

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

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ICS 75.200

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liquéfié — Conception des installations terrestres

Anlagen und Ausrüstung für Flüssigerdgas —
Auslegung von landseitigen Anlagen

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CEN

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Foreword

This European Standard 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of an identical text or by endorsement, at the latest by November 1997, and conflicting national standards shall be withdrawn at the latest by November 1997.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

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0 Introduction

The objective of this European Standard is to give functional guidelines for LNG installations. It recommends procedures and practices which will result in safe and environmentally acceptable design, construction and operation of LNG plants. It need not be applied retrospectively, but application is recommended when major modifications of existing installations are being considered.

1 Scope

This European Standard gives guidelines for the design, construction and operation of all onshore stationary liquefied natural gas (LNG) installations including those for the liquefaction, storage, vaporization, transfer and handling of LNG. Satellite plants with total storage capacity of less than 200 t are excluded from this European Standard.

This European Standard is valid for the following plant types:

- export terminals, between the designated gas inlet boundary limit, and the ship manifold;
- receiving terminals, between the ship manifold and the designated gas outlet boundary limit;
- peak-shaving plants, between designated gas inlet and outlet boundary limits;
- LNG satellite plants with total storage capacity above 200 t, including the loading station up to the designated gas outlet boundary limit.

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

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 287-1	<i>Approval testing of welders — Fusion welding — Part 1: Steels</i>	EN 473	<i>Qualification and certification of NDT personnel — General principles</i>
EN 288-1	<i>Specification and approval of welding procedures for metallic materials — Part 1: General rules for fusion welding</i>	EN 571-1	<i>Non-destructive testing — Penetrant testing — Part 1: General principles</i>
EN 288-2	<i>Specification and approval of welding procedures for metallic materials — Part 2: Welding procedure specification for arc welding</i>	prEN 823	<i>Thermal insulating products for building applications — Determination of thickness</i>
EN 288-3	<i>Specification and approval of welding procedures for metallic materials — Part 3: Welding procedure tests for the arc welding of steels</i>	prEN 970	<i>Non-destructive examination of fusion welds — Visual examination</i>
		prEN 1050	<i>Safety of machinery — Principles for risk assessment</i>
		prEN 1092-1	<i>Flanges and their joints — Circular flanges for pipes, valves and fittings — Part 1: Steel flanges — PN designated</i>
		prEN 1127-1	<i>Safety of machinery — Fire and explosions — Part 1: Explosion prevention and protection</i>
		EN 1160	<i>Installation and equipment for liquefied natural gas — General characteristics of liquefied natural gas</i>
		prEN 1435	<i>Non-destructive examination of welds — Radiographic examination of welded joints</i>
		prEN 1474	<i>Installation and equipment for liquefied natural gas — Design and testing of loading/unloading arms</i>
		prEN 1514-1	<i>Flanges and their joints — Dimensions of gaskets for PN-designated flanges — Part 1: Non-metallic flat gaskets with or without inserts</i>
		prEN 1532	<i>Installation and equipment for liquefied natural gas — Ship to shore interface for liquefied natural gas</i>
		prEN 1594	<i>Gas supply systems — Pipelines — Maximum operating pressure over 16 bar — Functional requirements</i>
		prEN 1714	<i>Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories — Part 1: Steel flanges, NPS ½ to 24</i>
		prEN 1759-1	<i>Gas supply — Natural gas measuring systems — Functional requirements</i>
		prEN 1776	<i>Quality systems — Model for quality assurance in design, development, production, installation and servicing (ISO 9001 : 1994)</i>
		EN ISO 9001	<i>Quality systems — Model for quality assurance in production, installation and servicing (ISO 9002 : 1994)</i>
		EN ISO 9002	<i>Rotodynamic pumps — Code for hydraulic performance tests for acceptance — Grades 1 and 2 (ISO/DIS 9906 : 1995)</i>
		prEN ISO 9906	<i>Metallic products — Types of inspection documents</i>
		EN 10204	

prEN ISO 10456	<i>Building materials and products — Procedures for determining declared and design thermal values (ISO/DIS 10456 : 1995)</i>	EN 50020	<i>Electrical apparatus for potentially explosive atmospheres — Intrinsic safety 'i'</i>
prEN 12008-1	<i>Specific functional requirements for the materials, design, construction, operation, maintenance and renovation of gas supply systems up to and including 16 bar — Part 1 : Polyethylene systems up to and including 10 bar</i>	EN 50028	<i>Electrical apparatus for potentially explosive atmospheres — Encapsulate 'M'</i>
prEN 12008-2	<i>Specific functional requirements for the materials, design, construction, operation, maintenance and renovation of gas supply systems up to and including 16 bar — Part 2 : Steel-systems up to and including 16 bar MOP</i>	EN 50039	<i>Electrical apparatus for potentially explosive atmospheres — Intrinsic electrical systems 'i'</i>
prEN 12065	<i>Installation and equipment for liquefied natural gas — Suitability testing of foam concentrates designed for generation of medium and high expansion foam and of extinguishing powders used on liquefied natural gas fires</i>	EN 50054	<i>Electrical apparatus for the detection and measurement of combustible gases — General requirements and test methods</i>
prEN 12066	<i>Installation and equipment for liquefied natural gas — Testing of insulation linings for liquefied natural gas retention bunds</i>	EN 50057	<i>Electrical apparatus for the detection and measurement of combustible gases — Performance requirements for group II apparatus indicating up to 100 % lower explosive limit</i>
prEN ISO 12241	<i>Calculation rules for the thermal insulation of pipes, ducts and other equipment in building and industrial installations (ISO/DIS 12241 : 1995)</i>	prEN 50145	<i>Electrical apparatus for potentially explosive gas atmospheres — Classification of hazardous areas</i>
prEN 12308	<i>Installation and equipment for liquefied natural gas — Suitability testing of gaskets designed for flanged joints used on LNG piping</i>	ISO 2548	<i>Centrifugal, mixed flow and axial pumps — Code for acceptance tests — Class C</i>
EN 25199	<i>Technical specifications for centrifugal pumps — class II (ISO 5199 : 1986)</i>	ENV 1991-2-2	<i>Eurocode 1 — Basis design and actions on structures — Part 2-2: Actions on structures exposed to fire</i>
EN 50014	<i>Electrical apparatus for potentially explosive atmospheres — General requirements</i>	ENV 1992-1-1	<i>Eurocode 2 — Design of concrete structures — Part 1-1: General rules and rules for buildings</i>
EN 50015	<i>Electrical apparatus for potentially explosive atmospheres — Oil immersion 'o'</i>	ENV 1992-1-2	<i>Eurocode 2 — Design of concrete structures — Part 1-2: Structural fire design</i>
EN 50016	<i>Electrical apparatus for potentially explosive atmospheres — Pressurized apparatus 'p'</i>	ENV 1993-1-1	<i>Eurocode 3 — Design of steel structures — Part 1-1: General — General rules and rules for buildings</i>
EN 50017	<i>Electrical apparatus for potentially explosive atmospheres — Powder filling 'q'</i>	ENV 1993-1-2	<i>Eurocode 3 — Design of steel structures — Part 1-2: General rules — Structural fire design</i>
EN 50018	<i>Electrical apparatus for potentially explosive atmospheres — Flameproof enclosure 'd'</i>	ENV 1994-1-1	<i>Eurocode 4 — Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings</i>
EN 50019	<i>Electrical apparatus for potentially explosive atmospheres — Increased safety 'e'</i>	ENV 1994-1-2	<i>Eurocode 4 — Design of composite steel and concrete structures — Part 1-2: General rules — Structural fire design</i>
		ENV 1998-1-1	<i>Eurocode 8 — Design provisions for earthquake resistance of structures — Part 1-1: General rules — Seismic actions and general requirements for structures</i>
		ENV 1998-1-2	<i>Eurocode 8 — Design provisions for earthquake resistance of structures — Part 1-2: General rules — General rules for buildings</i>
		ENV 1998-5	<i>Eurocode 8 — Design provisions for earthquake resistance of structures — Part 5: foundations, retaining structures and geotechnical aspects</i>

3 Terms and definitions

For the purpose of this standard, the following definitions apply.

3.1 LNG (Liquefied Natural Gas)

LNG (Liquefied Natural Gas) is defined in EN 1160.

3.2 LNG export terminal

In an LNG export terminal, the natural gas coming by pipe from one or several gas fields is liquefied then stored for subsequent transport to other destinations.

3.3 LNG receiving terminal

In LNG receiving terminals, LNG carriers (ships) are unloaded, LNG is stored in tanks, vaporized and sent to the gas networks or gas consumers. LNG receiving terminals can have loading stations for road, rail, barge or small LNG carriers.

3.4 LNG peak-shaving plant

LNG Peak-shaving plants are connected to a gas network. During the period of the year when gas demand is low, natural gas is liquefied and LNG is stored. LNG is vaporized during short periods, when gas demand is high.

3.5 LNG satellite plant

LNG satellite plants are connected to a gas network or gas consumers. LNG is supplied by road tankers, rail, barge or small LNG carriers. LNG is stored in insulated pressure vessels, vaporized and sent to the network.

3.6 actions

'Actions' (sometimes referred to as loads) are forces and couples of forces due to the loads and deformations which are imposed on an item of equipment.

3.7 combined actions

Actions are classified in three categories:

- 'permanent actions' for which intensity is constant or does not vary very much or always varies in the same direction while tending to a limit;
- 'variable actions' for which intensity is not constant. Variations are due essentially to actions during construction, testing, commissioning and normal operation of the installations, atmospheric conditions and operating basis earthquake (OBE);
- 'accidental actions' for which intensity is not constant. Its variations are due essentially to accidental internal or external actions including the safe shutdown earthquake (SSE).

Actions are combined to obtain two types of combined actions:

- 'normal actions' are combinations of actions which are permanent and variable;
- 'augmented actions' are the combination of normal actions and a single accidental action. Unless otherwise stated, accidental actions in combination need not be considered.

3.8 hazards

A physical situation which has the potential for human injury, damage to property, damage to the environment or some combination of these.

3.9 tank

The word 'tank' used in this standard corresponds to the equipment item in its entirety for the retention of LNG. The different types of tank are described in annex H.

3.10 OBE (Operating Basis Earthquake)

An OBE, defined for any installation, is the maximum earthquake for which no damage is sustained and restart and safe operation can continue. This higher probability event would result in no commercial loss to the installation and public safety is assured. An OBE event shall require a structural assessment to be carried out at the serviceability limit state.

3.11 SSE (Safe Shutdown Earthquake)

An SSE, defined for any installation, is the maximum earthquake event for which the essential fail-safe functions and mechanisms are designed to be preserved. 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.

3.12 level of risks

The combination of the consequence and the probability of a specific hazard occurring within a specified period under specified circumstances.

3.13 impounding area and bund wall

The impounding area is formed by the bund walls around the LNG storage tank which is a low construction of earth or concrete surrounding the storage tank, at a distance greater than 6 m from the tank, to contain spilled liquid.

3.14 primary container

The primary container is:

- the cryogenic container of the single containment tank;
- the cryogenic container of the spherical tank;
- the inner cryogenic container of the double containment tank, full containment tank or cryogenic concrete tank;
- the cryogenic membrane of the membrane tanks.

3.15 secondary container

The secondary container is:

- the bund wall of the single containment tank and the spherical tank;
- the outer container of double or full containment tanks;
- the concrete outer envelope of membrane tanks or cryogenic concrete tanks.

3.16 PASQUILL atmospheric stability factors

PASQUILL atmospheric stability factors are determined as a function of the wind speed and solar radiation (see P.1). The six factors are:

- A: extremely unstable;
- B: moderately unstable;
- C: lightly unstable;
- D: neutral;
- E: lightly stable;
- F: moderately stable.

3.17 NGL (natural gas liquid)

The NGL (Natural Gas Liquid) is composed of light hydrocarbons (typically ethane through hexane plus) condensed from the natural gas prior to its liquefaction.

3.18 limit states

Two categories of limit states shall be used in the design of the load bearing structures:

- the serviceability limit state (SLS), which is determined on the basis of criteria applicable to functional capability or to durability properties under normal actions;
- the ultimate limit state (ULS), which is determined on the basis of the risk of failure, large plastic displacements or strains comparable to failure under augmented actions.

3.19 impounding basin

Impounding basin is a special pit to collect LNG spillage.

3.20 flammable gases

Gas or vapour which, when mixed with air in certain proportions, will form an explosive gas mixture.

3.21 owner

The company responsible for the safe design, construction and operation of the installation as defined in 3.2 to 3.5.

3.22 ESD (Emergency Shut Down)

ESD is a system that safely and effectively stops the whole plant or individual units before an unrecoverable incident occurs.

3.23 PSD (Process Shut Down)

PSD is a system that safely and effectively stops individual units within the plant for process reasons.

3.24 safety management system

A formal system¹⁾ consisting for example in a series of checklists which are monitored and signed off as the project progresses to show that all safety concerns have been addressed.

4 Safety and environment

4.1 General

The design, procurement, construction and operation phases shall all be implemented in accordance with the requirements of the Quality Management System described in EN ISO 9001.

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

LNG installations shall be designed to minimize the risk to property and life outside and inside the battery limits. In particular, hazard assessments shall be carried out and all the safety measures defined in 4.5 shall be taken into account.

A hazard assessment, as defined in 4.4, shall be carried out where the inventory of LNG and natural gas on the site exceeds the threshold specified in the relevant local regulation. The assessment shall be carried out during the design of the plant and it is recommended if a major change takes place.

4.2 Installation and its environment

4.2.1 Description of the installation

A description of the installation shall be written by plant area and/or by process function.

4.2.2 Site study

The site study shall include, where appropriate:

- a soil survey;
- a study of terrain to enable the dispersion of liquid and gas clouds to be assessed;
- a study of vegetation to enable, in particular, vegetation fire risks to be identified;
- a study of ground water tables;
- a study of the marine aquatic environment and marine access;
- a study of sea water quality and temperature;
- a study of tidal conditions;
- a study of shock waves and flooding (tsunami, failure of dams, etc.);
- a survey of the surrounding infrastructure (e.g. industrial sites, built up areas, communications).

The soil survey shall include:

- the geotechnical survey that will enable the geomechanical 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. The size of the region to be investigated depends on the nature of the area around the site. Generally it is limited to a distance less than 320 km from the site, but in some instances it can include an entire tectonic province, larger than the above.

¹⁾ Standardization work is in progress.

A second level of analysis shall be made on the region within the 80 km from the site (regional seismotectonic investigation) with the aim of detecting the presence of any seismic faults.

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, soil liquefaction, mass movement, etc. and their relative impact shall be evaluated.

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 or within a distance to be determined from the soil morphology.

Other phenomena are not allowed under the tank and/or equipment foundations unless it can be proved that appropriate measures have been undertaken to overcome the potential problems.

4.2.3 Climatology

The climatic study shall include the following points, as a minimum:

- wind strength and direction including frequency and strength of hurricanes;
- temperatures;
- atmospheric stability;
- range and rate of change of barometric pressure;
- rainfall, snow;
- corrosive characteristic of the air;
- risks of flooding;
- frequency of lightning strikes;
- relative humidity.

4.2.4 Seismology

An earthquake is defined by the horizontal and vertical accelerations of the ground. These accelerations are described by:

- their frequency spectrum;
- their amplitude.

A site specific earthquake analysis shall be performed. This analysis shall be reported in a Seismic Report where geological and seismic characteristics of the location of the LNG facilities and the surrounding region as well as geotectonic information from the location have to be taken into account. As a conclusion this report shall recommend all seismic parameters required for the design.

The potential of earthquake activity in the vicinity of the proposed site is determined by investigating the seismic history of the region (320 km radius) surrounding the site, and relating it to the geological and tectonic conditions resulting from the soil survey (see 4.2.2).

These investigations involve thorough research, review and evaluation of all historically reported earthquakes that have affected, or that could reasonably be expected to have affected the site.

For details of the seismic investigations and format of response spectrum reference is made to ENV 1998.

The geological, tectonic and seismological studies help to establish:

- the Safe Shutdown Earthquake (SSE);
- the Operating Basis Earthquake (OBE).

They shall be established:

- probabilistically, as those that produce ground motions with the mean recurrence as a minimum interval of 10 000 years for the SSE and 475 years for the OBE; and/or
- deterministically, assuming that earthquakes which are analogous to maximum historically known earthquakes are liable to occur in future with an epicentre position which is the most severe with regard to its effects in terms of intensity on the site, while remaining compatible with geological and seismic data. In this case, the OBE accelerations shall be one-half those determined for the SSE.

NOTE. Both OBE and SSE define specific performance limits for seismic events of increasing severity for systems as defined in 4.5.8.

4.2.5 Environmental impact

4.2.5.1 Environmental impact assessment

During the feasibility study phase of the project, a preliminary Environmental Impact Assessment (EIA) shall be carried out for the proposed location in accordance with local regulations where the inventory of LNG and natural gas exceeds the threshold specified in these regulations.

When the site has been selected, a detailed EIA shall be carried out in conformance with the regulations.

All emissions from the plant, that is, solid, liquid (including water), and gaseous (including noxious odours) shall be identified and measures taken to ensure they will not be harmful to persons, property, animals or vegetation. This applies not only to normal, but also to accidental emissions. The standard of control of emissions shall be at least as good as required by limits set by local or national legislation and regulations.

An effluent management schedule shall be established. The precautions for handling toxic materials shall be identified.

The increased activity caused by 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 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.



4.2.5.2 Plant emissions

During the design Action 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.

Efficient process designs shall be preferred to limit in particular CO, H₂S, CO₂, NO_x and SO_x emissions to the atmosphere and the level of toxic substances in liquid effluents.

Equipment, valves, etc. shall be selected to limit noise.

4.2.5.3 Emission control

The following shall be safely controlled:

- combustion products from compressor drivers, submerged vaporizers, fired heaters for regeneration;
- normal or accidental venting of gas;
- normal or accidental flaring of gas;
- disposal of acid gas removal solvent;
- disposal of spent mercury removal reactant (as the demercurialization 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 this water from leaking exchanger tubes;
- disposal of waste products (including waste oil and chlorinated organic compounds);
- vaporizer water;
- odorant chemicals.

4.2.5.4 Boil off/flash gas management

Plants are to be designed around the principle of no continuous flaring or venting. The following steps shall be taken to ensure that potential gas waste streams never generate an excess during the normal operation of the plant:

- dryer regeneration gas shall as far as possible be recycled. This aspect shall be borne in mind when considering the removal of undesirable constituents on molecular sieves otherwise used for drying;
- end flash gas for nitrogen removal shall be minimized in quantity and/or in methane content;
- unless included in the send out gas, recycling for re-liquefaction of boil off gas shall be considered.

4.2.6 External communication routes

External traffic routes near to the LNG plant shall be listed, stating the volume and nature of present traffic and also any foreseeable development. In particular 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.

4.3 Threshold values

4.3.1 Heat radiation from LNG pool fires

Table 1 gives the recommended maximum incident radiation flux values in case these are not already defined in the local regulations. The radiation flux from an LNG fire shall be calculated using appropriate and validated models (some available methods are presented in EN 1160).

In any case, the maximum radiation flux levels acceptable for each main structure inside boundaries shall be confirmed using validated methods and using the curves defined in ENV 1991, ENV 1992, ENV 1993 and ENV 1994. The designer shall justify the maximum thermal radiation flux level used by calculating the surface temperature consistent with the expected duration of the fire to show that it is sufficiently low to maintain the integrity of the structure. The nature and the mechanical behaviour of the materials with respect to temperature shall be taken into account in the calculation.

For LNG storage tanks, the permissible radiation flux shall be determined taking into consideration the following factors as a minimum:

- if no water deluge system is installed, water cooling is deemed to apply after the time required to provide fire water in sufficient quantities from external sources;
- loss of strength of container;
- pressure built up within the container;
- the capacity of the safety valves;
- the temperature of the safety valve shall not reach the auto-ignition temperature of the flammable substance in the tank;
- surface emissive powers (see EN 1160).

Table 1. Allowable thermal radiation flux excluding solar radiation inside the boundary

Equipment inside boundary	Maximum thermal radiation flux (kW/m ²)
Concrete outer surface of adjacent storage tanks: unprotected ^{1) 3)} or behind thermal protection ²⁾	32
Metal outer surface of adjacent storage tanks: unprotected ³⁾ or behind thermal protection ²⁾ , (see P.3)	15
The outer surfaces of adjacent pressure storage vessels and process facilities (see P.3)	15
Control room, Maintenance workshops, laboratories, warehouses, etc. (see P.2)	8
Administrative buildings (see P.2)	5

¹⁾ For prestressed concrete tanks, maximum radiation fluxes may be determined by the requirements given in A.5.2.

²⁾ Such facilities are protected by means of water sprays, fire proofing, radiation screens or similar systems.

³⁾ Protection is provided by spacing alone.

Table 2 gives the recommended maximum incident radiation flux values in case these are not already defined in the local regulations.

Table 2. Allowable thermal radiation flux excluding solar radiation outside the boundary	
Outside boundary	Maximum thermal radiation flux (kW/m²)
Remote area ¹⁾	13
Urban area	5
Critical area ²⁾	1,5
¹⁾ An area only infrequently occupied by small numbers of persons, e.g. moorland, farmland, desert. ²⁾ This is either an unshielded area of critical importance where people without protective clothing can be required at all times including during emergencies or a place difficult or dangerous to evacuate at short notice (e.g. sports stadium, play ground, outdoor theatre).	

NOTE. The figures used in table 2 are taken from P.2.

4.3.2 Heat radiation from flare

Table 3 and table 4 give the recommended maximum incident radiation flux values in case these are not already defined in the local regulations. The predicted values used for the comparison can be calculated in accordance with P.3.

However alternative methods for prediction of flux level can be acceptable. In this case the designer shall justify that the method proposed is validated.

Table 3. Allowable thermal radiation flux excluding solar radiation inside the boundary		
Equipment inside boundary	Maximum thermal radiation flux (kW/m²)	
Flow rate as defined in 11.6	Normal	Accidental
Base of the flare in a restricted area where well trained operators will be present only for maintenance. (see P.3)	5	9
Roads and open areas	3	5
Tanks and process equipments	1,5	5
Control room, maintenance workshops, laboratories, warehouses, etc.	1,5	5
Administrative buildings	1,5	5

Table 4. Allowable thermal radiation flux excluding solar radiation outside the boundary		
Outside boundary	Maximum thermal radiation flux (kW/m²)	
Flow rate as defined in 11.6	Normal	Accidental
Remote area ¹⁾	3	5
Urban area	1,5	3
Critical area ²⁾	1,5	1,5
¹⁾ An area only infrequently occupied by small numbers of persons, e.g. moorland, farmland, desert. ²⁾ This is either an unshielded area of critical importance where people without protective clothing can be required at all times including during emergencies or a place difficult or dangerous to evacuate at short notice (e.g. sports stadium, play ground, outdoor theatre).		

NOTE. The figures used in table 3 and 4 are derived from P.3 and P.4.

4.3.3 Ignition limit of natural gas

The flammability range of mixtures of gas and air is given in 5.4.3 of EN 1160 : 1996.

4.4 Hazard assessment

4.4.1 Methodology

The methodology of the hazard assessment can be probabilistic and/or deterministic. The probabilistic approach consists of:

- collection of failure rate data;
- list of potential hazards of external and internal origin;
- determination and classification of the probability of these hazards (an example is given in annex J);
- determination of the consequences of each hazard and their allocation into classes of consequence (an example is given in annex K);
- classification of accidents in accordance with their consequences and probability criteria in order to determine the level of risk (an example is given in annex L);
- verification that no hazard comes within the 'Unacceptable Risk' category (for example, risk level 1 of annex L);
- justification of the measures necessary to limit risks (see 4.5.9).

The deterministic approach consists of:

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

The hazard assessment can be based on conventional methods such as:

- hazard and operability study (HAZOP);
- failure mode effect analysis (FMEA);
- event tree method (ETM);
- fault tree method (FTM).

Implementation of the over-all procedure shall be initiated as early as possible and shall be repeated when unacceptable risks are identified during the design.

4.4.2 Identification of hazards of external origin

The studies of the natural, urban and industrial environment and also of external communication routes enable hazards arising from outside the plant to be listed. Such hazards can be caused by:

- LNG carriers and ships at berth or when manoeuvring;
- heat radiation (fire);
- clouds of flammable, toxic or asphyxiant gas;
- the impact of projectiles (ship, truck, plane, etc.);
- natural events (lightning, flooding, earthquakes, etc.);
- high energy radio waves, etc.

4.4.3 Identification of hazards of internal origin

4.4.3.1 Hazard arising from LNG

Loss of containment of LNG and of natural gas shall be listed 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 of the hazard;
- the location of the leak;
- the nature of the fluid (LNG or gas, specifying the temperature thereof);
- the rate and the duration of the leakage;
- weather conditions (wind speed and direction, atmospheric stability, ambient temperature, relative humidity);
- for spillage of LNG, the effect of the nature and the topography of the ground (including any impounding area) and the effect on the properties of structural steelwork leading to brittle failure due to low or cryogenic temperatures.

In particular, the scenarios to be considered for various types of LNG tanks are listed in table 5.

Table 5. Scenario to be considered in the hazard assessment as function of tank types

Type of tank	All metallic or only with metallic roof	Prestressed concrete (including concrete roof)
Single containment	1)	
Double containment	2)	
Full containment	2)	3)
Membrane	2)	3)
Cryogenic concrete	2)	3)
Spherical	1)	
Inground	2)	3)

Scenarios to be considered:

- 1) In case of collapse of the tank primary container, fire pool size corresponds to the impounding area.
- 2) In case of collapse of the tank roof, the fire pool size corresponds to the secondary container.
- 3) No collapse is considered for these tank types.

The spacing between two adjacent tanks for which no collapse is considered, shall be minimum equal to an half diameter of the secondary container of the larger tank.

4.4.3.2 Hazards which are not specific to LNG

The following causes of hazards which are not specific to LNG shall be considered:

- LPG and heavier hydrocarbon storage;
- poor communication between ship and shore;
- traffic within the plant both during construction and operation;
- leakage of other hazardous substances, in particular flammable refrigerant;
- pressurized and steam raising equipment;
- rotating machinery;
- utilities, catalysts and chemicals (fuel oil, lubricating oils, methanol, etc.);
- electrical installations;
- harbour installations associated with the LNG plant.

4.4.3.3 Hazardous area classifications

All installations shall be subjected to an hazardous area analysis. The terms of reference for such an analysis shall be laid down in accordance with prEN 50145.

The extent of hazardous zones shall be as given in prEN 50145. The selection of equipment for use in particular locations shall be determined by the hazardous zone classification of these locations in accordance with prEN 1127-1.

4.4.4 Estimation of probabilities

The estimation of the probability associated with a given hazard, where utilized, shall be based on reliable data bases which are suitable for the LNG industry or on recognized methods as in 4.4.1 which will determine the probability range for this hazard (see annex J). The human factor shall be taken into account.

4.4.5 Estimation of consequences

The consequences of each scenario as defined above will depend on the characteristics of LNG and other phenomena described in clause 5 of EN 1160 : 1996. For the consequences of leakage or spillage of fluids other than LNG reference shall be made to their Material Safety Data Sheets.

4.4.5.1 Evaporation of spilled LNG

The phenomenon of instantaneous vaporization (flash) shall be taken into account.

Calculation of evaporation due to heat transfer shall be carried out using appropriate validated models.

The model shall, as a minimum, take the following into account:

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

The model shall enable the following to be determined:

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

4.4.5.2 Atmospheric dispersion of LNG vapours

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

The determination of dispersion shall, as a minimum, take into account:

- the diameter of the evaporating pool;
- the evaporation rate;
- properties of the vapour;
- the nature of the ground (roughness, 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;
- if the model is only for steady state systems, the rate of flow of gas from the source of gas shall be assumed equal to the maximum rate given by the evaporation model.

The atmospheric dispersion simulation shall be based on the atmospheric condition which gives the furthest distance to the Lower Flammability Limit. If no other information is available the following atmospheric condition shall be considered:

- F (PASQUILL) atmospheric stability or equivalent temperature gradient, for a wind 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.

4.4.5.3 Jet release of natural gas or LNG

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.

4.4.5.4 Overpressure

The ignition of gas can create an explosion generating an overpressure wave.

Recognized methods and models, for example the multi-energy method (see P.5) and/or deflagration at constant speed method (see P.6) which have been validated can be used to calculate the overpressure. In this case it will be assumed that a deflagrating explosion near the tank 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 over pressure shall be determined by dynamic calculation.

For the other structures stresses may be determined by static calculation.

4.4.5.5 Radiation

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 1160);
- ambient temperature and relative humidity;
- wind speed, atmospheric stability.

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

4.5 Safety measures on the LNG plant

Leaks of LNG and hydrocarbon liquids such as Natural Gas Liquid (NGL) and refrigerants produce flammable vapour clouds denser than air. The plant shall therefore be designed to eliminate or minimize the quantity and frequency of accidental and planned emissions of these fluids.

This shall be achieved by using a Safety Management System during design, procurement, fabrication, construction and operation of the plant to ensure that the best available rules of technology are implemented. Particular consideration shall be given to the following:

- design pressures and temperatures of piping and equipment shall be selected to cover all anticipated normal and upset conditions;
- wherever possible plant and equipment containing flammable fluid shall be located in the open; however, maintenance and climatic conditions will affect this decision;
- plant layout shall be designed to avoid congestion;
- appropriate piping flexibility to suit all operating conditions;
- the number of flanges in pipe runs shall be minimized by using welded inline valves where practical. Where flanges are used they should be oriented so that if a leak occurs the jet stream shall not impinge on nearby equipment;
- the orientation of flanges and relief valve tail pipes shall be such as to minimize hazard;
- design pressures shall leave a sufficiently wide margin above operating pressures so as to minimize the frequency of the lifting of relief valves;
- pumps with high integrity seals or submerged pumps and motors shall be used for LNG and LPG;
- structures supporting piping and equipment handling flammable fluids shall be designed to withstand the ultimate limit state;
- techniques for industrial risk management shall be employed from the design through to start up, operation, during maintenance and modifications.

4.5.1 Equipment and piping design for low temperature

Suitable materials are listed in EN 1160.

The stresses in pipework and equipment are affected by contraction/expansion phenomena due to temperature changes, the possibility of thermal shock and the method of insulation. The recommendations of clause 9 are applicable. It is recommended that the main pipelines are maintained cool e.g. by circulation of LNG.

4.5.2 Provisions for control of leaks and spillage

Correct design, fabrication, construction and operation will minimize the quantity and frequency of leaks of flammable fluids. However, where leaks can occur and dispersion calculations show that a leak can escalate to a more serious incident, consideration shall be given to the installation of fixed leak detection systems with executive action to stop the leak source, to isolate relevant sections of plant and to shutdown sources of ignition in the vicinity, in particular fired equipment.

When required by the hazard assessment, leaks of flammable refrigerant liquids from above ground pressure vessels and pipe sections shall be confined by dikes. Flammable liquid leaks can be conveyed in open channels to a remote impounding basin. These channels and the impounding basin can be covered with an insulating layer or built with special materials to limit evaporation (see prEN 12066).

The design of impounding basins shall be such that flammable fluids can not enter the surface water drainage system. Consideration shall be given to the installation of leak detection devices and means to control the evaporation rate in impounding basin (see 13.2.6 and 13.2.7).

The effect of leaking low temperature fluids on adjacent plant, equipment and structural steel shall be assessed and measures taken to prevent further serious damage, by suitable selection of materials of construction or by embrittlement protection such as insulation.

Isolation valves shall be fitted as close as possible to the nozzle of process liquid outlets of pressure vessels containing flammable liquids such as hydrocarbon refrigerants and LNG. These isolation valves shall be remotely closed either manually or automatically by ESD (see clause 14).

4.5.3 Internal overpressure protection

Safety devices shall be provided to cover all internal overpressure risks including those due to fire.

It is recommended that the discharge from conventional safety devices (safety valves, relief valves), unless those from tanks and vaporizers, are routed to the flare/vent system or the storage tank.

In fact, the temperature and the height of the discharge of the released gas from tanks and vaporizers allow a good atmospheric dispersion. This point shall be confirmed by the hazard assessment. In addition, this measure avoids pressure drop and/or obstruction inside the flare system and consequently reduces the risk.

If the hazard assessment shows that the consequences of the discharge directly to atmosphere are acceptable, then connection to the flare/vent system is not necessary.

4.5.4 Emergency depressuring

If no appropriate protection is installed such as fire insulation, water deluge system (see 4.5.7), etc., it is recommended that automatic or semi-automatic depressurizing systems are provided when a BLEVE risk due to overpressure and elevated wall temperature is present (see EN 1160).

The intention of this measure is to:

- reduce the internal pressure;
- reduce the effect in case of leakage;
- avoid the risk of failure of LNG or gas filled pressure vessels and piping from external radiation including those due to fire.

Devices for depressuring high pressure equipment shall allow the pressure of one or more than one item of equipment to be reduced quickly. Reduction from the design pressure to 50 % of the design pressure, or 7 bar (gauge) if that value is higher than 50 % of the design pressure, in 15 min, should generally be provided for. The gases thus extracted shall be sent to the flare system which shall be capable of handling the low temperatures generated during depressuring.

Isolating valves, activated from the control room or other remote location shall be provided so that the unit can be isolated into several sub-systems and where it is required to isolate sensitive equipment. This will make it possible to depressurize only one part of the plant, while limiting the entry of hydrocarbons into a fire containing zone.

4.5.5 LNG Plant layout

The siting of an LNG plant with respect to the surroundings shall be covered by a hazard assessment as described in 4.4 (see also P.7, P.8, P.9, P.10).

The prevailing wind direction shall be considered in LNG plant layout. Where practicable, buildings and ignition sources shall not be downwind of accidental and planned releases of flammable materials, but they shall be located as far as possible outside hazardous areas, assuming a wind in any direction.

The LNG plant shall be laid out to provide safe access for construction, operation, maintenance and for fire fighting.

Separation distances shall take into account, in particular:

- radiation flux levels;
- lower flammability limit contours;
- noise;
- blast effects.

The LNG plant main control room shall be located outside hazardous areas, as defined in 4.4.3.3. Furthermore, it shall be designed to suit explosive atmospheres resulting from gas dispersion and to resist overpressure created by explosions. The control room shall be designed to protect the occupants for as long as necessary to effect the emergency procedures and then allow them to safely escape from the incident.

For diesel driven fire water pumps and emergency generators the air intake shall be located outside the predicted vapour cloud envelope.

4.5.6 Emergency shutdown

An emergency shutdown (ESD, see 14.3.2) system independent from the process control system shall be provided.

4.5.7 Fire protection

Equipment, including ESD valves and vessels containing quantities of liquid hydrocarbon which can cause an escalation of an incident shall be protected from thermal radiation. Piperack supports and vessel skirts and ESD valves which can receive thermal radiation resulting from an ignited leak shall be provided with at least 90 min protection (see 16.2).

Fire protection in the form of insulation or water deluge shall be provided for pressure vessels which can receive thermal radiation fluxes from external sources in excess of that defined in 4.3.1., to prevent such vessels failing and releasing superheated liquid, which can result in a BLEVE, (see EN 1160).

It shall be recognized that pressure vessels subject to radiation in excess of that defined in 4.3.1. from a major incident such as an LNG tank fire shall require protection for much more than 90 min. This is not likely to be achieved by insulation and a water deluge system is necessary.

The calculation of water deluge, insulation for fire protection of structures etc. as protection against fires shall be performed for the fluid which gives rise to the highest radiation flux. Adaptation of methods proposed elsewhere in this European Standard for LNG may be used.

Protection of the tanks and safety equipment against radiation from fire in the retaining basin, if any, of adjacent tanks shall be taken into account.

4.5.8 Seismic protection

The following systems shall withstand actions resulting from earthquake:

- systems for which rupture can create a hazard for the plant;
- protection systems for which operation is required to keep a minimum safety level.

For earthquake design purpose, the plant systems and their components shall be classified on basis of their importance, from a safety point of view, such classification being analysed during hazard assessment:

- Class A: systems which are vital for the plant safety. They shall remain operational for both OBE and SSE.
- Class B: systems performing vital functions for the plant operation or for which collapse could cause a major impact on the environment or could lead to additional hazard. These systems shall remain operational after OBE and shall keep their integrity in case of SSE. Class B shall include as a minimum the secondary containment of all LNG tanks.
- Class C: other systems. These systems shall remain operational after OBE and shall not fall on or impact other systems classes and components after SSE.

The systems include the related equipment, piping, valves, instrumentation, power supply and their supports. Structures shall be designed as for the class of the most stringent system component they are supporting.

The buildings shall be designed to keep their integrity in case of SSE. Heating, ventilating and air conditioning shall be designed in order to fulfil the criteria of the classified systems which are located in the buildings.

The most commonly used methods for qualification are hereafter listed:

- time history analysis;
- modal spectral analysis;
- load coefficient method;
- spacing chart.

They range from the most sophisticated one (time history analysis), containing the least undue conservatism, to the most coarse (spacing chart), including a very high degree of conservatism.

When it is estimated that qualification by analysis is unfeasible, qualification by test shall be performed.

4.5.9 Safety improvement

Where the hazard assessment demonstrates that threshold values defined in 4.3 are exceeded or shows that the level of risk requires improvement (see annex L), measures shall be taken, as for example:

- selection of equipment in accordance with the hazardous zone classification (see 4.4.3.3) and their locations in accordance with prEN 1127-1;
- setting up a safety system which allows early detection of a leak and limitation of the consequences of ignitions; this system includes:
 - leak detectors in sufficient number (gas or cold sensors);
 - a centralized system which analyses the data from the sensors in order to confirm the leaks detected and their location;
 - a remote-controlled system (stoppage of pump and, if appropriate, closure of valves) which acts on order from the control room to stop the leakage;
- increasing the dilution of the flammable cloud;
- elimination of potential sources of ignition inside a flammable cloud;
- reducing evaporation rates through the use of foam or cellular glass;
- reducing heat radiation by water curtains, deluge systems, foam or insulation;
- increasing spacing between equipment;
- protection of the installation against blast;
- alarm systems such as breakglass units, telephones, paging systems, closed circuit television and sirens.

4.5.10 Confinement

Confined or partially confined zones shall be avoided as far as possible, in particular:

- gas and LNG pipework shall not be situated in enclosed culverts when it is possible to avoid this for example where road bridges cross pipe ways;
- the space situated under the base slab of raised tanks, if any, shall be sufficiently high to allow air to circulate;

- culverts for cables, cable trays, etc. shall be filled with compacted sand and covered with flat slabs featuring ventilation holes cast in situ on top of the sand to minimize the possibility of flammable gases travelling along the culverts through voids above the sand. As the sand settles the slabs will sink. They can be restored to their original elevation by adding sand.

4.6 Hazards and operability study (HAZOP)

All LNG projects shall be subjected to a preliminary process hazard review at process flow sheet definition stage, for example to minimize the number of equipment items and the total inventory of hazardous materials.

A HAZOP shall be conducted when the piping and instrumentation diagrams (P&IDs) are sufficiently developed and approved by the Owner.

The HAZOP has been developed to identify and eliminate or minimize hazards (see P.11).

The HAZOP shall be conducted by a multi-disciplinary team who shall systematically address the P&IDs and identify credible events caused by deviations from the design intent.

The analysis shall include the following principles:

- be systematic, following a proven approach (see P.11 and P.12) based on piping and instrumentation diagrams (P&IDs), applied to all normal modes of operation, to commissioning, to start-up, to emergency shutdown and to normal shutdown;
- be conducted by a review panel to be chaired by an experienced and competent engineer, and including other persons competent in design and operating. At least one member of the team should have intimate knowledge of this type of installation;
- the review panel shall be given sufficient resources, for example in terms of time and access to specialist knowledge;
- give rise to a formal written report describing the findings and recommendations concerning the changes to plant design or operating procedures;
- proper follow up leading to the resolution of all points shall be documented.

New facilities shall be analysed before start-up. To allow the necessary modifications to be made without compromising the start-up schedule a full analysis will normally have been performed before the Approved for Construction issue of the P&IDs. In this case a review and approval procedure shall be established for the management of change during construction, with if necessary a full and final analysis based on 'As Built' drawings.

Operating facilities shall be analysed following a plant modification, with if necessary a full and final analysis before restart. A review and approval procedure shall be established for the management of minor change during normal operating periods.

5 Liquefaction plants

5.1 General description

This clause deals with LNG export terminal and LNG peak-shaving plants (see clause 3), where natural gas is treated and liquefied for subsequent storage.

Annex M contains an informative description of the most common processing options and main process parameters.

5.2 Gas treatment

The natural gas feed to an LNG export terminal plant is a mixture of light hydrocarbons, coming more or less directly from the gas field, and in which the main component is methane, with varying proportions of ethane, propane, butane and gasoline. It can also contain inert gases such as nitrogen and helium, and acid gases such as carbon dioxide and hydrogen sulfide (see EN 1160).

The gas feed to an LNG peak-shaving plant will normally be to pipeline specification but can contain some undesirable constituents.

Before liquefaction, undesirable constituents of natural gas, such as water, methanol, carbon dioxide and sulfur compounds shall be removed as they solidify on cooling and cause blockages. Mercury will cause components made from aluminium such as heat exchangers to fail and shall therefore be removed. Mercury is extremely toxic and removal shall be carried out safely and in an environmentally acceptable manner.

Account can need to be taken of the co-adsorption of H_2S with CO_2 on the molecular sieves, where used, and the resulting SO_2 which arises from the flaring of the regeneration gas.

5.3 Cold box design

For certain items of cold equipment, it can be preferable to provide for common heat insulation within a cold box. The principle consists of enclosing all the items of equipment, within a metal box which will be completely filled with powdery heat insulation. Seals are to be provided at the inlets and outlets of the cold box pipework. To prevent any ingress of moisture and to be able to detect possible leakage of hydrocarbons within the coldbox, permanent scavenging of the cold box with nitrogen shall be carried out. Drainage shall be provided away from the cold box.

LNG peak shaving plants conventionally use cold boxes.

5.4 Refrigerant storage

Hydrocarbon refrigerants are generally stored in pressure vessels at ambient temperature with the exception of ethylene, which can be stored at cryogenic temperatures.

The design, installation and operation of such storage shall be in conformity with local regulation²⁾.

6 Storage and retention systems

6.1 Tank categories

Tank categories which meet the requirement mentioned in 6.2.1 are for example:

- single containment cylindrical metal tank;
- double containment cylindrical metal inner tank and metal or concrete outer tank;
- full containment cylindrical metal inner tank and metal or concrete outer tank;
- prestressed cylindrical concrete tank with an internal metal membrane;
- cryogenic cylindrical concrete tank: internal concrete tank and prestressed concrete outer tank;
- spherical tank.

These tank categories are described in annex H³⁾.

Tanks can be placed on the ground, or semi-buried, or in ground. The raft of the tank can be supported by raised piles. The type of foundation depends on the result of the soil report and seismic study.

6.2 Design principles

6.2.1 General requirements

Equipment for which the design pressure is more than 500 mbar shall meet the requirements of applicable standards or codes used for the design of pressure vessels²⁾.

Cylindrical metal LNG tanks, cylindrical cryogenic concrete tanks and spherical tanks for LNG shall be designed in accordance with the requirements from applicable standards or codes^{2) 3)} and all requirements relating to LNG storage contained in this standard.

Spherical LNG tanks are commonly used on LNG carriers (IMO code) and the same design principles can be used for land based storage tanks.

The LNG tanks shall be designed to:

- safely contain the liquid at cryogenic temperature;
- permit the safe filling and removal of LNG;
- permit the boil off gas to be safely removed;
- prevent the ingress of air and moisture except as a last resort to prevent unacceptable vacuum conditions in the vapour space;
- minimize the rate of heat in leak, consistent with operational requirements and prevent frost heave;

²⁾ Work is in progress by CEN/TC 54, Work Item 7 : Unfired pressure vessels.

³⁾ Work is in progress by CEN/TC 265, Work Item 2 : Flat bottom vertical cylindrical site built metallic welded storage tanks for containment of refrigerated liquids at temperature between $-5^{\circ}C$ and $-196^{\circ}C$.

- withstand the damage leading to loss of containment due to credible external factors as defined in clause 4;
- operate safely between the design maximum and minimum (vacuum) pressures;
- withstand the number of filling and emptying cycles and the number of cool down and warming operations which are planned during its design life.

6.2.2 Fluid tightness

The tank shall be gas and liquid tight in normal operation.

The degree of resistance to leakage required in the event of external overloads such as impact damage, thermal radiation and blasts shall be defined in the hazard assessment (see clause 4).

LNG tightness of the primary container shall be ensured by a continuously welded plate, membrane or cryogenic concrete prestressed with cryogenic reinforcement.

LNG tightness of the secondary container shall be ensured by:

- continuously welded plate;
- concrete with lining;
- compacted earth or sand provided LNG tightness can be ensured;
- other proven suitable material.

The outer envelope of the tank which is exposed to the atmosphere (metallic or concrete) shall be designed in such a way as to prevent all water penetration, whether this is surface water, firewater, rainwater or atmospheric humidity. The humidity could introduce some corrosion problems, deterioration of the insulation and of the concrete.

To contain liquid in case of LNG leakage the following requirement shall be followed:

- for double and full containment tanks where the secondary container is made of metal, it shall be of cryogenic grade;
- when the secondary container is made of prestress concrete, the temperature of the prestress cables shall remain compatible with the strength of the maximum hydrostatic head. It is to be assumed for calculation that the temperature of the LNG is applied directly onto the internal face, including the insulation, if any.

6.2.3 Tank connections

External connections shall be designed to accept loads imposed from the external piping and internal piping, if any.

The fluid and gas transfer pipelines which penetrate the container shall satisfy the following requirements:

- penetrations shall not give rise to excessive heat input;
- where penetrations are subject to thermal contraction and expansion which can be rapid; if necessary the internal connections shall be strengthened and the external connections shall be designed to transmit external piping loads to a thermal expansion compensating system;

- there shall be no penetrations of the primary and secondary container walls or base. Overflow pipes are not recommended. If overflow pipes cannot be avoided, the associated additional risk shall be included in the hazard assessment (see clause 4);
- if needed, connections shall be provided for nitrogen into the annular space between the inner tank and the outer containment to enable air to be purged out before commissioning and LNG to be purged out after emptying for maintenance.

The absence of wall or base penetrations requires the use of submerged pumps. A platform on the roof shall be provided to allow pumps to be removed for maintenance.

The design shall prevent any siphoning effects.

6.2.4 Thermal insulation

Materials used for thermal insulation should be chosen from those defined in EN 1160.

The minimum thermal conductivity of insulating materials shall be specified by the owner.

The installed insulation systems shall be free from contaminants which can corrode or otherwise damage the pressure-containing components with which they come into contact.

Base insulation is installed beneath the primary container base to reduce heat transfer from the foundation and so that heating of the ground if required, to prevent frost heave, can be minimized.

Base insulation shall be designed and specified to be able to withstand any kind of action combinations as defined in annex A.

If insulation is used in the interspace of full containment tanks, it will be exposed to the boil-off gas.

The thermal expansion of components shall be taken into account; therefore insulation installed outside the primary container, when it is made up of expanded perlite, can be protected from settling, for example, by glass wool padding which absorbs variations in the diameter of the primary container.

The thermal insulation of a membrane tank shall withstand the hydrostatic load.

Insulation of spherical tanks are outside the sphere and are not exposed to any hydraulic or mechanical actions.

External insulation shall be protected from moisture by cladding and the installation of vapour seals.

Exposed insulation shall be non-combustible.

The quality of insulation shall be such that no single point of the external envelope of the tank will remain at a temperature below 0 °C by an air temperature above or equal to 5 °C. The relevant conditions (atmospheric, soil, design, etc.) have to be taken into account for the thickness calculations. If no information concerning atmospheric condition are available the following can be used.

In case of above ground storage tanks:

- wind of 0 m/s;
- atmospheric temperature of 5 °C.

In case of inground storage tank:

- for the roof as above;
- for the wall, with a heating system take account of insulation degradation in order to avoid freezing.

6.2.5 Operating actions

LNG tanks shall be capable of withstanding the combinations of actions as defined in annex A and those resulting from changes in temperature and pressure during:

- initial cool down and warm up to ambient temperature;
- filling and emptying cycles.

The manufacturer shall indicate the maximum rate of temperature change which the tank can withstand during cool down and warm up operations.

For double and full containment tanks, the primary container shall be designed to withstand the maximum differential pressure which could occur during all operating phases and a system shall be provided to prevent lifting of the floor.

6.3 General design rules

The structures of the tank shall be designed to withstand at least the combination of actions defined in annex A. These actions are determined in accordance with clause 4.

In addition, structures and structural elements shall:

- perform satisfactorily during normal conditions, with regard to degradation, displacement, settling and vibration;
- have adequate safety with regard to resisting fatigue failure;
- show optimum ductile properties and little sensitivity to local damage;
- be simple to make;
- provide simple stress paths with small stress concentrations;
- be suitable for simple condition monitoring, maintenance and repair.

The rebars for reinforced or prestressed concrete shall be designed to avoid any damage of the concrete aggregate during the lifetime of the tank.

The materials selected for the load bearing structures shall be suitable for the purpose. The quality of the materials shall be documented.

Requirements for the fabrication, testing and control shall be determined on the basis of the significance of the various parts with regard to the overall safety of the structure.

6.4 Foundations

Foundations are designed to prevent differential settling higher than the permissible limit for the raft.

A study of the thermal characteristics shall be carried out for the foundation and the ground to ensure that frost heave is avoided. If frost heave cannot be excluded, a heating device shall be installed. The heating device shall be replaceable and repairable without taking the tank out of service. 100 % redundancy of heating device is required.

Seismological analysis and the geotechnical analysis of the nature of the ground shall define the criteria for foundation design.

Anti vibration pads can be necessary in order to reduce the consequences of an earthquake. They shall be replaceable without decommissioning of the tank.

The raft can be raised, laid on the ground, semi-buried or inground.

When the raft is raised, the clearance left shall be sufficiently large to permit natural circulation of air which will maintain the lower face of the raft at a temperature not more than 5 °C cooler than atmospheric temperature.

Spherical tanks founded on solid rock do not need any heating device when the ground is properly drained and the space between the insulation envelop and the rock is properly ventilated or purged.

6.5 Operating instruments

Sufficient instrumentation is required to enable the tank to be commissioned, operated and decommissioned in a safe manner. Instrumentation will include at least the following:

- liquid level;
- pressure;
- temperature;
- density, (except at peak shaving plants if provisions as defined in EN 1160 are taken to prevent rollover).

In general, the reliability of such measurements is to be ensured by the following minimum arrangements:

- where possible, instrumentation shall be able to be maintained in normal operation of the tank;
- instrumentation related to safety and operation for which maintenance requires decommissioning of the tank shall have sufficient redundancy;
- threshold detectors which have a safety function (pressure, LNG level, etc.) are to be independent of the measurement sequence;
- measurements shall be transmitted to control room;
- alarms shall be transmitted directly to the designated operator.

6.5.1 Liquid level

High accuracy and independent level devices are recommended as the means for protection against overflow in preference to overflow-pipes.

The tank shall be fitted with instruments which enable the level of LNG to be monitored and which enable protective action to be taken. These instruments shall in particular allow:

- continuous measurement of the fluid level from at least two separate systems (except for peak shaving tanks), of suitable reliability; each system shall include high level alarms and high level alarms;
- detection of high level based on instrumentation of suitable reliability which is independent of the above mentioned continuous measurements of level; detection shall initiate the ESD function for feed pumps and valves in feed and recirculation lines.

6.5.2 Pressure

The tank shall be fitted with instruments, permanently installed and properly located which enable the pressure to be monitored as follows:

- continuous pressure measurement;
- detection of too high pressure, by instrumentation which is independent of the continuous measurement;
- detection of too low pressure (vacuum) by instrumentation, which is independent of the continuous measurement. Following vacuum detection, the boil off compressors and pumps shall be stopped and if necessary, vacuum breaker gas injected under automatic control;
- if the insulated space is not in communication with the internal container, differential pressure sensors between the insulation space and the internal container or separate pressure sensors in the insulation space shall be installed.

For energy saving purposes, to reduce the boil off it is recommended that a constant absolute pressure be maintained inside the tank.

6.5.3 Temperature

The tank shall be fitted with properly located, permanently installed instruments which enable the temperature to be monitored as follows:

- the liquid temperature shall be measured at several depths; the vertical distance between two consecutive sensors shall not exceed two metres;
- gaseous phase temperature;
- the wall and the bottom temperature of the primary container;
- the wall and the bottom temperature of the secondary container except for the impounding area.

6.5.4 Density

The density of the LNG shall be monitored throughout the liquid depth (except at peak shaving plants if provisions are taken to prevent rollover).

6.6 Pressure and vacuum protection

The various reference flow rates of gaseous discharges which shall be taken into consideration for sizing the boil off circuit and the pressure relief valves are defined in annex B. They are applicable to each tank taken individually. Sufficient margin shall be provided between the operating pressure and the design pressure of the tank to avoid unnecessary venting.

6.6.1 Discharge of boil off gas

Irrespective of the means for recovery of boil off gas which might exist elsewhere (e.g. re-liquefaction, compression), the vapour space of the tank shall be connected to a flare/vent (see clause 11), safety valve, or possibly a rupture disc which is capable of discharging flow rates from any likely combination of the following:

- evaporation due to heat input;
- displacement due to filling;
- flash at filling;
- variations in atmospheric pressure;
- the recirculation from a submerged pump.

6.6.2 Pressure relief valves

The tank shall be fitted with at least two over pressure valves directly relieving to the atmosphere except in cases where a vapour emission in an emergency leads to an unwanted situation as described in 4.5.3. In this case, the valves shall be linked to the flare network or vent system. Sizing of valves shall be on the assumption that one of them is out of service. The maximum flow to be discharged, at maximum operating pressure, is either the gas flow due to the heat input in the event of a fire or any likely combination of the following flow due to:

- evaporation due to heat input;
- displacement due to filling;
- flash at filling;
- variations in atmospheric pressure;
- the recirculation from a submerged pump;
- control valve(s) failure;
- rollover, in case of no other device is envisaged (for example see 6.6.3).

6.6.3 Rupture disc

If the calculation of the overpressure valves or the flare/vent system does not take into account the rollover, a rupture disc or equivalent shall be installed whatever the other measures taken (for example, stock management policies, various filling lines).

A rupture disk can be used to protect the tank from overpressure. This device which is regarded as a last resort makes it possible to retain overall tank integrity without interrupting plant operation by temporarily sacrificing gas tightness (for designing this facility see P.13).

It shall be designed in such a way that:

- it can be replaced in operation following failure;
- fragments will not fall into the tank;
- fragments will not damage any other part of the tank.

Rupture of the disk shall cause all boil off gas compressors to trip automatically.

6.6.4 Vacuum

The tank shall be prevented from going into negative pressure beyond the permissible limit, by timely automatic shutdown of pumps and compressors and by two vacuum breaker systems:

- a gas or nitrogen injection system which shall act first;
- vacuum relief valves which allow air into the tank; as introduction of air can bring about a flammable mixture, this safety device shall act only as a last resort in order to prevent permanent damage to the tank.

6.6.4.1 Gas injection system

Gas shall be injected under automatic control following too low pressure detection (see 6.5.2).

6.6.4.2 Vacuum relief valves

The tank shall be fitted with at least two vacuum relief valves. Sizing of valves shall be on the assumption that one of them is out of service. The flow to be admitted at maximum negative pressure to 1,1 times that required to mitigate any likely combination of the following causes:

- the variation of the atmospheric pressure;
- pump suction;
- boil off gas compressor suction.

6.7 Bund wall and impounding area

For single cylindrical containment tanks and for spherical tanks, an individual impounding area is required as the secondary container.

For these tanks if installed in an excavation, the ground could act as the impounding area provided that its properties are suitable (see 6.2.2).

The impounding areas of two tanks may be adjacent.

6.7.1 Materials

Retention system materials shall be impermeable to LNG. The thermal conductivity of the material affects the rate of evaporation following a spill which is an important factor in the hazard assessment (see 4.4). The need for insulation will depend on the result of the hazard assessment (see clause 4). For the insulation coating of retention basins refer to EN 1160. The insulation coating shall be tested in accordance with prEN 12066.

The bottom shall not be made up of gravel and shall not include vegetation.

6.7.2 Recovery of water

Impounding areas for LNG in which rain or firewater can collect shall include a means for removing it to ensure that the required volume is maintained and to prevent flotation of the tank.

The water shall drain to an extraction sump within the impounding basin within the impounding area (see 6.7.3.) and be removed by pumping or by gravity flow. A reliable method shall be provided for preventing spilled LNG from being transferred from the pond.

6.7.3 Retention capacity

The dimensions of each impounding area shall be such that its equivalent capacity will be at least 100 % of the maximum volume which can be stored in the tank.

When the edges of the bund wall are more than 15 m away from the tank, consideration shall be given to the installation of an impounding basin. The needs of such will be identified in the hazard assessment in 4.4. The basin shall be capable of collecting leaks from LNG pipework including the overflow pipe (if any) within the pond. The following design principles apply:

- capacity shall be equal to or greater than the amount of liquid which would be spilled by breakage of the pipeline with the highest leakage rate for the time necessary for detection and for interruption of flow;
- an impounding basin shall be open to the atmosphere.

In addition, means for limiting evaporation and reducing the rate of burning of ignited spills shall be considered.

6.8 Safety equipment

6.8.1 Anti-rollover devices

In order to avoid rollover at least the following measures shall be taken except at peak shaving plants if other provisions are taken as defined in 6.5:

- filling systems as defined in 6.9.2;
- a recirculation system;
- monitor boil off rate;
- temperature/density measurements throughout LNG depth.

Other preventive measures can be used, such as:

- avoiding storing significantly different qualities of LNG in the same tank;
- appropriate filling procedure considering the respective densities of the LNG;
- nitrogen content of LNG at filling below 1 mol %.

These measures lead to the practical elimination of stratification of LNG.

6.8.2 Protection against lightning

The tank shall be protected from lightning in accordance with 12.2.

6.8.3 Reliability and monitoring of structure

6.8.3.1 Reliability

LNG tanks are structures which shall have high reliability.

This requires a design which ensures that changes in the structural condition of the tank are slow and limited, on the one hand, and permits monitoring of representative parameters of this condition, on the other.

The level of reliability which it is necessary to achieve as required by clause 4 can lead to the back-up of certain components of the structure: the dual hydraulic barrier (primary container and then secondary container) concept forms part of this type of back-up.

6.8.3.2 Monitoring of structure

Devices for monitoring the general condition of the structure, including the foundation, shall be designed in such a way as to leave sufficient time for action if anomalies are detected.

The monitored values shall be interpreted in terms of predefined:

- normal values;
- alarm values;
- critical values.

The parameters which are deemed to be representative of the general condition of the structure are stated below.

6.8.3.3 Temperature sensors

Three sets of temperature sensors shall be considered:

- on the outer skin of the primary container wall and bottom, to monitor cool down and warm up, except for membrane tanks;
- on the warm side of the insulation (wall and bottom) to detect any leakage and to monitor any deterioration of the insulation due for example to settling;
- on the outer surface of concrete wall of full containment tanks and/or membrane tanks and on the outer surface of concrete raft or point of support for all types of tanks to monitor the temperature gradient.

Plots from all sensors shall be recorded in the control room and any confirmation of leakage shall sound the alarm. The covering of sensors shall be sufficient to ensure that any leakage is detected and the temperature gradient is monitored.

6.8.3.4 Heating system control

In the case of tanks which have a heating system, consumption of power by the system shall be continuously recorded.

6.8.3.5 Settling monitoring

Monitoring of foundation settling is recommended if local characteristics of the subsoil are poor.

6.8.3.6 Primary container leak detection

For all tanks where the insulation space is not in communication with the primary container, a system shall be provided for nitrogen circulated within the insulation space. Monitoring of the tightness of the primary container is then possible by detection of hydrocarbons in the nitrogen purge.

6.8.3.7 Tank external leak and fire detection

The kind of detectors to be used and their location are defined in clause 13.

6.9 Tank piping

6.9.1 Cool down piping

A system for cool down shall be provided to prevent cold liquid from falling onto the bottom of a warm tank. It can terminate for example, in a spray nozzle or a perforated ring.

The pipe used for filling by spraying can also be used for cool down.

6.9.2 Filling piping

Filling shall be able to be carried out, as a function of the LNG quality, either from the roof or at the lower part by a line going to the bottom of the tank.

For the bottom filling, at least one of the following features shall be provided (except for tanks used for peak shaving):

- jet nozzles placed at the bottom of the tank and oriented toward the surface;
- a vertical pipe perforated for part or for all of its length;
- a jet breaker, located at the extremity of a pipe for spray filling.

6.9.3 LNG pumping

Transfer of LNG from the tank and LNG recirculation shall be done with electrically driven submerged pumps.

6.9.4 Overflow

The overflow pipe, if envisaged as a last resort and authorized by the hazard assessment, shall be sized to handle a flow corresponding to the maximum flow rate of the filling pumps. The overflow pipe crosses the side sheet of the primary container at a height at least equal to the level of the high level alarm. It shall be equipped at its base with one or more rupture disks with a burst pressure determined from the hydrostatic head of the liquid in the overflow pipe. One or more valves shall allow maintenance of the disk(s) without releasing gas. A temperature alarm shall detect the presence of liquid in the lower portion of the overflow pipe.

The design of this pipe shall take account of the movements due to differential temperatures between the two walls.

6.10 Distance between tanks

The minimum distance between tanks shall be determined in accordance with the hazard assessment (see clause 4).