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Risk Analysis of LNG Terminal: Case Study

Chiara Vianello, Giuseppe Maschio

[a] Dipartimento di Ingegneria Industriale, University of Padova, Via F.Marzolo 9, 35131 Padova, Italy
giuseppe.maschio@unipd.it

The aim of this paper is the study of the emerging risk related to the problems of safety and security linked to the use of new and alternative technologies for LNG re-gasification, like a off shore LNG terminal.
The methodology of quantitative risk analysis (QRA) has been applied to the case study of a Floating Storage and Re-gasification Unit terminal (FSRU).

1. Introduction

The use of natural gas is growing worldwide because of the market's interesting price and of energetic and ecological characteristics of this fuel. Its combustion produces mainly water vapour and carbon dioxide in limited quantity respect than oil and coal, and very reduced quantities of other heavy residue.
The advantage of the re-gasification process is the diversification of imports and hence the competitiveness related to the purchase price of natural gas. This kind of transportation is an economical alternative to gas pipelines that, on the contrary of LNG terminals, tie in a monopolistic way the importing country to the exporting country and those countries crossed by the pipeline.
Natural Gas is an important part of the European energy market, both for power generation, heating and, domestic use. More than 50% of the Natural Gas used in Europe is imported (almost all from three only countries: Russia, Norway and Algeria). The Natural Gas import is expected to increase up to 70% in 2020 (EUROSTAT, 2011). Reliability of the supply, where the diversification of the sources plays an important role, is an important issue for the energy future of Europe and a specific European Directive (2004/67/CE) is dedicated to this issue.
Considering this scenario, the realization of re-gasification terminals is important from the energy point of view, but these new infrastructures highlight the question of the acceptability of the risks. In fact these infrastructure are defined as emerging risk inasmuch the hazards associated to these installations were not fully explored to date.
The issue of security of these systems should be addressed through careful and thoughtful assessment of the risks related and an proper communication to the population.
The aim of this work is the risk analysis an Offshore re-gasification terminal. The process of risk analysis involves three basic steps, as described in literature (Brito & Dealmeida, 2009; Marhavilas, Koulouriotis, & Gemeni, 2011; TNO, 1999):

- Description of the system;
- Identification of the risk: estimate of the frequency of event, estimate of the consequences and risk assessment;
- Acceptance of the risk.

2. Off- shore LNG terminal: FSRU Plant

LNG terminal is an important part of the system of supply and distribution of natural gas. The importance of this kind of infrastructure is increasing in the time.

The case study of risk analysis concerns an hypothetical Floating Storage and Re-gasification Unit terminal (FSRU), reported in Figure 1, for the importation, storage and re-gasification of LNG, located

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offshore at some tens of kilometres from the coast, and capable of providing the network with national gas about 5 billion Nm^3 of gas natural per year.

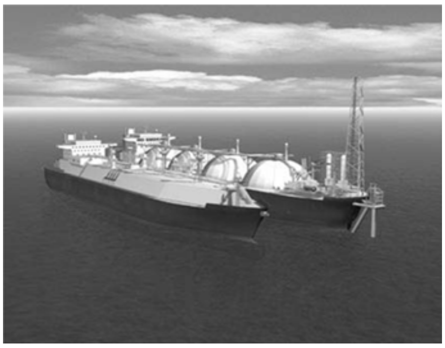

Figure 1 Floating Storage and Re-gasification Unit terminal (FSRU*)*

The block diagram of re-gasification plant is shows in Figure 2.

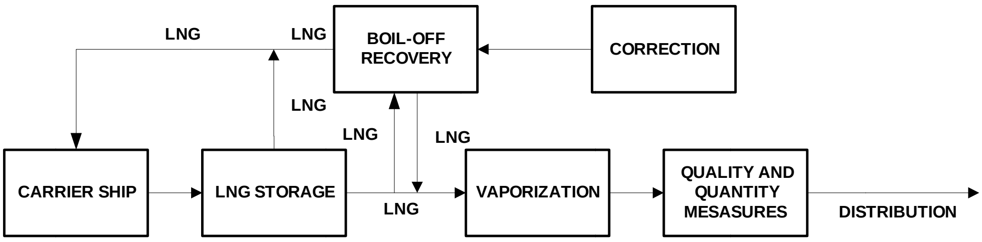

Figure 2 Block diagram

LNG handling facilities of LNG-FSRU generally comprise the following main systems and equipments:

- LNG Storage Tanks, it is composed by 4 spherical tanks whit total storage capacity of 170,000 m3. The tanks are kept at a relative pressure range from 0.07 to 0.25 bar and temperature of -163 ° C. Each tank is equipped with valves to prevent any effects caused by excessive pressure or depression in the tanks. These valves are collected to the ventilation system.
- Cargo Handling Equipments: high and low duty compressors and high and low duty heaters and LNG vaporizers,
- LNG Pumps in Storage Tanks,
- Re-gasification Plant: Booster pump suction drum, LNG booster pumps and LNG vaporizers,
- Gas Export Metering,
- Submerged Turret Loading System is of the type SPM (Single Point Mooring),
- Knock-out Drum and Flare Tower or Cold Vent Stack,
- Unloading Arms.

3. Consequences Analysis for off-shore LNG terminal

3.1 Scenarios

The possible accident scenarios in FSRU can be derived by:

- Release from equipment and pipeline;
- Accidents due to process deviation;
- Risk associated whit the ballast system of floating;
- Risk associated whit work on board.

The release events from equipment or pipeline may be caused to random phenomena such as wear, corrosion, defects etc… They are not directly related to process failures and therefore can occur regardless of the existing plant configuration. Three typical dimensions of release are generally considered, defined as follows:

- Small release: associated to a hole equal to diameter of 10 mm;
- Medium release: associated to a hole whit diameter equal to 25 mm;

- Large release: associated to a rupture of diameter more than 10% of pipe diameter.

The full bore rupture of FRSU ship pipeline is excluded on the basis of the precautions taken during the design and the characteristics of plant.
The structural characteristics of tankers (double hull) and the historical experience shows that a scenario of loss caused by release of LNG from the storage tank is considered non-credible (Pitblado, R.M., Baik, J., Hughes G.J., Ferro C., 2004).
The deviation of process that can generate a hazardous substance release, may be: overpressure in storage tank, formation of empty storage tanks, overfilling of storage tanks, low temperature leaving the evaporator and subsequent release from natural gas transmission line, overpressure in vaporizers, discharge from the Pressure Safety Valve.
The hypothetical events initiators of depression in the tank to be taken into account are: emptying a tank, cooling of the gas phase (filling in rain), pressurization of the space between the hull and the tank, recall of excessive evaporation.
It should be note that whatever the initial cause of depression in the tank, the thermodynamic behaviour tends to favour the LNG vaporization and minimize vulnerability to depression.
In the face of such events are planned protection systems such as alarms and locks to low temperature, high pressure, low pressure nitrogen injection for the control of pressure in the tanks, etc...
Using these protection system is excluded the deviation of process.

3.2 Identification of events

The consequences and frequency estimation of event is developed through an event tree analysis.
An event tree shows graphically the possible consequences that derive from an event initiator: the dispersions according to the weather conditions and for release of flammable substance according to presence of ignition source. Below the generic event tree for continuous release of flammable gas and flammable liquid are shown in Figure 3.

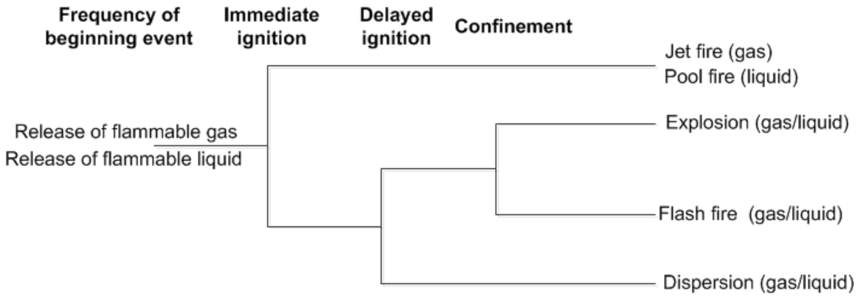

Figure 3 Generic event tree of flammable gas and flammable liquid

The hypothetical accidental events are nine, see
Table *5*.

3.3 Estimation of frequency

To estimation of frequency, value of the international literature databases were used as reference (API, 2008; Cox W., Lees F.P, 1990). The frequency of accidental scenario is calculated through the event tree analysis, using appropriate probability for ignition and weather conditions. The failure frequencies of releases from piping and equipment installation were calculated using the methodology in the standard API 581 "Risk Based Inspection Guidelines". The ignition probability was determinate considering the standard API 581. In this case the ignition is a function of flow rate released. The value are listed in Table 1 for gas and liquid release

Table 1 Ignition probability in function of release rate

Flow rate [Kg/s]	Ignition Probability [-]	
	Gas release	Liquid release
<1	0.01	0.01
1 – 50	0.07	0.03
>50	0.30	0.08

The value adopted for the probability of explosion or flash fire are given in Table 2, based on references to technical literature (Cox W., Lees F.P, 1990).

Table 2 Explosion and flash fire probability

Flammable mass [Kg]	**Explosion Probability [-]**	**Flash Fire Probability [-]**
<100	0	0.01
100 – 1000	0.001	0.03
>1000	0.03	0.1

In order to assess the appropriate probabilities to be included in events trees, it is therefore necessary to calculate the flow of release and the flammability mass for each event.
The package PHAST (Software for the Assessment of Flammable, Explosive and Toxic Impact) has been used in the simulation, it is by far the most comprehensive quantitative tool available for assessing process plant risks. It is designed to perform all the analytical, data processing and results presentation elements of a QRA within a structured framework.

3.4 Consequences: PHAST simulation methodology

In the estimation of consequences, the fluid under consideration is a natural gas like a mixing. The composition of mixing methane changes in function of import country. The case study considers the methane from Algeria, the composition shows in

Table 3.

Table 3 Composition of mixing methane

Component	Unit	Average composition
Nitrogen	Mol%	0.5
Methane	Mol%	88.0
Ethane	Mol%	9.0
Propane	Mol%	2.0
Component > C_4	Mol%	0.5
Total	Mol%	100.0

The methodology that is applied to the case study for the evaluation of the consequences is the following:

1. Map and characteristic of system
2. Definition of substance. Pure Methane is present as a default substance in PHAST, while for natural gas is necessary to define a new mixture) and assign the molar composition (Component - Molar Amount%). To calculate the properties of the mixture is used Soave Redlich Kwong equation of state for which are required the interaction parameters (Nasri & Binous, 2007) (http://www.chemsof.com/)
3. Definition of damage threshold, see
4. Table *4*.

Table 4 Damage thresholds for LNG plant

Damage thresholds	Damage level: High lethality	Beginning lethality	Irreversible injury	Reversible injury	Structural damage – domino effect
Fire	12.5 kW/m^2	7 kW/m^2	5 kW/m^2	3 kW/m^2	12.5 kW/m^2
Flash fire	LFL$^{(2)}$	0.5 LFL	---	---	---
VCE	0.3 bar (0.6 bar in open land)	0.14 bar	0.07 bar	0.03 bar	0.3 bar
Fireball Bleve	Radius of Fireball	350 kJ/m^2	200 kJ/m^2	125 kJ/m^2	100m from storage tank, 600m from spherical storage tank,800m from silo tank.

5. Definition of weather conditions: Pasquill class F corresponds to "*Stable night with moderate clouds and light/moderate wind",* temperature is 15°C, wind velocity is 3 m/s and relative humidity 80%
6. Definition of release model: considering that the suppose release regarding tank and pipeline, the model is Vessel/Pipeline. At this point, each event is located on the map, as shown in figure 5-1. Then the following parameters are defined:
    a. Substance: methane or mixing

b. Mass (kg)
c. Operated condition: temperature (°C), pressure (bar), fluid phase (Liquid/vapour/biphasic), typology of fluid (liquid/gas pressurized, etc...)
d. Type of scenario: full bore rupture, hole etc…

7. Simulation of events: the software provides a report for each event in which they are reported the inputs and outputs required to consequences determine and graphs representing the scenarios.

The simulations were carried out without considering the presence of the LNG ship that supplies the LNG terminal, considering that the software used in this work excludes the presence of obstacles in the neighbourhood of the study area.

4. Local risk for LNG terminal

To determinate the local risk (LR) for FSRU plant it is necessary to identified the probability of death. This probability, indicate with P_E, indicates the probability that an individual should died from exposure. The individual is assumed to be outside and unprotected.

The probability of death are:

- Flash fire: the lower flammable limit causes a great impact then probability of death is equal to 1.
- Explosion: the overpressure of 0,3 bar generates a P_E equal to 1.
- Jet fire: the probability of death is a function of heat radiation, to radiation equal to 12.5 kW/m^2 causes a P_E of 0,635.

The

Table *5* summarizes the selected scenarios and the their frequency , that were used to calculated the local risk.

Table 5 Scenarios to calculated the local risk

Scenarios	Release Frequency [event/y]	Scenario	Probability	Cons. level	P. of deth	Frequency [event/year]	Damage Distance [m]
1.Delivery arm	1.51E-05	Pool Fire	0.3	12.5 kW/m^2	0.065	2.94E-07	41
2.Transfer pipe to the tanks	2.25E-05	Jet fire	0.3	12.5 kW/m^2	0.065	4.39E-07	105
		Flash fire	0.0027	LFL	1	6.08E-08	107
		Explosion	0.000091	0,6 bar	1	2.05E-09	28
3.LNG Storage	4.00E-05	Flash fire	0.0001	LFL	1	4E-09	9
4.Vapor return line to LNG ship	2.25E-05	Jet fire	0.07	12.5 kW/m^2	0.065	1.02E-07	43
		Flash fire	0.000093	LFL	1	2.09E-09	176
5.Gas return line from BOG compressor	3.01E-05	Jet fire	0.07	12.5 kW/m^2	0.065	1.37E-07	11
		Flash fire	0,000093	LFL	1	2.80E-09	7
6.Line at low pressure between the tanks and high pressure pumps.	3.77E-05	Jet fire	0.07	12.5 kW/m^2	0.065	1.71E-07	40
		Flash fire	0.00086	LFL	1	3.24E-08	47
7.Line at high pressur to vaporizer.	3.77E-05	Jet fire	0.07	12.5 kW/m^2	0.065	1.71E-07	63
		Flash fire	0.0012	LFL	1	4.52E-08	46
8.Downstream gas export line of vaporizers	9.80E-06	Jet fire	0.3	12.5 kW/m^2	0.065	1.91E-07	75
		Flash fire	0.00091	LFL	1	8.91E-09	41
9.Riser	1.97E-06	Jet fire	0.3	12.5 kW/m^2	0.065	3.83E-08	216
		Flash fire	0.0091	LFL	1	1.79E-08	34
		Explosion	0.00273	0,6 bar	1	5.37E-09	49

The re-composition of local risk is reported in Figure 4.

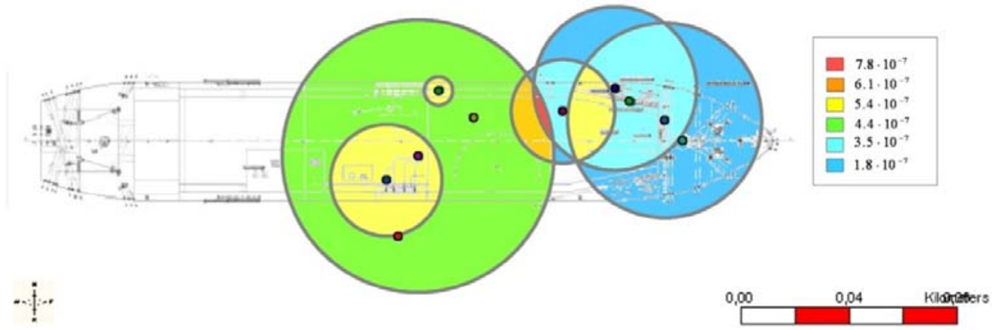

Figure 4 Re-composition of local risk in FSRU plant

Considering the risk acceptability criteria for new installation equal to 10^{-6}, the local risk can be considered acceptable also because of the limited number of people present on the terminal.

5. Conclusion

The objective of this work is exploring the emerging risk related to the safety and security of new and alternative technologies for LNG re-gasification, like a off shore terminal.

The study focused on Off shore LNG terminal in particular a Floating Storage and Re-gasification Terminal Unit (FSRU).

As evidenced by the analysis of the events trees, the consequences that can occur during the transport of natural gas can cause fire and explosion, as the substance is flammable.

The determination of local risk highlights that the case study is under the acceptability criteria, because the frequencies of these events are less of 10-6. The area most at risk arrives at a frequency of 7.8 *10-7.

This analysis is preliminary in fact, the simulations were carried out without considering the presence of the LNG ship that supplies the LNG terminal, considering that the software used in this work excludes the presence of obstacles in the neighbourhood of the study area.

Future studies will focus on the dispersion of natural gas in areas of complex and thus the study of confined areas that could create more damage. This study will be carried out through the study of a release of gas in a 3D geometry through the use of Computational Fluid Dynamic (CFD) software.

Acknowledgements

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