LNG Hazards, Spills, Dispersion, Pool Fires and Rollover

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LNG properties

- LNG = liquefied natural gas.
  - Liquefied : cooled down to a temperature of about - 162° C at atmospheric pressure.
  - Natural gas: a mixture of mainly methane, minor fractions of heavier hydrocarbons and nitrogen.

LNG composition

COMPOSITION	% MOL		
	Lean Case	Average Case	Rich Case
Methane	94.1	90.1	88.7
Ethane	4.0	7.1	8.2
Propane	1.1	2.2	2.6
Iso-Butane	0.35	0.3	0.14
Normal Butane	0.35	0.18	0.06
Nitrogen	0.1	0.12	0.3

LNG properties

- Natural gas = highly flammable.
  - Flammability range: 5% - 15% vol.
- Liquid at very low temperature.
  - Contact may cause frost bite or cold burns.
- Asphyxiant
  - High concentrations can dilute or displace air, causing asphixiation.
- Non-toxic.
- Odourless.

LNG properties

- Density usually ranges from 430 kg/m³ to 470 kg/m³.
- One volume of LNG produces approximately 600 volumes of gas.

LNG behaviour

- On first contact with soil: fast evaporation.
- Cold vapour is denser than air.
- Gas cloud disperses into atmosphere as it warms up.
- After some time evaporation rate decreases.

Evaporation rate

Material	Rate per unit area after 60 s kg / (m^2h)
Aggregate	480
Wet sand	240
Dry sand	195
Water	190
Standard concrete	130
Light colloidal concrete	65

Evaporation rate

- On ground:
  - Initial period of intense boiling
  - Rate of evaporation determined by thermal characteristics of the ground and heat gained from surrounding air.
- On water:
  - Due to convection the evaporation rate remains constant and high.

Evaporating LNG

- White visible cloud: condensation of water vapour.
- Natural gas is colourless.
- At temperature above -80° C natural gas becomes lighter than air.

Vapour cloud dispersion

Hazards Associated with LNG

- **Toxicity**
  - Non toxic but risk of asphyxia
- **Cryogenic temperature**
  - Severe frost injury to men
  - Sudden brittle rupture of non cryogenic materials
  - Denser cloud due to low temperature
  - Rapid Phase Transition with water (RPT)
- **Behaviour in storages**
  - Specific hazard in LNG storage : Rollover
- **In case of gas ignition**
  - slow deflagration in open environment
  - Fast deflagration in presence of obstacles and confinement
  - Radiation in case of fire

Hazards Associated with LNG

Thus LNG presents three distinct type of Hazards for three basic reasons:

- Its extremely low temperature presents a cryogenic hazard
- Its flammability presents combustion hazard
- The displacement of air creates an asphyxiation hazard

Hazards to Personnel

Among the major hazards to personnel are:

- **Asphyxiation**
- **Cryogenic burns and hypothermia**
- **Burns from Fire**

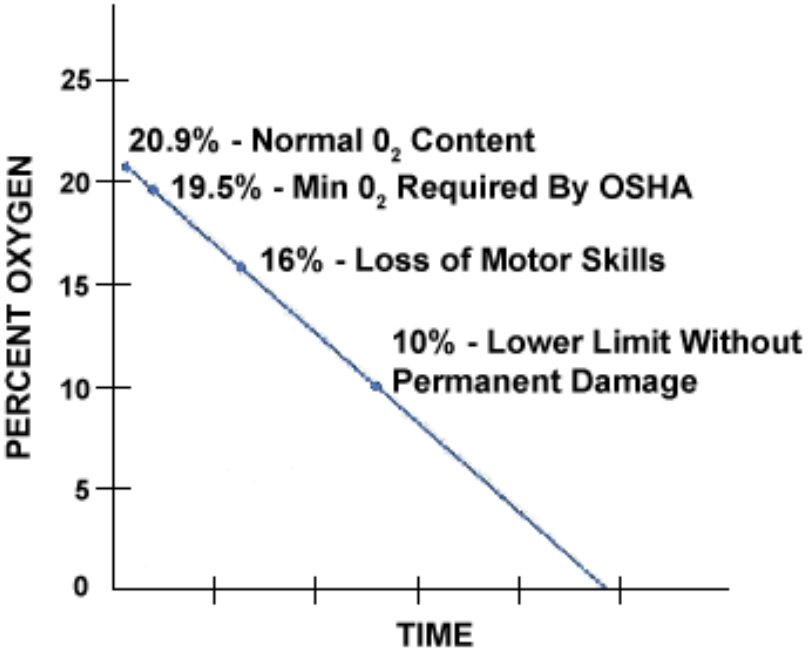
Asphyxiation

The normal O_2 content in air is 20.9%.

The minimum O_2 required by OSHA for tank entry is 19.5%.

At 16% O_2 content, mental accuity and judgment deteriorate, which also results in a loss of motor skills.

Oxygen content of 10% is generally considered the lower limit of exposure without permanent damage to the human body. This O_2 content corresponds to a methane concentration of 52.4%.



Asphyxiation

- Sufficient release of vapours displace the air causing suffocation
- Breathing cold air for short term causes breathing discomfort, and long term can lead to serious injury
- Only after 4 to 5 breaths of oxygen deficient air a person can pass out

Never attempt to help a person who has passed out from asphyxiation without protecting yourself

Cryogenic Burns

- Cryogenic burns are the result of direct skin contact with:
  - Cryogenic liquid
  - Cryogenic Vapours
  - Metal surface cooled by cryogenic fluid
- Direct contact with liquid is most damaging, because of rapid freezing of Tissues due to high heat transfer
- Direct contact with Jet stream of vapours containing liquid droplets is still worse as they magnify the heat transfer and make freezing potential significantly worse and can spread to a larger area.
- Contact with cold metal surface can cause adhesion of the skin. Flesh will be torn when skin is removed from the metal

Hypothermia

Hypothermia is a life-threatening drop in body temperature that occurs as a result of prolonged exposure to temperatures below 50°F, without adequate protection.

As body temperature falls, the ability to perform physical and mental tasks decreases.

Cardiac disturbances can occur at body temperatures below 80.5°F.

Further reduction in body temperature can cause death.

Personnel Protection

- Use Personnel Protection Gears:
  - Face Shields, Cryogenic Gloves, Aprons, Hard Hats, Safety Glasses; Hearing Aids
- Follow safety guidelines
- Clothing and gloves should be loose fitting (but not hanging) for easy removal
- Jewellery should never be worn
- Ensure proper training for the on site operations

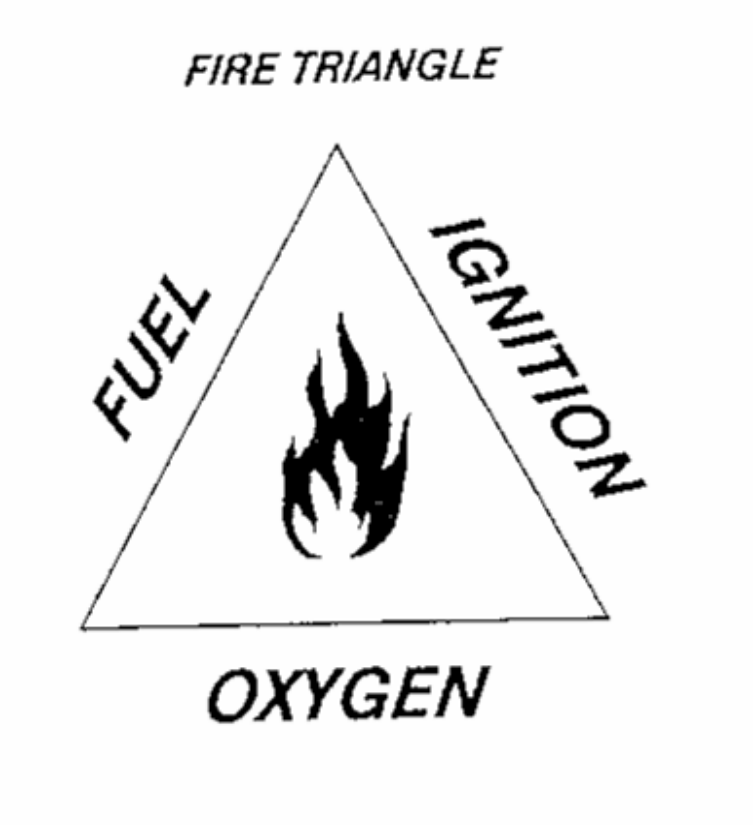
Heat or Ignition Sources

- The Temperature necessary to ignite Natural Gas is 540 deg C
- By comparison ignition temperature for gasoline is 310 deg C
- Ignition Sources include:
  - Open Flames
  - Naked Lights
  - Sparks
  - Static Electricity
  - Hot Surfaces
  - Lightening

Flammability limit

- LFL: 5% vol.
- HFL: 15% vol.
- At atmospheric pressure.
- In air.

Fire hazard



Fire prevention

- No fuel
- No oxygen
- No ignition

Fire hazards

- No unconfined vapour cloud explosions.
- BLEVE not very likely: insulated pipes and vessels. Storage tanks at near atmospheric pressure.

Fire extinguishing

- Limit the amount of fuel: close valve; stop leak.
- Extinguishing by using dry chemical.
- Extinguishing not always necessary:
  - Gas cloud / LNG pool
  - Re-ignition can occur
- NEVER USE WATER ON LNG !

LNG fire

- Deflagration, unconfined area.
- Detonation (explosion), confined area e.g. buildings, sewers or congested area e.g. around process equipment: racks, structures…

RPT

- Rapid Phase Transition.
- Physical explosion (no combustion).

Software Models for LNG Behaviour prediction

- **DEGADIS – DENSE GAS DISPERSION MODEL**
- **LNGFIRE3: A THERMAL RADIATION MODEL FOR LNG FIRES**
- **SOURCE5 – This program can predict the vaporization rate and radius of the LNG pool as a function of time.**

Cold burn, frostbite

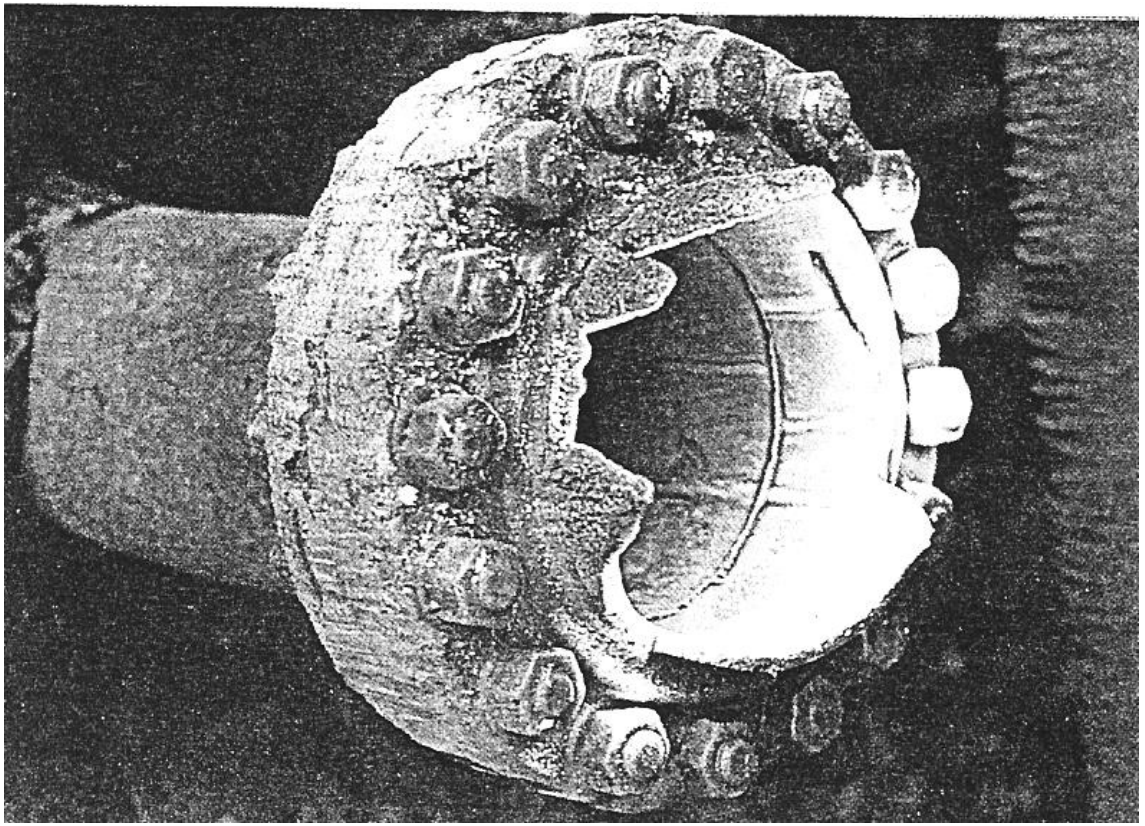
- Blistering effect on skin similar to a burn.
- Direct contact with LNG (spill, leak).
- Indirect contact: uninsulated pipework / equipment.

- Prolonged exposure to cold can cause freezing and subcooling (hypothermia).

Asphyxiation

Danger
asphyxiant

Cold embrittlement



Cold embrittlement

- Material suitable for cryogenic service.
- Temporary connections.

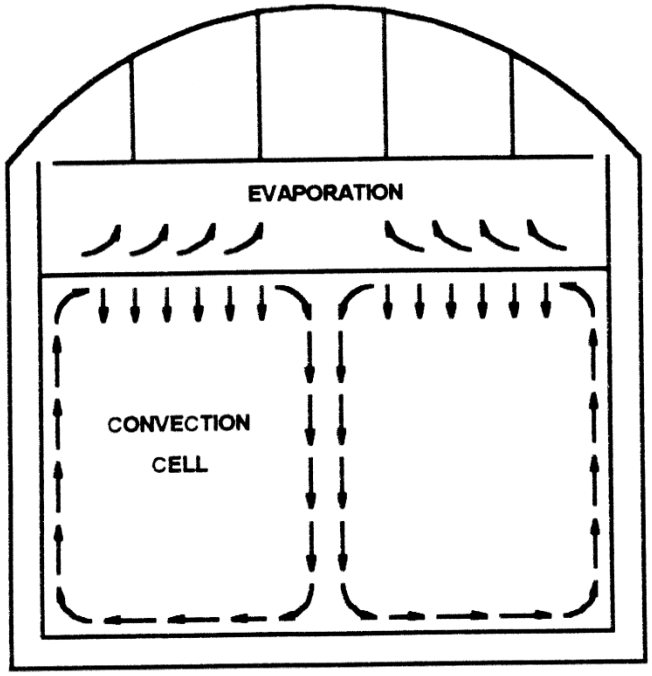
Thermal stress

- Deformation / leaks
- Temperature gradient

Rollover

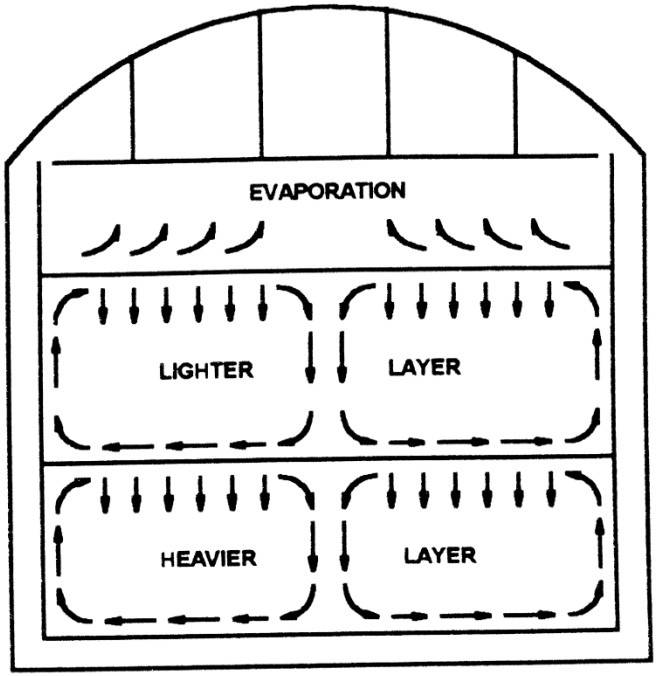
- Large quantities of gas released over a short period of time.
- Caused by rapid mixing of stratified layers.
- Superheated liquid flashes.
- High nitrogen content in LNG can also cause rollover.

Rollover



HOMOGENEOUS LNG

Figure 1



STRATIFIED LNG TANK

Figure 2

Rollover prevention

- Limit allowable amount of nitrogen in LNG.
- Tank management:
  - Top and bottom filling.
  - Boil-off rate monitoring.
  - Density profile monitoring.
  - Liquid mixing:
    - Recirculation
    - Tank-to-tank transfer
- Send-out rate.

Condensation induced water hammer

- Superheating, bubble nucleation, vapour expulsion, liquid re-entry.
- Equilibrium disturbance due to pressure changes.

PRESENTATION

on

Codes & Standards For LNG Industry

Industry-Academia Workshop on A To Z of Natural Gas and LNG

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Presentation Frame

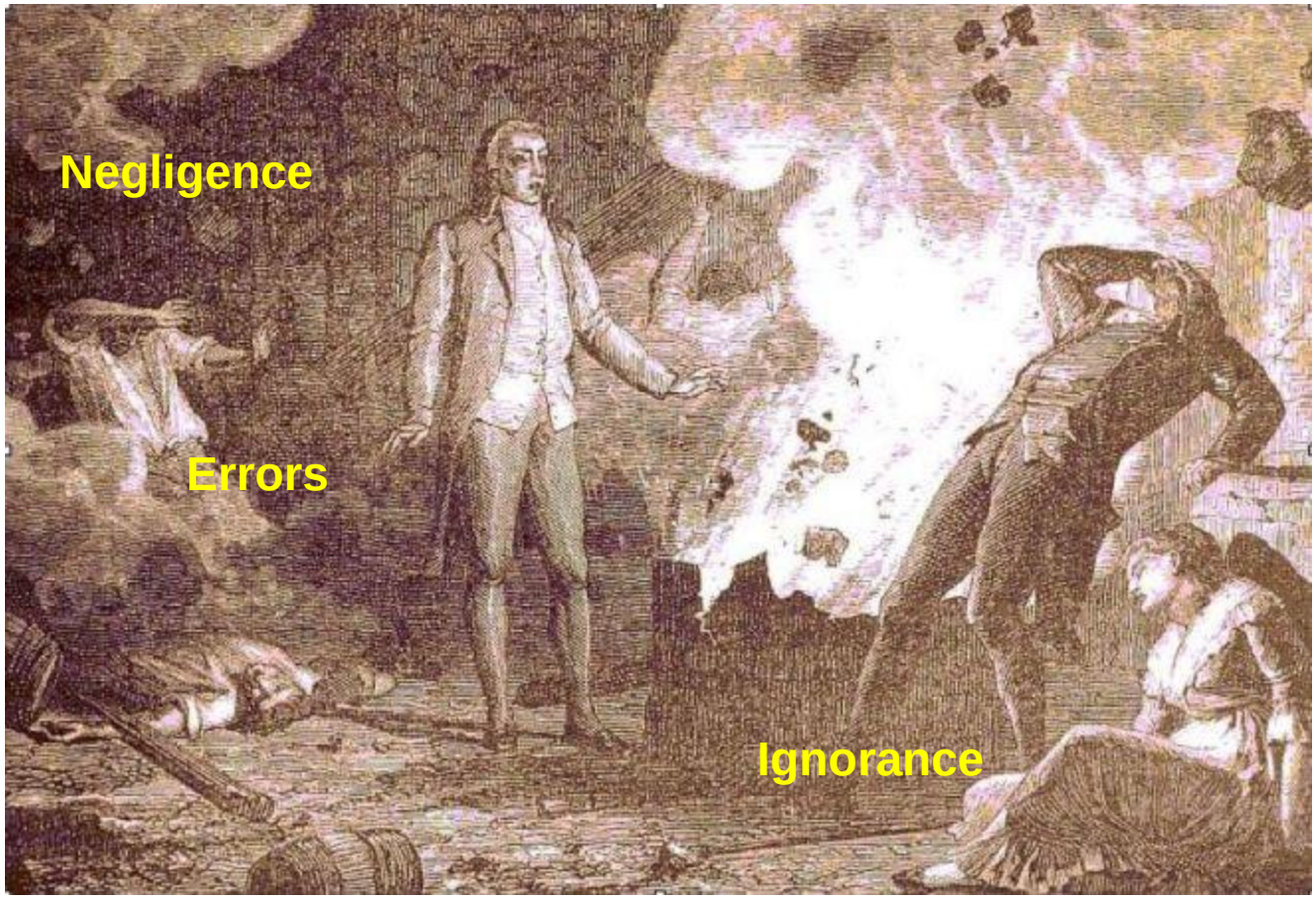
- Why are Codes & Standards Required.
- Types of codes & Standards
- Codes
- Standards
- Maritime Transportation
- Advantages of Codes & Standards.

Why are Codes & Standards Required

Traditionally codes and standards have been written in response to a major accident / incident

For example the rules governing life boats & distress calls were amplified in early 1900 after the luxury liner Titanic sank

Why are Codes & Standards Required



INDUSTRIAL ACTIVITY NEEDS BORDERS

Cleveland 1944

- 1942: East Ohio Gas Company – constructs LNG plant with four 3.5% Ni steel LNG tanks in Cleveland, Ohio
- Oct 1944: One of the tank leaks, fire results, LNG ran into sewer system and vapourizes, confined methane finds ignition source and explodes in the sewer & basements. – Most deadly accident in US
- 130 fatalities, more than 700 homeless
- At the time of incident – no specific regulation governing storage & handling of LNG existed.
- Twenty year later LNG Specific codes came into existence

Cleveland Lessons Learnt & Development of Codes

There are some of the facts that became "lessons learnt" after the disaster in Cleveland

- Some metals, steel in particular becomes brittle at low temperatures
- LNG spills do not evaporate instantly and release / spread of liquid must be avoided and restricted
- Facilities should be designed to protect public at large

Subsequent Codes that were developed contained sections on:

- Strict specifications for Material of construction for low temperatures
- Spill handling & containment
- Restrictions on layout for protection of public

Cleveland Lessons Learnt & Development of Codes

- An impounding basin is required for single containment tanks
- Consequences
  - Dikes
  - Foam generators
  - Distances from the dikes wall
  - Additional water flow rate for fire fighting

Why are Codes & Standards Required

- For imbibing experience in the design.
- Reliable and safe operation of Plant.
- Safety of the Plant Personnel & Public.
- Loss prevention.
- For curbing the business lust & for addressing community concerns
- For flexibility of equipment procurement
- For having common testing facilities.
- For flexibility of installation.

Types of Codes and Standards

Codes : "any set of standards set forth and enforced by a local government for the protection of public safety, health, etc." These carry weight of the Law.

Standards : Generally prepared by Professional bodies or government agencies and "something considered by an authority or by general consent". These are based on accepted design practices. The Standards do not carry the weight of the Law unless adapted by an Authority having jurisdiction

Codes are often legal requirements that are adopted by local jurisdictions that then enforce their provisions. Standards tell the user how to do it and are usually regarded only as recommendations that do not have the force of law.

Note: 49 CFR 193 is federal law in US. NFPA 59A is a Standard. Though 49 CFR 193 has adopted most of NFPA 59A

CODES

US Codes

- 49 CFR 193: Dealing with LNG facilities; Federal safety regulations., issued February 11, 1980, by the Department of Transport (DOT); last revised march 2003, based largely on the NFPA -59A. The code mainly covers:
  - Siting requirements
  - Design
  - Construction
  - Equipment
  - Operation & Maintenance
  - Personal Qualification & Training
  - Fire Protection & Security

Japanese Codes

- Three Standards are De-facto Law
  - Recommended Practice for above ground LNG Storage
  - Recommended Practice for burried LNG Storage
  - Recommended Practice for LNG Facilities

The applicable regulations are those drafted by the Gas Utility Industry Law and includes several detailed implementation decrees concerning LNG notably as concern safety distances

Europe Codes

•No specific regulation in the community, but Directives involve the operator in a management of health, safety an environment

•Directive 82-501/EEC, dated June 24, 1982 concern all LNG depots with capacity greater than 200 tons.

•This Directive, drafted in response to the Seveso, Italy chemical plant accident of July 10, 1976, is the result of an agreement between EEC members and aims harmonizing the legislations as concern the prevention of major accident resulting from industrial activities and at limiting their consequences on humans and the environment.

Indian Codes

OISD – 194; prepared in Aug 2000, is under revision; adopted by most authorities

- **It covers the safety and design aspects of all the major components of LNG receiving terminal such as:**
  - **Unloading**
  - **Storage**
  - **Regasification**
  - **Sendout**

- **It also outlines the operating practices for protection of personnel & property and provides guidelines to all personnel concerned with the operation of LNG receiving, storage, regasification and other associated facilities.**

Codes – Main Points

- Compulsory
- Minimum Level of What Should be done
- Depends Upon Continent / Country
- Impact On
  - Design
  - Operation
  - Land Use planning

STANDERDS

Standards – Main Points

- Formal consensus of technical experts
- Share good practices among operators
- Enable compatibility, interchange
- Overcome technical barrier in commerce
- Different continents, different standards

Main Recommendations & Standards

USA

- NFPA 59 A: "Standard for Production, Storage & Transportation of LNG" ; Latest edition issued in 2006; widely used; Covers:
  - Siting Requirement;
  - Earth quake considerations
  - Design of Process Equipment; Piping Systems & Components
  - Instrumentation & Electrical;
  - Transfer of LNG; Fire Protection; Safety & Security
  - Operation & Maintenance; Personnel training;
- The standard incorporates many other standards by reference. These include ASME Section VIII; API 620; ASME / ANSI B 31.3

Main Recommendations & Standards

EUROPE

- **EN 1160 (1996):** General characteristics of LNG
- **EN 1473 (2007):** Design of onshore installations
- **EN 13645 (2002):** Design of onshore installations with a storage capacity between 5 t and 200 t
- **EN 1532 (1997):** Ship to shore interface
- **EN 1474 (2008):** Design and testing of loading/unloading arms
- **EN 14602 (2010):** Design of Flat-Bottomed Vertical Cylindrical Storage Tanks for Low-Temperature Service

Main Recommendations & Standards

EUROPE

- **EN 1626 (1999):** Cryogenic vessels - Valves for cryogenic service
- **EN 13275 (2000):** Cryogenic vessels - Pumps for cryogenic service
- **EN 13648 (2002):** Cryogenic vessels - Safety devices for protection against excessive pressure
- **EN 12065 (1997):** use of medium and high expansion foam and of extinguishing powders used on liquefied natural gas fires

International Standards ISO

Gas Quality

- **Physical characteristics of natural gas**
  - ISO 6976 (1995) - Calculation of calorific values, density, relative density and Wobbe index from composition
  - ISO 12213 (1997) - Calculation of compression factor
- **Analysis of natural gas**
  - ISO 6326 (1994) - Determination of sulphur compounds
  - ISO 6568 (1981) - Simple analysis by gas chromatography
  - ISO 6570 (2001) - Determination of potential hydrocarbon liquid content
  - ISO 6974 (2000) - Determination of composition with defined uncertainty by gas chromatography
  - ISO 6978 (2003) - Determination of mercury

International Standards ISO

Measurement

- **Custody transfer**
  - **ISO 13398 (1997)** - Liquefied natural gas - Procedure for custody transfer on board ship
- **Measurement of liquid levels in tanks containing liquefied gases**
  - **ISO 10574 (1993)** - Float-type level gauges
  - **ISO 8309 (1991)** - Electrical capacitance gauges
  - **ISO 13689 (2001)** - Microwave-type level gauges
- **Measurement of temp. in tanks containing liquefied gases**
  - **ISO 8310 (1991)** - Measurement of temperature in tanks containing liquefied gases - Resistance thermometers and thermocouples
- **Calibration of tanks**
  - **ISO 8311 (1996)** - Calibration of membrane tanks and independent prismatic tanks in ships - Physical measurement

Maritime Transport

Maritime Transport Regulations

- **Regulations**
  - **– International regulations (International Maritime Organisation – IMO– & Vega for LNG carriers)**
  - **– National and local regulations (terminal state)**
  - **– Recommendations : unanimously recognized (SIGTTO, OCIMF)**
  - **– Construction requirements and controls (classification societies)**
- **International organisations**
  - **– Society of International Gas Tankers and Terminal Operators (SIGTTO)**
  - **– Oil Companies International Marine FORUM (OCIMF)**

International Maritime Organisation IMO

- **Created in 1948 by the UNO to improve maritime safety and pollution prevention**
- **Conventions are adopted by countries which have to implement them in their national regulations.**
- **Main texts for LNG maritime transport**
  - SOLAS 74 Convention : Safety
    - IGC Code, ISM Code, ISPS Code
  - COLREG 72 : Preventing collision regulation at sea
  - MARPOL 73/78 Convention : Pollution
  - STCW78/95 : Standard of training for crew and watch keepers
  - LL66 : Load line on the boat

SOLAS

- SOLAS 74 Convention
  - Safety of Life at Sea
  - Linked codes :
    - I.G.C. « International Gas Carrier »
    - I.S.M. « International Safety Management »
    - I.S.P.S. « International Ship and Port facility Security »
- SOLAS - Chapter XI/1 (July 2004)
  - Ship identification
    - Licence plate
    - Data base with all information : “CSR” Continuous synopsis record

Advantages of Codes & Standards

Standards realize a direct return on investment by:

- lowering installation and startup costs
- reducing need to maintain large inventories
- enabling interchangeability of components
- improving design with less "custom" effort
- increasing safety
- quality

Advantages of Codes & Standards

Use of standards in industry

- improves communication
- provide uniformity within a class to improve operability.
- provides practical application of expert knowledge
- Prevents re-inventing of the wheel; represents years of experience and avoids necessity of starting each project from ground up.

Advantages of Codes & Standards

Standards help to achieve operational excellence by:

- Consolidating the vast knowledge in one single document
- improving performance
- lowering maintenance Costs
- reducing downtime
- enhancing operability
- saving money.

Codes & Standards - Cautions

- Codes & Standards are minimum requirements; compliance helps in safe & reliable operation, but it does not guarantee the same.
- Also codes & standards can be slow to reflect new technologies. Close interaction between Authorities, users, professional organizations & Technology developers has to be faster & continuous.
- Owners and operators should not totally depend upon contractors & vendors for compliance. They should have own program to ensure compliance

Thank you