# Risk assessment of an LNG storage tank release

## Case study of LNG storage unit in Skikda LNG terminal

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**Abstract:** Liquefied natural gas (LNG) terminals ensure the production, storage and transportation of LNG. Therefore, it assembles critical equipment that can cause hazards to personnel, assets and the environment.
This paper presents a risk assessment for an LNG storage tank release in an LNG terminal. Risk assessment was conducted by applying a HAZOP study, Bowtie analysis, fault tree analysis and ALOHA (Areal Locations of Hazardous Atmospheres) simulation.
The results were to identify causes, consequences and safeguards of hazards related to over and under pressure in an LNG storage tank. Moreover, a bowtie analysis was established for LNG loss of containment (LOC) from flammable liquids storage tanks. In addition, a fault tree analysis was presented to identify the causes of tank failure considering pressure hazards. Finally, the consequences of LNG released from the storage tank were simulated using the ALOHA software.

**Keywords:** LNG terminal, LNG storage tank, HAZOP, Bowtie analysis, Fault tree analysis, ALOHA, LOC.

## 1. INTRODUCTION

Liquefied natural gas (LNG) is the cleanest burning fossil fuel, obtained from natural gas that has been cooled to -162 ºC under atmospheric pressure, to become liquid. The composition of LNG is approximately 90% of methane, varying according to the source [1].
LNG consumption is tremendously growing all over the world due to the increasing demand for utilization in personal daily life and industrial plants. The LNG supply chain begins with extracting natural gas and then sending it to an LNG terminal where the gas is liquefied, stored in atmospheric storage tanks and then loaded to LNG carriers to be transported to regasification plants and finally to the end-users.
LNG terminals are critical infrastructures in the LNG supply chain that produces and stores LNG in specific atmospheric storage tanks. LNG leakage may cause severe hazards to people, assets and the environment. Therefore, risk assessment for loss of containment from LNG storage tanks is really important to avoid catastrophic consequences.
This paper aims to identify causes and consequences for LNG leaks from storage tanks by applying a bowtie analysis. Also, a HAZOP study, fault tree analysis was conducted for over and under pressure in an LNG tank. Moreover, dangerous consequences were simulated using ALOHA software.
This paper is organized as follows: the next section presents the LNG storage Unit; section 3 provides the methods applied for risk assessment of an LNG storage tank; section 4 concludes this paper.

## 2. DANGEROUS GOODS

"Hazardous Goods" are characterized by flammability, explosiveness, toxicity, corrosiveness, radioactivity, and oxidability [2]. The IMDG code grouped dangerous goods into 9 classes as shown in Table 1.

Table 1 The IMDG code for dangerous goods

| class | *Dangerous Goods* |
|---|---|
| 1 | Explosives |
| 2.1 | flammable gases |
| 2.2 | non-flammable, non-toxic gases |
| 2.3 | toxic gases |
| 3 | Flammable liquids |

| | |
|---|---|
| 4.1 | flammable solids, self-reactive substances, solid desensitized explosives and polymerizing substances |
| 4.2 | substances liable to spontaneous combustion |
| 4.3 | substances that, in contact with water, emit flammable gas |
| 5.1 | oxidizing substances |
| 5.2 | organic peroxides |

Major hazards of the dangerous goods are leakage, fire, explosion, personnel poisoning and injury, property loss and environmental pollution, etc.[2]. Therefore, identification of risk factors and consequences is essential to prevent such hazardous scenarios

## 3. METHODS AND MATERIALS

The methods that are used to identify risks, causes and consequences of accident scenarios are HAZOP study, Bow-tie analysis, fault tree analysis and ALOHA simulation. Many scholars have discussed risk assessment related to LNG plants (offshore and onshore terminals) and storage tanks [4]–[12].

### *HAZOP study*

Hazard and Operability Analysis is a qualitative tool to identify process deviations and examine their possible causes, consequences and appropriate safeguards to help prevent the deviation from occurring[13].

### *Bowtie analysis*

Bowtie analysis is a graphical tool of pathways from the causes of an event to its consequences. It is considered a useful tool for risk assessment and identification of hazards, causes, consequences and barrier management. It can be considered as a simplified representation of a fault tree (analyzing the cause of an event) with preventive barriers and an event tree (analysing the consequences) with reactive barriers [14]

### *Fault tree analysis*

Fault Trees Analysis is one of the numerous techniques employed in risk assessment when generating the possible causes for an undesired event [4]. The logical relationship between these causes is represented by several gates such as AND, and OR gates[15].

### *Aloha simulation*

ALOHA (Areal Locations of Hazardous Atmospheres) is a modelling program that estimates threat zones associated with hazardous chemical releases, including toxic gas clouds, fires, and explosions. Many scholars have used ALOHA to simulate the consequences of natural gas release [16], [17].

## 4. CASE STUDY

### *Unit description GL1K*

GL1K complex belongs to the LNG supply chain where natural gas is produced and exported after liquefaction by LNG carriers.

Its main activity is the liquefaction of natural gas and the separation of ethane, propane, butane and gasoline.

The natural gas liquefaction complex currently comprises

- liquefaction units;
- an LNG storage and loading unit;
- an LPG processing, storage and loading unit;
- an isobutane production unit;
- Ancillary units (gasoline storage etc.).

“Fig.1” shows the location of the GL1K complex.


Fig. 1. A view of the GL1K complex

The purpose of unit 71 in the GL1K complex is to ensure the storage of LNG in tank 71-MF01. The LNG stored is produced by the new mega train and by the existing units of the G1LK complex.

The LNG produced is then loaded to LNG carriers by four loading pumps 71-MJ01-A/B/C/D, which are provided to evacuate the LNG from the tank to the vessels at the loading station

The wasted gas generated during the loading operation is recovered by the BOG "Boil-Off-Gas" recovery system which is mixed with the BOG coming from the LNG storage tanks 71-MF01 of unit 71 and the other storage tanks existing LNG TK103 /104 of unit 81.

The LNG collected from the casting line is injected into the 71-MD01 BOG collector to control and regulate the temperature and send it to the BOG compressors 71-MJ05-A/B/C. The compressors take the gas at virtually atmospheric pressure and compress it to 31 bar.

The LNG accumulated in 71-MD01 will be returned to the LNG storage tank 71-MF01 and the LNG casting line upstream of the 71-ESDV-1170 thanks to the LNG return pumps 71-MJ06 / 06-A.

The different types of equipment in the operational system are presented in Table 2.

The piping and instrumentation diagram (P&ID) of unit 71 is presented in "Fig.2".

## 5. Results

Table 4 summarizes the input data loaded to ALOHA to proceed with the simulation. The scenario is the release of LNG from the vertical cylindrical storage tank.

The HAZOP study for over-pressuring and under-pressuring considered for the LNG storage tank in unit 71 is shown in Table 5.

A bowtie analysis was established for "Loss of containment of LNG from flammable storage tanks is presented in "Fig.3"

The fault tree analysis for tank failure is caused by overpressure and under pressure is presented in "Fig.4"

A simulation for the dangerous consequence scenarios of LNG released from a storage tank is realized using the ALOHA software.

The possible consequences of LNG released from a storage tank are

- A burning puddle (a pool fire), potential hazards from a burning puddle are shown in "Fig.5

Table 2 operational system equipment in unit 71

| ***Equipment code*** | ***Equipment's*** |
|---|---|
| 71-MF01 | Storage tank |
| 71-MD01 | BOG recondenser |
| 71-MJ01-A/B/C/D | Loading pumps |
| 71MJ06/06A | Return pumps |
| 71-MJ05-A/B/C | BOG compressor |
| 71-MC01-A/B/C | Air-cooled chillers inside BOG compressors |
| 71-MC02-A/B/C | |

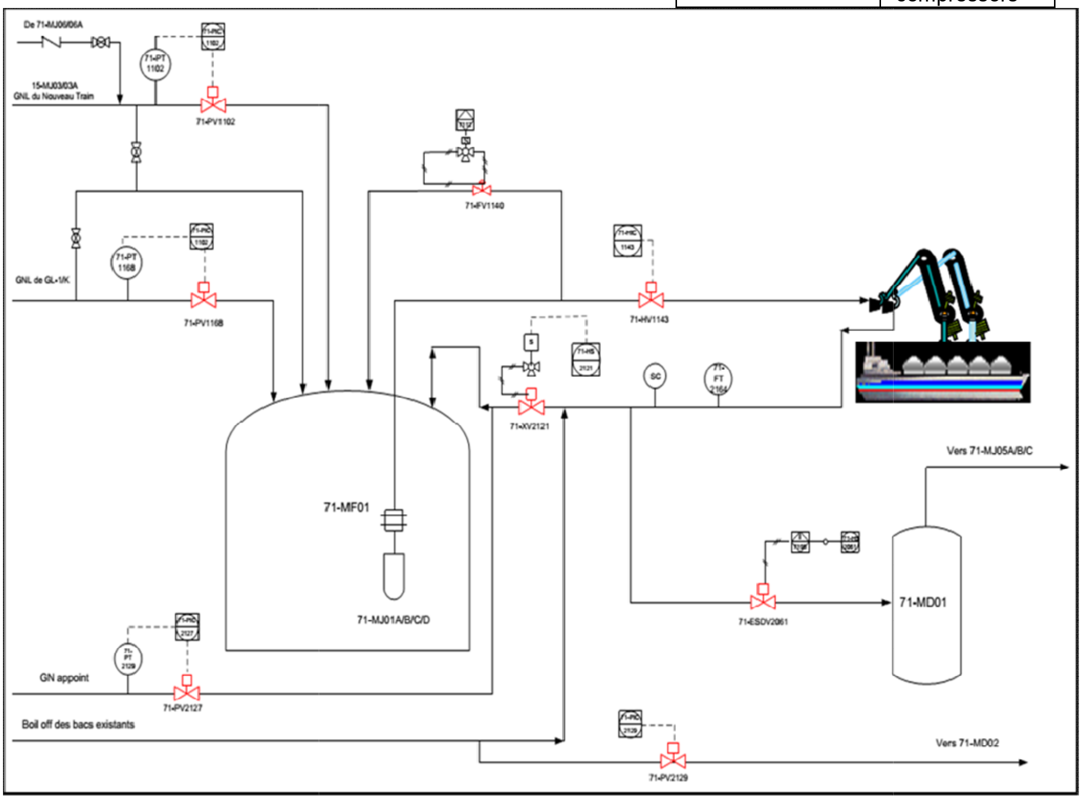


Fig. 2. The piping and instrumentation diagram (P&ID) of unit 71

Table 2 operational system equipment in unit 71

| | |
|---|---|
| Site | SKIKDA-G1LK-ALGERIA, ALGERIA |
| Chemical data | Chemical Name: METHANE<br>Molecular Weight: 16.04 g/mol<br>PAC-1: 65000 ppm<br>PAC-2: 230000 ppm<br>PAC-3: 400000 ppm<br>LEL (lower explosion limit): 50000 ppm<br>UEL (upper explosion limit): 150000 ppm<br>Ambient Boiling Point: -161.5° C<br>Vapour Pressure at Ambient: greater than 1 atm |
| Atmospheric data | Wind: 5 meters/second<br>Air Temperature: 19° C<br>Stability Class: D<br>Relative Humidity: 75% |
| Tank data | vertical cylindrical tank<br>Tank Diameter: 57.92 meters<br>Tank Length: 26.6 meters<br>Internal Temperature: -161.4° C<br>Tank Volume: 700000 m3<br>Tank is 80% full |

Table 5 Hazard and Operability Analysis of the LNG storage tank in unit 71 due to over-pressuring and under-pressuring

| ***Item*** | ***Parameter*** | ***Deviation*** | ***Causes*** | ***Consequences*** | ***Safeguards*** | ***Recommendations*** |
|---|---|---|---|---|---|---|
| **1.1** | **Pressure** | Pressure High in 71-MF01 | (1) 71-PV 2127 is fully open when it should be throttling or Bypass is open.<br><br>(2) 71-XV 2121 is closed when it should be open.<br>(3) 71-ESDV 2061 is closed when it should be open<br><br>(4) 71-MJ05 stop<br><br>(5) 71-PV-2129 is closed when it should be controlled. | Internal tank rupture | (1) Pressure indicator in a storage tank 71-PI-1105 with High Alarm Isolation of storage tank using 71-PT-1104A/B/C with Hi Hi alarm<br><br>(3,4) 71-PV-2129 | Confirm the size of bypass of 71-PV-2127.<br>Confirm 71-PV-2129 is sized to handle 100% of the flow on 71-2127(or bypass) being full open |
| **1.2** | | Pressure Low in 71-MF01 | (1) 71-MJ05 running more than required<br><br>(3) 71-PV-2129 is full open when it should be controlling | Internal tank failure<br><br>Potential Air ingress | Pressure indicator with low alarm 71-PI-1105<br><br>71-PT-1104A/B/C With low low alarm<br><br>Pressure indicator in BOG compressor 71-PI-2123 with low alarm | |

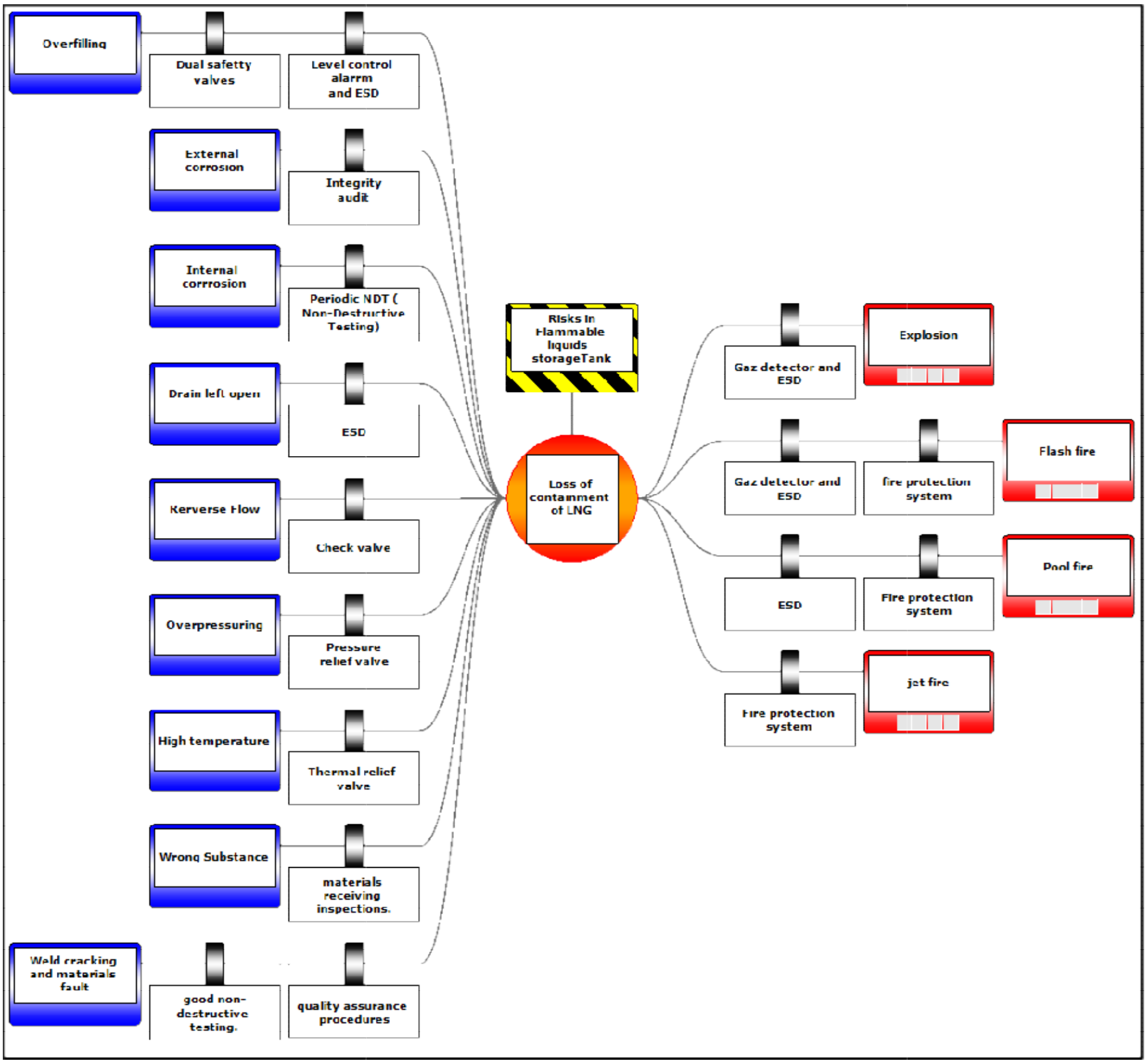


Fig.3 A bowtie analysis for “Loss of containment of LNG from flammable storage tanks”

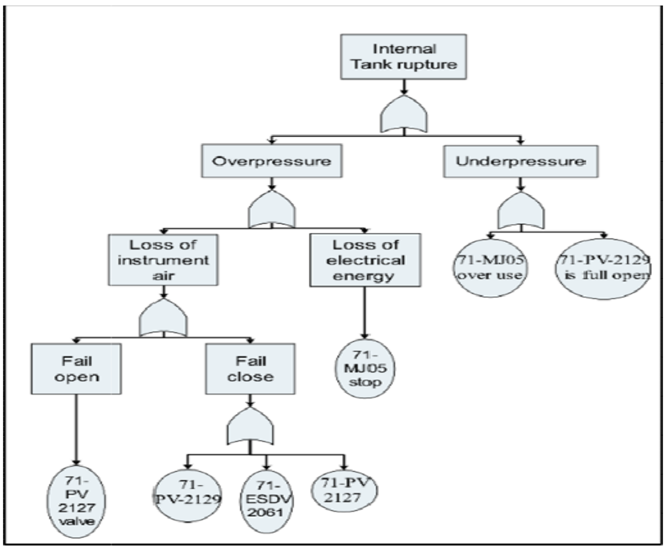


Fig.4 Fault tree analysis for tank failure caused by over and under pressurization

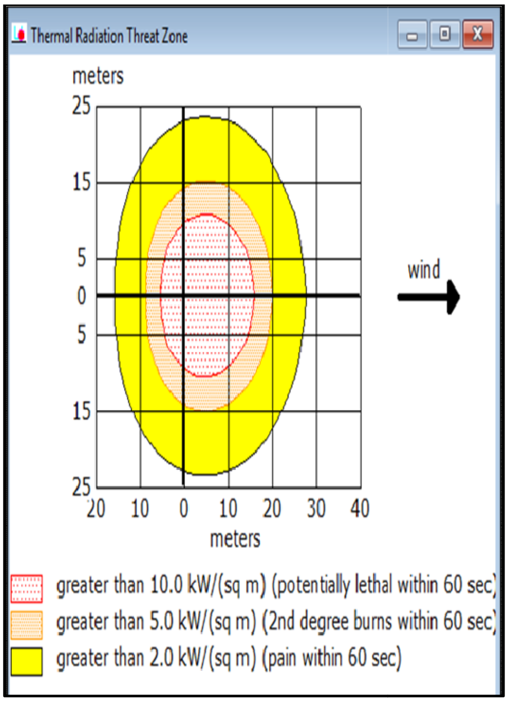


Fig. 5. Thermal radiation threat zone (pool fire)

If the released LNG is not on fire, three possible consequences may occur: toxic and flammable vapour cloud and blast of vapour cloud explosion. Threat zones are shown in “Fig.6-8”.

A threat zone is an area within which ALOHA predicts the hazard level to exceed your Level of Concern (LOC) at some time after a release begins. ALOHA can model multiple hazards (toxicity, flammability, thermal radiation, or overpressure), and the type of LOC that you choose will vary based on the hazard.

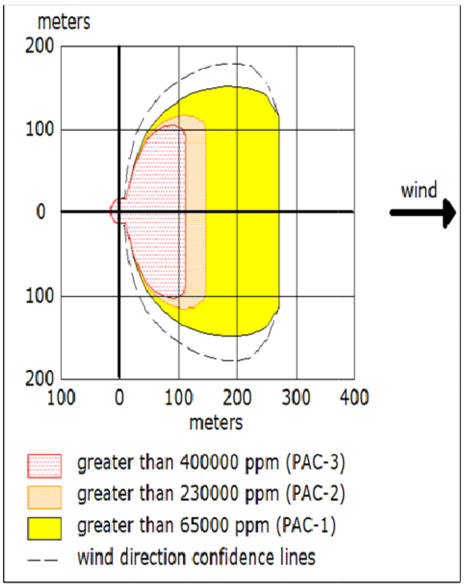


Fig.6. Threat Zones for Toxic vapour cloud

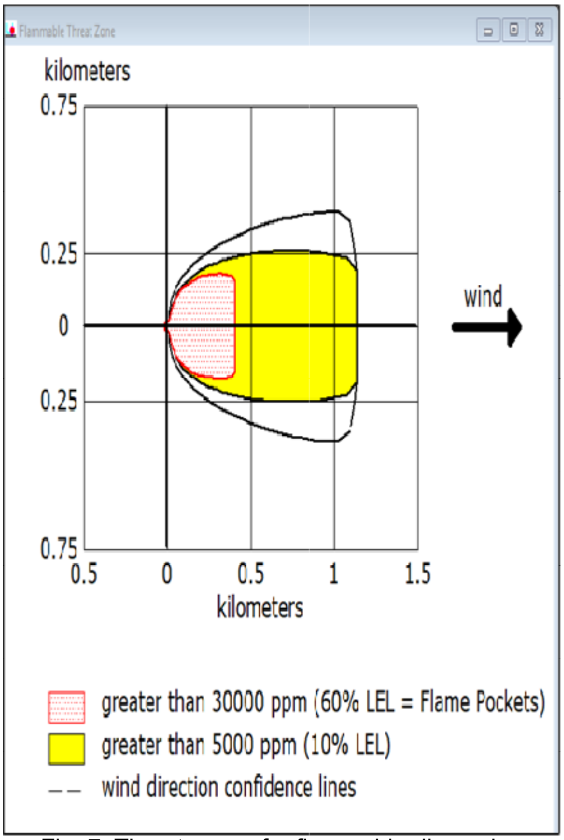


Fig. 7. Threat zones for flammable dispersion

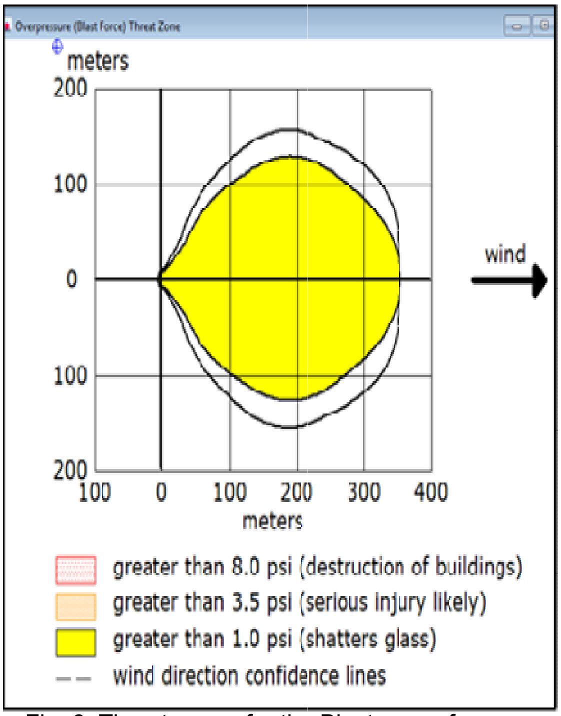


Fig. 8. Threat zones for the Blast area of vapour cloud dispersion

ALOHA display the threat zones in red, orange, and yellow, overlaid on a single picture. By default, the red zone represents the worst hazard. The threat distances and risk levels are summarized in Table 6.

Table 6. summarized threat distances and risk levels of different consequences scenarios

| ***Release Scenario*** | ***Source and leak size of release*** | ***Modelled Consequence*** | ***Threat zones (distance)*** | | | | | |
|---|---|---|---|---|---|---|---|---|
| Liquefiednatural gas release | Vertical cylindrical storage tank (Hole of 500 mm) | Thermal radiation from pool fire hazard | Red | Risk | Orange | Risk | Yellow | Risk |
| | | | 15m | Very High | 20m | High | 28m | Medium |
| | | Toxic vapour cloud | 110 m | Very High | 150m | High | 270 m | Medium |
| | | Flammable area of vapour cloud | 300 m | Very High | No level of concern | | 1100 m | Medium |
| | | Blast area of vapour cloud dispersion | No level of concern | | | | 350 m | Medium |

## 5. Conclusion

This paper presents risk assessment tools to identify causes, consequences, safety barriers and scenarios simulation of risks related to LNG storage tanks. In this study:

A HAZOP study was conducted for an LNG storage operating system to identify pressure hazards causes, consequences and safeguard to prevent such risks.

A bowtie analysis was conducted for LOC of flammable liquids from storage tanks

A fault tree analysis was also illustrated for the top event "tank failure" to present a logical sequence related to level pressure variation that leads to the undesired event.

The outcomes for the LNG release scenario have been identified and the threat zones are plotted in the ALOHA software as contours for thermal radiation, toxicity, flammability, and overpressure.

## References


[1] M. R. Martins, M. A. Pestana, G. F. M. Souza, and A. M. Schleder, "Quantitative risk analysis of loading and offloading liquefied natural gas (LNG) on a floating storage and regasification unit (FSRU," *J. Loss Prev. Process Ind.*, 2016.

[2] T. Xie, X. Lu, G. Wang, and F. Lin, "Research on Safety Risk, Prevention and Control in Port Dangerous Goods Container Yard," *J. Phys. Conf. Ser.*, vol. 1910, no. 1, 2021.

[3] *IMDG CODE INTERNATIONAL MARITIME DANGEROUS GOODS CODE*, 2018 EDITI., vol. V. INTERNATIONAL MARITIME ORGANIZATION, 2018.

[4] M. A. Ramos, E. L. Droguett, M. R. Martins, and H. P. Souza, "Quantitative risk analysis and comparison for onshore and offshore LNG terminals: The port of Suape - Brazil case," *Proc. Int. Conf. Offshore Mech. Arct. Eng. - OMAE*, vol. 2, no. November 2017, pp. 885–892, 2011.

[5] C. Vianello and G. Maschio, "Risk

analysis of LNG terminal: Case study," *Chem. Eng. Trans.*, vol. 36, no. October 2015, pp. 277–282, 2014.

[6] S. Kabir and Y. Papadopoulos, "Applications of Bayesian networks and Petri nets in safety, reliability, and risk assessments: A review," *Saf. Sci.*, vol. 115, no. November 2018, pp. 154–175, 2019.

[7] S. Dan, C. J. Lee, J. Park, D. Shin, and E. S. Yoon, "Quantitative risk analysis of fire and explosion on the top-side LNG-liquefaction process of LNG-FPSO," *Process Saf. Environ. Prot.*, vol. 92, no. 5, pp. 430–441, 2014.

[8] I. Animah and M. Shafiee, "Application of risk analysis in the liquefied natural gas (LNG) sector: An overview," *J. Loss Prev. Process Ind.*, vol. 63, no. October 2019, 2020.

[9] K. G. W. Budiarta, D. W. Handani, and A. A. B. Dinariyana, "Quantitative Risk Assessment of LNG Terminal," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 557, no. 1, 2020.

[10] M. Giardina and M. Morale, "Safety study of an LNG regasification plant using an FMECA and HAZOP integrated methodology," *J. Loss Prev. Process Ind.*, vol. 35, pp. 35–45, 2015.

[11] R. Bubbico, S. Di Cave, and B. Mazzarotta, "Journal of Loss Prevention in the Process Industries Preliminary risk analysis for LNG tankers approaching a maritime terminal," *J. Loss Prev. Process Ind.*, vol. 22, no. 5, pp. 634–638, 2009.

[12] G. W. Yun, W. J. Rogers, and M. S. Mannan, "Risk assessment of LNG importation terminals using the Bayesian-LOPA methodology," *J. Loss Prev. Process Ind.*, vol. 22, no. 1, pp. 91–96, 2009.

[13] American Bureau of Shipping, *RISK ASSESSMENT APPLICATIONS FOR THE MARINE AND OFFSHORE INDUSTRIES*, no. May. American Bureau of Shipping, 2020.

[14] ISO/IEC 31010: Risk management, *INTERNATIONAL STANDARD*. 2019.

[15] J. Koo, H. Soo, W. So, K. Hwoi, and E. Sup, "Safety Assessment of LNG Terminal Focused on the Consequence Analysis of LNG Spills," 2009.

[16] H. Shao and G. Duan, "Risk quantitative calculation and ALOHA simulation on the leakage accident of natural gas power plant," *Procedia Eng.*, vol. 45, no. 4, pp. 352–359, 2012.

[17] E. Y. Prasetyo, H. B. Santosa, F. Kasim, Nikita, and Y. Ayash, "Risk assessment and mitigation of fire in compressed natural gas (CNG) station using ALOHA and fault tree method at PT. Sarihusada Generasi Mahardhika 2 Klaten," *AIP Conf. Proc.*, vol. 2223, 2020.