



BSI Standards Publication

Installation and equipment for liquefied natural gas — Design of onshore installations

National foreword

This British Standard is the UK implementation of EN 1473:2021. It supersedes BS EN 1473:2016, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/38, Installation and equipment for LNG.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

Installation and equipment for liquefied natural gas - Design of onshore installations

Installation et équipements de gaz naturel liquéfié -
Conception des installations terrestres

Anlagen und Ausrüstung für Flüssigerdgas - Auslegung
von landseitigen Anlagen

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European foreword

This document (EN 1473:2021) has been prepared by Technical Committee CEN/TC 282 “Installation and equipment for LNG”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2021, and conflicting national standards shall be withdrawn at the latest by November 2021.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1473:2016.

Due to the incorporation of pressurized storage the standard has been re-structured and revised. In comparison with EN 1473:2016, the following changes have been made:

- duplications detected and deleted;
- terms and definitions adjusted;
- normative references updated;
- changed subject in Annex H;
- risk assessment requirements improved;
- storage tanks classification improved.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The objective of this document is to give functional guidelines for on-shore LNG installations. It recommends procedures and practices that will result in safe and environmentally acceptable design, construction and operation of LNG plants.

Given the wide range of facilities from small to large, with high and low risk profile, etc., the acceptability criteria could vary depending on the project and are subject to conclusions by the normative risk assessment.

Seveso, PED, and ATEX Directives are expected to be followed. Where national and/or local regulations exist in which some of the requirements are equal or more stringent than in this document, it is up to agreement with national and/or local regulators to determine which of the requirements apply.

It does not need to be applied retrospectively, but application is recommended when major modifications of existing installations are being considered.

This document is also recommended for debottlenecking, revamping and plant life extension in the limits that will be defined by the local authority. The appliance of the European Directives to the existing facilities is part of the limits to be defined together with the local authority.

In case of plant expansion, this document is applicable for the new facilities. The application of these recommendations for the tie-ins and connections to the existing facilities will be defined by the local authority. The limits of such application should consider the practicality of such appliance. In the same way, the limits of the European Directives appliance will be accurately defined with the local authority.

1 Scope

This document gives guidelines for the design, construction and operation of all onshore liquefied natural gas (LNG) installations for the liquefaction, storage, vaporization, transfer and handling of LNG and natural gas (NG).

This document is applicable for plants with an LNG storage capacity above 200 t.

The designated boundary limits are LNG inlet/outlet by the ship's manifold including vapour return connection, the truck loading/unloading connection including vapour return, the rail car loading/unloading connection including vapour return and the natural gas in and outlet boundary by piping systems.

Terminals or plant types have one or more boundary limits as described in this scope (see Figure 1).

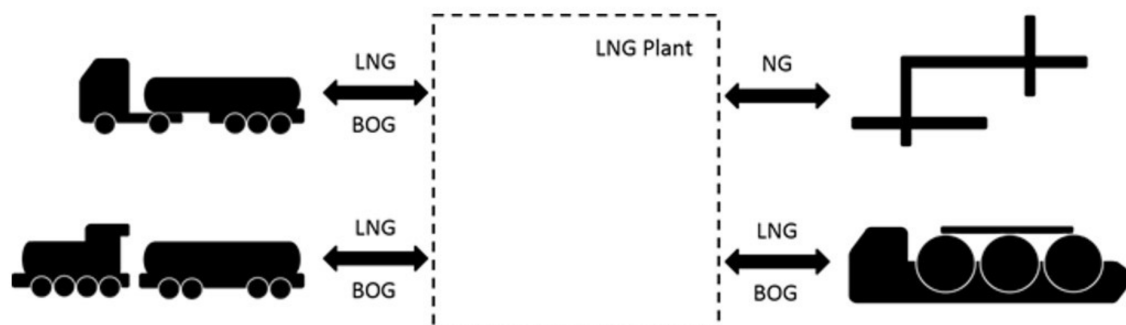


Figure 1 — Boundary limits of onshore liquefied natural gas (LNG) installations

A short description of each of these installations is given in Annex G.

Feed gas for LNG liquefaction installations (plant) can be from gas field, associated gas from oil field, piped gas from transportation grid or from renewables.

Floating solutions (for example FPSO, FSRU, SRV), whether off-shore or near-shore, are not covered by this document even if some concepts, principles or recommendations could be applied. However, in case of berthed FSRU with LNG transfer across the jetty, the following recommendations apply for the jetty and topside facilities.

In case of solutions using floating storage unit (FSU) and land-based re-gasification solution, the on-shore part is covered by these standard recommendations.

Plants with a storage inventory from 5 t up to 200 t are covered by [5].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 809, *Pumps and pump units for liquids - Common safety requirements*

EN 1092-1, *Flanges and their joints - Circular flanges for pipes, valves, fittings and accessories, PN designated - Part 1: Steel flanges*

EN 1127-1, *Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology*

EN 1474-2, *Installation and equipment for liquefied natural gas - Design and testing of marine transfer systems - Part 2: Design and testing of transfer hoses*

EN 1514-1, *Flanges and their joints - Dimensions of gaskets for PN-designated flanges - Part 1: Non-metallic flat gaskets with or without inserts*

EN 1591 (all parts), *Flanges and their joints - Design rules for gasketed circular flange connections*

EN 1776, *Gas infrastructure - Gas measuring systems - Functional requirements*

EN 1990, *Eurocode - Basis of structural design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1992 (all parts), *Eurocode 2: Design of concrete structures*

EN 1993 (all parts), *Eurocode 3: Design of steel structures*

EN 1994-1-1, *Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings*

EN 1994-1-2, *Eurocode 4 - Design of composite steel and concrete structures - Part 1-2: General rules - Structural fire design*

EN 1997-1:2004,¹ *Eurocode 7: Geotechnical design - Part 1: General rules*

EN 1997 (all parts), *Eurocode 7 - Geotechnical design*

EN 1998 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

EN 10204, *Metallic products - Types of inspection documents*

EN 12065, *Installations and equipment for liquefied natural gas - Testing of foam concentrates designed for generation of medium and high expansion foam and of extinguishing powders used on liquefied natural gas fires*

EN 12162, *Liquid pumps - Safety requirements - Procedure for hydrostatic testing*

¹ As impacted by EN 1997-1:2004/AC:2009.

EN 12483, *Liquid pumps - Pump units with frequency inverters - Guarantee and compatibility tests*

EN 13445 (all parts), *Unfired pressure vessels*

EN 13458 (all parts), *Cryogenic vessels - Static vacuum insulated vessels*

EN 13480 (all parts), *Metallic industrial piping*

EN 13766, *Thermoplastic multi-layer (non-vulcanized) hoses and hose assemblies for the transfer of liquid petroleum gas and liquefied natural gas - Specification*

EN 14197 (all parts), *Cryogenic vessels - Static non-vacuum insulated vessels*

EN 14620 (all parts), *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C*

EN 60079-0, *Explosive atmospheres - Part 0: Equipment - General requirements (IEC 60079-0)*

EN 60079-1, *Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d" (IEC 60079-1)*

EN 60079-2, *Explosive atmospheres - Part 2: Equipment protection by pressurized enclosure "p" (IEC 60079-2)*

EN 60079-5, *Explosive atmospheres - Part 5: Equipment protection by powder filling "q" (IEC 60079-5)*

EN 60079-6, *Explosive atmospheres - Part 6: Equipment protection by liquid immersion "o" (IEC 60079-6)*

EN 60079-7, *Explosive atmospheres - Part 7: Equipment protection by increased safety "e" (IEC 60079-7)*

EN 60079-10-1, *Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres (IEC 60079-10-1)*

EN 60079-10-2, *Explosive atmospheres - Part 10-2: Classification of areas - Explosive dust atmospheres (IEC 60079-10-2)*

EN 60079-11, *Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i" (IEC 60079-11)*

EN 60079-13, *Explosive atmospheres - Part 13: Equipment protection by pressurized room "p" and artificially ventilated room "v" (IEC 60079-13)*

EN 60079-14, *Explosive atmospheres - Part 14: Electrical installations design, selection and erection (IEC 60079-14)*

EN 60079-15, *Explosive atmospheres - Part 15: Equipment protection by type of protection "n" (IEC 60079-15)*

EN 60079-17, *Explosive atmospheres - Part 17: Electrical installations inspection and maintenance (IEC 60079-17)*

EN 60079-18, *Explosive atmospheres - Part 18: Equipment protection by encapsulation "m" (IEC 60079-18)*

EN 60079-19, *Explosive atmospheres - Part 19: Equipment repair, overhaul and reclamation (IEC 60079-19)*

EN 60079-20-1, *Explosive atmospheres - Part 20-1: Material characteristics for gas and vapour classification - Test methods and data (IEC 60079-20-1)*

EN 60079-25, *Explosive atmospheres - Part 25: Intrinsically safe electrical systems (IEC 60079-25)*

EN 60204-1, *Safety of machinery - Electrical equipment of machines - Part 1: General requirements (IEC 60204-1)*

EN 60529, *Degrees of protection provided by enclosures (IP Code) (IEC 60529)*

EN 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems (IEC 61508 series)*

EN 61800 (all parts), *Adjustable speed electrical power drive systems (IEC 61800 all parts)*

EN 62305 (all parts), *Protection against lightning (IEC 62305 all parts)*

EN ISO 1460, *Metallic coatings - Hot dip galvanized coatings on ferrous materials - Gravimetric determination of the mass per unit area (ISO 1460)*

EN ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods (ISO 1461)*

EN ISO 3452-1, *Non-destructive testing - Penetrant testing - Part 1: General principles (ISO 3452-1)*

EN ISO 6974 (all parts), *Natural gas - Determination of composition with defined uncertainty by gas chromatography (ISO 6974 all parts)*

EN ISO 6976, *Natural gas - Calculation of calorific values, density, relative density and Wobbe indices from composition (ISO 6976)*

EN ISO 9606-1, *Qualification testing of welders - Fusion welding - Part 1: Steels (ISO 9606-1)*

EN ISO 9712, *Non-destructive testing - Qualification and certification of NDT personnel (ISO 9712)*

EN ISO 9906, *Rotodynamic pumps - Hydraulic performance acceptance tests - Grades 1, 2 and 3 (ISO 9906)*

EN ISO 10380, *Pipework - Corrugated metal hoses and hose assemblies (ISO 10380)*

EN ISO 10497, *Testing of valves - Fire type-testing requirements (ISO 10497)*

EN ISO 10715, *Natural gas - Sampling guidelines (ISO 10715)*

EN ISO 10723, *Natural gas - Performance evaluation for analytical systems (ISO 10723)*

EN ISO 12241, *Thermal insulation for building equipment and industrial installations - Calculation rules (ISO 12241)*

EN ISO 12944 (all parts), *Paints and varnishes - Corrosion protection of steel structures by protective paint systems (ISO 12944 all parts)*

EN ISO 13709, *Centrifugal pumps for petroleum, petrochemical and natural gas industries (ISO 13709)*

EN ISO 15607, *Specification and qualification of welding procedures for metallic materials - General rules (ISO 15607)*

EN ISO 15609-1, *Specification and qualification of welding procedures for metallic materials - Welding procedure specification - Part 1: Arc welding (ISO 15609-1)*

EN ISO 15614-1, *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1)*

EN ISO 16903:2015, *Petroleum and natural gas industries - Characteristics of LNG, influencing the design, and material selection (ISO 16903:2015)*

EN ISO 16904, *Petroleum and natural gas industries - Design and testing of LNG marine transfer arms for conventional onshore terminals (ISO 16904)*

EN ISO 17636-1, *Non-destructive testing of welds - Radiographic testing - Part 1: X- and gamma-ray techniques with film (ISO 17636-1)*

EN ISO 17636-2, *Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors (ISO 17636-2)*

EN ISO 17637, *Non-destructive testing of welds - Visual testing of fusion-welded joints (ISO 17637)*

EN ISO 17640, *Non-destructive testing of welds - Ultrasonic testing - Techniques, testing levels, and assessment (ISO 17640)*

EN ISO 20519, *Ships and marine technology - Specification for bunkering of liquefied natural gas fuelled vessels (ISO 20519)*

EN ISO 21012, *Cryogenic vessels - Hoses (ISO 21012)*

EN ISO 28460, *Petroleum and natural gas industries - Installation and equipment for liquefied natural gas - Ship-to-shore interface and port operations (ISO 28460)*

EN ISO 28921 (all parts), *Industrial valves - Isolating valves for low-temperature applications (ISO 28921 all parts)*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 61511, *Functional safety - Safety instrumented systems for the process industry sector*

ISO 6578, *Refrigerated hydrocarbon liquids - Static measurement - Calculation procedure*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1.1

abnormal operation

operation of the plant, or plant thereof, under the effect of internal failures or under the effect of foreseeable influences outside the specified operational conditions

[SOURCE: ISO 23552-1:2007, 3.10]

3.1.2

accidental event

event that arises from an uncontrolled or unplanned situation with safety and/or environmental consequences

3.1.3

action

- a) set of forces (loads) applied to the structure (direct action) or
- b) set of imposed deformation or accelerations (indirect action)

Note 1 to entry: Imposed deformation or acceleration could be caused, for example, by temperature changes, moisture variation, uneven settlement or earthquakes.

3.1.4

base slab

continuous concrete base supporting the tank (either on the ground or elevated)

3.1.5

boil-off gas

BOG

natural gas resulting from slow evaporation of LNG at its equilibrium state or rapid evaporation of LNG, also called flashing, inside equipment

3.1.6

boundary

property line on land or water inside of which the operator/owner has full control and authority, or exclusive use

3.1.7

bund wall

raised impermeable structure, able to withstand the hydrostatic pressure and temperature of the spilled liquid, around the perimeter of an impounding area for the confinement of hydrocarbon spills, usually associated with storage areas

3.1.8

condensate

hydrocarbon liquids (liquid state at standard conditions) produced from primary separation of natural gas from a reservoir

Note 1 to entry: Natural gas condensates consist primarily of pentanes and heavier components, although quantities of propane and butane could be dissolved within the mixture.

3.1.9

control room

core functional entity, and its associated physical structure, where control room operators are stationed to carry out centralized control, monitoring and administrative responsibilities

[SOURCE: EN ISO 11064-5:2008, 3.9]

3.1.10

control room operator

individual whose primary duties relate to the conduct of monitoring and control functions, usually at a control workstation, either on their own or in conjunction with other personnel both within the control room or outside

Note 1 to entry: In special cases based on the evaluated risk, control room operators may perform their duties for the installation via remote access.

[SOURCE: EN ISO 11064-3:1999, 3.5]

3.1.11

conventional onshore LNG terminal

LNG export or receiving terminal that is located on-shore and has a marine transfer facility for the loading or unloading of LNG carriers

Note 1 to entry: The transfer facility is located in a harbour or other coastal location and consists of a fixed structure, or wharf, capable of withstanding the berthing loads of a fully laden LNG carrier of a given specification and mooring the vessel safely alongside. The structure is connected to the shore by a trestle, tunnel or other means, facilitating the LNG transfer and ancillary services and providing safe access and egress for personnel performing maintenance or operational duties.

3.1.12

emergency shut down

ESD

method that safely and effectively stops the whole plant or individual sections to minimize incident escalation

3.1.13

fire area

area of the plant delimited by physical boundaries or separations from other fire areas by boundaries such as site roads

Note 1 to entry: Multiple trains in a large plant are each a fire area. Different processing units each separated by plant roads are individual fire areas. A fire area is often self-defining in that it may be a single plant unit, a storage or utility area or a separate operating area such as a road tanker loading bay.

Note 2 to entry: The typical firewater ring main routing often encloses each fire area.

Note 3 to entry: Pipe racks joining plant areas are not considered to affect fire area considerations.

3.1.14**fire zone**

area of the plant or process system within a fire area that requires it to be isolated by ESD valves in the event of a fire to control and minimize the fire event, or in the event of a process upset or malfunction to minimize the extent of the process upset

3.1.15**flammable gas**

gas or vapour which, when mixed with air in certain proportions, will form a combustible gas mixture

3.1.16**flare**

system to ignite the vapour on a safe location in a controlled manner

3.1.17**flash gas**

gas resulting from sudden evaporation of LNG due to change of equilibrium condition

3.1.18**foundation**

element of the construction required to support equipment

3.1.19**frequency**

number of occurrences per unit of time

3.1.20**harm**

physical injury or damage to the health of people or damage to property or the environment

[SOURCE: ISO/TS 16901:2015, 3.13]

3.1.21**hazard**

potential source of harm

[SOURCE: ISO/TS 16901:2015, 3.14]

3.1.22**impounding area**

area defined at the site for the purpose of collecting any accidental spill of hydrocarbons

3.1.23**impounding basin**

container or leak-tight area connected to an impounding area or spill collection area where liquid hydrocarbon spills can be collected and safely confined and controlled

3.1.24**inner tank**

metallic self-supporting cylindrical primary container

3.1.25

leakage

situation in which liquid or gas escapes through an opening

Note 1 to entry: Openings leading to leakage can consist of holes, cracks, etc.

3.1.26

liquefied natural gas

LNG

colourless and odorless cryogenic fluid in the liquid state at normal pressure composed predominantly of methane which can contain minor quantities of ethane, propane, butane, nitrogen, or other components normally found in natural gas

[SOURCE: EN ISO 16903:2015, 3.3]

3.1.27

LNG bunkering station

LNG station where LNG is brought by road, rail, waterway, cryogenic pipe from a neighbouring terminal, and delivering LNG to ships using LNG as a marine fuel

Note 1 to entry: Delivery of the LNG can be done by road, sea or by fixed dispenser along the jetty.

3.1.28

local regulation

set of rules, laws, national agreements, international conventions which apply to a site

3.1.29

low pressure tank

equipment for the storage of LNG at pressure below 50 kPa (0,5 bar)

3.1.30

maximum allowable pressure

PS

maximum pressure for which the equipment is designed, as specified by the manufacturer

3.1.31

normal operation

operation including intermittent operation such as ship loading or unloading, start-up, maintenance, planned shutdown and commissioning

3.1.32

operating basis earthquake

OBE

maximum earthquake for which no damage is sustained and restart and safe operation can continue

Note 1 to entry: This higher probability event would result in no commercial loss to the installation and public safety is ensured.

3.1.33

operating company

company responsible for the operation of the installation

3.1.34**operating personnel**

any person who is authorized to act on the control of the plant, remotely or locally

3.1.35**PASQUILL stability class**

factors that are determined as a function of the wind speed and solar radiation

Note 1 to entry: See [19].

Note 2 to entry: The six factors are:

— A: extremely unstable;

— B: moderately unstable;

— C: lightly unstable;

— D: neutral;

— E: lightly stable;

— F: moderately stable.

3.1.36**plant**

site area inside of which public access is unauthorized, e.g. the whole location under the control of an operator where dangerous substances are present in one or more installations, including common or related infrastructures or activities

3.1.37**pool fire**

turbulent diffusion fire burning above a horizontal pool of vaporising hydrocarbon fuel where the fuel has zero or low initial momentum

[SOURCE: <https://www.hse.gov.uk/offshore/strategy/pool.htm>]

3.1.38**pooling**

consequence of an event when liquid product is leaving the LNG containment and spilled and retained on a not sloped surface and not transferred to the spill collection system

3.1.39**pressurized tank**

equipment for the storage of LNG at pressure above 50 kPa (0,5 bar)

3.1.40**process shut down system****PSD**

system that safely and effectively stops individual units within the plant for process reasons

3.1.41**risk**

combination of the consequence and the frequency of a specific hazard occurring within a specified period under specified circumstances

3.1.42

roll-over

uncontrolled mass movement of stored liquid, correcting an unstable state of stratified liquids of different densities and resulting in a significant evolution of product vapour

3.1.43

roof

structure on top of a shell or wall containing the vapour pressure and sealing off the contents from the atmosphere

3.1.44

safe shutdown earthquake

SSE

maximum earthquake event for which the essential fail-safe functions and mechanisms are designed to be preserved

Note 1 to entry: Permanent damage can be expected of this lower probability event, but without the loss of overall integrity and containment. The installation would not remain in continuous service without a detailed examination and structural assessment at the ultimate limit state.

3.1.45

safety integrity level

SIL

level of integrity required of a safety related system in terms of EN 61508 (all parts)

3.1.46

safety management system

management process which defines and monitors the organizational structure, responsibilities, procedures, processes and resources for determining and implementing the major accident prevention policy

3.1.47

spill

to cause liquid especially accidentally or unintentionally to flow, or run out so as to be lost or wasted

3.1.48

spill collection area

area at LNG production or transfer areas where leakages can be confined or controlled, often by the use of kerbing and/or controlled sloping of paved areas

3.1.49

storage system

storage unit

low pressure or pressurized tank

3.1.50

transfer area

loading area/unloading area

area containing a piping system where flammable liquids or gases are introduced into or removed from the plant or where piping connections are connected or disconnected routinely

3.1.51**validated model**

mathematical model, the scientific basis of which is accepted to be sound and is proven to provide mathematical outputs to the relevant mathematical problem, and is shown to cover the full range of usage of the model and which has been calibrated or checked using realistic test data or results for LNG

3.1.52**vapour barrier**

barrier to prevent entry of water vapour and other atmospheric gases into the insulation

3.1.53**vent stack**

system to vent vapour to a safe location in a controlled manner

Note 1 to entry: Reference [21] requires that the vent be designed with the assumption that it could become ignited and cause damage or injury due to thermal radiation.

3.1.54**zip failure**

when a steel tank wall ruptures almost instantaneously over its full height and is torn off from the bottom plate in whole or in part, which will allow the stored liquid to spread around in an uncontrolled way

3.2 Abbreviations

BLEVE	boiling liquid expanding vapour explosion
BTA	bow-tie analysis
CAD	computer-aided design
CCTV	closed circuit television camera
ESD	emergency shut down
EPS	emergency power supply
ETM	event tree method
FERA	fire and explosion risk analysis
FMEA	failure mode effect analysis
FTM	fault tree method
GC	geotechnical category
HAZID	hazard identification study
HAZOP	hazard and operability study
HVAC	heating, ventilation, aircon and cooling
KO	knockout
LOPA	layer of protection analysis
OBE	operating basis earthquake
PCS	process control system
QRA	quantified risk assessment

SIL	safety integrity level
SIS	safety instrumented system
SSE	safe shutdown earthquake
UPS	uninterruptible power supply

4 Quality management system

A quality management system should demonstrate adequate capability for the design/development, manufacture, testing, installation, commissioning, decommissioning and servicing of the plant and its associated equipment.

5 Site assessment

5.1 General and plant description

The design, procurement, construction and operation phases shall all be implemented in accordance with the requirements of the Quality, Health, Safety and Environment management systems.

Furthermore, each phase shall be controlled by an acceptable Safety Management System.

In case of plant expansion or debottlenecking, the environmental and safety impacts shall be appraised in accordance with the following recommendations. The potential consequences shall be analysed and current local regulation is expected to be taken into account.

In case of revamping for life extension, the environmental and safety impacts shall be appraised in accordance with the following recommendations. The appliance of the current local regulation, and the extent of such appliance, is expected to be agreed upon with the local authority.

In case of revamping without life extension and without debottlenecking, the principle of non-retroactivity shall prevail.

A functional description of the installation shall be written by plant area and/or by process function, for use in the safety assessment.

5.2 Geotechnical

5.2.1 Characteristics of the soil

Site studies shall be executed to address the specific risks related to the project scope and location. The extent of information required depends on the nature, the phase and complexity of the facilities to be constructed, the nature and complexity of the ground and the acceptable risk level related to direct effects and economic damage that can result.

The site study shall include a soil survey including:

- the geotechnical survey that will enable the geo-mechanical characteristics of the subsoil to be defined;
- the geological and tectonic investigation.

The geological characteristics of the region shall be investigated in sufficient detail to provide a clear understanding of the physical processes that formed the area, as well as the potential for the future seismic activity.

A more specific survey shall be done on the site and its vicinity to detect the presence of karst, gypsum, swelling clays, soluble salt deposits, liquefiable soil, etc. and their relative impact shall be evaluated.

Site studies will include both geophysical and geotechnical desktop and survey studies and will in general be phased. The primary objectives of site studies are one or more of the following:

- data acquisition for geological purposes, such as establishing the general stratigraphy between boreholes/CPTs, weathering profiles, erosional or structural features (buried channels, cavities, faults, dykes, etc.);
- derivation of ground parameters (shear wave velocity and stiffness, electrical and thermal conductivity);
- resource assessment, such as location and nature of aquifers, sand and gravel deposits, rock for aggregates;
- detection of geotechnical hazards, such as karst, gypsum, swelling clays, soluble salt deposits, soil liquefaction, mass movement;
- detection of voids and buried objects, such as mine workings, natural cavities, old foundations, buried tanks;
- detection of environmental hazards, such as hydrocarbon pollution, mine tailings.

The site investigation shall provide information on properties and behaviour under the full range of conditions that can be expected on the site and might include the following:

- soil classification, strength, stiffness, compressibility and consolidation;
- temporary or permanent changes as a result of the construction project or natural phenomena such as: changes in stress and associated strain, changes in water content and associated volume changes, changes in groundwater level and flow pattern, changes in temperature and electrical potential, and changes in soil properties such as strength and compressibility;
- effects of earthquakes, e.g. liquefaction and lateral spread;
- aggressiveness to materials placed in the ground, such as concrete and steel;
- potential borrow areas and quarries for construction materials (fill and aggregates).

The soil investigation report shall include the risks of geotechnical failure mechanisms following:

- seismically active faults;
- slope stability;
- liquefiable soils;
- lateral spreading;
- tsunami and seiche.

NOTE Seiche usually occurs in lakes and means a cyclical variation in the level of inland lakes.

A soil and groundwater contamination study shall be done prior to construction. This study may be part of site selection. Ground investigation and testing shall be in accordance with EN 1997-2.

Geotechnical and foundation design shall be as per EN 1997-1. Geotechnical and foundation design of structures for earthquake resistance shall be as per EN 1998-5.

5.2.2 Marine geotechnical characteristics for jetty design and marine access

Marine geotechnical characteristics for jetty design and marine access are outlined in EN ISO 28460.

5.2.3 Harbour dredging

Requirements to harbour dredging are to be defined with the responsible harbour authority (see [38]).

5.3 Meteorological and Oceanographic

5.3.1 General

The site study shall cover meteorological investigations as outlined below.

Site studies shall be executed to address the specific risks related to the project scope and location.

The extent of information required depends on the nature, the phase and complexity of the facilities to be constructed, the nature and complexity of the ground and the acceptable risk level related to direct effects and economic damage that can result.

Site studies will include both desktop and met-ocean survey studies.

5.3.2 Met-ocean data effects

Met-ocean data effects shall include:

- a study of sea water quality and temperature;
- a study of tidal, wave and wind conditions (EN ISO 28460);
- risks of flooding from rain or seaside.

5.3.3 Air temperatures and humidity effects

Air temperatures and humidity effects shall include:

- temperatures;
- atmospheric stability;
- corrosive characteristic of the air;
- relative humidity.

5.3.4 Lightning effects

EN 62305 (all parts) provides study-guidelines to identify the risks and consequences of lightning and determine the mitigations required.

5.3.5 Wind and barometric data effects

Wind and barometric data effects shall include:

- wind strength and direction including frequency and strength of severe storms;
- range and rate of change of barometric pressure.

5.3.6 Precipitation data effects

Precipitation data effects shall include:

- rainfall;
- snow;
- icing.

5.3.7 Climate change

Climate change is a recent phenomenon, that the past climate data might not fully reflect. LNG facilities designers shall use the most recent climate forecast data which upon they shall apply reasonable margins, according with the life expectancy of the projected facilities.

With the purpose of building and maintaining a more climate resilient infrastructure the meteorological input data concerned by climate projections and their uncertainties shall be updated in the design. Consequently, the recurrence intervals for those events shall be adjusted accordingly.

NOTE A typical method to incorporate this objective is increasing the loads for flood, wind and snow to the 100 years recurrence values. This is to be considered during risk assessment based on national regulations.

5.4 Environmental

5.4.1 Environmental impact assessment

An Environmental Impact Assessment (EIA) shall be carried out for the proposed location. Consideration should be given to formally recording the base line site environmental characteristics.

All emissions from the plant, that is, solid, liquid (including water), and gaseous (including noxious odors) shall be identified and measures taken to ensure they will not be harmful to persons, property, animals or vegetation.

During or prior to operation an effluent management procedure shall be established. The precautions for handling toxic materials shall be identified and be regularly updated by the operator/occupier.

The environmental impact due to construction and operation shall also be assessed and undesirable levels of activities shall be eliminated or minimized and restricted. The following checklist covers the main items:

- increased population, permanent and temporary;
- increased road, rail and ship traffic;
- increased noise levels, sudden and intermittent noise;
- increased vibration levels, sudden and intermittent;
- increased night working, effect of lights and their intermittent use;
- flaring, intermittent and/or continuous;
- warming or cooling of water.

5.4.2 Plant emissions/emission control

During the design, plans shall be developed to eliminate, minimize or render harmless emissions resulting from commissioning tests, operations and maintenance activities, and shall set targets for quantities and concentrations of pollutants in emissions.

The following shall be safely controlled and monitored:

- combustion products;
- venting of gas;
- flaring of gas;
- disposal of acid gas removal solvent;
- disposal of spent mercury removal reactant (as the demercurization process is not regenerative, it is necessary to store and then treat the used absorbent mass or have it removed by a licensed waste disposal contractor);
- oily water condensed during dryer regeneration or from machines;
- in the case of water cooled equipment, hydrocarbon contamination of cooling water from leaking exchanger tubes;
- disposal of waste products (including waste oil and chlorinated organic compounds);
- vaporizer water;
- odorant chemicals.

5.4.3 Flare/venting philosophy

Plants are to be designed around the principle of no flaring or venting under normal operating conditions. Provisions shall be taken during design and operation to ensure that potential gas waste streams, wherever practically possible, are recovered and not routed to flare or vent during the normal operation of the plant.

Flare systems shall be used for the safe disposal of vapours and gases to prevent hazardous conditions. Vents may be also used when allowed by risk assessment.

5.4.4 Noise control

The design of the plant shall consider the effects caused by all sources of noise on people within the plant and the effect of noise on any community surrounding the plant. It is recommended that the noise design procedure of the plant complies with ISO 15664.

5.4.5 Biological environment

The impact of water discharges excluding rainwater case shall be minimized and monitored (temperature, currents, salinity, quantities and concentrations of pollutants, etc.)

5.5 Surroundings

5.5.1 External traffic routes

External traffic routes near to the LNG plant shall be addressed, stating the volume and nature of present traffic as well as any foreseeable development caused by or impacting the plant. The following shall be examined:

- overland routes (roads, railways);
- navigable routes (sea or river routes, canals);
- air routes and the proximity of airports and aerodromes.

5.5.2 Surrounding infrastructures

The site study shall include, where appropriate:

- a survey of the surrounding infrastructure (e.g. industrial sites, built up areas, communications);
- a study of vegetation to enable vegetation fire risks to be identified;
- a study to identify sources of stray electrical currents (e.g. those emanating from high voltage power lines, railways);
- a study of terrain to enable the dispersion of liquid and gas clouds to be assessed.

5.5.3 Nautical and environmental

The site study shall include, where appropriate:

- a study of the marine aquatic environment and marine access;
- manoeuvring areas, safety distances whilst an LNG carrier is in transit within the port and at berth (see 7.7, then EN ISO 28460 and [33]).

5.5.4 Underground utilities

(reserve)

5.6 Seismic

5.6.1 General

An earthquake is defined by the horizontal and vertical accelerations of the ground. These accelerations are described in accordance with EN 1997 (all parts) and EN 1998 (all parts) by the ground response spectra.

A site-specific earthquake analysis shall be performed. This shall include assessments of the risks of earthquake, tsunamis, landslides and volcanic activities. This analysis shall be presented in a Seismic Report where geological and seismic characteristics of the location of the facility and the surrounding region as well as geo-tectonic information shall be considered. As a conclusion, this report shall define all seismic parameters required for the design.

The size of the region to be investigated depends on seismicity around the site and the geological and tectonic conditions. In general a distance of 200 to 300 km around the site will be sufficient, but in some instances, it can include an entire tectonic province, larger than the above (see [39] for the principle).

The depth of soil investigations shall be at least 30 m (for sediments) or up to the depth of the rock.

In case of seismic faults in the immediate vicinity of the site, further investigations shall be conducted to estimate their possible activity. Faults for which inactivity cannot be confirmed are not allowed inside the site.

For details of the seismic investigations, surveys, analysis and format of response spectrum, reference is made to EN 1997 (all parts), EN 1998-1 and EN 1998-5.

The geological, tectonic and seismological studies help to establish:

- the safe shutdown earthquake (SSE);
- the operating basis earthquake (OBE).

These shall be established:

- probabilistically, as those that produce ground motions with the mean recurrence as a minimum interval of 4975 years for the SSE and 475 years for the OBE.

NOTE Both OBE and SSE define specific performance limits for seismic events of increasing severity for systems as defined in 7.2.7.

5.6.2 Tsunamis

If the facility is identified as being at risk from tsunami or seiche a detailed hazard assessment shall be carried out.

5.7 Hydrology

5.7.1 Drainage effects

(reserve)

5.7.2 Aquifers, erosion and ground water impact study

The site study shall include, where appropriate:

- a study of ground water tables;
- ground water quality.

5.8 Social

5.8.1 Community health, safety and security

(reserve)

5.8.2 Population settlements

During the feasibility study phase of the project site location assessments shall be carried out to ensure the suitability of the location options with regards to adjacent development. The assessment shall as a minimum consider the following:

- residential development;
- retail and leisure developments;
- sensitive developments (schools, hospitals, retirement homes, sports stadium, etc.);
- industrial development;
- transportation and utilities infrastructure, both onshore and offshore;
- emission limits.

When the site has been selected, a detailed site location assessment shall be carried out. The location assessment methodology and scope shall have regard for the proposed inventory of hazardous material contained on the plant and the presence and scale of adjacent existing and identified future developments, whilst being in conformance with local and national regulatory requirements.

It shall be ensured that:

- the assessment is updated on a regular basis and when major modifications or changes take place;
- the development around the plant is controlled to minimize the subsequent incompatible development.

Guidance for the probabilistic assessment acceptance criteria of site location are presented in Table K.2. These minimum acceptance criteria can be adopted in the event that no such criteria exist in the country where the plant is to be built.

5.8.3 Other subjects

Livelihood, land use, occupation, ownership, economic activity, natural resources, public facilities, education, health, archaeological and cultural heritage, landscape and visual aspects shall be investigated when assessing potential sites.

6 Risk management

6.1 General

LNG installations shall be designed to provide generally accepted levels of risk (see Annex K) for life and property outside and inside the plant boundaries. To ensure this high level of safety in the LNG facilities and its surroundings, safety shall be considered throughout all the project phases: engineering, construction, start-up, operation and decommissioning including plant modifications. Risk assessments shall be carried out and the required safety measures implemented to ensure acceptable risk levels.

ISO/TS 16901 gives an approach to address the potential scenarios, their frequency of occurrence and the consequence analysis.

The operator shall produce a safety report to demonstrate for example the implementation of a MAPP (major-accident prevention policy).

NOTE More information on the requirements for a safety report can be found in [54].

A risk assessment shall be carried out during the design of the plant and it is also recommended if a modification or change takes place.

Detail assumptions on accidental events within this document (e.g. on LNG releases) remain subject to confirmation by risk assessment. Their consistency with the applicable policy for major-accident prevention shall be checked on a case-by-case basis.

General requirements on safety measures within this document (e.g. on monitoring duties) could be subject to adaptation under the double condition of: specific allowance within the document, and risk-based justification.

The main potential hazards at an LNG processing and storage plant are a combination of hydrocarbons related and operations related hazards. In general, as minimum the following consequences shall be considered in the design and operation.

Injury or death of personnel:

- cryogenic burns to people (frostbite);
- asphyxiation from lack of oxygen in a hydrocarbon cloud;
- fire injuries;
- injury from explosion pressure wave.

Damage of equipment:

- cold embrittlement of equipment consisting of materials not resistant to cryogenic temperatures;
- vapour cloud explosion;
- flash fire;
- pool fire;
- jet fire;
- damage or explosion of combustion engines, turbines or air compressors by suction of combustible gas from a cloud, including contamination of instrument air;
- loss of control or damage of process equipment if mixture of air with combustibles is delivered into the process equipment instead of air.

6.2 Hazard and risk assessment methodologies

6.2.1 General

Both prescriptive and risk-based approaches are used in the planning, design, and operation of LNG facilities.

Prescriptive (deterministic) approaches represent industry experience and practices. Risk-based approaches use the principles aiming at demonstration that the risk acceptance criteria are met with a proper selection of design and operational measures and use quantified risk assessment. A risk assessment can be qualitative, semiquantitative or quantitative.

The easiest way to differentiate is that one methodology uses numbers and figures (quantitative), one uses range of numbers and figures (semiquantitative) and one uses descriptions and words (qualitative) to assess the risk level.

The qualitative risk assessment is an assessment of risk occurrence likelihood against the potential severity of the risk outcomes (impact) to determine the overall severity of a risk.

Qualitative risk assessment requires that the frequency and consequences of the risk be evaluated using established qualitative-analysis methods and tools, describing them in terms such as very high, high, moderate, low, very low or related to the industry experience. These assessments of the two dimensions of a risk are applied to each specific risk event and the result can be plotted using a risk matrix. It illustrates the simple multiplication of the scale values assigned to determine qualitatively the risk level (i.e. low, moderate, high...).

The deterministic approach consists of:

- list of potential hazards of external and internal origin;
- establishment of credible hazards;
- determination of the consequences;
- justification of the necessary safety improvement measures to limit the consequences.

The risk based approach can consist of:

- list of potential hazards of external and internal origin;
- determination of the consequences of each hazard and their allocation into classes of consequence (an example is given in Annex J);
- collection/input of failure rate data;
- determination of the probability or frequency of each hazard;
- summation of frequency for all hazards within any one allotted consequence class and classify the frequency range for that consequence class (an example is given in Annex I);
- classification of hazards in accordance with their consequences class and frequency range, to determine the level of risk (an example is given in Annex K).

If the risk determination indicates “Unacceptable Risk” levels (for example, risk level 3 of Annex K) the plant design or operating practices shall be altered and the assessment repeated until such time that no such “Unacceptable Risk” levels exist. If the risk determination indicates normal, acceptable, risk levels (for example, risk level 1 of Annex K) no further action is considered necessary. For risk levels determined as requiring further reduction (for example risk level 2 of Annex K) additional safety measures shall be considered to limit the risk to as low as reasonably practicable.

Hazard and risk assessment can be based on methods such as:

- Hazard Identification Study (HAZID);
- Hazard and Operability Study (HAZOP);
- Failure Mode Effect Analysis (FMEA);
- Event Tree Method (ETM);
- Fault Tree Method (FTM);
- Bow-Tie Analysis (BTA);
- Layer of Protection Analysis (LOPA);
- Safety Integrity Level (SIL) verification;
- Quantified Risk Assessment (QRA);
- Fire and Explosion Risk Analysis (FERA).

The risk assessment procedure shall be carried out during all stages of the design process. Implementation during the early stages of a project or design modification is recommended, this allows unacceptable designs to be improved in the most cost effective manner.

The minimum acceptance criteria given in Table K.1 are based on risk to operating personnel inside the plant boundary. Comparable categories for mass of hydrocarbon released are also given for guidance in Annex J. Alternative risk assessment methods can be used to assess the suitability of the plant design, typically business and hazardous incident escalation risk assessments. However, as a minimum operating personnel risk should be assessed and verified as acceptable during the plant design and following major modifications.

6.2.2 Risk matrix

The risk matrix is an effective tool for qualitative risk assessment and screening. It is normally used in workshops in support of HAZIDs and FMEA. The results from the detailed analysis in terms of frequency and consequences can be reported in the matrix. This enables to track and tune the efficiency of the risk-reducing measures, qualify initial assumptions, and confirm the initial scenario ranking.

6.2.3 Hazard Identification Study (HAZID)

The HAZID is a technique used for early identification of potential hazards and threats. It is also suited to the identification of non-process related hazards such as ship collision, dropped objects, extreme weather etc. The effect or possible consequence of an untoward incident is itemized and the possible causes determined.

The HAZID technique is a:

- means of identifying and describing occupational HSE hazards and threats at the earliest practicable stage of a development or venture;
- meeting employing a highly experienced multi-discipline team using a structured brainstorming technique, based on a checklist of potential HSE issues, to assess the applicability of potential hazards; and
- rapid identification and description process only, not a forum for trying to solve potential problems.

A common HAZID meeting organization should involve a facilitator supported by experienced representatives from process design, safety engineering, instrumentation, operations and other specialists if required. ISO/TS 16901 provide more information about HAZID methodology.

6.2.4 Failure Mode Effect Analysis (FMEA)

The definition of failure mode and effect analysis is an analytically derived identification of the conceivable equipment failure modes and the potential adverse effects of those modes on the system and mission. It is primarily used as a design tool for review of critical components. Further details are given in EN IEC 31010 and EN ISO 17776.

6.2.5 Hazard and Operability Study (HAZOP)

HAZOPs are used to identify both hazards and operability problems. Although hazard identification is the focus, operability problems are also identified to the extent that they could have the potential to lead to safety or environmental hazards, or have a negative impact on plant availability.

The HAZOP team involves a group typically consisting of operators, designers, technical specialists (both external and internal to the design team), and maintainers focussing on specific portions of the process called “nodes”. These sections are defined from the P&IDs (piping and instrumentation diagram) prior to the study.

A process parameter is identified, e.g. flow and then typical guidewords are then applied to the specified sections to identify possible deviations (e.g. a guideword “no” is combined with the parameter “flow” to create a deviation, “no flow”). The team then lists all the credible causes of a “no flow” deviation beginning with the cause that can result in the worst possible consequence.

HAZOP is applicable during the basic design (FEED), when P&IDs are issued, as well cause-effect matrix has been produced. It is usually carried out during the detail design as well and may even be reapplied during a management of changes. ISO/TS 16901 provide more information about HAZOP methodology.

HAZOP is a standardized methodology described in several standards (see for instance [7]).

A first HAZOP study on the process systems shall be carried out during the basic design of a plant when the P&ID's are developed.

Further HAZOP studies shall be carried out during the detailed design of a plant, on process systems and vendor packages.

The recommendations from the HAZOP studies shall be managed throughout the project.

HAZOP studies may also be carried out during the operational phase of a plant, for instance to improve safety or performance of the plant.

6.2.6 Event Tree Method (ETM)

The event tree method uses a graphical way of showing the possible outcomes of a hazardous event, such as a failure of equipment or hydrocarbon release. With use of the event tree this method explores the possible outcome of the initial event and determines the resulting frequencies of the different end events which represent different consequences. As such the event tree is a logical tool to aggregate probabilities and risks.

6.2.7 Fault Tree Method (FTM)

The fault tree method is an analysis of those events in a process that can result in particular malfunctions or failures, shown in the form of a tree diagram. Fault trees are very useful in simple systems and can be used to illustrate the contribution from the various parts of a system such as instrumentation. However, in fault trees it is very difficult to identify all the contributors to the failure and to recognize common mode failures.

6.2.8 Bow-tie analysis (BTA)

The bow-tie is a design tool that can be used to assess barriers to prevent occurrence of top events and recovery measures to reduce the consequences. It is based on a model that represents how a hazard can be released, escalate, and how it is controlled. The bow-tie model provides for the assessment of hazards in order to:

- identify the potential hazard release, escalation, and consequence scenarios;
- identify the controls (i.e. barriers and escalation factor controls) required to effectively manage these hazards, (e.g. the HSE critical elements, HSE critical tasks, and procedures);
- support the ALARP demonstration;
- provide visibility and communicate the above information to those responsible for managing, or who could be affected by the hazards;
- in the event of an incident, have the ability to relate causes of incidents to the controls that failed, thus enabling improved incident learning and prevention.

6.2.9 Layer of Protection Analysis (LOPA)

LOPA is a semiquantitative method for estimating the risks associated with an undesired event or scenario. It analyses whether there are sufficient measures to control or mitigate the risk.

A cause-consequence pair is selected and the layers of protection which prevent the cause leading to the undesired consequence are identified. An order of magnitude calculation is carried out to determine whether the protection is adequate to reduce risk to a tolerable level according to EN IEC 31010.

6.2.10 Safety Integrity Level (SIL) analysis

Safety integrity level (SIL) analysis as described in EN 61508 (all parts) complements the HAZOP analysis and the risk assessment study by defining the level of confidence required from the instrumented safety systems including mechanical devices and software, intended to prevent hazardous situations affecting safety of persons and/or the environment or to mitigate their consequences. The referenced standard also introduces the notion of safety life cycle that aims to secure the reliability of the implemented safety systems throughout the life of the system. The SIL assessment should be based on layers of protection analysis.

6.2.11 Quantified Risk Assessment(QRA)

QRA provides a prediction of frequency with which accidents inside a plant can occur, using recognized and verifiable methodology, and in so doing QRA produces risk values for people and compares them with tolerable risk criteria. QRA is based on the site layout and its surroundings.

The objectives of a QRA can be to:

- reduce risks by identifying areas of high risk and areas where risks can be further reduced, demonstrate compliance with authority and company requirements inside and outside fence;
- assess the risks for workers;
- compare several options;
- assess effectiveness of risk reduction measures;
- provide criteria for occupied building location and design;
- assess the risk on maintenance crew when some parts of the plant remain in operation;
- provide inputs to other safety studies like FERA.

Further details are given in EN ISO 17776 (risk analysis section in Annex C).

6.2.12 Fire and Explosion Risk Analysis (FERA)

Using recognized modelling tools, FERA predicts:

- the design accidental loads (overpressure and drag) for structure, equipment and piping systems;
- the potential fire load effects on structure and equipment.

The main objective of fire and explosion risk assessment is to estimate the risk for escalation inside the plant (and outside the plant if necessary) and provide decision support for design modifications in respect to fire loads and explosion overpressures.

Further details are given in EN ISO 17776.

6.3 Scenario identification

6.3.1 Identification of risk sources and causes of external origin

Studies shall be undertaken to identify risk sources and causes, which can lead to the release of hazard arising from outside the plant. Release of LNG hazards can be caused by:

- LNG carriers approaching the berth at excessive speed or angle;
- the possibility of collision with the jetty and/or LNG carrier at berth by heavy displacement vessels passing the berth (see [40]);
- the impact of projectiles;
- consequences of collision (ship, truck, plane, etc.);
- natural events (hurricane, lightning, flooding, earthquakes, tidal bores, icebergs, tsunamis, seiches, etc.);
- weather conditions (barometric pressure incl. pressure fluctuation, rain, snow and ice, ambient temperature);
- ground conditions (weak strata, liquefiable layers, lateral spreading, presence of caverns, voids and defects);
- proximity of airport and/or flight paths;
- a “domino effect” resulting from fires and/or explosions at adjacent premises.

Ignition of a flammable gas cloud can be due to:

- high energy radio waves (see [41]);
- permanent sources of ignition, such as high voltage power lines (corona effect);
- the proximity of the site to any external uncontrolled sources of ignition.

6.3.2 Identification of scenarios arising from LNG

Loss of containment of LNG and of natural gas shall be considered for all items of equipment including the loading or unloading of road tankers or LNG carriers. To simplify the study, scenarios may be established.

These scenarios shall be defined in terms of:

- the probability or frequency of the hazard;
- the location of the leak;
- the nature of the fluid (LNG or gas, specifying the temperature);
- the rate and the duration of the leakage;
- the weather conditions (wind speed and direction, atmospheric stability, ambient temperature, relative humidity);
- the thermal properties and the topography of the ground (including any impounding area);
- the proximity of structural steelwork that could be susceptible to brittle failure due to low or cryogenic temperatures.

Under certain circumstances when quantities of LNG have been introduced into water, over-pressurization without combustion has been known to occur; this phenomenon is referred to as a Rapid Phase Transition (RPT). Refer to EN ISO 16903 and see [47], [48] and [49].

6.3.3 Identification of other hazards and scenario causes of internal origin

The following hazards and causes that are not specific to LNG shall be considered:

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

6.4 Consequence and impact assessment

6.4.1 General

A wide range of computational tools is available to assess the consequences from accidental events comprising both empirical tools and tools developed from the basic physical equations. The burning characteristics depend strongly on the type of fuel (natural gas, LPG) and shall be reflected in the assessment.

The consequences of each scenario as defined above will depend on the characteristics of LNG and other phenomena described in EN ISO 16903. For the hazardous characteristics of fluids other than LNG reference shall be made to their Material Safety Data Sheets.

The inherent safety protection shall be provided to:

- contain LNG spills within the fence, and reduce likelihood of the credible scenarios where there could be the risk that vapour clouds spread beyond the plant periphery fence;
- minimize the possibility of a fire in any one area of the plant spreading to another area;
- minimize damage in the immediate area of a fire using separation distances, minimizing the hydrocarbon inventory feeding a possible fire (by segregating the plant in different fire-zones, by isolation valves).

6.4.2 Gas cloud dispersion

6.4.2.1 General

The atmospheric dispersion simulation shall be based on the combination of wind speed and atmospheric stability that can occur simultaneously.

If no other information is available, the following atmospheric condition shall be considered at ground level: F (PASQUILL stability classes) atmospheric stability or equivalent temperature gradient, for a wind speed of 2 m/s and a relative humidity of 50 %.

The model shall enable the determination of:

- concentration contours;
- the distance to the lower flammability limit.

6.4.2.2 LNG release

LNG at exit of a hole will be shared between flashed vapour (natural gas), liquid droplets that are entrained in the jet (aerosols), and the liquid that deposits on the ground (rainout). Aerosols only include airborne droplets that will not deposit on the ground, and will therefore transform into vapour within the cloud. Rainout includes the liquid that deposits just after the hole area and further away as droplets fall down.

The mass flowrate through a hole area is calculated using methods based on fluid mechanics.

6.4.2.3 Flashed gas and aerosols from LNG jet release

The phenomenon of instantaneous vaporization due to depressurization (flash, including possible aerosol formation) shall be considered.

The flash shall be calculated.

The model shall take the following into account:

- LNG flow rate and duration;
- LNG composition.

Sources of jet releases shall include releases from pressure relief valves, un-ignited flare and vents.

6.4.2.4 Dispersion of LNG vapours and natural gas from jet release

Calculation of atmospheric dispersion resulting from jet release shall be carried out using appropriate validated models to determine as minimum, the height or the distance reached by the jet and the concentration of gas at any given point.

The model shall take the following into account:

- atmospheric conditions (ambient temperature, humidity, wind velocity);
- atmospheric stability or temperature gradient;
- site topography (surface roughness, etc.).

6.4.2.5 Rainout and pool formation

The occurrence of rainout is estimated from a method based on a criterion for droplets to fall down.

The model shall take the following into account:

- LNG flow rate and duration;
- LNG composition;
- nature of the ground (thermal conductivity, specific heat, density, etc.);
- temperature of the ground or of the water;
- atmospheric conditions (ambient temperature, humidity, wind velocity);
- atmospheric stability or temperature gradient.

The model shall enable the following to be determined:

- pool propagation speed;
- wetted area in terms of time, and the maximum wetted area;
- rate of evaporation in terms of time and the maximum evaporation rate.

6.4.2.6 Pool evaporation

Calculation of the atmospheric dispersion of the cloud resulting from evaporation of LNG due contact with the ground or water shall be carried out using appropriate validated models.

The determination of dispersion shall, as a minimum, consider:

- the surface of the evaporating pool;
- the evaporation rate;
- properties of the vapour;
- the nature of the ground (thermal conductivity, specific heat, density, etc.);
- the temperature of the ground or water;
- the atmospheric conditions (ambient temperature, humidity, wind speed);
- atmospheric stability or temperature gradient;
- site topography (surface roughness, etc.).

6.4.3 Fire

Calculation of the radiation caused by ignition of the vapour from a pool or jet of LNG or release of natural gas shall be carried out using appropriate validated models.

The model shall take the following into account:

- area of the pool fire or the dimensions of the flame;
- surface emissive power of the pool fire or of the flame (see EN ISO 16903);
- ambient temperature, wind speed/prevalled direction and relative humidity.

The radiation calculation shall be based on the combination of wind speed and atmospheric conditions that can occur simultaneously.

The model shall enable the determination of the incident radiation at various distances and elevations.

6.4.4 Explosion

The ignition of natural gas can create in certain circumstances (e.g. congested areas) an explosion generating an overpressure wave. The flammability range of mixtures of natural gas and air is given in EN ISO 16903.

Recognized methods and models, for example the multi energy method (see [23]) and/or deflagration at constant speed method (see [24]) which have been validated can be used to calculate the overpressure. This overpressure shall be specified where applicable for equipment, buildings and structures.

Where overpressure on a tank, equipment item, building or structure is specified, it shall always be the incoming wave characteristics. In this case it may be assumed that a deflagrating explosion in the near vicinity of the tank or at a credible distance (e.g. process area of the liquefaction plant) gives rise to an overpressure that is applied, as a worst case assumption, to a half perimeter of the tank. The stresses in the tank caused by overpressure shall be determined by dynamic calculation. For the other structures, the stresses may be determined by static calculation.

The effect of potential overpressure under elevated tank basis due to the ignition of a flammable mixture under the tank shall be considered, if applicable.

The effects of wave reflection on the objects shall be considered.

A boiling liquid expanding vapour explosion (BLEVE) shall be considered for pressurized tanks.

6.4.5 Pooling

The effect of LNG pooling is determined by:

- the stored LNG condition (temperature, pressure, composition);
- ambient conditions;
- the size and shape of the leak-source;
- outflow impingement into objects.

The higher the pressure and LNG temperature in a system, the more turbulence will occur at a leak causing more flash effect and lowering the rain-out fraction. Detailed analysis shall determine if pooling is a potential risk and further mitigation like liquid spill containments or liquid spill control are required.

Scenarios to be considered for various types of LNG tanks are listed in Table 1.

Table 1 — Pool fire sizing for tank spillage as function of tank types

Storage Concept ^a	Low pressure storage		Pressurized storage
	Metallic or with metallic roof only	Prestressed concrete with concrete roof	
Single containment	Impounding area	n/a	Remote impounding
Double containment	Secondary container	n/a	Secondary container
Full containment	Secondary container	No pool fire	No pool fire
^a For definition, see 7.8.4.			

Spillage from piping to be guided into a remote impounding. The size of the remote impounding shall be sufficient for receiving the volume of LNG discharged from full line break prior to closure of internal integrated shut-off valve reduced of the vaporization before achieving the impounding.

6.4.6 Safety distances

The distance between plant components shall be determined in accordance with the hazard and risk assessment (see Clause 6) but shall not be less than the minimum criteria given in 7.2.6.

The safety spacing shall be calculated considering possible fire radiation levels and gas dispersion zones. The allowable exposure levels are specified in Annex A. Safety distances between LNG tanks, process units, control rooms etc. shall comply with the minimum requirements to achieve these threshold values.

6.5 Estimation of frequencies and probabilities

The estimation of the frequency or probability associated with a given hazard and its consequences, where utilized, shall be based on reliable databases available in public domain and which are suitable for the LNG industry or on recognized methods which will determine the frequency range (see Annex I). The human factor shall be considered.

6.6 Safety improvement

Where the risk assessment demonstrates that threshold values defined in Annex A are exceeded or shows that the level of risk requires improvement (see Annex K), measures shall be taken, as for example:

- setting up a safety system which allows early detection of a leak and limitation of the consequences of ignitions (see 7.2.3 and Clause 6);
- increasing the dilution of the flammable cloud;
- elimination of potential sources of ignition inside a flammable cloud;
- reducing evaporation rates through minimization of heat transfer;
- reducing heat radiation by water curtains, deluge systems, foam or insulation;
- reducing vapour dispersion distance by warming the cloud using foam or spraying;
- increasing spacing between equipment;
- protection of the installation against blast;
- alarm systems such as break-glass units, telephones, paging systems, closed circuit television and sirens.

6.7 Reviews

The reviews shall be organized through a strict application of an all-encompassing QA system (see Clause 4).

Depending on the complexity of the project, the following reviews shall be considered as a minimum:

- Preliminary Risk Analysis;
- layout review;
- HAZOP;
- maintenance and accessibility review;
- SIL review;
- pre-start-up review
- constructability review.

6.8 Safety during operation

6.8.1 Operational procedures

Safety during the operational phase shall be achieved by the following features and measures:

- operation control, monitoring and safeguarding systems including work permits;
- control of ignition sources;
- local and remote control of the firefighting system;
- emergency response.

6.8.2 Maintenance procedures

The maintainability of the plant shall be verified during design. The preparation for plant operation shall include also procedures for:

- maintenance;
- inspection.

Inspection and maintenance shall be incorporated into the plant management system by documentation that defines the specific maintenance program for each plant component concerned. Proper maintenance of the firefighting equipment is of primary importance.

Maintenance procedures shall address the safety of personnel and integrity of equipment while under repair. Ways of inspection, type of tests as well as their frequencies shall be covered.

6.8.3 Training

The preparation for plant operation shall include operating personnel training, as outlined below.

Written operating procedures shall be provided for the plant and be readily available for those operating the plant. These shall cover all normal and emergency operating procedures.

Protective equipment (personal protection) shall be provided and worn as determined by risk analysis.

Operators involved in emergency activities shall be equipped with the necessary protective clothing and equipment. Portable flammable gas detectors shall be readily available.

Persons engaged in the management, production, handling and storage of LNG shall be trained in the hazards and properties of LNG with attention to emergency response procedures.

Operation and maintenance staff shall be well trained in all aspects of their work to ensure that they can work in a safe and competent manner under both normal and emergency conditions. Initial training shall consider the background of the individual. Re-training shall be undertaken at regular intervals and all records of their training kept.

For management and staff, training schemes shall be structured according to the individual's experiences, duties and responsibilities within the organization and independently validated.

All persons visiting a site for whatever purpose shall be instructed in the hazards and properties of LNG, the depth to which this training is undertaken shall be appropriate to their level of involvement in site operations.

In all projects, there shall be consultation between the terminal owner, port operator, ship operator, pilots and tug-masters. Pre-operational training and regular refresher courses, using simulators, shall be undertaken, involving all relevant parties.

See [40].

Accordingly, and with respect to emergency situations, the interest of operating personnel shall be kept high by suitable drills including the use of equipment.

All operating personnel shall be adequately trained for emergency situations including the use of equipment through for example drills.

6.8.4 Emergency response

The preparation for plant operation shall include development of safety and security procedures, which integrate with the overall port emergency procedures and International Ship and Port Facilities Security (ISPS) code, where relevant.

Emergency notification devices (e.g. horn and beacon, SMS, signage, etc.) shall be installed risk based at strategic locations to warn people in case of incidents.

NOTE Local regulations could apply.

A detection system shall be provided to give warning of any leakage of LNG or natural gas and to give warning in the event of fire. Activation of this system shall automatically initiate an ESD of the ship-shore transfer system and give alarms in the jetty operator room, terminal control rooms and be communicated to the ship by the means as recommended by EN ISO 28460.

7 Design

7.1 General

This Clause design is split into different sections setting out specific requirements per engineering discipline.

The design shall be in line with the industry good practices, applicable codes and standards, as well as with the specific requirements set by local regulation.

Minimum and maximum design pressures and temperatures of piping and equipment shall be selected to cover all anticipated operation and upset conditions.

7.2 Civil structures

7.2.1 General

The design of civil structures follows the Eurocode principles and supports the loads definition and calculation methods accordingly.

7.2.2 Area drainage and spill control

7.2.2.1 Prevention of LNG Leak and detection

Restricting the extent of a potential LNG or hydrocarbon leak is achieved by:

- limiting the volume by isolation of the leak source;
- containing these spills within defined spill collection impounding areas and impounding basins, to prevent their spreading to other areas of the plant or outside the plant boundary and minimizing the vapour cloud dispersion distance;
- controlling leaks and spillage.

Where dispersion calculations show that a leak can escalate to a more serious incident fixed leak detection systems with advisory or executive action to stop the leak source, are required to isolate sections of plant and to shutdown sources of ignition.

Spill detection devices shall be provided.

7.2.2.2 Impounding basin purpose and location

Liquid spills within the plant shall be confined within a spill collection area and shall be drained to and accommodated in an impounding basin based on a risk assessment.

Subject to the results of risk analysis, the impounding basin may be combined with, located inside, in the vicinity of, or remote from, the spill collection area. The spill collection area and the impounding basin shall be connected by open channel.

The design of the impounding area shall ensure that the leakage scenarios shall not result in any escalation effect to the adjacent tank(s) or equipment. The location of the impounding basin shall be confirmed by thermal radiation and dispersion analysis.

7.2.2.3 Capacity of the impounding basin

For process areas, the spill collection system or impounding basin capacity shall be at least 110 % of the largest expected spill according to the risk analysis performed. Flash may be considered for capacity calculation. In case of plant expansion or plant debottlenecking, the spill collection system and impounding basin capacity shall be checked to suit the new inventories.

For low pressure tank, the impounding basin within the bund walls shall be large enough to contain at least 110 % of the capacity conforming to the maximum design liquid level according to EN 14620 (all parts) of the biggest tank of single containment low pressure tank design.

For pressurized LNG storage, the volume of the impounding basin according to Table 1 shall be based on hazard identification and risk assessment. If impounding basin is necessary, it shall contain at least 20 % of the volume of the largest pressurized tank assuming the depth of the basin is not larger than 2 meters, unless demonstrated otherwise. The remote impounding basins of two or more tanks may be combined.

NOTE The increase of depth reduces the heat transfer surface of the bottom.

The impounding basin of storage tanks shall also be capable of collecting leaks from LNG pipe-work within impounding area. The capacity shall be greater than the amount of liquid which would be spilled by breakage of the pipe with the highest leakage rate for the time necessary for detection and interruption of flow.

The capacity of the impounding basins and spillage collection channel for LNG and hydrocarbon pipe-systems and equipment shall be evaluated as a part of the risk management.

In general, it has been found that the collection of spill from interconnecting LNG and hydrocarbons piping, without branch, flanges or instrument connections, is not justified by risk assessment.

Transfer lines between tanks and jetty should be considered separately.

7.2.2.4 Design of the impounding basin

An impounding basin shall be open to the atmosphere.

Grading of the impounding area under and surrounding the storage system, where potential leak-points are present, shall direct any liquid leaks or spills a safe distance away from equipment to the remote impounding basin by sloping.

LNG entering into an enclosed equipment for oil separation from rainwater collection system shall be subject of risk assessment.

The design shall demonstrate that the wall of the impounding basin will not be overtopped, even in case of the most severe failure identified by risk assessment.

Means for limiting evaporation and reducing the rate of burning of ignited spills and consequences shall be considered.

The thermal conductivity of the material affects the rate of evaporation following a spill. The need to insulate the impounding area and impounding basins will depend on the results of the risk assessment. Insulation coating of such systems shall be designed in accordance with EN ISO 16903.

The bottom of impounding basins may be covered with an insulation layer or built with special materials to minimize evaporation.

The bottom of the impounding area or of the impounding basin is not recommended to be covered with gravel, as heat transfer properties would increase vaporization, or vegetation, as it could pose a fire risk.

For tanks if installed in an excavation, the ground could act as the impounding basin if its properties are suitable.

7.2.2.5 LNG draining and water removal

Plant surface water and fire water drainage systems and LNG spill collection systems shall be designed to minimize the possibility of fire water increasing the vaporization rate of any LNG spill.

Rain or fire water which could accumulate in the basin shall be removed by relevant means. Pumping shall be inhibited from starting, should LNG leakage be detected.

LNG spills shall not enter any closed drainage network (e.g. by sealing the entry points into the drainage networks) or flow towards any building areas (e.g. via impoundment areas).

LNG or hydrocarbon shall not enter public rain water drains or other sewer systems.

Separation systems relying on the differential densities of water and LNG are not acceptable.

Siphons with presumed freezing of water for plugging with ice may be used based on a risk assessment (size of basin) and if approved by authority.

7.2.3 Crash barriers

Crash barriers shall be installed to protect vulnerable equipment against accidents involving vehicles. The location and design of the crash barriers shall be done via a risk assessment.

The crash barrier system shall be designed to absorb the design impact energy by deformation without collapse.

Vehicle traffic shall be controlled inside the facility zone to minimize impact.

7.2.4 Fire protection

7.2.4.1 General

The determination of the plant fire safety shall be based on a risk assessment of selected fire and hydrocarbon leakage scenarios.

The results obtained from the calculations performed during the hazard consequence modelling will reveal which equipment would be most likely to fail causing further escalation of the fire emergency. This provides the basis for the selection of fire protection measures (water spray systems, fixed fire-water monitors, mobile monitors, manual water application by emergency responses, passive fire protection, firefighting vehicle etc.).

Fire prevention, fire protection and firefighting measures shall be based on the risk assessment. The extent of fire protection is related to operating manpower levels, operating personnel safety requirements, environmental concerns, potential for business interruption.

7.2.4.2 Fire protection systems

Fire protection systems are divided into:

- Passive fire protection;
- Active fire protection.

Passive fireproofing could be relevant:

- at the early stages of a fire when the active fire-protection has not been activated or to allow the depressurisation of a vessel or pipe;
- when active fire protection will not mitigate the scenario.

One objective of passive fire protection is to improve the resistance of an equipment and/or its supports against a pool fire or a jet fire, for example supports of vessels containing large quantities of liquid hydrocarbon.

Another objective is to maintain operability of an equipment when exposed to a fire: for example, the actuator and cables of a valve which operability (closure or opening) has been assessed to be needed during a fire. In particular fire proofing could be relevant:

- To ensure that valves that are not fail safe by design (for instance valves which are electrically activated) can go, if necessary, to their safe position under a fire challenge;
- To maintain operability under fire of fail-safe valves with a delayed action (for instance emergency depressurisation valves operating in sequence for depressurisation of large equipment).

ESD valves which are fail-safe and fire-tested as per EN ISO 10497 do not require fire-proofing unless requested by a risk assessment. The cables of such valves do not need to be fire resistant either.