reaches the agreed level or amount to be transferred (and before the maximum design filling level according to class rules is reached) /7/.

The filling sequence may be aborted at any time by three systems which together shall provide the required level of redundancy:

- the vessel's integrated control and automation system (IAS)
- the ESD system
- manual shut down procedures.

6.5.12 Draining of the transfer lines

The transfer lines shall be drained of LNG after the transfer operations. The system shall be designed with a zero tolerance of methane emissions to the atmosphere during drainage of the lines.

The bunker lines and piping shall be gas-free during extended periods when they are not in use.

6.5.13 Inerting operations post transfer

The inerting operations after draining the liquid lines shall be carried out as specified in the operational procedures and checklists.

The purpose of purging after transfer is to remove natural gas from the system to eliminate potential hazards.

6.5.14 Bunkering complete and disconnection of systems

The bunker line(s), vapour return line(s), communication link and ESD link shall be disconnected in this order when the lines are confirmed drained and inerted and all the valves are in their final position.

6.5.15 Quantity and properties of the supplied liquefied natural gas

There shall be equipment and reporting routines in place to document the LNG energy content and transferred volumes. A bunker delivery note documenting the quantity and properties of the supplied LNG shall be checked and signed after transfer is complete. A sample of an LNG delivery note stating LNG properties and composition is included in ISO/TS 18683, Annex E /1/.

Guidelines on the quantity and quality control of the supplied LNG are included in [Sec.7](#).



6.5.16 General maintenance

Maintenance, inspection routines and testing procedures shall be integrated into the maintenance planning system, with intervals and specifications according to the maker's recommendations. The integration of the maintenance system in the SMS is described in [\[5.2.4\]](#).

Maintenance related testing of equipment shall be completed according to Tables 1 and 2 of ISO/TS 18683 /1/.

The release of natural gas directly to the atmosphere as a result of inspection or testing operations shall be avoided. All natural gas released during an inspection shall be properly disposed of without venting.

While not in use, equipment shall be stored to avoid damage from accidental mechanical impact or environmental influences. The manufacturer's recommendations shall be followed.

SECTION 7 DETERMINATION OF LIQUEFIED NATURAL GAS QUANTITY AND PROPERTIES

This chapter contains recommendations that can be used by the parties involved in LNG bunkering to develop and implement a measurement system for determining the quantity and essential properties, referred to as the quality, of the transferred LNG. This system ensures transparency in billing and that the use of LNG as a fuel is safe and fit for purpose. During bunkering, the energy content and essential properties of the transferred LNG shall be determined. More specifically, the LNG energy content shall be the basis for the billing (custody transfer), while the properties determine the LNG's fitness for purpose. The receiving ship shall be able to rely on the specification of fuel quality for safe use.

LNG bunkering is developing rapidly and some of the aspects regarding the verification and traceability of measurement techniques still need to be addressed. At present, the guiding principle should be that the cost associated with implementing a measurement system is proportional to the financial risk involved. Larger transferred volumes with a higher commercial value justify the higher cost of a more accurate measurement system.

7.1 Background

LNG is produced at different locations around the world. Due to differences in natural gas sources, production technologies and the target markets for the LNG, the composition may vary substantially depending on the geographical origin. App.E provides an overview of the different LNG production locations and their typical LNG characteristics. The variations in composition of the commercially available LNG lead to variation in key characteristics such as density (Figure 7-1) and calorific value (Figure 7-2).

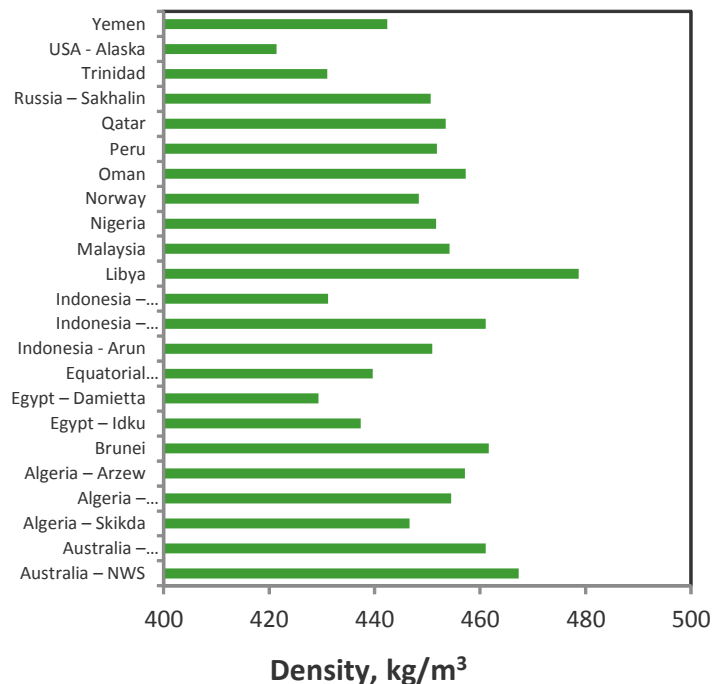


Figure 7-1 Density of commercially available LNG, data taken from GIIGNL 2014 /25/

The most elementary billing methods that can be applied are based on the volume or mass of the LNG bunkered. Given the large spread in the density and calorific value of the available LNG, these methods could result in a substantial variation in the energy content of the LNG bunkered. As illustrated in Figure 7-2, across the range of internationally shipped LNG (GIIGNL 2014 /25/), the energy/volume of regasified LNG varies by 12 - 17% and the energy/kg varies by 2 - 3%. If the energy content is not determined, this variation leads to uncertainty about the bunkered energy. This uncertainty not only affects billing, but also impacts the expected voyage distance.

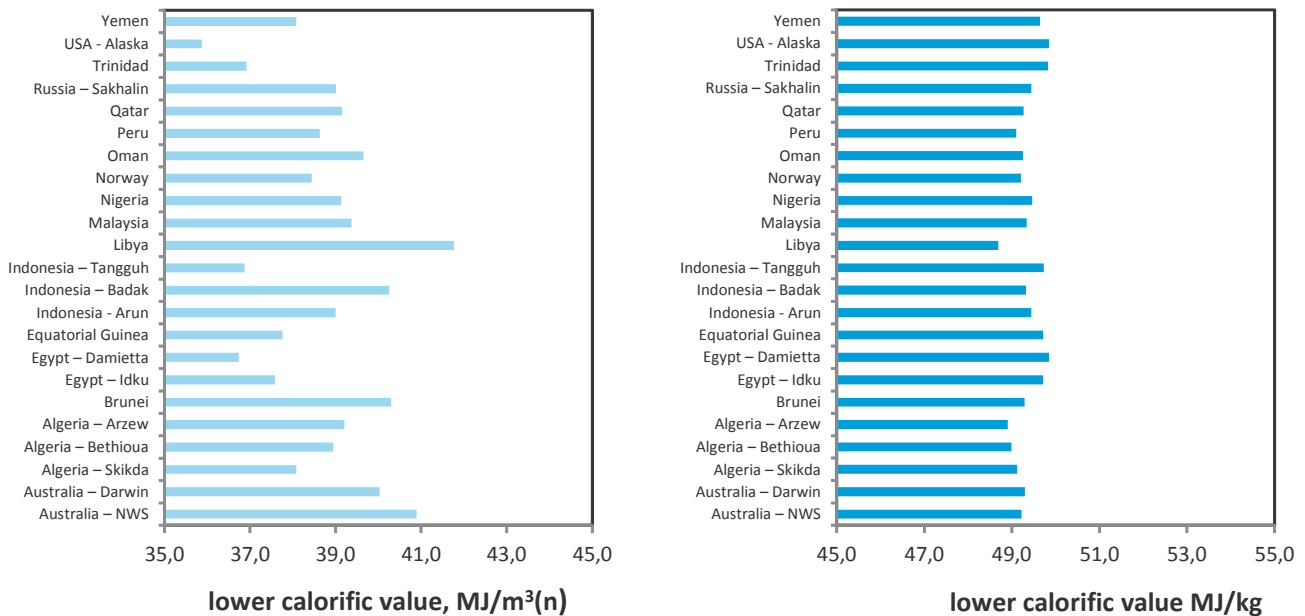


Figure 7-2 a) Lower calorific value on volume base of commercially available LNGs: b) Lower calorific value on mass base of commercially available LNGs, data taken from GIIGNL /25/

In addition to transparency regarding the amount of energy bunkered, it is essential to safeguard that the engines to be used in LNG-fuelled ships are matched with the expected variations in fuel composition (fitness for purpose). Specifically, the knock resistance of the fuel shall be determined unambiguously. It shall be noted that the engine knock phenomenon is only relevant for engines with an Otto cycle design (gas-fired reciprocating engines). Engine knock occurs when the compressibility of the gas causes the gas to auto-ignite before it is consumed by the flame from the spark plug, resulting in high local pressure waves propagating through the combustion chamber.

The occurrence of engine knocking leads to significant loss of performance (power reduction), potential engine shutdown and potentially extensive damage. The knock resistance of LNG is characterized by a methane number, which is similar to the octane number used in gasoline engines. To illustrate the effects of the variation in gas quality on the knock resistance, the PKI Methane Number (PKI method /24/) for the commercially available LNG is presented in Figure 7-3. Across the range of LNG, the variation in PKI Methane Number is more than 32 points, which is far too much to be neglected.

Furthermore the “boil-off” of the volatile components in the LNG stored leads to a change in composition, which decreases the knock resistance of the stored LNG over time.

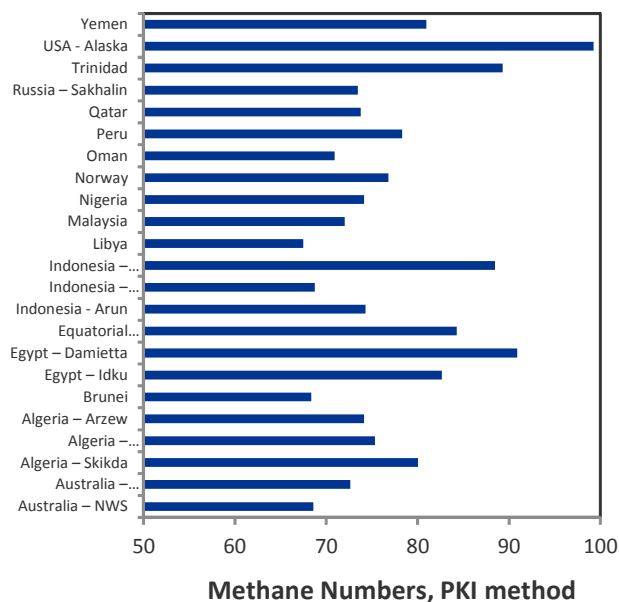


Figure 7-3 PKI Methane numbers of commercially available LNG, data taken from GIIGNL /25/

7.2 Determination of energy content

The objective is to measure the energy content loaded from the LNG bunkering facilities into a ship. The LNG supplier shall be responsible for determining the energy content.

To correctly determine the energy content of the LNG transferred, the following quantities shall be measured and/or calculated:

- Both LNG volume and LNG density, to determine the mass, or by measuring the mass of the LNG directly, and
- The LNG's lower calorific (heating) value.

During the LNG transfer, the following quantities should also be assessed:

- The energy content of the vapour return to the bunkering facility during the transfer of LNG, and
- The energy content of any gas consumed in the LNG bunkering facility.

An overview of the parameters and characteristics used to determine the energy content is shown in [Figure 7-4](#). The dashed boxes show the parameters to be measured from which the energy is calculated by using the relations given in [App. F](#).

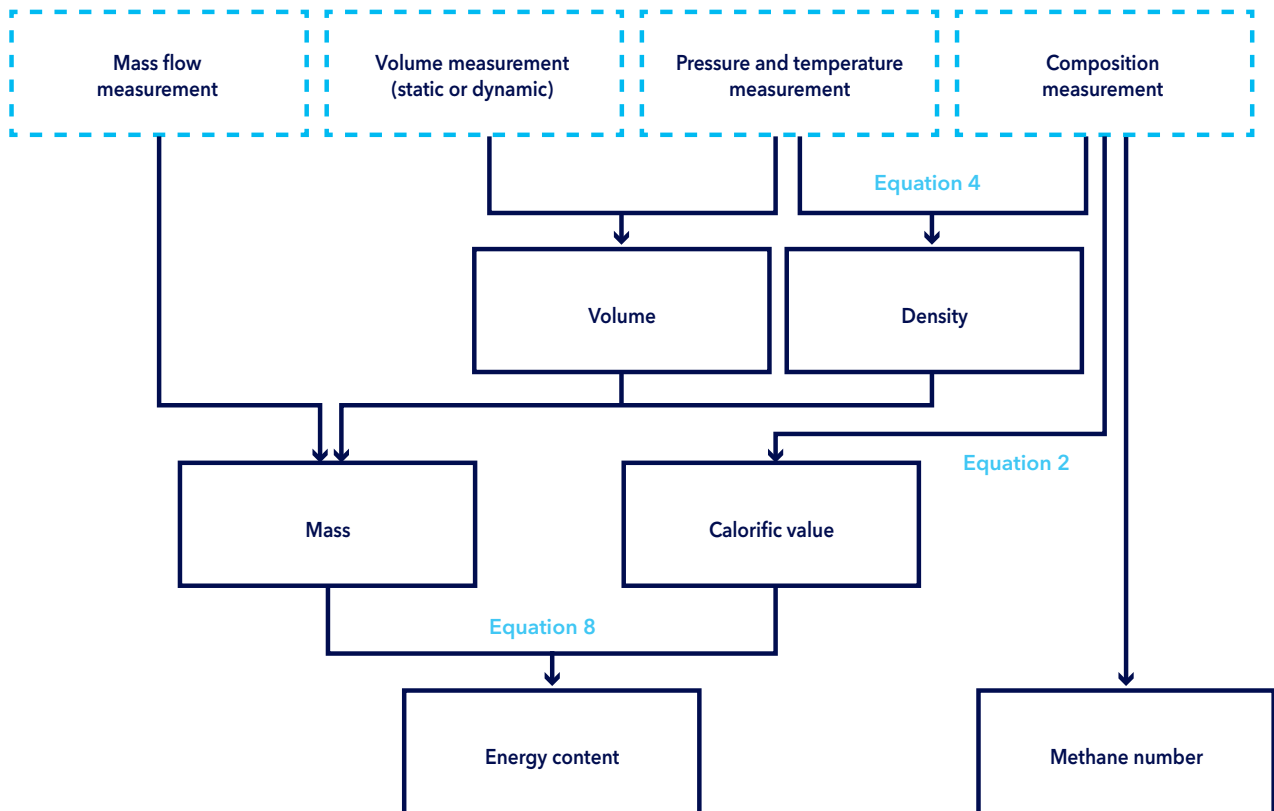


Figure 7-4 Parameters and characteristics for determining energy content

7.2.1 Mass of liquefied natural gas transferred

The quantity of LNG shall be expressed in mass. The mass of LNG transferred may be determined statically or dynamically. Three options for LNG quantity determination are:

- tank level volume measurement (static),
- volumetric flow measurement (dynamic) or
- mass flow measurement (dynamic).

Given the market developments referred to above, in addition to the minimum requirements for using one of these options, reference is also made to viable measurement methods.

Option 1: Tank level volume measurement (static)

In order to determine the LNG quantity transferred based on static volume measurements, the changes in the LNG level in the tank of the bunkering facility and density of the LNG shall be determined. The volume bunkered requires an initial level measurement just prior to loading and a final level measurement after loading has been completed. Level corrections shall be made using correction tables provided for the LNG tank gauge tables for temperature and for trim and list (for bunker ships). In order to determine the density, the temperature and LNG composition must be known.

Option 2: Volumetric flow measurement (dynamic)

In order to determine the LNG quantity transferred based on dynamic volumetric flow measurements, the flow rate and density of the LNG shall be determined. The flow rate requires a flow meter. For density determination, the temperature and LNG must be known. The temperature measurement shall be carried out at the flow meter.

Especially when bunkering small volumes, where static level measurements are more accurate, volumetric flow measurements are a viable alternative. One of the techniques available is the ultrasonic flow meter which has no moving parts and a low pressure drop, reducing the risk of LNG vaporization at the meter.

Option 3: mass flow measurement (dynamic)

In order to determine the LNG quantity transferred based on dynamic mass flow measurements, the mass flow rate shall be measured, for example using a Coriolis flow meter.

Measuring the mass flow directly allows the accurate measurement of small quantities of LNG bunkered and avoids intermediate determination of the LNG density.

7.2.2 Composition of liquefied natural gas – quality

The composition of the LNG shall be measured to determine the following properties:

- Calorific (heating) value (see ISO 6976:2005 /20/).
- Density, gas (see ISO 6976:2005 /20/) and liquid (see ISO 6578:1991 /22/).
- Methane number (see PKI method /24/).

In order to determine the LNG calorific (heating) value, density and methane number, the composition is required and shall include the following components: methane (CH₄), ethane (C₂H₆), propane (C₃H₈), butanes (n-C₄H₁₀, i-C₄H₁₀), pentanes (n-C₅H₁₂, i-C₅H₁₂ & neo-C₅H₁₂) and nitrogen (N₂). The composition may be measured in the liquid phase (in-situ) or vapour phase.

The LNG composition may be determined in-situ (liquid phase) by using Raman analysers or by sampling and vaporising the LNG and analysing the gas phase with a gas chromatograph, IR-analyser or correlative analysers that are based on a combination of measurement techniques. The main advantage of in-situ measurement is that this avoids the necessity of vaporizing LNG, with its attendant uncertainty, for the analysis. The in-situ method is being further verified for acceptance.

To determine the composition of the LNG in the gas phase, the sample must be brought from liquid state (low temperature) to gaseous state at ambient temperature. During this process, the LNG should be vaporized instantaneously, without any partial vaporization or loss of components. In order to analyse the composition in the gas phase, the gas chromatograph is the accepted technology in the gas industry due to its high and well-known accuracy. The gas chromatograph needs frequent calibration and the operation has to be carried out by a specialist. Alternatives such as the IR-analyser and correlative analyser tend to be less accurate, but have a faster response time and are easier to operate; they are therefore potential alternatives for lower volumes.

7.2.3 Vapour return

During loading, the vapour in the ship's tank may be transferred back to the bunkering facility and should be discounted during billing. The energy content of the vapour return is based on the transferred LNG volume, and the information needed to determine the density and calorific (heating) value of the vapour, i.e., the pressure, temperature and gas composition, should be determined. To convert the volume of the returned vapour to energy content, two methods may be used:

- The gas composition of the vapour return, as well as the pressure and temperature, should be determined by actual measurements.
- Alternatively, the values for gas composition, pressure and temperature should be set by mutual agreement, without actual measurement.

7.2.4 Energy consumption during bunkering

The LNG bunkering facility may use LNG as fuel in its engines or utilities during the loading operation, and this should be discounted during billing. If the bunkered quantity is determined by a static level measurement (Section [7.2.1], option 1), the LNG used to power the utilities should be accounted for. The volume of the LNG consumed may be determined by a gas flow meter and other parameters such as the gas composition, pressure and temperature needed for the density and calorific (heating) value. As for the vapour return discussed in [7.2.3], above, the values for gas composition, pressure and temperature may be set by mutual agreement, in which case no actual measurement is needed.

7.3 Liquefied natural gas delivery note

The LNG bunker supplier shall deliver a document (the bunker delivery note or its equivalent, see /1/) clearly stating the energy content, properties and composition of the fuel transferred. Such a document shall be signed by the supplier's responsible officers as well as by the receiver.

To ensure that the engine(s) used in the receiver's ship are matched with the LNG to be bunkered, the methane number of the LNG in storage at the supplier should be made available to the receiver beforehand.

Not only the buyer and seller but also the customs authorities may request an independent cargo surveyor. The perceived risks, both financial and technical, will strongly influence the need for an independent cargo surveyor. The bunker ship's tank calibration tables shall be certified by an approved classification society or by suitable independent cargo surveyors. In addition, the operation and calibration certificates for the measurement techniques shall be verified.

7.4 Measurement process management

An effective management system for measurement processes, such as ISO 10012:2003 /26/, ensures that the measuring equipment and processes are fit for determining the LNG energy content and properties. The measurement management system shall be aligned and compatible with the SMS described in Sec.5.

The LNG bunkering facility shall have policies in place to ensure fair trade, by:

- Compliance with (and traceability to) international standards and references.
- Avoiding systematic measurement error.
- Minimizing measurement uncertainty.

The cost associated with implementing these policies should be proportional to the financial risk involved. The larger the transferred volumes, and thus the larger the commercial value, the more compliant, accurate and reproducible the measurement should be.

The measurement management system shall be defined by the LNG supplier and should comprise:

- Documentation of measurement equipment and measurement data.
- Calibration of measurement equipment (within operational range).
- Verification of measurement equipment (at operational point).
- Organizing maintenance checks.

The LNG supplier shall define the measurement organization, which includes:

- Responsible personnel.
- Metrological confirmation (functionality checking, maintenance, adjustments of parameters).
- Measurement data responsibilities (corrections, validation of data, approval).

The measurement uncertainty shall be determined and documented for the LNG energy content and properties measurement processes, and should be within the agreed limits.

The measurement management system shall be periodically audited by an independent third party, and incidentally in the case of a dispute.

SECTION 8 REFERENCES

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- /3/ ISO 31000, *Risk Management*, 2009
- /4/ DNVGL-ST-0026:2014-04, *Competence Related to the On Board Use of LNG as Fuel*, 2014-04
- /5/ Myrland F., Danielsen H. K., *Guideline LNG QRA*, DNV (Internal document), 2012
- /6/ ISO/TS 16901, *Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface*, 2013
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- /8/ IMO IGC Code, *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, as amended
- /9/ Resolution IMO MSC 391(95), *Adoption of International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IGF Code)*, 2015-06-19
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- /20/ ISO 6976:2015, *Natural gas – Calculation of calorific values, density, relative density and Wobbe indices from composition*
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- /22/ ISO 6578:1991, *Refrigerated hydrocarbon liquids -- Static measurement -- Calculation procedure*
- /23/ *IP-15 - area classification for installations handling flammable liquids – Annex C – Part 2*, page 118: background to a risk-based approach; 3rd edition, July 2005.
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- /25/ GIIGNL, *The LNG Industry*, 2014
- /26/ ISO 10012:2003 *Measurement management systems - Requirements for measurement processes and measuring equipment*

APPENDIX A DNV GL RISK MANAGEMENT FRAMEWORK

The DNV GL risk management framework complies with ISO 31000.

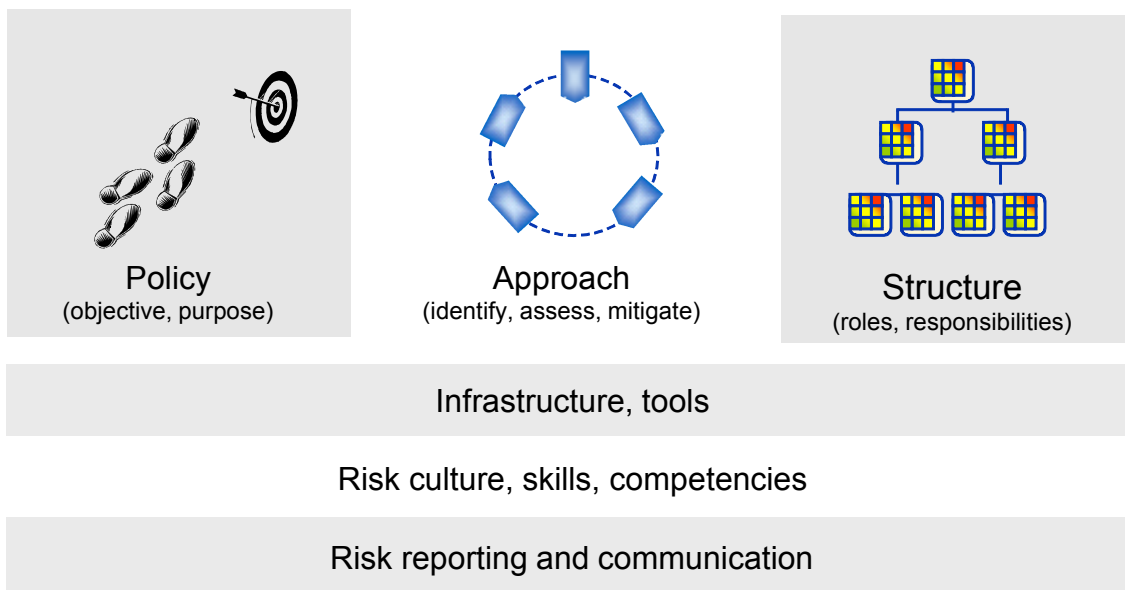


Table A-1 Framework


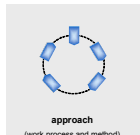
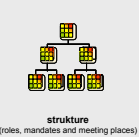
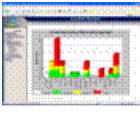

Step	Purpose
<p>Policy</p>  <p>policy (goal, strategy, acceptance criteria)</p>	<p>Outlines <i>what</i> principles and guidelines are to be followed when working with risk management. Ensures uniform rules and risk management criteria.</p>
<p>Approach</p>  <p>approach (work process and method)</p>	<p><i>How</i> the risk management shall be implemented as regards methodology. Which risk management approach shall be applied? This will ensure a systematic and uniform approach.</p>
<p>Structure</p>  <p>structure (roles, mandates and meeting places)</p>	<p>The risk management structure describes <i>where</i> and <i>with whom</i> in the organization the responsibilities for risk management lie. The structure shall ensure that risk management becomes an integrated part of the daily business and thus a naturally running process.</p>
<p>Tools</p> 	<p>The risk management tool shall <i>support</i> a high number of risk factors and give an overall view of the changes in risk exposure. This to ensure the smooth and continuous follow up of risks, risk-reducing actions and risk events.</p>
<p>Culture</p> 	<p>A prerequisite for an <i>effective</i> risk management process is the right risk culture. A risk culture is a key success factor and shall be evolved to ensure continuous risk awareness and focus.</p>

Table A-2 Approach (work process and method)

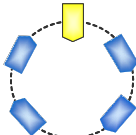
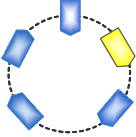
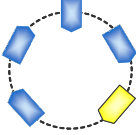
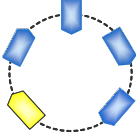
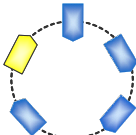
<i>Level</i>	<i>Purpose</i>
<p><i>Initiation</i></p> 	Specify and prepare the foundation for risk management. Compromise and come to an understanding about the basis for risk management.
<p><i>Identification</i></p> 	Reveal risks that threaten the achievement of goals and systematically structure the risks to ensure they are manageable.
<p><i>Analysis</i></p> 	Visualize how risks (threats and weaknesses) influence goal achievement, and assign responsibilities for handling and following up risks (risk ownership).
<p><i>Action planning</i></p> 	Decide where to initiate actions and develop an action plan to ensure the efficient handling of risk factors.
<p><i>Implementation and follow-up</i></p> 	Ensure the effective implementation of action plans, continuous follow-up of the risk picture, periodical update of the risk picture, and reporting of the risk and action status.

Table A-3 Initiation



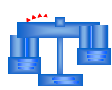

<i>Activity</i>	<i>Purpose of the activity</i>
<p><i>Method</i></p> 	Find an appropriate risk analysis method.
<p><i>Goal</i></p> 	Identify, develop and describe the relevant risk management goals.
<p><i>Scales</i></p> 	Set the probability and consequence scale to ensure a uniform evaluation of the risk level.
<p><i>Value chain</i></p> 	Identify the processes and activities that are within the risk evaluation scope.

Table A-3 Initiation (Continued)



Activity	Purpose of the activity
<p><i>Categories</i></p> 	Establish risk categories (sources/causes of risks) to ensure structured and systematic risk identification.
<p><i>Guide</i></p> 	Develop a risk questioning guide to ensure that all relevant aspects are included for systematic identification.

Table A-4 Identification

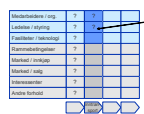

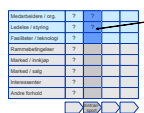

Activity	Purpose of the activity
<p><i>Identify</i></p> 	Identify threats and weaknesses of importance to the risk management goal(s).
<p><i>Describe</i></p> 	Compose good names and precise descriptions of risks to ensure effective communication and handling.
<p><i>Structure</i></p> 	Prepare a collection of risks which are mutually exclusive and formulated at the same level of detail.
<p><i>Identify</i></p> 	Identify threats and weaknesses of importance to the risk management goal(s).
<p><i>Describe</i></p> 	Compose good names and precise descriptions of risks to ensure effective communication and handling.

Table A-5 Analysis




Activity	Purpose of the activity
<p><i>Analyse risks</i></p> 	Decide on the risk level (probability x consequence in relation to the risk management goal) for identified risks in order to differentiate between critical, significant and negligible risks.
<p><i>Appoint risk owner</i></p> 	Attach each risk to a responsible organizational unit and a risk owner (person/role) in the unit.
<p><i>Prioritize risks</i></p> 	Prioritize which risks are to be treated with actions.

Table A-6 Planning of actions







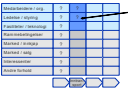

Activity	Purpose of the activity
<p data-bbox="225 338 400 365"><i>Identify actions</i></p> 	<p data-bbox="480 338 1142 365">Find reasonable risk-reducing actions for the prioritized risks.</p>
<p data-bbox="188 490 437 539"><i>Analyse and decide on actions</i></p> 	<p data-bbox="480 490 1433 568">Prioritize which actions to be implemented based on an evaluation of their risk-reducing effect. Also define potential risks for which there are no adequate treatments and that therefore need to be accepted.</p>
<p data-bbox="177 651 453 725"><i>Appoint a person to be responsible for the action (action- responsible)</i></p> 	<p data-bbox="480 651 1426 701">Locate the person in the organization that is to be made responsible for completing the action.</p>
<p data-bbox="188 831 437 857"><i>Develop an action plan</i></p>	<p data-bbox="480 831 1066 857">Establish a detailed plan for implementing the actions.</p>

Table A-7 Implementation and follow-up

Activity	Purpose of the activity
<p data-bbox="169 996 459 1050"><i>Implement the actions and update the risk level</i></p> 	<p data-bbox="480 996 1378 1050">Implement the planned actions, investigate whether the actions are successful and possibly initiate new actions.</p>
<p data-bbox="197 1178 430 1205"><i>Determine the status</i></p> 	<p data-bbox="480 1178 1209 1205">Determine the status of risks and actions after the implementation.</p>
<p data-bbox="185 1332 440 1359"><i>Monitor the risk picture</i></p> 	<p data-bbox="480 1332 1417 1386">Continuously identify risks that have been left out or identify new risks that arise from changed circumstances in own organization or the surroundings.</p>
<p data-bbox="188 1482 437 1536"><i>Update the risk picture periodically</i></p> 	<p data-bbox="480 1482 1444 1536">Periodically update the risk picture by carrying out a systematic identification and analysis of new risks and re-evaluating the current risks.</p>
<p data-bbox="240 1650 387 1677"><i>Report status</i></p> 	<p data-bbox="480 1650 1150 1677">Report important risks and actions to the management group.</p>

APPENDIX B HAZARDS ASSOCIATED WITH LIQUEFIED NATURAL GAS

B.1 Release of liquefied natural gas

This chapter describes the characteristics of LNG as well as the typical hazards associated with an LNG release or leak.

At atmospheric pressure, LNG will boil at -162°C , presenting a cryogenic hazard causing embrittlement of carbon steel structures and potential frost burns to exposed personnel.

Evaporated natural gas will be cold and heavier than air, and will thus be spread by gravity.

LNG is neither carcinogenic nor toxic. It is, however, an asphyxiant which dilutes or displaces the oxygen-containing atmosphere, leading to death by asphyxiation if exposure is long enough. Since natural gas in its pure form is colourless and odourless, confined spaces are subject to special attention. With large uncontrolled release quantities, personnel in direct surroundings may be suffering from low oxygen concentrations ($<6\text{-}15\%$), which should be counteracted by technical and procedural solutions.

When the natural gas is mixed with air, it will gradually become flammable. Natural gas is only flammable within a narrow range of concentrations in the air (typically between 5% and 15% for pure methane). Less air does not contain enough oxygen to sustain a flame, while more air dilutes the gas too much for it to ignite. In the event of a spill, LNG vapours will disperse with the prevailing wind. Cold LNG vapour will appear as a white cloud.

The cryogenic nature of LNG facilities represents a risk of the personnel, structural steel, equipment, instrumentation or control and power cabling being exposed to potentially injurious low temperatures. The cryogenic exposure of personnel causes frost burns. The cryogenic exposure of carbon steel causes embrittlement, possibly resulting in structural failure. Consequently, protection from cryogenic exposure, as well as from fire exposure, is needed.

Since hazardous concentration levels of methane, resulting in asphyxiation, are much higher than the combustible range, this additional hazard is usually not considered in a QRA.

B.2 Non-pressurized liquefied natural gas spill

LNG is stored in bulk storage tanks at its atmospheric boiling point (approximately -162°C). Any boil-off gas is collected and pressure relief valves are set to only allow a very low net positive pressure.

Most spill scenarios for the storage tank occur at atmospheric pressure plus any liquid head of LNG (i.e. the static liquid column above the point of release). The significance of this is that there is no pressure flashing of LNG to methane; the phase change occurs due to very rapid heat transfer and boil-off.

In small spills of LNG discharged from height, most of the LNG will vaporize before reaching the impoundment trenches, soil or water, due to heat transfer with air and concrete. For very large spills, air cannot transfer enough heat to vaporize all of the LNG, so the spill forms a pool.

Spilled LNG will simultaneously undergo several physical processes. These include pool formation, spread and boil-off. Pool formation for cryogenic boiling liquids is a dynamic process balancing the LNG input rate, gravitational spread, surface tension effects, heat transfer and gas boil-off.

B.3 Pressurized liquefied natural gas spill/leakage

In an LNG fuel supply chain, pressurised storage and transfer of LNG can occur via a truck storage tank and other smaller intermediate storage units, as well as in piping.

In such cases, the spill rate of LNG will depend on the pressure in the intermediate storage tank in addition to the static head, and in cases where LNG has been stored for some time, the immediate flashing will depend on the level of superheating.

Due to the pressure, the reach of liquid sprays and jet scan can be significant, but the formation of liquid pools will be similar to unpressurised non-pressurized LNG spill.

B.4 Dispersion

Methane gas (plus other associated heavier hydrocarbons if present) that boils off from the pool will form a dense gas due to its cold temperature (initially -162°C). The condensation of atmospheric moisture will further contribute to increased gas density above the pool.

As the cloud disperses with the wind, it spreads due to gravitational (density) effects and mixes with air due to atmospheric turbulence (characterized by a stability measure). Processes also affecting this mixing include heat transfer with the air and the re-evaporation of condensed moisture.

Eventually, the cloud will reach a point of neutral density, at which point dense gas processes cease to be important and atmospheric turbulence dominates the mixing.

Depending on circumstances, the cloud may eventually become buoyant as methane is much lighter than air (mole weights of 16 g/mol and 29 g/mol respectively); however, the presence of heavier hydrocarbons and cold will reduce the buoyancy and the cloud may be so diluted before this occurs that the effect may not influence flammable hazards.

B.5 Rapid phase transformation

Rapid phase transformation (RPT) is a physical phase transformation of LNG to methane vapour mainly due to submersion in water. RPT does not involve any combustion and cannot be characterised as a detonation. The pressure pulse created by small pockets of LNG that evaporate instantaneously when superheated by mixing in water will travel at the speed of sound and decay like any other pressure pulse. This is unlikely to damage a ship's large structural elements. No specific modelling is undertaken for RPT as it is unlikely to increase the hazard range of a major spill that has already occurred.

B.6 Flash fire

Dispersing clouds of methane (and any other hydrocarbons present) can be ignited anywhere where the concentration in the air is above the Lower Flammable Limit (LFL) and below the Upper Flammable Limit (UFL) for the given temperature and pressure.

The majority of clouds which are ignited do so at their edge as they disperse and meet a strong ignition source (e.g. open flame, internal combustion engine, sparks). An ignited cloud will "flash back" across all its flammable mass (i.e. that part within the flammable range – between the UFL and LFL). It will then burn at the UFL boundary until the entire hydrocarbon is consumed. This will almost always flash back to the source and ignite the pool.

Flash fire zones move at different speeds through flammable clouds. Factors affecting this include the material flame speed, the concentration (maximum speed at stoichiometric concentrations, lower speeds at LFL and UFL), the temperature, the condensed moisture, the degree of turbulence and the presence of congestion or objects that enhance turbulence.

When the flash fire reaches the evaporating spill of LNG, it will cause this to ignite and burn as a pool fire.

B.7 Pool fire

If LNG spills near an ignition source, the evaporating gas in a combustible gas-air concentration will burn above the LNG pool. A pool fire may result after a flash fire. An LNG pool fire generates significant thermal radiation. Large LNG fires tend to be smoky (experience indicates little smoke for pool fire diameters exceeding 30 metres) and this smoke absorbs a substantial fraction of the thermal radiation. An additional factor is that the spreading LNG spill pool can become fairly thin. Once combustion is added to evaporation, the pool will shrink significantly in size – to a sustainable pool fire diameter.

B.8 Fireball/BLEVE

Fireballs are very rapid combustion processes most often associated with Boiling Liquid Expanding Vapour Explosions (BLEVE) and these are only associated with pressurized liquids. When these are released quickly, the gases flash and this creates extreme speeds and turbulence. This in turn allows a flame front to travel rapidly across the whole flammable envelope. As these releases often do not have much air entrained, the fireball burns across the entire external envelope and causes the flammable mass to rise and radiate large amounts of heat in typically 20 to 40 seconds.

Fireballs are also possible with large releases of gases (e.g. large town gas tank failures), but these are much less radiant than a BLEVE and require special high turbulence conditions, unlikely to exist with an LNG spill in the open.

The normal mechanism for BLEVE is a pressure vessel containing pressurized liquefied gas (e.g. a recondenser) that is subjected to external fire impingement or is catastrophically failing due to other causes. Insulating a pressurised tank generally helps to reduce the risk of escalation from an impacting fire.

B.9 Vapour cloud explosion

A vapour cloud explosion (VCE) can occur when a large flammable mass of hydrocarbon vapour is ignited in a confined or partially confined space. The thermodynamics of the combustion of a stoichiometric mixture of hydrocarbon in air will result in an 8 times volume increase of hot combustion products compared to ambient reactants. This is mainly due to the high temperature of the combustion gases and partly due to an increase in the number of moles of gas. In a confined space (e.g. an enclosed box), the final pressure will be a maximum of 8 bar (about 120 psi). In an open space, an outdoors situation, there is no confinement and the experimental evidence is that methane gas will burn relatively slowly (in the order of 10 m/s) with all the expansion resulting in a vertical rise of gas. Ignition trails on dispersed unconfined LNG vapour clouds have confirmed that no significant overpressures are developed (<1 mbar).

Within methane (natural gas) clouds, flame propagation is slow and the flame may be extinguished prematurely and not be sustained throughout the cloud. Sufficient flame velocity (i.e. >100 m/s) to create significant explosion overpressures will not occur over water if there is no congestion or confinement.

It is, however, prudent to examine the facility's design to identify areas where vapour cloud explosions (VCE) may cause damage, particularly if the damage may extend off site. An area of potential interest for VCE is the jetty structure, between the jetty and the vessel, while LNG is being bunkered. There is some degree of congestion between the jetty/associated equipment and vessel.

B.10 Jet fire

Dispersing clouds of hydrocarbons can be ignited anywhere where the concentration is above the LFL and below the UFL. The majority of clouds which are ignited do so at their edge as they disperse and meet a strong ignition source (e.g. open flame, internal combustion engine, sparks). An ignited cloud will "flash back" across all its flammable mass (i.e. that part within the flammable range – between the UFL and LFL). It will then burn at the UFL boundary until all the hydrocarbon is consumed. This will almost always flash back to the source and lead to a residual jet fire. Factors affecting this include the material flame speed, the concentration (maximum speed at stoichiometric concentrations, lower speeds at LFL and UFL), the temperature, condensed moisture, the degree of turbulence and the presence of congestion or objects that enhance turbulence.

APPENDIX C FUNCTIONAL REQUIREMENTS AS STATED IN ISO GUIDELINES FOR LIQUEFIED NATURAL GAS BUNKERING FACILITIES

Table C-1 Functional requirements for LNG bunkering facilities /1/

<i>Functional requirement</i>	<i>Short description</i>
F1	Check of compatibility check between supplier and ship
F2	Can the system be commissioned and operated (purged and inerted) without release of LNG or natural gas to the atmosphere
F3	Is the system closed and leak tested prior to bunkering
F4	Design should reflect operating temperature and pressure and be in accordance with recognized standards
F5	The design shall reflect the required operational envelope (motions, weather, visibility)
F6	The transfer system shall be capable of being drained, de-pressurized and inerted before connections and disconnections are made
F7	The bunkering transfer system shall be designed to avoid trapped liquid
F8	Operating procedures shall be established and documented to define the bunkering process, and ensure that components and systems are operated in a safe way within their design parameters during all operational phases Note: for truck loading the procedures will normally be defined for the truck operation, but need to be aligned to specific ship requirements
F9	All systems and components shall be maintained and tested according to, as a minimum, vendor recommendation to maintain their integrity
F10	An organisational plan shall be prepared and implemented in operational plans and reflected in qualification requirements
F11	Operating procedures shall include a checklist to be completed and signed by both parties prior to the commencement of bunkering
F12	Emergency equipment and personnel shall be mobilized in accordance with the emergency response plan
F13	Operating procedures shall not be applied as an alternative to a particular fitting, material or item of equipment
F14	Minimize the likelihood of igniting potential LNG releases. This is accomplished by elimination of ignition sources in classified areas and by controlling activities in the proximity of the bunkering operation. No smoking signs
F15	Elimination of the potential spark or high currents from static or galvanic cells when the bunkering system is connected or disconnected
F16	Effective detection of release of LNG and natural gas Note: Manual detection may be accepted for continuously monitored short duration operations
F17	The transfer operation shall be capable of being stopped safely and effectively without release of liquid or vapour, either manually or by an ESD signal
F18	The transfer system shall be provided with an ERS (emergency release system) or break-away coupling, to minimise damage to the transfer system in case of ships drift or vehicle movement. This should be designed for minimum release of LNG if activated. The ERS may be linked to the ESD system (where this may be referred to as ESD-2)
F19	The release of LNG or cold vapour should not lead to an escalation due to brittle fractures of steel structure
F20	Personnel shall use PPE (personnel protective equipment) as appropriate for the operations.
F21	A safety zone shall be implemented around the bunkering operation into which only essential personnel shall have access
F22	Activities in the area adjacent to the bunkering operation shall be controlled to reduce possible ignition sources
F23	A contingency plan shall be in place
F24	Copies of the plan shall be communicated to all parties involved in the bunkering operation including the planned emergency response team and be part of the training program. This should be practiced at regular intervals both as "table top" and practical exercises

APPENDIX D RECOMMENDED PRACTICES FOR RISK ASSESSMENTS OF LIQUEFIED NATURAL GAS BUNKERING FACILITIES

The ISO/TS 18683 guideline for systems and installations for the supply of LNG as fuel to ships /1/ stipulates that the development of a bunkering facility shall include a risk assessment. How to perform a risk assessment for the design of onshore LNG installations, including the ship/shore interface, is described in ISO/TS 16901 /6/. This appendix refers to and is in accordance with both these ISO specifications.

A schematic approach for how to perform a risk assessment as part of the development process for an LNG bunkering facility is illustrated in Figure D-1 /1/. The main decision gates throughout the process are highlighted, indicating the required follow-up activities and next steps.

The figure also illustrates when a qualitative risk assessment suffices for the scenario assessed and when a more comprehensive, quantitative risk assessment (QRA) is required. The path where the answers are exclusively "yes" represents the "standard bunkering scenario" as defined in [4.3]. The opposite defines the "non-standard bunkering scenario". The difference between the qualitative and quantitative risk assessment methodologies and recommendations for how to encompass them respectively are discussed in the following sections.

This appendix describes the different main steps and decision gates included in the risk assessment process. How to assess the different main steps according to Figure D-1 by e.g. using different risk techniques is discussed for the main steps. The sections in this appendix are structured as follows:

- Definition of study basis.
- Initial qualitative risk assessment.
- Lay-out planning for LNG bunkering facilities (including determination of safety distances).
- Quantitative risk assessment (QRA).
- How to address SIMOPS in a risk assessment.

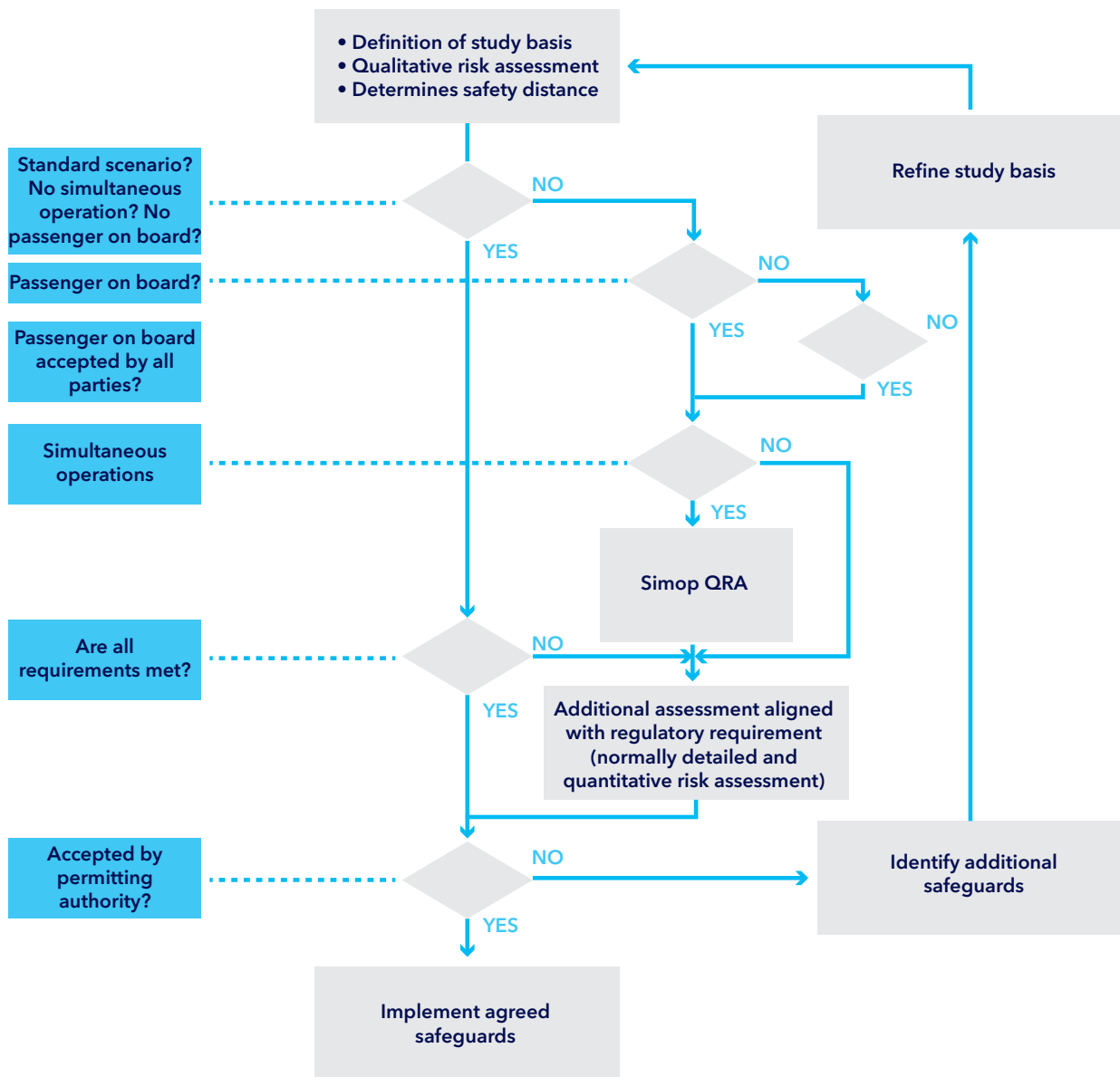


Figure D-1 Schematic approach to risk assessment for LNG bunkering operations /1/

D.1 Definition of study basis

The first step in a risk assessment for the LNG bunkering facility is to define the study basis. The definition of the basis shall cover, but not be limited to, the following:

- Description and layout of the bunkering facility.
- Description of potential SIMOPS, stakeholders and third parties in the area.
- Description of all systems and components with regard to function, design, operating procedures and relevant operational experience.
- Description of operational limitations.
- Organization of the bunkering activities with clear definitions of roles and responsibilities for the crew of the receiving vessel and bunkering personnel.
- Identification of authority stakeholders.
- Acceptance criteria for the project in alignment with regulatory requirements.

D.2 Initial qualitative risk assessment

An initial qualitative risk assessment shall at a minimum comprise a hazard identification (HAZID) exercise. A risk matrix should be used to prioritize hazards. The risk matrix provided below is as per ISO/TS 18683 /1/.

Consequence					Increasing probability			
Severity rating	People	Assets	Environment	Reputation	A	B	C	D
					Has occurred in E&P industry	Has occurred in operating company	Occurred several times a year in operating company	Occurred several times a year in location
0	Zero injury	Zero damage	Zero effect	Zero impact	Manage for continued improvement			
1	Slight injury	Slight damage	Slight effect	Slight impact				
2	Minor injury	Minor damage	Minor effect	Limited impact				
3	Major injury	Local damage	Local effect	Considerable impact				
4	Single fatality	Major damage	Major effect	Major national impact	Incorporate risk-reducing measures		Fail to meet screening criteria	
5	Multiple fatalities	Extensive damage	Massive effect	Major international impact				

Figure D-2 Risk matrix, /1/

D.2.1 Objective of the hazard identification study

The objective of the HAZID study is to identify:

- Hazards and assess the risks using a risk matrix that is agreed with the authorities.
- Major actions required (i.e. additional risk mitigation measures to be implemented, design modifications, etc.)
- The maximum credible accidental release (that shall be the basis for the definition of the safety zone in cases where a deterministic approach is chosen).
- A list of medium- and high-risk hazards that shall be analysed numerically in a QRA if relevant.

D.2.2 The hazard identification study process

The HAZID process shall comprise the following, but not be limited to:

- A workshop meeting with a multidisciplinary team using a structured brainstorming technique based on a checklist of potential HSE issues.
- A means of identifying, describing, assessing and reporting HSE hazards and threats at the earliest practicable stage of the development.
- Documentation and logging of follow-up activities.

Due to the complexity of the LNG bunkering operations, it is important to identify potential major hazards and operability difficulties within the process design and operation. Structured techniques are therefore required to systematically list these hazards in a detailed and systematized manner.

DNV GL recommends using the structured "What-If" methodology as an efficient technique for providing effective hazard identification in early stages of the development. The process follows the diagram shown in Figure D-3.

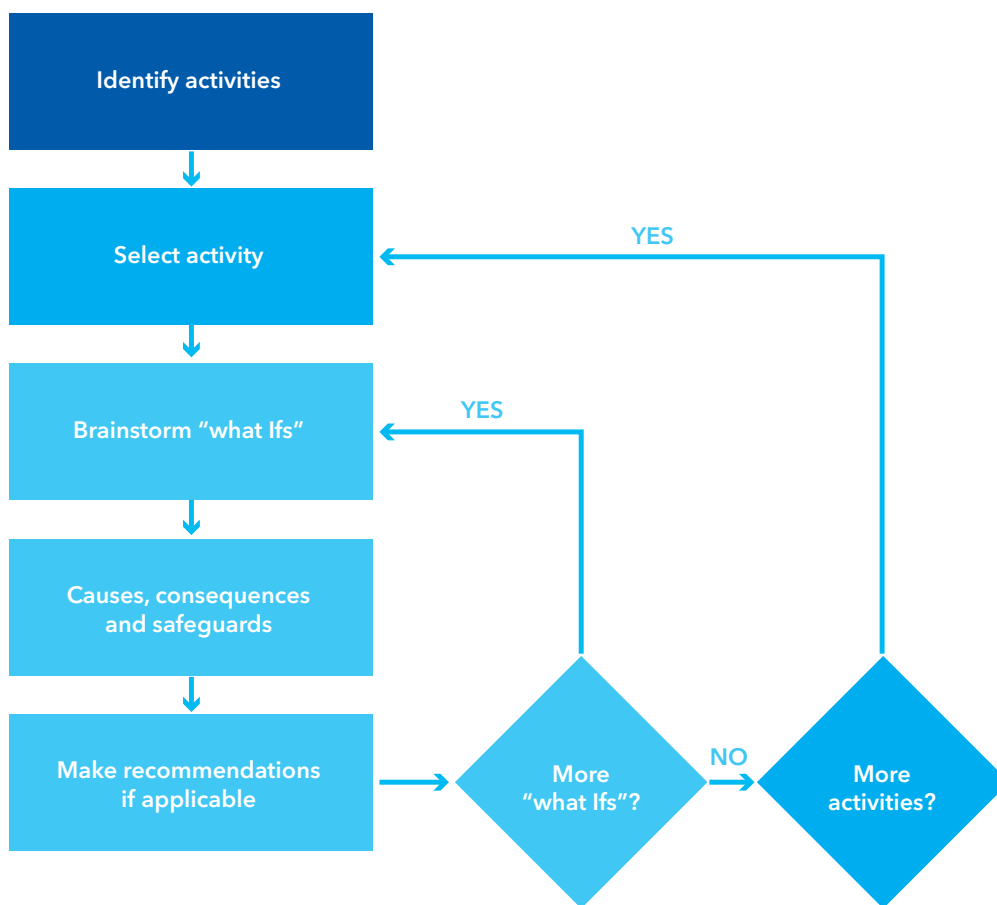


Figure D-3 The HAZID process

“Activities” are the different steps in the LNG bunkering operation, such as “mooring”, “securing the truck”, “purging”, “connecting the bunker lines”, etc. The activities will depend on the bunkering scenario. Activities outside the bunkering location shall be assessed for their risks with regard to the bunkering.

The HAZID shall be recorded in a worksheet that captures the identified hazards, their causes and possible consequences, identified barriers and proposed risk-reducing measures. [Figure D-4](#) is an example of a worksheet applied in a HAZID workshop illustrating the discussion process.

The *causes* (or hazards) are conditions which exist and which may potentially lead to the top event “Release of LNG or NG” (see [\[4.4\]](#)).

ID #	Hazard	Cause	Possible consequence	Existing safeguards and barriers	Risk-reducing measures/comments	Risk screening	
						L	C
Bunkering operation							
1	Small leakage in flange connection for liquid filling line	<ul style="list-style-type: none"> • Human error • Design and equipment • Production error • Wear and tear • Currently there is a lack of regulations and best industry practice on LNG bunkering • No standard flange connection for LNG bunkering today 	<ul style="list-style-type: none"> • Small liquid release, e.g. droplets • Released gas will dissolve quickly • No immediate risk of fire due to the small spill amount 	<ul style="list-style-type: none"> • Emergency shutdown system (ESD) on bunker ship/barge or terminal and receiving vessel • Drip tray in bunker station to protect the ship structure from cryogenic damage (brittle fracture) • Watchmen/supervision of the operation • Bunker station classified as Hazardous Zone 1 according to IMO Interim Guideline • EX-proof equipment required • Restricted access to bunker area • Personal protective equipment (PPE) • Gas detection and ventilation in bunker station (only required if enclosed space) • IGC code requirement is 30 seconds closing time for ESD valves • Pressure measurement upstream and downstream of the manifold • Weather restrictions • Short ESD time -5 seconds 	Comments: <ul style="list-style-type: none"> • Small leaks are in general more difficult to detect; however, the evaporated gas will be seen as a white cloud and should thus be easy to see • Same risk level should be applied for all vessel types, and we should attempt to reduce the frequency in order to reduce the risk 	5	1

Figure D-4 Example of a HAZID worksheet

D.2.3 The structured “What-if” technique (SWIFT)

Question categories intended to structure and stimulate discussions in a HAZID workshop are commonly used in a structured What-If analysis for process installations. During the assessment, applicable categories are selected and, if needed, additional categories are added.

Example question categories relevant for an LNG bunkering facility are given below.

D.2.3.1 Material problems

This question category provides an opportunity to explore the known or documented potential hazards and the special conditions which may need to be maintained in order to safely store, handle and process the LNG or natural gas. A particular focus shall be put on failures associated with the cryogenic properties of LNG.

D.2.3.2 External effects or influences

This question category is intended to help identify the effects of outside forces or demand scenarios which might result in the development of some of the hazards identified.

Natural phenomena ranging from flooding to hurricanes or tsunamis impacting the bunkering facility and operations shall be assessed.

Man-made external events such as arson, civil disturbances, terrorism or a nearby explosion which might impact the unit shall also be considered.

D.2.3.3 Operating errors and other human factors

For each mode of operation (e.g. mooring, connecting, purging, start-up, shutdown, stand-by, etc.), the SWIFT team shall imagine itself in the operator’s role and devise questions related to every conceivable way to mistreat the LNG bunkering process. Many operating errors are the result of inadequate training or poorly written or incomplete instructions.

For this reason, possible errors in the installation's development phase shall be considered.

D.2.3.4 Analytical or sampling errors

The team shall consider and devise questions related to all potential analytical or sampling requirements or operations. This category of questions could range from the importance of controlling the oxygen concentration in the bunker line, to failing to obtain critical process control data or injuries to personnel taking fuel samples.

D.2.3.5 Equipment or instrumentation malfunction

The team shall consider and devise questions related to potentially significant mechanical and instrumentation failures (excessive boil-off gas and over-pressurisation, leakage, sweating, etc.). Instrumentation and control system failures shall be reviewed. The team shall pay attention to protective devices and systems. Proof-testing schedules for protective devices and systems shall also be reviewed.

D.2.3.6 Process upsets of unspecified origin

This question category is intended to be a "catch all" for additional hazards or scenarios which were somehow overlooked (may not have been obvious, or just did not fit into any of the previous categories) during discussions of other question categories.

D.2.3.7 Utility failures

This question category is straightforward, but care shall be taken to note that external effects or influences, analytical errors, operating errors and other human factors and equipment/instrumentation malfunctions may create hazards which may directly cause a utility-failure-type hazard to develop.

D.2.3.8 Integrity failure or loss of containment

Integrity failure or loss of containment hazards may introduce additional considerations such as venting in normal conditions or venting in accidental conditions. A combination of the hazards that have been previously identified will represent the basis for integrity failures or loss of containment. All elements of the connection from the supplying tank to the receiving tank shall be reviewed for integrity failures or loss of containment and the extent of any discovered failure shall be specified and documented. A particular focus shall be put on failures resulting from the cryogenic properties of LNG.

D.2.3.9 Emergency operations

Emergency operations shall be reviewed independently. The possible escalation of minor situations during emergencies shall also be evaluated by the team. It shall be considered how the process will be operated or shut down if emergency conditions occur.

D.2.3.10 Environmental release

The most obvious release will be that caused by integrity failure or loss of containment. Mechanical failures and operating errors leading to environmental release shall also be considered. Depending on the qualitative risk assessment, resultant effects such as cold clouds, fires or explosion scenarios which are identified as possible may need to be developed further as fault trees or event trees with the identified environmental release as the starting point. Methane slip from bunkering operations shall be reviewed and the findings shall be documented.

D.2.3.11 Safety devices

In this question category, the team shall review personal protective equipment (PPE), safety devices and systems. Protective-system proof-testing schedules shall also be reviewed.

Intended and unintended releases of methane through emergency release valves shall be reviewed if they constitute a hazard in any phase of a bunkering activity.

D.2.3.12 Operability concern

The team shall consider questions related to the operator's abilities and his/her working environment. Questions will address the physical condition (e.g. strength, agility, good vision, good hearing) and physical size (e.g. minimum or maximum height) of the operators as well as the physical conditions (temperature, pressure, humidity, etc.) of the work area, the access to this area and the required staffing level. Some hazards may already have been identified as the result of previous Operating Errors and Other Human Factors discussions.

D.2.3.13 Quality factor

This question category is intended to explore items related to product quality. As a minimum, LNG specifications (e.g. concentration, density, colour, etc.), LNG contamination and the formation of gases and waste and their effect on operations shall be reviewed.

D.2.3.14 Process control

If the team has been thorough in its analysis of the previous categories, new issues will rarely be discovered at this stage. However, a review of the operations and the equipment used is very useful for keeping proper control of the process. Consider how the process will be operated in normal and emergency conditions and which instrumentation is critical for control.

D.2.3.15 Facility siting

This question category is very broad and reviews the layout, characteristics and equipment of the site on which the process under investigation is or will be installed. Items to be reviewed are the structural design and location of the buildings and process units and the spacing between them, the presence of toxic or flammable substances (including in other ships or on land), the presence of drainage systems, pressure relief and explosion venting systems, firewalls, emergency exits, air intakes for HVAC systems, etc. Some hazards may already have been identified as the result of a review of previous categories. Even if the team has been thorough in its analysis of all the previous categories, some new issues may be discovered at this stage (especially for larger sites).

Safety zones and security zones shall be considered in the facility siting review if they are established as described in this document. This shall include an assessment of nautical conditions such as traffic intensity, energy distribution, etc.

D.3 Lay-out planning for liquefied natural gas bunkering facilities

As part of the planning of a LNG bunkering facility, any restrictions on the area during bunkering need to be determined and implemented during operations. The restrictions will generally encompass the following:

- A hazardous zone (area classification) to ensure that all installed equipment is suitable for operation in an area that may have a flammable atmosphere. Area classification in the form of hazardous zoning around the area where gas may be present shall be in accordance with IEC 60092 (for ship) and IEC 60079 (for shore) as a minimum.
- A safety zone around the bunkering position where only essential and trained personnel, activities and equipment are allowed during the LNG bunkering. The determination of the safety zone is described in the following sections.
- An additional exclusion zone may be established outside the safety zone to further limit the number of personnel exposed to risk. Port regulations may apply to specific local ports.
- Passing distances, i.e. the minimum distance for passing ships, may be defined based on a risk assessment as part of the traffic control in the port to minimise the risk of ship impact during bunkering. Minimum passing distances may be defined as part of the port regulations.
- A security zone for the area around the bunkering facility where ship traffic and other activities are monitored and controlled to mitigate harmful effects. The security zone is defined in the following sections.

D.3.1 Different risk assessment approaches for lay-out planning

The risk assessment methodology (and acceptance criteria) as per regulatory requirements may differ per country.

Different approaches for a risk assessment in support of the land-use planning (LUP) process (in particular relevant for bunkering facilities in European countries) are summarized and described in /16/. Land-use planning aims to prevent and limit the consequences of possible major accidents and deals with the potential conflicts between sources of risk and surrounding land uses.

It shall be noted that the risk assessment approach for LNG shore-ship activities and establishments are (or will be) mostly covered in national LUP regulations (e.g. for SEVESO establishments in the EU). For the LNG activities (e.g. ship-to-ship bunkering) that are not governed by (regional/national) regulators other than

the port authorities, a specific risk assessment approach may need to be followed. Therefore, the risk assessment approach should be discussed upfront with the relevant authorities.

- The most common risk assessment approaches for LNG bunkering are the deterministic and risk-based approaches, where the deterministic approach is normally only used to determine a safety zone. In addition, initial semi-qualitative risk assessments are often conducted for LNG bunkering facilities and operations. In general, the existing methodologies can be divided into the following four categories:

D.3.1.1 Consequence-based approach

The consequence-based approach is based on the assessment of consequences of credible (or conceivable) accidents, without explicitly quantifying the likelihood of these accidents. The consequences of the accidents are mostly taken into consideration by calculating the distance reached by the physical and/or human health impacts (e.g. heat radiation), for a given exposure period and a threshold value (e.g. irreversible health effect/harm or fatality). The external safety zone is thus defined according to the LUP restriction applied. This method has been generally used in Luxembourg, Spain and Austria.

D.3.1.2 Deterministic approach with implicit judgement of risk

A simplified form of the consequence-based approach is the use of “generic” separation distances. These distances are usually derived from selected scenarios and developed on a conservative basis. In their most simple form, they are derived from expert judgement, including consideration of historical data or experience from operating similar plants. The generic-separation-distances approach has been established and is used in Germany.

D.3.1.3 Risk-based approach

The risk-based approach defines the risk as a combination of the consequences derived from a range of possible accidents and the likelihood of these accidents occurring. The results are represented as individual risk and/or societal risk. The LUP criteria are based on specific acceptability criteria with respect to the calculated risk. In general, the approach is similar to the QRA methodology described in paragraph [D.4]. This approach is followed in e.g. the United Kingdom, Belgium (Flanders), the Netherlands and Switzerland (only societal risk).

D.3.1.4 Hybrid approach

The hybrid (or semi-quantitative) approach combining the risk and consequence-based approaches is extensively used in France and Italy. In this method, one of the elements (usually frequency) is assessed more qualitatively, i.e. using classes rather than continuous figures. The use of a risk matrix is a typical example. For instance, France has adopted a hybrid approach that combines a consequence-based approach to determine the safety zones that correspond to damage thresholds and a risk-based approach for the determination of the considered accident scenarios. Italy has adopted a hybrid criterion that takes into account the frequencies as a mitigation factor for the damaged zones, identified using a consequence-oriented approach.

D.3.2 How to establish a safety zone

A safety zone shall be established around the bunkering station to ensure that only essential personnel and activities are allowed in the specific area that could be exposed to a flammable gas in the case of an accidental release of LNG or natural gas during bunkering (definition as per ISO/TS 18683 /1/).

The purpose of a safety zone is primarily to control ignition sources in order to reduce the likelihood of igniting a flammable gas cloud due to an accidental release of LNG or natural gas during bunkering. This is achieved by excluding uncontrolled and controlled ignition sources from the zone (except those necessary and related to the bunkering operation).

The safety zone is part of the second layer of defence. Importantly, the safety zone shall help to reduce the risk to personnel/people by:

- Limiting the number of people present in the vicinity of the bunkering operation to an absolute minimum as only dedicated personnel are allowed in the area and;
- Physically keeping other personnel not dedicated to the operation away from the bunkering area (potential hazard source) and outside the safety zone perimeter.

ISO/TS 18683 /1/ provides detailed guidance on two methods that can be used to determine the safety zone to be established for bunkering operations:

- *Deterministic approach*: the safety zone is determined by a consequence-based methodology, where representative conservative scenarios and their consequences are selected.
- *Risk-based approach*: this approach uses a QRA methodology. It shall be used if the bunkering is of a “non-standard scenario” (see Figure D-1), such as if deviations from the functional requirements (see Appendix C) in ISO/TS 18683 pertain, or if required by the local authorities. The QRA is a more complex, risk-based approach with the possibility of accounting for risk-reducing measures in the design. This may provide shorter safety distances compared to the results of the deterministic approach. Shorter safety distances may be accepted provided it can be demonstrated that the risk acceptance criteria (as agreed with authorities) can be met for 1st, 2nd, and 3rd party personnel.

Note that the safety distance shall never be zero and shall never be less than the hazardous zone or the minimum distance as defined by national authorities and marine requirements for the receiving ship.

The safety zone should be implemented as a safety distance all around the bunkering area and is complementary to the minimum required external safety distance (to e.g. neighbouring industry, residential or vulnerable areas) as determined based on national criteria for land-use planning. It shall be noted that the risk criteria set by (national) authorities shall also be evaluated in the risk-based approach for safety zone determination (relating to the total risk acceptance).

More details on both the deterministic and risk-based approaches are provided below.

D.3.2.1 Deterministic approach

The deterministic approach defines the safety zone as the area within the distance to LFL as determined by a recognised and validated dispersion model (e.g. PHAST) for the maximum credible release as defined as part of the HAZID. The methodology is displayed in Figure D-5.

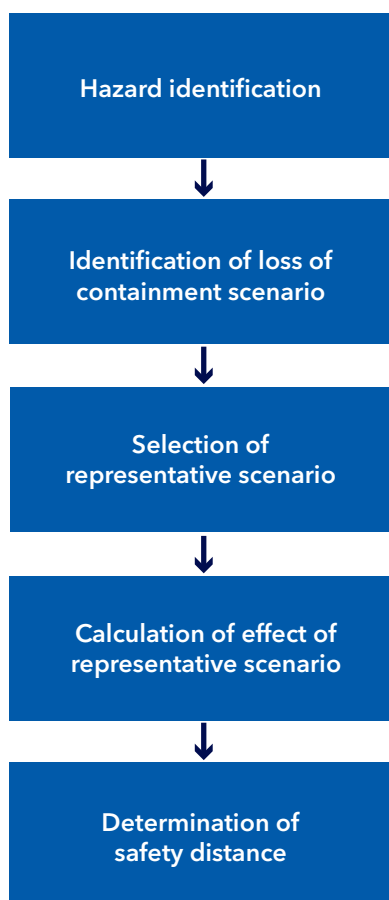


Figure D-5 Methodology for determining the safety distance by a deterministic path

The selection of the representative scenario is based on the initial hazard identification which is focused on hazards that can result in a loss of containment of LNG. It shall reflect the project-specific factors which shall include, but not be limited to:

- Transfer rates and inventory in the bunkering facilities.
- Operational modes.
- Implemented safeguards.
- Properties of the LNG in the bunkering system (temperature, pressure).
- Distance to other facilities or operations.
- Location-specific and representative weather conditions.

The representative scenario shall be determined on a conservative, but realistic basis considering the operation and the implemented safeguards. The maximum effect of the representative scenario shall be used to determine the safety distance.

Examples of maximum credible releases are provided in ISO/TS 18683 /1/. One relates to a trapped volume release scenario where the LNG in the hose/arm is 'trapped' between ESD valves and the other to a pressurized release scenario due to a broken instrument connection. The former scenario can be caused by the ship drifting off due to a collision or mooring failure. This scenario shall be discussed during the HAZID, taking into account the local circumstances (e.g. likelihood of collision and mooring failures, etc.).

Note that the selection of the maximum credible scenario (and definition of scenario parameters) is considered subjective and somewhat arbitrary. Hard selection criteria are not well-defined and usually depend on the location-specific risks and operational experiences and/or opinions of the HAZID team members with regard to what can be considered as a 'maximum credible' release.

The dispersion assessment of this maximum, realistic release needs to reflect all relevant factors and shall be conducted using a recognized and validated (in particular for LNG) dispersion model.

The dispersion assessment shall include the following steps:

- Determine the release rate and duration based on the failure size, pressure, inventory and effect of ESD. For large-size failures, the release rate shall reflect the time to activate the ESD.
- Determine initial flash and vapour generation due to the pressure loss. For "warm" LNG, the initial flashing will be significant.
- Determine the liquid LNG pool and evaporation rate dependent on the ground or water properties.
- Determine whether the characteristic dimensions of obstacles in the surroundings are such that a vortex, recirculation or preferential direction for gas dispersion may occur. If that is the case, the dispersion model chosen for the dispersion assessment shall be able to take such obstacle effects into account.
- Assess the dispersion dependent of the weather conditions (e.g. speed and stability) and substrate data (e.g. surface roughness).

Defensible, representative and sufficiently conservative scenario and model parameters should be subjected to scrutiny and well-documented. The most important parameters that could significantly influence the size of the deterministic safety zone are (the relevance of some parameters will also depend on the chosen scenario): the hole size, total released mass, temperature and pressure in the hose, wind speed and stability, surface roughness, availability of liquid spill containment and potential for liquid release to water or land.

The maximal effect of the representative scenario is a flash fire. A flash fire can occur when the released flammable cloud is ignited. This ignition could occur down to the Lower Flammable Limit (LFL) concentration. The distance effect shall normally be calculated by the distance to LFL to determine the safety distance, which is in agreement with established industry practice based on area classification and hazardous areas.

D.3.2.2 Risk-based approach

The risk-based approach defines the safety zone using QRA methodology. The risk-based approach is a more comprehensive analysis than the deterministic approach and will generally result in a smaller safety zone as probabilities and safety barriers are accounted for.

The approach provides a more rational basis for making informed decisions than an approach based on single, large-event scenarios (life for the deterministic approach). A key feature of the risk-based approach is its explicit consideration of the likelihood of an event; the assessment is thus based on both the consequence estimates and the probabilities for the quantity of release, location of release, probability of ignition as a function of time after the release and environmental factors. The effectiveness of barriers can be modelled and quantified in a QRA.

A smaller safety zone may be accepted provided it can be demonstrated by the QRA that risk acceptance criteria can be met for 1st, 2nd, and 3rd party personnel. In such cases, the emergency response plan needs to address scenarios where flammable gas may occur outside the safety zone /1/.

This requires a quantitative risk assessment which should address all the release scenarios identified in the HAZID and reflect validated (or conservative) failure data. The risk assessment can recognize implemented, "hard-wired" safeguards based on conservative assumptions. Furthermore, all release scenarios from all equipment (piping, pumps, valves, connectors, hoses etc.) and other factors such as SIMOPS should be assessed.

The risk assessment shall assess all hazard scenarios identified in the HAZID and as a minimum assess flash fires, jet fires, pool fires and explosions (if relevant).

The risk assessment shall normally assume that:

- 1st party personnel (crew and bunkering personnel) are continuously present in the safety zone during bunkering.
- 2nd party personnel (port and terminal operator, other ship crew) are continuously present directly outside the safety zone during bunkering.
- 3rd party personnel (passengers and other persons visiting the site) may be present, but will not be continuously exposed to the risk.
- 3rd party personnel continuously present (residential areas, schools hospitals) will be outside the risk contour for 3rd party acceptance.

The risk assessment relates to the total project acceptance and therefore considers the risk exposure for 1st, 2nd and 3rd party personnel. The evaluation of risk to 1st party personnel does not suggest that the bunkering personnel (1st party) are not allowed inside the safety zone. When determining the acceptability for a given size of the safety zone, risk acceptance for 1st party personnel is not a deciding factor. At the same time, a number of safety measures will be implemented to protect the personnel directly involved in the bunkering operation, e.g.:

- Personal Protective Equipment.
- Minimizing the exposure time by providing remote control and monitoring (CCTV, ESD, instrumentation).
- Training and qualifications.

The minimum required safety zone is determined by the distance to the perimeter of the individual-specific and/or location-specific individual risk contours based on the defined individual risk criteria for 2nd party and 3rd party personnel as agreed with the authorities. As described previously, if the risk is acceptable in accordance with the acceptance criteria, a smaller safety zone is acceptable. However, in accordance with ISO/TS 18683 /1/, the safety zone shall not be less than the hazardous zoning for the specific installation.

D.3.3 How to establish a security zone

The security zone is the area around the bunkering facility where ship traffic and other activities are monitored and controlled to mitigate harmful effects (definition as per ISO/TS 18683 /1/).

It shall be stressed that this definition is not the same as the term 'security zone' conforming to the International Ship and Port Facility Security Code (ISPS), which is more a measure to prevent the perceived threats to ships and port facilities by e.g. terrorism. On land, however, the ISPS border may overlap the perimeter of the security zone if the implemented measures serve the same purpose.

The purpose of a security zone is to reduce the frequency of loss of containment; e.g. to mitigate intrusions and harmful effects threatening the physical integrity of the operations and ships (e.g. due to potential collisions). The security zone is part of the first layer of defence.

The size of the security zone should be based on the actual intrusion risk to the bunkering operation, which depends on the location of the bunkering. For instance, the collision risk is much greater when bunkering in relatively narrow waterways with high nautical activity than when bunkering in a dedicated basin. Hence, the security zone should be sized accordingly. The security zone should be established based on the findings from a location-specific risk assessment (HAZID) or agreed with the port authority in order to:

- Monitor and control external activities e.g. ship movements that may lead to incidents threatening the operation.
- Guard against collisions with or interaction from passing vessels, other marine traffic or activities in the port/quay.
- Identify areas where personnel may be accidentally affected – this may result in limited access for personnel and/or specific actions in the emergency response plan.

The HAZID team shall decide if a security zone shall be implemented. For example, for bunkering in a dedicated basin in a remote location, a security zone might not even be necessary, whereas for bunkering in a waterway with high nautical or shore activity the security zone should be extended to a point where physical intrusions to the bunkering operations can be mitigated sufficiently by controlling and monitoring external activity. The security zone, if implemented, shall extend beyond the safety zone.

The location-specific risk assessment shall take into consideration parameters including but not limited to the:

- Energy spectrum of passing traffic.
- Possible arrangement of the supply side/receiving ship.
- Terminal operations.
- Passenger operations.
- Loading on/off operations.

Note that ignition sources may be accepted/tolerated (e.g. tugs, service vessels, trucks operating in the port) inside the security zone.

D.4 Quantitative risk assessment (QRA)

A quantitative risk assessment (QRA) is a well-known and widely accepted methodology to quantify risks in a structured approach. The technique determines risk levels associated with accidental loss of containment events (e.g. spills, gas releases).

A QRA calculates the risks to human life or property of a certain activity by calculating the potentially hazardous effects of a variety of scenarios and considering the probability of these scenarios occurring.

In cases where the bunkering scenario deviates from the standard scenarios (as defined in ISO/TS 18683 /1/ and explained in [4.3] and Figure D-1), or where any of the functional requirements specified in items F1 through F24 in Appendix C /1/ are not met, deviations shall be assessed by the QRA in agreement with local authorities.

Only adequate input data shall be used to ensure that valid and robust results will be obtained. If suitable information is available, a preliminary QRA may be used in the early stages of a design and can help to optimize the arrangement of the bunkering facility and operations. The operational envelope (size of safety zones, capacities, bunkering rates etc.) shall be assessed at this stage.

A QRA shall only be undertaken by personnel with adequate skills and competencies. The QRA model shall effectively reflect reality, so those familiar with the facilities and their operation need to be involved in the evaluation. This is particularly relevant in relation to the preparation of input data and assumptions and the review of the results of the analysis.

D.4.1 Objectives of the QRA

The objective of the QRA is to /5/:

- Quantify the level of safety risk (to people and/or property) associated with the operation of the bunkering facility or activity.

- Demonstrate that overall safety targets are met and comply with risk acceptance criteria as agreed with the authorities.
- Evaluate and select safeguards and risk-reducing measures, if needed.
- Confirm or develop safety zones (if a QRA is required).

The QRA shall model the operations in as much detail as is necessary for the analysis. Simultaneous operations, major construction/maintenance in or near LNG bunkering facilities and bunker vessels in operation shall be part of the risk assessment. The total risk shall be separated into two main contributors: the inherent risk from the hardware used at the facility and in its operations, and the contribution from external activities/domino effects at or near the bunkering location.

D.4.2 QRA methodology

The QRA methodology is visualized in Figure D-6. The individual steps are further detailed in the following sections.

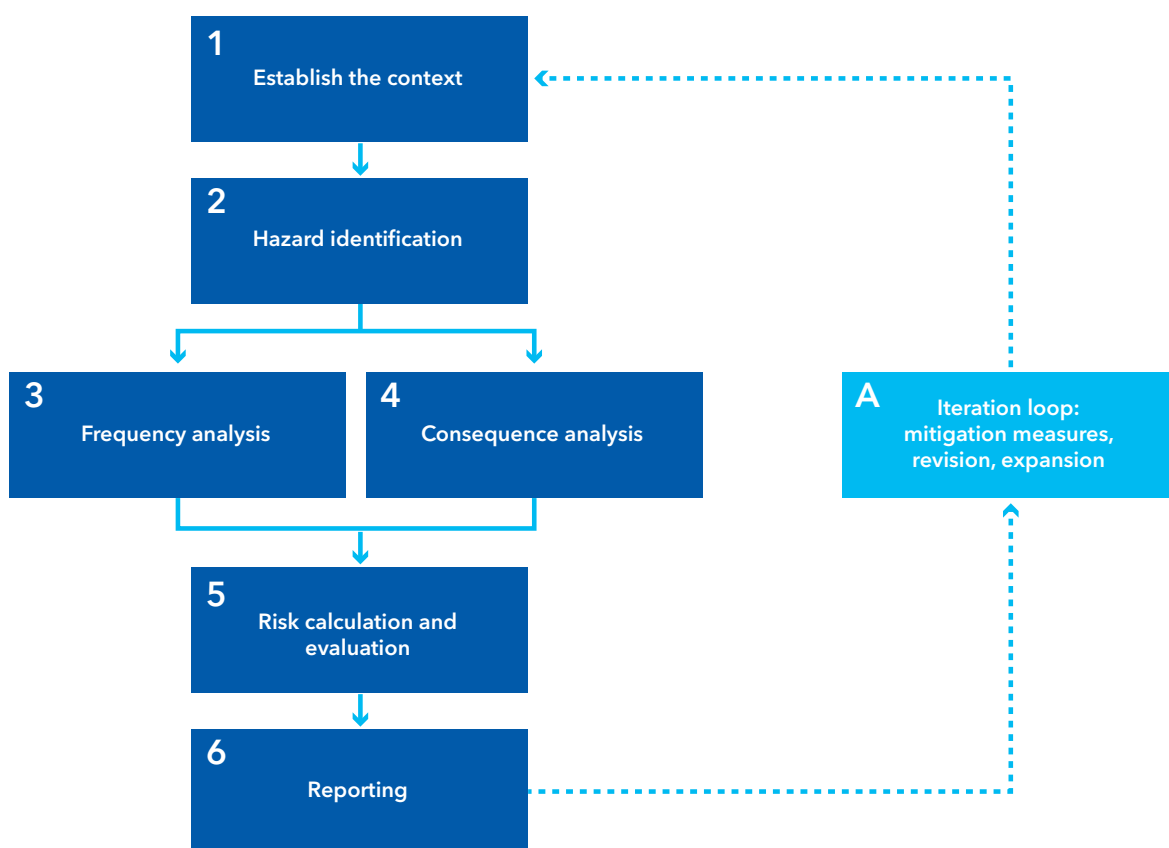


Figure D-6 QRA methodology

The first part of the QRA is similar to the qualitative risk assessment, i.e. to establish the context (study basis) and perform a HAZID to identify and screen potentially hazardous situations.

Additional factors are:

- The study basis shall be elaborated on with regard to additional safeguards that shall be implemented to compensate for deviations from functional requirements or requirements for components and systems, training or documentation as laid down in ISO/TS 18683 /1/.
- The hazard identification report shall include a list of accident scenarios that shall be analysed numerically in the QRA.
- The study shall include an assessment of possible domino effects caused by the bunkering operations to nearby activities and vice versa.

D.4.3 Accident scenarios

Typical accident scenarios and loss of containment scenarios for LNG bunkering facilities that shall be assessed for relevance are listed in [Table D-1](#). Reference is made to ISO/TS 16901 for more LNG accident scenarios specifically applicable to LNG import/export terminals. However, the specifics of the given accident scenarios (e.g. release size and associated base frequencies) are not provided.

If, after a preliminary risk analysis, a certain scenario is considered not relevant, this shall be documented in the project documentation.

Table D-1 LNG accident scenarios

<i>Source of release</i>	<i>Scenario</i>	<i>Possible causes</i>
General process and cargo handling	Accidental release from equipment and piping	Lack of flange tightness
		Defective gasket
		Weld defects
		Corrosion
		Impact
		Supporting structure damage
		External fire
		Overpressure (e.g. pressure tests during commissioning)
		Embrittlement
		Earthquake, floods and other natural hazards
Accidental release from LNG tanks at jetty or on ships	Ship collision	Passing ship adrift
	Ship pressure relief valve	Overpressure
		Rollover
Onshore storage	Tank leakage	Dropped in tank pump
		Internal or external leak in tank bottom or wall
		Earthquake
		Catastrophic rupture and leakages
	Tank PSV release	Tank overfilling
		Tank overpressure
		Rollover
BLEVE	Fire impact on pressurized hydrocarbon liquid containers. BLEVE is only considered as a potential threat for pressurised storage tanks where the loadbearing structure is exposed to fire loads.	
Loading/unloading lines	Leaks from piping and manifold	See general
Accidental release from the loading arm or hose	Leak/full bore rupture	Mechanical failure mode
		Loss of mooring, drift off
		Passing ship adrift
		Ship collision
LNG truck	Releases during transfer	Rupture of transfer hoses, truck or piping. Operational errors, mechanical errors
		Catastrophic rupture, warm BLEVE
LNG supply ship	Leakage from cargo tank	Structural damage
		Collision damage if this is identified as a credible risk in the HAZID

D.4.4 Frequency assessment

Once the hazards of a system or process have been identified, the next step in performing the QRA is to estimate the frequency at which the hazardous events may occur. The following are common techniques and tools available for a frequency assessment:

- analysis of historical data
- fault tree analysis
- event tree analysis
- simulations.

The selected technique will depend on the availability of historical data and statistics. Unfortunately, no LNG-specific failure frequencies are currently accessible due to the lack of available incident data. Risk analysts are forced to use release frequency data from generic sources. The Netherlands and Belgium have issued two different onshore frequency datasets for use in Seveso Directive risk assessments, and some companies and consultants have their own data. It shall also be stressed that nominated frequencies are tightly integrated with national risk criteria.

DNV GL recommends using data from the UK Health and Safety Executive's Hydrocarbon Release Database (HCRD), which are based on historical data from oil platforms in the North Sea and are representative for equipment used in those installations. This is considered the most extensive dataset of its type and superior to current published datasets, which often contain much smaller and older data and do not reflect current integrity management programs. The data form the basis for onshore and offshore QRAs and, in the absence of LNG-specific data, are 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.

There is, however, a strong belief among owners and designers of LNG equipment that release frequencies from LNG-specific equipment and piping should have lower values than those from their equivalent on offshore platforms. Therefore, QRA results based on HCRD release frequencies are believed to be conservative for LNG applications. It is unknown to what extent this conservatism could potentially lead to an increase in the calculated risk for an LNG facility, thus requiring the implementation of (expensive) risk-reduction measures or large safety distances.

More information on failure frequencies for use in QRAs is provided in DNV GL's *Failure frequency guidance, Process equipment leak frequency data for use in QRA 03-2013*.

D.4.5 Consequence assessment

Consequence modelling evaluates the resulting effects of the particular accidents, including their impact on people and assets. For example, ignited flammable releases can result in various consequences such as jet, pool or flash fires, fireballs or vapour 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 are capable of determining the resulting effects and their impact on personnel, equipment and structures. These tools should be validated by experimental test data appropriate for the size and conditions of the hazard to be evaluated.

The consequence modelling involves the following consecutive steps:

Discharge calculations shall be carried out to set release characteristics for the LNG (including depressurization to ambient condition). Scenarios which shall be modelled include releases from pipes/hose (e.g. leaks or catastrophic ruptures), in-building releases and release from cold masts. Leak scenarios to be considered are both un-pressurised and pressurised releases, depending on the storage and bunker system.

Figure D-7 illustrates a two-phase release of LNG:

- The accidental release develops a jet flow.
- The liquid jet breaks into aerosol.
- The droplets partly or fully evaporate, and some liquid rains out to form a pool of LNG.

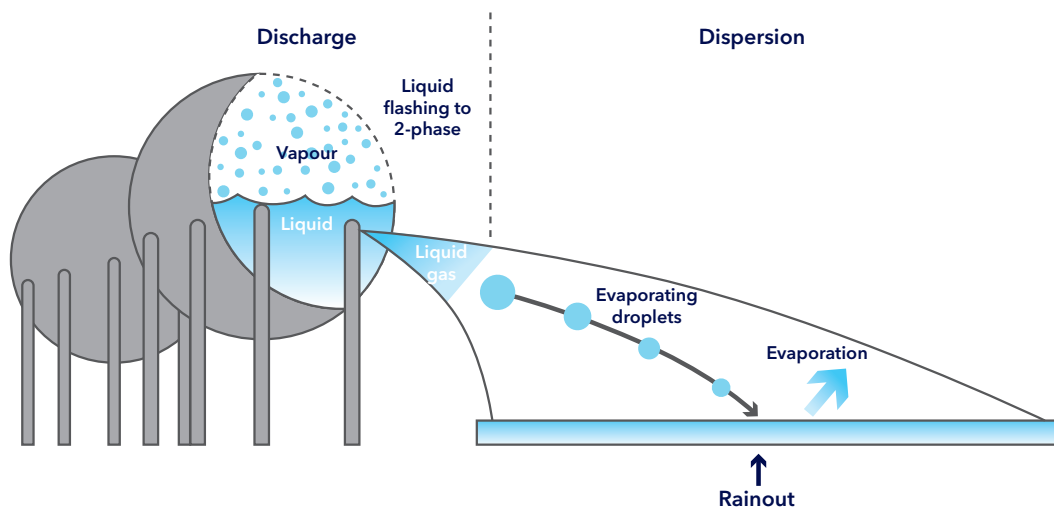


Figure D-7 Illustration of two-phase release of LNG

Dispersion calculations shall be carried out to determine the concentrations of gas when the cloud travels in a downwind direction. This includes the effects of jet, heavy-gas and passive dispersion. In the case of a two-phase release, rainout may occur, and pool formation/spreading and re-evaporation shall be modelled. Fire calculations shall be carried out.

Explosion calculations may be required if conditions for vapour cloud explosions cannot be eliminated.

The resulting effects shall be compared to the impact criteria recognized by the authorities and used in practice by the industries (e.g. fire radiation with or without escape and shelter).

All assumptions, modelling, identified uncertainties and calculation parameter settings shall be documented.

D.4.6 Barriers

Barriers constitute the levels of defence as described in [4.2]. Examples of barriers are (in increasing order of effectiveness): crew training, competence and certification, emergency response procedures (ERP), designing the loading arm/hose according to best industry practice, an ESD system and alarms, etc. Some of the barriers can be taken credit for in a QRA.

For further information regarding barriers and related functional and operation requirements, reference is made to [Sec.4](#) and [Sec.6](#).

D.4.7 Risk calculation

Once the potential physical damage zones are estimated by a consequence analysis, the probability of actual damage realization (i.e. safety risk) is calculated by taking various event probabilities into account. For example, the frequent occurrence of an undesirable event by itself may not cause damage. Actual damage realization depends on several event probabilities such as:

- weather stability class
- wind direction probability
- wind velocity probability
- ignition probability (immediate and delayed)
- presence of people and property in the effect zone.

The likelihood of damage realization is determined by an event tree analysis taking the above event probabilities into account. Another important factor that determines the actual damage caused is the vulnerability of people/property in the affected zone and the duration of exposure using relevant vulnerability criteria.

Various software tools have been developed to calculate risk (e.g. DNV GL's proprietary software SAFETI™).

D.4.8 Risk criteria

The next stage is to establish the risk criteria which are yardsticks to assess whether the risks are “acceptable”, “tolerable” or “negligible” or to make some other value-judgement about their significance.

If local authorities do not propose criteria, the two-band risk criteria stated in ISO/TS 18683 /1/ shall be used (see also Table D-2).

The simplest risk-criteria framework is a single risk level which separates tolerable risks from intolerable ones (i.e. acceptable activities from unacceptable ones). This framework is based on two bands (implies a single risk criterion).

D.4.8.1 The three-band risk criteria

Another approach is the three-band risk criteria; dividing risks into three hierarchic levels (see Figure D-8):

- The upper band is where the risks are usually considered intolerable irrespective of the benefits the activity may bring, and risk-reduction measures are essential whatever their cost.
- The middle band is where risk-reduction measures are desirable, but may not be implemented if their cost is high relative to the benefit gained (i.e. the ALARP principle should be demonstrated).
- The lower band is where risks are negligible, or so small that no risk-reduction measures are needed.

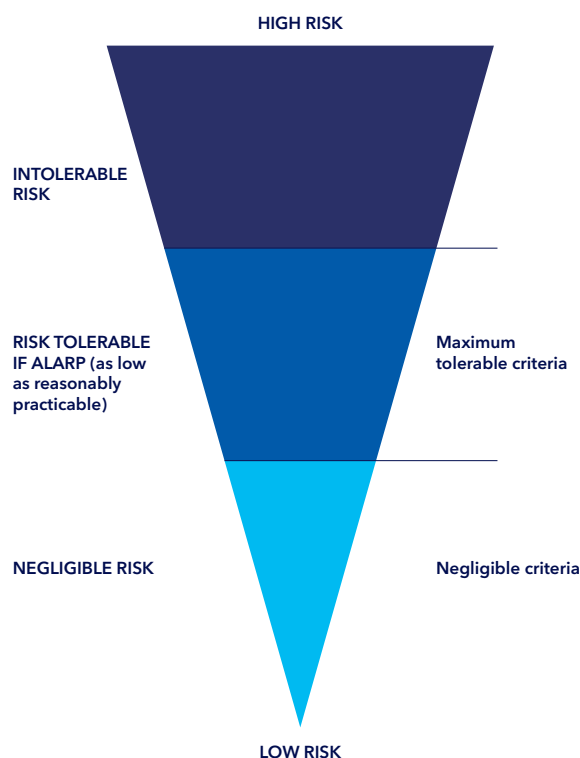


Figure D-8 Framework for three-band risk criteria

D.4.8.2 Individual risk

The most common risk criteria used in the LNG industry are individual risk (IR) and societal risk (F-N), concerning safety for people.

The Location-Specific Individual Risk (LSIR) is the risk of death for a hypothetical individual who is present at a particular location continuously all year (i.e. 24 hours a day, 7 days per week) without wearing personal protective equipment. Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from the realization of specific hazards. It is a standard output from a QRA, suitable for risk contour plots.

However, the individual risk should apply to the risk of real individuals, so corrections might be needed. The Individual-Specific Individual Risk (ISIR) can be calculated to account for the fact that not all individuals are continuously present. Risk estimates may need to be converted to this form before comparing them with risk criteria.

Individual Risk is presented as iso-contours similar to elevation contours on a map. The inner contour is the highest risk (often 10^{-3} or 10^{-4} per annum), and contours are plotted in declining order of magnitude circles. An example is shown in Figure D-9.



Figure D-9 Example of risk contours

Individual risks for workers are commonly expressed as the fatal accident rate (FAR), which is the number of fatalities per 10^8 exposed hours. FARs are typically in the range of 1-30.

The individual risk acceptance criteria shall be acknowledged by the appropriate authority and the following are examples of acceptance criteria.

Table D-2 Risk acceptance criteria, /1/

	Acceptance criteria	Comment
Individual risk 1 st party personnel	$IR < 10^{-5}$	Applies to crew and bunkering personnel directly involved in (or dedicated to) the bunkering activity
Individual risk 2 nd party personnel	$IR < 5 \cdot 10^{-6}$	Port and terminal personnel, other ship crew
Individual risk 3 rd party personnel with intermittent risk exposure	$LSIR < 5 \cdot 10^{-6}$	Third-party personnel should not have access for prolonged periods. Examples are passengers, visitors or people passing by regularly. Corrections might be needed for certain individuals before the calculated risk criteria can be compared to this criterion (i.e. to calculate ISIR, see also below).
Individual risk 3 rd party personnel with prolonged risk exposure	$LSIR < 10^{-6}$	The general public without any involvement in the activity. No residential areas, schools, hospitals, etc. inside this risk contour.

Individual risk to 1st party personnel:

Individual risks for workers are commonly measured in terms of the fatal accident rate (FAR), which is the number of fatalities per 10^8 exposed hours. When calculated in a risk analysis, the FAR is usually derived from the calculated individual risk of death per year divided by the number of hours exposed to the risk in a year $\times 10^8$. During bunkering, the number of hours exposed to the risks related to bunkering per year depends on the number of bunkering operations and their duration. In addition, bunkering personnel are also exposed to other sources of risk not related to the bunkering operations. [Table D-2](#) specifies an individual risk criterion for 1st party personnel of 10^{-5} /year [/23/](#). This criterion compares well with work carried out by the UK Health and Safety Executive, which calculates an actual FAR of $0.56/10^8$ exposure hours due to the accidental ignition of flammable substances. This is equivalent to an IR of $1.07E-5$ /year. Note that the total individual risk of a typical (onshore) petrochemical plant worker in the UK is in the order of 1×10^{-4} /year, which also includes occupational risks [/23/](#).

Individual risk to 2nd party personnel:

The risk acceptability for second-party personnel should naturally be stricter than for 1st party personnel directly involved in the operation. The basis of this criterion is unclear (not given in ISO/TS 18683) and is intended as a starting point for discussions with the authorities. 2nd party personnel (e.g. port and terminal personnel and ship crew) are assumed to be continuously present during the bunkering activity and exposed to the risk. The criterion could be compared to the LSIR when the bunkering takes place during the normal working hours of one specific 2nd party individual who is continuously exposed to the risk. Otherwise, an individual-specific individual risk (ISIR) calculation might be required. It may also be necessary to make corrections if port or terminal personnel are not continuously present and exposed to the risk (see also below).

Individual risk to 3rd party personnel with intermittent and prolonged risk exposure:

Individual risk is normally calculated assuming that the individual is continuously present at a given location (i.e. LSIR). This is a defensible assumption for those personnel who it is reasonable to assume are continuously exposed to the risk (e.g. 3rd party personnel with prolonged risk exposure, such as residents). However, individual risk criteria should apply to the risks of real individuals and therefore corrections should be made before comparing the calculated individual risks. This accounts for the fact that, in reality, individuals are not continuously present (i.e. ISIR needs to be calculated). It shall be stressed that in some cases these corrections are also implicitly represented in the criteria, so that no modifications are needed (e.g. this is the case for the Australian criteria).

The suggested risk criteria in [Table D-2](#) show that the risk criteria for 3rd party personnel with intermittent risk exposure are a factor 5 higher than those for 3rd party personnel with prolonged risk exposure. This implies that "the most exposed" individual is present at the location and exposed to the risk for an average of 36 hours per week (this would result in a factor 5 reduction of the location-specific individual risk, hence 10^{-6} /year for a 3rd party). It should be noted that individual risk criteria should be applied to all individual members of the public with equal weight. Thus, the individual whose risks are most critical to the acceptability of the activity is "the most exposed individual", i.e. the member of the public with the highest individual risk.

If needed, for 3rd party individuals (e.g. people passing by) with lower exposure time, a correction factor can be applied to the calculated risk. This should be assessed on a case-by-case basis and discussed with the authorities before the calculated individual risks are compared to the criteria.

D.4.8.3 Societal risk

Societal risk is defined as the (cumulative) frequency per year of a particular group of people dying concurrently as a result of accidents. Societal risk criteria have not been as widely used as individual risk criteria because the concepts and calculations involved are much more difficult. Societal risk is usually represented in an F-N curve, which is a Log-log graph: the X-axis represents the number of fatalities and the y-axis the cumulative frequency of the accidents, with the number of fatalities equal to N or more.

An example of an F-N curve is provided in [Figure D-10](#).

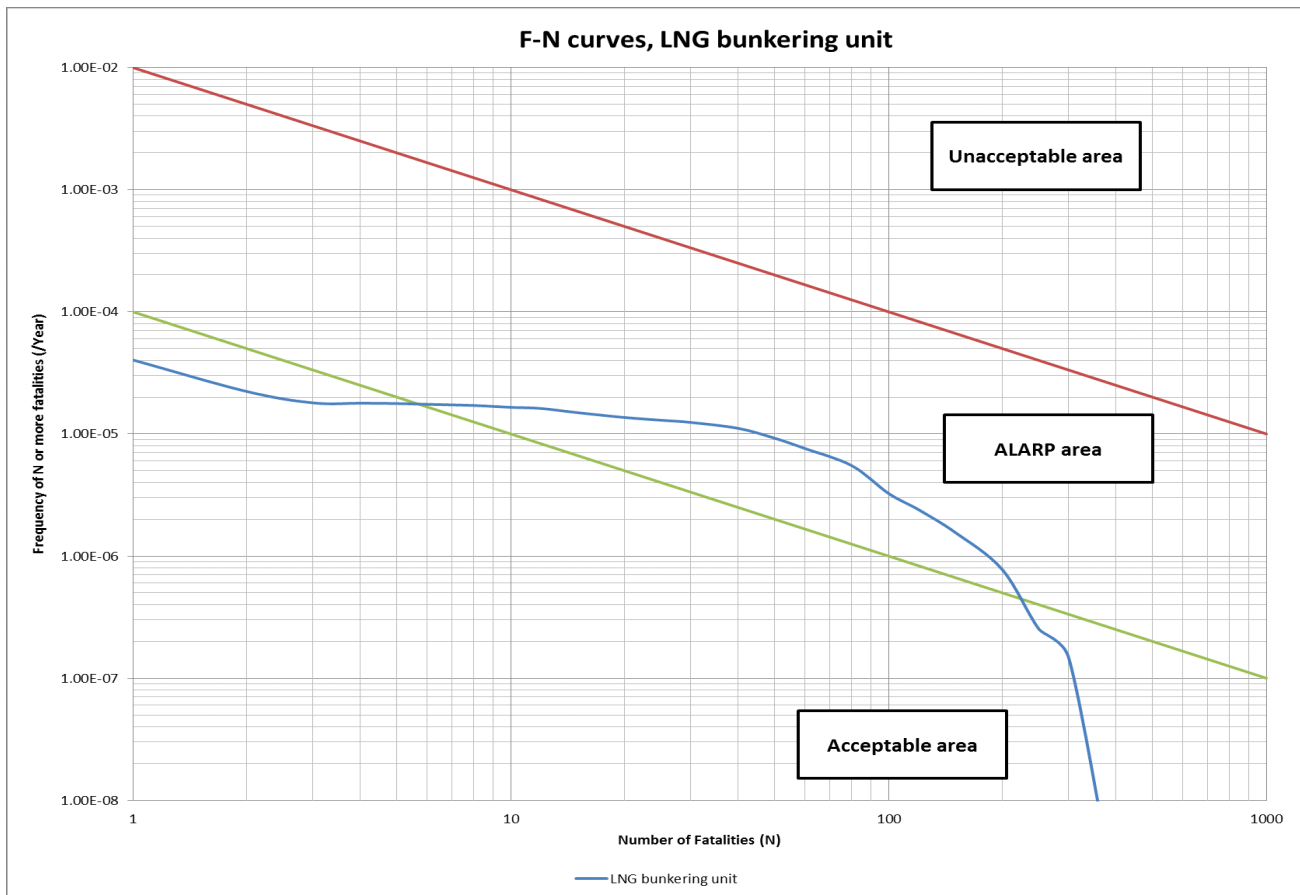


Figure D-10 Example of risk curves for populations (F-N curves)

D.4.9 Risk evaluation and risk reduction

The QRA shall involve a comparison of the calculated risk level with the acceptance criteria.

The risk evaluation may also include a comparison of alternative designs or activity plans. Risk-reduction measures may be necessary in order to make the risks acceptable. The benefits from these measures can be evaluated by recalculating the risk. Risk mitigation measures and their impact on the calculated risk can also be investigated to demonstrate that the residual risk is "As Low As Reasonably Practical" (ALARP). For a risk to be ALARP it shall be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.

Possible risk-reducing measures within the three layers of defence shall normally be identified throughout and as part of the risk assessment process.

The assessment shall identify the following measures, in order of priority:

- Design measures that provide an inherently safer design.
- Preventive measures that reduce the probability of accidental events occurring.
- Mitigation measures that reduce the consequences if accidental events should occur.

The identification and evaluation of risk-reducing measures shall be documented and a list of different risk-reducing options should be presented. Risks related to the installation of the measure should also be addressed if relevant.

D.4.10 Documentation of risks and findings

The results of the cause analysis, consequence evaluation and risk assessments shall be documented in a report which shall include, but not be limited to, the following topics:

- executive summary
- main conclusions and recommendations
- introduction, objective and scope
- description of the installation or system
- QRA methodology
- hazard identification
- description of the HAZID team
- model descriptions, data and their sources
- parameter settings
- risk results and mitigation alternatives
- total risk presentation and discussion
- limitations, sensitivities and uncertainties in the assessment
- references.

D.5 How to address SIMOPS in a risk assessment

Simultaneous operations (SIMOPS) during LNG bunkering operations shall be addressed in a risk assessment. This assessment can be both qualitative (HAZID) and quantitative (QRA) depending on the type of SIMOPS planned. The focus in the HAZID should be on identifying mitigating measures to reduce the additional risks introduced by the SIMOPS. The effectiveness of the identified mitigating measures can be demonstrated by means of a QRA.

Examples of simultaneous operations can be (not intended as an exhaustive list):

- Loading/unloading of cargo, provisions and other goods on the receiving vessel.
- Activities in the vicinity of the bunker area (e.g. hoisting, maintenance activities or hot work).
- Passenger embarking/disembarking during bunkering or bunkering with passengers on board.
- The simultaneous transfer of other bunker fuels (SIMOPS).


Usually the (port) authorities will specify the requirements and limitations for simultaneous operations and are likely to ask for a risk assessment. The (flag state) approved operational documentation of the bunker or receiving vessel should contain the risk mitigating measures for simultaneous activities. The limitations should be clearly understood by all parties and documented by means of e.g. a bunkering checklist, which should be completed before actual transfer operations start. The LNG bunkering operations should be suspended when the limitations cannot be met. The local authorities will finally grant permission for simultaneous operations during LNG bunkering based on the outcomes of the risk assessment (and suggested mitigating measures/limitations).

The study should focus on the possible safety and operational issues associated with the concurrent operations and should take into account the common operational use of e.g. vapour return, LNG transfer lines, etc. It is strongly recommended to perform a QRA to evaluate the acceptability of the risk in the case of SIMOPS or non-standard bunkering scenarios.

A common and clear approach in guidelines or technical specifications (e.g. ISO/DTS 16901) to address SIMOPS in a risk assessment (QRA) is currently lacking in the regulatory framework.

DNV GL recommends that a risk assessment approach for SIMOPS be based on the following principles:

- A QRA can be developed for two situations, where the risk is calculated for 1st, 2nd and 3rd party personnel:
 - the LNG bunkering operations *without* taking SIMOPS into account
 - the LNG bunkering operations *with* SIMOPS and defined mitigating measures.

- 
- SIMOPS may be allowed if it is demonstrated that the relative increase in risk is not significant (e.g. <10%), provided that the overall project risk criteria can be met.
 - Furthermore, an ALARP demonstration should be used to show that the proposed mitigating measures are effective in reducing the risk, taking into account the costs and benefits of any further risk reduction by implementing more (or other) mitigating measures.

The ultimate criterion for acceptability/tolerability is if it can be demonstrated that the project risk criteria are met. The criteria should be established in agreement with the relevant authorities.

APPENDIX E LIQUEFIED NATURAL GAS CHARACTERISTICS

The average composition is chosen as being representative among compositions reported by the different receiving terminals. Source: GIIGNL, The LNG Industry 2014 /25/.

Origin	Nitrogen N ₂ %	Methane C ₁ %	Ethane C ₂ %	Propane C ₃ %	C ₄ + %	Total	LNG Density ⁽¹⁾ kg/m ³	Gas Density ⁽²⁾ kg/m ³	Expansion ratio m ³ (n)/m ³ l	Gas GCV ⁽²⁾ MJ/m ³ (n)	Wobbe Index ⁽²⁾ MJ/m ³ (n)	PKI Methane number ⁽³⁾
Australia – NWS	0.04	87.33	8.33	3.33	0.97	100	467.35	0.83	562.46	45.32	56.53	68.6
Australia – Darwin	0.10	87.64	9.97	1.96	0.33	100	461.05	0.81	567.73	44.39	56.01	72.7
Algeria – Skikda	0.63	91.40	7.35	0.57	0.05	100	446.65	0.78	575.95	42.30	54.62	80.0
Algeria – Bethioua	0.64	89.55	8.20	1.30	0.31	100	454.50	0.80	571.70	43.22	55.12	75.3
Algeria – Arzew	0.71	88.93	8.42	1.59	0.37	100	457.10	0.80	570.37	43.48	55.23	74.1
Brunei	0.04	90.12	5.34	3.02	1.48	100	461.63	0.82	564.48	44.68	56.18	68.4
Egypt – Idku	0.02	95.31	3.58	0.74	0.34	100	437.38	0.76	578.47	41.76	54.61	82.7
Egypt – Damietta	0.02	97.25	2.49	0.12	0.12	100	429.35	0.74	582.24	40.87	54.12	90.9
Equatorial Guinea	0.00	93.41	6.52	0.07	0.00	100	439.64	0.76	578.85	41.95	54.73	84.3
Indonesia – Arun	0.08	91.86	5.66	1.60	0.79	100	450.96	0.79	571.49	43.29	55.42	74.3
Indonesia – Badak	0.01	90.14	5.46	2.98	1.40	100	461.07	0.82	564.89	44.63	56.17	68.7
Indonesia – Tangguh	0.13	96.91	2.37	0.44	0.15	100	431.22	0.74	581.47	41.00	54.14	88.5
Libya	0.59	82.57	12.62	3.56	0.65	100	478.72	0.86	558.08	46.24	56.77	67.5
Malaysia	0.14	91.69	4.64	2.60	0.93	100	454.19	0.80	569.15	43.67	55.59	72.0
Nigeria	0.03	91.70	5.52	2.17	0.58	100	451.66	0.79	571.14	43.41	55.50	74.2
Norway	0.46	92.03	5.75	1.31	0.45	100	448.39	0.78	573.75	42.69	54.91	76.8
Oman	0.20	90.68	5.75	2.12	1.24	100	457.27	0.81	567.76	43.99	55.73	70.9
Peru	0.57	89.07	10.26	0.10	0.01	100	451.80	0.79	574.30	42.90	55.00	78.3
Qatar	0.27	90.91	6.43	1.66	0.74	100	453.46	0.79	570.68	43.43	55.40	73.8
Russia – Sakhalin	0.07	92.53	4.47	1.97	0.95	100	450.67	0.79	571.05	43.30	55.43	73.4
Trinidad	0.01	96.78	2.78	0.37	0.06	100	431.03	0.74	581.77	41.05	54.23	89.3
USA – Alaska	0.17	99.71	0.09	0.03	0.01	100	421.39	0.72	585.75	39.91	53.51	99.2
Yemen	0.02	93.17	5.93	0.77	0.12	100	442.42	0.77	576.90	42.29	54.91	81.0

(1) Calculated according to ISO 6578 [T = -160°C] /22/.

(2) Calculated according to ISO 6976 [0°C / 0°C. 1.01325 bar] /20/.

(3) PKI method /24/.

APPENDIX F MAIN CALCULATION TO DETERMINE THE ENERGY CONTENT

In order to determine the calorific value, the LNG composition shall be known. ISO 6976:2005 /20/ describes the calculation of calorific value from the composition of natural gas. The composition of the gas should be known in mole fractions. The ideal-gas calorific value on a molar basis, at a temperature t , of a mixture of known composition is calculated from the equation

$$\bar{H}^{\circ}(T_1) = \sum_{j=1}^N x_j \cdot \bar{H}_j^{\circ}(T_1) \quad [1]$$

Where

$\bar{H}^{\circ}(T)$ is the ideal molar calorific value of the mixture (either higher or lower);
 $\bar{H}_j^{\circ}(T)$ is the ideal molar calorific value of component j (either higher or lower);
 x_j is the mole fraction of component j

The numerical values of \bar{H}_j° for different temperatures are given in ISO 6976:2005 /20/. The calorific value on a mass basis is calculated from the molar composition, molar mass and calorific value on a molar basis of the components.

$$\hat{H}^{\circ}(T_1) = \frac{\sum_{j=1}^N x_j \cdot \bar{H}_j^{\circ}(T_1)}{\sum_{j=1}^N (x_j \cdot M_j)} \quad [2]$$

The calorific value on a volume basis is calculated from the molar composition, compression factor Z_{mix} , molar volume V_m at T_2 and P_2 and calorific value on a molar basis of the components.

$$\tilde{H}^{\circ}(T_1, V_m(tT_2, P_2)) = \frac{\sum_{j=1}^N x_j \cdot \bar{H}_j^{\circ}(T_1)}{Z_{mix} \cdot \frac{P_2}{R \cdot T_2}} \quad [3]$$

For liquid density determination (see ISO 6578:1991 /22/), the temperature and LNG composition must be known and can be calculated by, for example, using the empirical Klosek-McKinley method, see below. The uncertainty of this simple method is $\pm 0.1\%$ when either the nitrogen or butane content does not exceed 5% and the pressure and temperature limits are complied with. The density of the LNG is calculated by using:

$$\rho_{LNG} = \frac{M_{LNG}}{\bar{V}_{LNG}} \quad [4]$$

Wherein ρ_{LNG} is the density of LNG expressed in kg/m^3 , $M_{LNG} = \sum x_i \cdot M_i$, x_i is the molar fraction of component i , and \bar{V}_{LNG} is expressed as:

$$\bar{V}_{LNG} = \sum x_i V_i - [(K_1 - K_2)] \frac{x_{N_2}}{0.0425} x_{CH_4} \quad [5]$$

Herein V_i is expressed as the molar volume of component i at the temperature of the LNG, and K_1 and K_2 are the correction factors expressed in l/mole for various molecular weights and temperatures.

For gas density determination (see ISO 6976:2005 /20/), the temperature and LNG composition must be known and can be calculated from the equation:

$$\rho(T, p) = \frac{\rho^\circ(T, p)}{Z_{mix}(T, p)} \quad [6]$$

Where $\rho(t, p)$ is the density of the real gas and $Z_{mix}(T, p)$ can be calculated from the equation:

$$Z_{mix}(T, p) = 1 - \left[\sum_{j=1}^N x_j \cdot \sqrt{b_j} \right]^2 \quad [7]$$

where the summation is taken over all N components of the mixture. Values of the so-called summation factor $\sqrt{b_j}$ are given in ISO 6976:2005 /20/ at different metering reference conditions.

The energy of the LNG bunkered can be calculated from the equation:

$$E_{LNG} = m_{LNG} \cdot \hat{H}_{LNG} = V_{LNG} \cdot \rho_{LNG} \cdot \hat{H}_{LNG} \quad [8]$$

The volume of LNG transferred V_{LNG} is determined by measurement. Temperature correction may be required due to the influence from contraction or expansion of the tank, level measuring devices or flow measurement devices. Alternatively the mass m_{LNG} is determined directly.

Taking into account the energy content of the vapour return to the bunkering facility during the transfer of LNG $E_{gas\ displaced}$, and the energy content of any gas consumed in the LNG bunkering facility $E_{gas\ consumption}$, equation 8 can be rewritten to

$$E_{bunkered} = E_{LNG} - E_{gas\ displaced} - E_{gas\ consumption} \quad [9]$$

With

$$E_{gas\ displaced} = V_{gas\ displaced} \cdot \tilde{H}_{gas\ displaced}$$

$$E_{gas\ consumption} = V_{gas\ consumption} \cdot \tilde{H}_{gas\ consumption}$$



DNV GL

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