DNV·GL

TECHNICAL MEMO

Review of Vapour Cloud Explosion and BLEVE Risk

Project No:
PP208234
Memo No:
119XBY25-2/ NPO
Revision No:
Rev 1
Date of issue:
2018-06-19

To:

AGL Energy Ltd

Attn:

Jay Gleeson; Brian Kitney, Will Pulsford

Copied to:

From: Oil & Gas
O&G Australia Operations

Prepared by: Neil Pollock B.Eng MSc C.Eng MRINA

Approved by: Mike Johnson MA CPhys MInstP

Applicable contract(s) governing the provision of this Report:

1 SUMMARY

DNV GL has provided a peer review of the content and assumptions used within the academic paper “Fire and explosion risk analysis and evaluation for LNG ships LI Jianhuaa, HUANG Zhenghuab”. The paper makes three separate calculations to estimate the consequences of a catastrophic incident affecting a large volume of gas in a marine application of LNG.

Three methods were used to establish values for dispersion, volume and radius of lethal exposure following ignition of a gas cloud, these are as follows;

1. Fireball resulting from a gas leak from an LNG Cargo tank followed by BLEVE event. Calculation method specified as “International Labour Organisation”.
2. “DOW safety assessment method” assumed to be the “Dow's Fire and Explosion Index”
3. Vapor Cloud Explosion. Based on “TNO 1979”.

For the application of BLEVE to marine LNG storage there must be liquefied gas held at pressure with direct fire impingement on the structure of the tank. Marine LNG tanks are cryogenic tanks separated from external heat sources and are not pressure vessels and as such cannot fail in a way that will cause a BLEVE or any similar catastrophic failure. Additionally, there is no reference for the calculation they have used as the International Labour Organisation does not provide technical guidance in such areas. Similar calculation forms have been identified for LPG but several magnitudes less severe.

The Vapour Cloud Explosion risk calculation presented within the paper is again unreferenced beyond “TNO 1979”. While not clear this appears to be a reference to the TNO Multi-Energy Method. The calculation provided to determine the explosion energy of a vapour cloud explosion assumes that the total volume of gas in the vapour cloud is 92million cubic meters. This equates to the total volume of LNG within the vessel, vapourised instantly without any dispersion and mixed with air to make a flammable mixture. The authors have not provided an explanation of how the cargo escapes the LNG carrier or how the gas could mix with air and create this scenario. In addition, they have taken no

account of the conditions required to generate a Vapour Cloud Explosion. DNV GL has conducted leading experimental research into this topic, demonstrating the need for process congestion or confinement, neither of which are present in this case, hence delayed ignition of any vapour cloud would not generate damaging pressures in the area around the vessel.

Of the above only Dow's Fire and Explosion Index is from a recognised text used within industry. The reference would more accurately be the "Fire and Explosion Index Hazard Classification Guide 7th Edition" and is presented/authored by the American Institute of Chemical Engineers. The method is applicable to chemical plant processing units and above ground storage of products in tanks and exposed spheres. The LNG tanks in an LNG Carrier are not exposed but protected by structural steel and insulation. The LNG carrier is not located within a chemical processing facility and the associated co-related risks.

In summary the Li and Huang Paper presents explosion scenarios that are not relevant to LNG ships and makes reference to unclear sources. They have applied generic hazard assessment methods without any understanding of the physical mechanisms involved and as such the paper is, at best, naïve in its statements. Its hazard scenarios are incorrect as are its conclusions regarding potential hazards at distance from a marine LNG Carrier.

2 INTRODUCTION

2.1 Qualification and Experience of DNV GL

DNV GL are one of the leading Classification and advisory organisations in LNG industry. DNV GL have been involved in the design and approval of ship based transportation of LNG since 1954. 60% of the global FSRU fleet is Classified by DNV GL, and over 25% of all LNG carriers are similarly classed by DNV GL.

DNV GL is also a leader in the management and modelling of risks and their consequences. DNV GL operate and markets the world-leading consequence analysis program Phast, and operates one of the world leading explosion and consequence modelling facilities at Spadeadam in the UK.

2.2 Types of LNG Cargo Containment

The type of containment of LNG Carriers is an important factor in considering the potential hazards. The following description is a brief summary of the main aspects of LNG cargo tank design.

LNG Carrier (Tanker) general arrangements consist of a high sided tanker hull construction containing either 4 or 5 LNG cargo tanks. The cargo tanks are separated from the outer hull by double sided structural arrangement that contains the ships ballast water tanks. Aft of the cargo containment are the ships machinery spaces, engines, steering systems and all accommodation and control facilities. See Figure 1.

Two principal LNG cargo containment systems are used for trading LNG Carriers. Spherical tanks, also known as Moss tanks, and Membrane Containment. Roughly 20% of the world LNG fleet are built with Moss tanks, the remainder membrane. The proportion of membrane ships is growing as this is the more favoured construction type for new ships. A very small number of trading LNG Carrier have a tank system referred to as SPB type. This type is considered for some offshore production facilities.

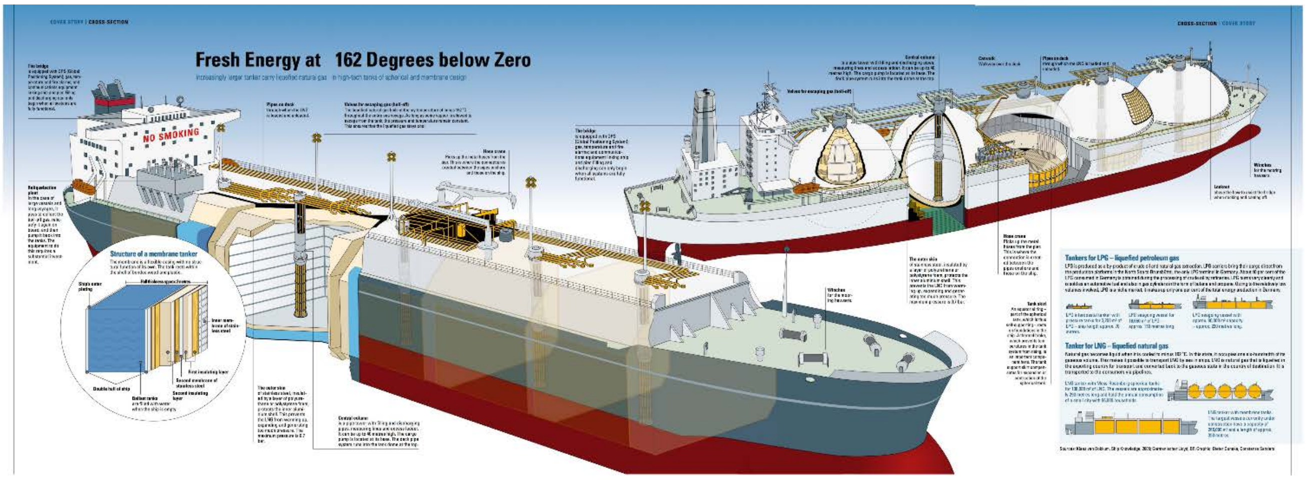

Figure 1 LNG Carrier Arrangements

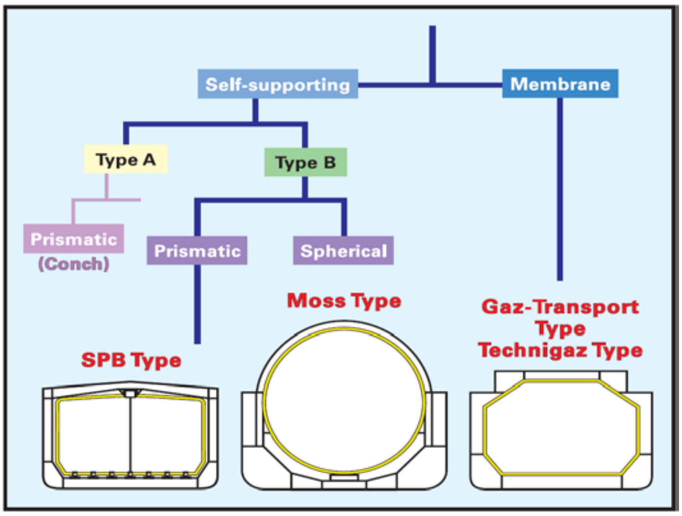

Figure 2 Different types of LNG Carrier Cargo Tanks

2.2.1 Moss Type LNG Cargo Tanks

Also known as IMO Type B self supporting tank, the tanks are thick aluminium, stainless steel or rarely 9% Nickel steel spheres. LNG is contained at cryogenic temperatures (-163degC) and at atmospheric pressure with a design overpressure of 0.03bar, twin redundant pressure relief valves are set at 0.025bar to prevent over pressure. The tanks are insulated by applying insulation foam or panels to the side of the spherical tank. This insulation is then encased in a metal foil. The space between the metal foil and tank is then inerted using nitrogen.

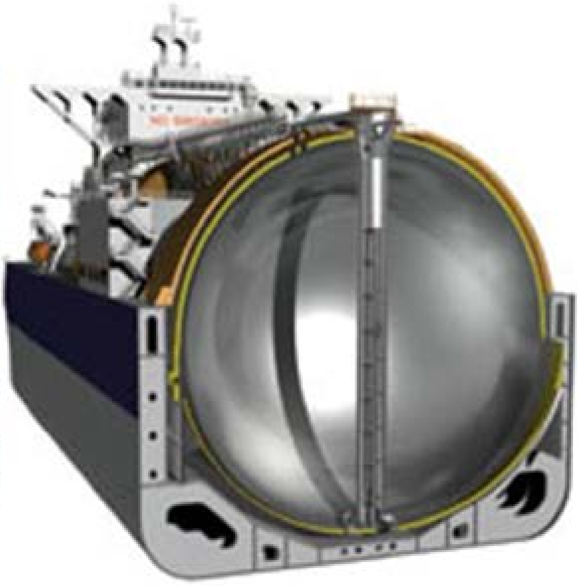

Figure 3 Moss (Spherical) type LNG Carrier

2.2.2 Membrane Type LNG Cargo Tanks

LNG is maintained at atmospheric pressure within two independent thin metal membranes. These membrane layers are insulated from each other and then from the ships inner hull. As with the Moss tanks the space between the membranes is inerted. The pressure relief valves for membrane cargo tanks are designed for the same settings as that listed above.

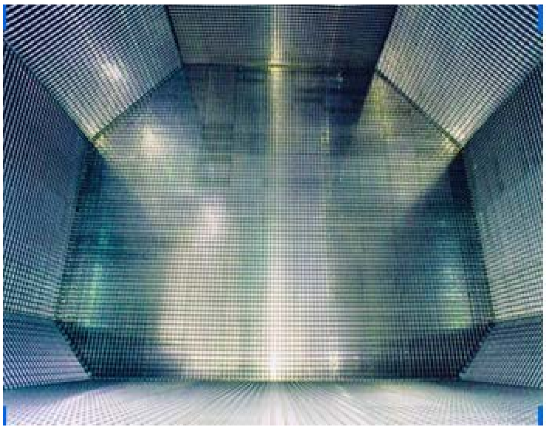

Figure 4 Membrane type LNG Carrier

3 REVIEW OF LI AND HUONG PAPER

3.1 Introduction to the Li and Huong Paper

This section gives a critical review of the paper written by LI Jianhuaa, HUANG Zhenghuab, both of the Chinese People's Armed Police Force Academy given at an event called the 2012 International Symposium on Safety Science and Technology held in Nanjing. The title of the paper given is "Fire and explosion risk analysis and evaluation for LNG ships". It also appears on the first page of Google when searching for explosion/LNG/Ship searches.

The paper appears to written by two unknown authors in the field of explosion science (neither author has presented similar papers at earlier or later conferences or in searches of academic paper databases). The authors are referenced as being from the Fire Faculty of the Chinese People Armed Police Force Academy.

The paper presents consequence calculations for extreme explosion events for LNG storage derived from three different methods. The LNG tank type and vessel size is given as a 147,000m^3 capacity Moss type LNG Carrier. The capacity of a single tank modelled is approximately 40,000m^3 and is in line with the size of tanks for the vessel shown in Figure 3 (Grand Helena). Crucially the paper makes an error in assuming the pressure of the cargo tanks as "design pressure 0.5 MPa, the maximum working pressure 0.45 MPa", (5.0 and 4.5 bar respectively) as outline above this is incorrect.

Three methods were used to establish a value for dispersion, volume and radius of lethal exposure, these are as follows;

1. Fireball resulting from a gas leak from an LNG Cargo tank by BLEVE event. Calculation method specified as "International Labour Organisation".
2. "DOW safety assessment method" assumed to be the "Dow's Fire and Explosion Index"
3. Vapor Cloud Explosion. Based on "TNO 1979".

3.2 BLEVE Risk for Marine LNG Cargo Containment

3.2.1 What is a BLEVE?

A description of a Boiling Liquid Expanding Vapour Explosion (BLEVE) is given in Lees (Mannan, 2005) explains the mechanism:

"When a vessel containing liquid under pressure is exposed to fire, the liquid heats up and the vapor pressure rises, increasing the pressure in the vessel. When this pressure reaches the set pressure of the relief valve, the valve operates. The liquid level falls as the vapor is released to the atmosphere. The liquid is effective in cooling that part of the vessel wall which is in contact with it, but the vapor is not. The temperature in the proportion of the vessel wall which has the benefit of liquid cooling falls as the liquid vaporizes. After a time, metal which is not cooled by liquid becomes exposed to the fire; the metal becomes hot and weakens and may then rupture. This can happen even if the relief valve is operating correctly. A pressure vessel is designed to withstand the relief valve set pressure, but only at the design temperature conditions. If the metal has its temperature raised, it may lose it strength sufficiently to rupture."

The figure shown below appears in many text, online articles.

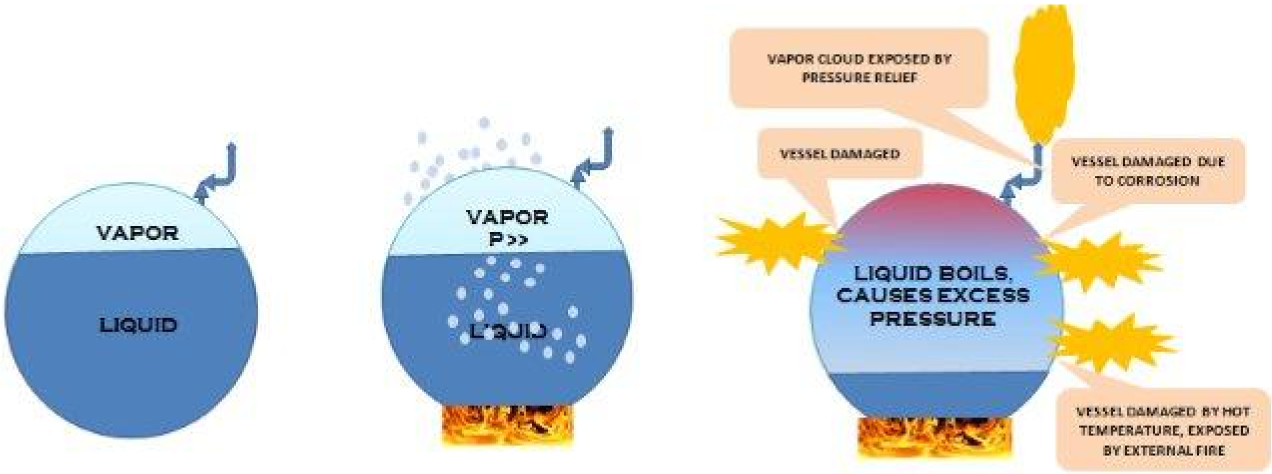

Figure 5 Schematic of a fire event leading to a BLEVE

As per Mannan's description fire impingement on a pressurised liquefied gas tank can result in a BLEVE. BLEVE incidents occur primarily in the LPG industry as explosion events for static LPG tanks or explosion events for mobile storage tanks. The biggest risk of LPG tank BLEVE is in the event of a road accident where a fire occurs that then impinges on the LPG storage tank. In recent years, a number of BLEVE incidents for occurred for LNG tanks used for road transport (Catalonia, Spain, in June 22, 2002 – 1 fatality and 2 injured, China October 6, 2012 5 killed including 3 firefighters). While natural gas explosion events have less power than LPG events these incidents have still involved fatalities.

It is important to note that LNG road tankers will have tanks that can contain the LNG at pressure, with the LNG being well above its ambient boiling point. This is a very different situation to marine LNG tanks.

3.2.2 Can Marine LNG Cargo Tanks BLEVE?

As described above, a BLEVE requires the following conditions;

1. direct high temperature (fire) impingement and;
2. a method of building pressure within a tank to take the liquid well above its ambient pressure boiling point, essential for a BLEVE event.

Marine LNG tanks, as described above, are insulated from the outside environment (to prevent excessive vaporisation of product) and operated at cryogenic temperatures but at pressures only slightly above ambient. The pressure relief systems fitted to the cargo tanks are rated for the scenario of fire impingement to the insulated tank, and 100% redundant. This lack of fire loading to directly impinge on a tank and the inability to develop any significant pressure means **a BLEVE cannot occu**r.

LNG BLEVE incidents have occurred globally but only in road traffic accidents and have occurred in the same manner as LPG tanks subject to fire. These road tankers are pressurised LNG.

The following academic text also support the statement that Marine LNG tanks do not BLEVE. The author has relied on these texts.

Publicly Available.

"LNG RISK BASED SAFETY Modeling and Consequence Analysis" John L. Woodward and Robin M. Pitblado, Copyright © 2010 by John Wiley & Sons.

Internal

DNV LNG QRA GUIDELINE (Internal) Prepared by: F Myrland, Hans Kristian Danielsen, DNV GL Australia, 28. August 2012

3.2.3 BLEVE Calculation

As already stated, the consideration of a BLEVE event in relation to marine LNG tanks is incorrect. However, even given this there are comments that can be made on the application of the calculation method the paper quotes.

The reference to the ILO text is "Major Hazard Control – A practical manual International Labour Organisation 1988.

The book gives the following definition for BLEVE.

1.2.2.1. Boiling liquid expanding vapour explosion (BLEVE)

Sometimes referred to as a fireball, a BLEVE is a combination of fire and explosion with an intense radiant heat emission within a relatively short time interval. As implied by the term, the phenomenon can occur within a vessel or tank in which a liquefied gas is kept above its atmospheric boiling-point. If a pressure-vessel fails as a result of a weakening of its structure, the contents are instantaneously released from the vessel as a turbulent mixture of liquid and gas, expanding rapidly and dispersing in air as a cloud. When this cloud is ignited, a fireball occurs, causing an enormous heat-radiation intensity within a few seconds. This heat intensity is sufficient to cause severe skin burns and deaths at several hundred metres from the vessel, depending on the quantity of the gas involved. A BLEVE can therefore be caused by a physical impact on a vessel or tank which is already overstressed or damaged, for example from a traffic accident with a tank-car or a derailment of a tank-wagon, or it can be caused by fire impinging upon or engulfing a vessel and thus weakening its structure. A BLEVE involving a 50-tonne propane tank can cause third-degree injuries at distances of approximately 200 metres and blisters at approximately 400 metres.

Figure 6 definition of BLEVE from ILO text

As described above the BLEVE event is defined for pressure vessels only. The subsequent text does include the 1973 Staten Island LNG plant fire as an LNG related fire. The fire occurred in a storage tank designed to hold LNG when it was out of service, and contained no LNG, and construction work was being undertaken.

Calculation Method.

The following calculation differences are observed between those presented in the Li and Huang paper and the original ILO text.

	ILO original	Li and Huang
	LIQUEFIED PETROLEUM GAS (LPG) **1.1. BLEVE fireball** (a) Fireball radius : $R = 29M^{1/3}$ where R = fireball radius (m) M = mass of fuel (te) (b) Fireball duration : $t = 4.5M^{1/3}$ where t = duration (sec.) M = mass of fuel (te)	Radius of fireball $R = 2.9W_f^{1/3}$ Duration of fireball $t = 0.45W_f^{1/3}$ --- where R is radius of fireball, m; W_f is the mass of combustible consumed in fireball, kg
Mass	M in the ILO text is in Tonnes	Wf in the paper is in kg.
Constant	29	2.9
Specified Mass		When using the equation provided in the paper and the result given the paper uses a mass of material in the explosion as 59,000tonnes. Each cargo tank of the vessel assumed contains approximately 19,000tonnes of LNG.

As shown above the BLEVE calculation presented in the paper is incorrect in both the applicability to nominally atmospheric LNG tanks and the values used in the calculation.

3.3 Vapour Cloud Explosion

The Vapour Cloud Explosion risk calculation presented within the paper is again unreferenced beyond “TNO 1979”. While not clear this appears to be a reference to the TNO Multi-Energy Method. The calculation provided to determine the explosion energy of a vapour cloud explosion assumes that the total volume of gas in the vapour cloud is 92 million cubic meters. This equates to the total volume of LNG within the vessel, vaporised instantly without any dispersion but also mixed with sufficient air to make a flammable mixture. The authors have not provided an explanation of how the cargo escapes the LNG carrier in such a way.

In addition, they have taken no account of the conditions required to generate a Vapour Cloud Explosion. DNV GL has conducted leading experimental research into this topic at its Spadeadam Research and Testing facility in the UK. This work demonstrated that damaging pressure is only generated by combustion of a vapour cloud in two special sets of circumstances.

The first mechanism for generating pressure involves confinement of the vapour cloud. Combustion raises the temperature of the gases in the cloud, but the confinement prevents expansion. As a consequence, the pressure will rise until the confining structure fails. In the case of a marine LNG tanker, there is no significant confinement available and certainly none that could contain the full vapour cloud. This pressure generation mechanism can therefore be excluded.

The other way pressure can be generated is by the vapour cloud engulfing significant areas of congestion (most likely process pipe work). In this case, expansion of the combustion products is possible as there is no confinement. The expansion generates flow that interacts with the congestion in a way that enhances the rate of combustion. This mechanism leads to flame acceleration to high speeds and it is the speed of the flame that generates the damaging pressures. Typically, flame speeds well in excess of 100 m/s are required.

Again, for marine LNG Carriers, there is no significant congestion in their vicinity and therefore the application of the generic vapour cloud explosion calculation methods shows a lack of understanding of the physical mechanisms involved. The scenario they consider is not possible.

3.4 Dow Method

Of the above only Dow's Fire and Explosion Index is from a recognised text used within industry. The reference would more accurately be the "Fire and Explosion Index Hazard Classification Guide 7th Edition" and is presented/authored by the American Institute of Chemical Engineers. The method is applicable chemical plant processing units and above ground storage of products in tanks and exposed spheres. Again, the LNG tanks in an LNG Carrier are not exposed but protected by structural steel and insulation. The LNG carrier is not located within a chemical processing facility and the associated co-related risks, i.e. the LNG carrier cargo tanks are not exposed and the adjacent risks are very different. DNV GL have found no previous studies equating the Dow method to LNG shipping risks.

4 CONCLUSION

In summary, the Li and Huang Paper presents explosion scenarios that are not relevant to LNG ships and makes reference to unknown sources, or erroneous applies techniques to the LNG mariner risks. They have applied generic hazard assessment methods without any understanding of the physical mechanisms involved and as such the paper is, at best, naïve in its statements. Its hazard scenarios are incorrect as are its conclusions regarding potential hazards at distance from a marine LNG tanker.