PEMBINA

April 1, 2015

André Baugh, Chair
Planning and Sustainability Commission
City of Portland
1900 SW 4th Avenue, Suite 7100
Portland, OR 97201-5380

**RE: Terminal 6 Environmental Overlay Zone Text and Map Amendment Quantitative Risk Assessment Workshop Video and DNV-GL Review of the Northwest Citizen Science Initiative March 7, 2015 Report**

Dear Chairman Baugh and Commissioners:

On March 10th, 2015, Pembina coordinated a technical workshop hosted by Det Norske Veritas (DNV) on the facility's Quantitative Risk Assessment (QRA). DNV is the leading global risk assessment firm hired to review Pembina's safety mitigation design and produce a risk assessment report for the facility. The workshop comprised of technical experts, community members, city and PSC staff, area first responders and safety personnel. Pembina has prepared a video of this workshop that can be accessed through the following link:

http://www.pembina.com/propaneterminal/qra-video/ .

Pembina requested DNV review the March 7, 2015 report "Proposed Propane Marine Terminal in Portland" that was prepared by A. Roxborough, R. Ebersole, T. Helzer and the Northwest Citizen Science Initiative. Their review of this report is provided in the attached memo for your information.

Regards,

Eric Dyck
Vice President, Marine Terminals

Pembina Marine Terminals Inc.
4000, 585 – 8th Avenue S.W., Calgary, Alberta Canada T2P 1G1
Telephone: (403) 231-7500 Fax: (403) 237-0254

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| **Memo to:** | | **Memo No.:** | 1MIJD63-1/ LLAT Rev 1 |
| Chris Hayes | | **Prepared by:** | Lindsay Deal<br>Senior Consultant |
| | | **Date:** | 30 March 2015 |
| **Copied to:** | | **Reviewed by:** | Tone Rice |
| Eric Dyck, Gail Feltham, Dennis O'Mara, Cynthia Spitzenber | | | Head of Section, Safety Risk Analysis |

# Evaluation of Northwest Citizen Science Initiative (NWCSI) March 7,2015 Report

## Summary

The Proposed Propane Marine Terminal in Portland report issued by the Northwest Citizen Science Initiative (NWCSI) on March 7, 2015 applies the NOAA's Areal Locations of Hazardous Atmospheres (ALOHA) model to estimate the consequences for a range of scenarios. DNV GL has reviewed the report and identified a couple of areas for clarification:

- The ALOHA model is designed to estimate radiation and vapor cloud dispersion results in a conservative manner. Additionally, assumptions applied within the ALOHA software represent event series that are IMPOSSIBLE.
  - The ALOHA model is unable to estimate overpressures generated by a mechanical explosion from boiling liquid expanding vapor explosions (BLEVE). A fireball that follows the mechanical explosion consumes the flammable material preventing a subsequent vapor cloud explosion.
  - A catastrophic release from the refrigerated tank is modeled as if the tank instantly disappears, all liquid propane vaporizes over the course of one hour, and the resulting vapor cloud disperses only igniting when it gets to the end of the furthest extent of the dispersion. Each of these event attributes are conservative and in reality would take significantly more time to develop.
- A key point in the identification of potential hazardous events at the terminal is the concept of the domino amplifying effect. Events can occur in a cascading fashion like dominos in that they are both causal and sequential but they are not amplifying. Each subsequent event is not necessarily worse than the previous one and the released energy from each event is not strictly additive.
- An earthquake exceeding the design capacity of the facility can initiate a release. Both the frequency of such an event and the potential extent of the consequences are clarified.
- Consequences are only one portion of the picture. To fully understand the impact to workers onsite and the community at-large, the frequency of such scenarios should be considered as well.

## ALOHA Model Use

The ALOHA model is conservative by design as explicitly stated by the associated technical documentation:

"*ALOHA is designed to provide a close upper bound to the threat distances associated with chemical spills. Wherever uncertainty is unavoidable, ALOHA will err in favor of overestimating rather than underestimating threat distances. In some cases, ALOHA will significantly overestimate threat zones*." (1)

The conservative nature of the ALOHA model is appropriate given uncertainty in the input information available to the NWCSI at the time of the estimates but should be noted. All consequence modeling tools, even the most conservative, require the user to have a thorough understanding of the sequence of events expected for each scenario.

The NWCSI report includes results from 3 scenarios modeled at the Pembina site:

1. BLEVE of a single 125,000-gal pressurized tank
2. BLEVE of a hypothetical 1,000,000-gal pressurized tank
3. Release of unignited vapor from a hypothetical 33.6-million gal refrigerated storage tank

Fireball diameters and thermal radiation from BLEVE modelling are relatively simple in nature and align well with more extensively validated models. However, overpressures from a BLEVE are the result of a mechanical explosion, the vapor pressure within the tank overcomes the strength of the containment, rather than a vapor cloud explosion, a flammable mixture of fuel and air which ignites and combusts at high speeds. ALOHA is unable to model the blast force from the mechanical explosion associated with a BLEVE. The methodology applied to estimate overpressures from BLEVE releases in the NWCSI report is unclear but appears to be the result of a detonation of a vapor cloud, presumably using the mass of propane originally within the tank. A more appropriate estimation method for a mechanical explosion is outlined in the CCPS book (2) and is applied using Phast Risk in the Facility QRA Report (3).

The ALOHA model is also unable to model the range of projectiles associated with a BLEVE. The NWCSI report applies a common and accepted method for estimating the extent of the projectile range, applying a factor to the fireball radius. A full description of the applied method is discussed in the Projecting Fragments section.

NWCSI also estimated the unignited vapor cloud distance from a hypothetical 33.6-million gallon refrigerated tank using the Direct Source model within ALOHA, which "*allows the user to directly specify the amount of chemical vapors introduced into the air from a point in space*." (1). The implied assumption is that the tank walls disappear and the entire content of the hypothetical tank vaporizes within 1 hour. A more accurate representation of a catastrophic release of the hypothetical tank would be initial vaporization and the formation of a large liquid pool. If unignited, the liquid in the pool would warm up and continue to vaporize, at an average rate of about 590 gal/s in daytime summer conditions, forming a vapor cloud that is carried downwind. The ultimate cloud size is, therefore, dependent on the rate of the pool vaporization rather than the release rate of the material. The pool vaporization rate varies with ambient temperature of the catastrophic tank event and is considered for all weather cases in the Facility QRA Report (3).

# Nature of BLEVE and Cascading Events

## BLEVE

Boiling liquid expanding vapor explosions (BLEVE) are serious explosion events caused by catastrophic failure of Pembina's proposed steel, pressurized tank. During prolonged exposure to an external fire, the steel below the liquid level is cooled as the liquid propane vaporizes and the tank structure remains strong. The propane vapor generated by boiling discharges through the relief valve and the tank pressure remains at close to normal operating level. However, above the liquid level in the tank, the steel is poorly cooled by vapor and is heated by the fire. Hydrocarbon fires burn at approximately 2000°F and once the steel reaches 1020°F it is about half as strong as steel at ambient temperature. The reduction in strength near 1020°F may result in catastrophic failure of a typical steel tank shell. Since the typical tank design includes a safety factor of 2, i.e. it is designed to be twice as strong as it needs to be under normal conditions, it is typically overcome by the weakening due to temperatures near 1020°F.

A BLEVE is significantly less likely to occur with higher liquid levels with which Pembina plans to operate. Additionally, Pembina plans to monitor the facility using both instrumentation and 24-hour trained personnel. Active monitoring further reduces the probability that prolonged heat exposure which may initiate a BLEVE is present. Both fire protective coating and water deluge delay the rate at which the steel tank shell increases temperature and can delay or prevent BLEVE effects.

Upon catastrophic failure of the steel tank shell, the entire liquid contents of the tank is released, immediately vaporizes and is ignited by the fire that caused the structural failure. This creates

1) An overpressure wave that affects anything in the immediate vicinity
2) Large fragments from the ruptured vessel which can be projected
3) A ground-level fireball that burns and rises upwards radiating a powerful thermal hazard zone

## Cascading Events

The fragments from a BLEVE can cause additional secondary or cascading events. The BLEVE, itself, is a cascading event since it requires a catastrophic tank failure to initiate and is included in the Facility QRA Report (3). These events are like a cascade of dominos in that they are both causal and sequential. Cascading events do not, however, imply any directionality (either increase or decrease) in severity from one event to the next.

The consequences from each subsequent event are not always additive. Since cascading events are necessarily separated by time, certain short-duration consequences (radiation from fireballs, overpressure waves and projectiles) are independent, rather than an amplification of the short duration consequences from previous and subsequent events. The scenario of 1) a prolonged fire exposure leading to 2) a BLEVE of a pressurized tank resulting in a fireball and projectiles that impact a second pressurized tank, and 3) a BLEVE of the second pressurized tank, would have overpressure, projectile impact and radiation consequences. However, only the radiation consequences are likely to be additive.

## Overpressure

Each overpressure wave is the result of a mechanical explosion, rather than a vapor cloud explosion, and moves at sonic speeds (4). Given the extremely short duration of the overpressure waves, a near-simultaneous event is not equivalent to a simultaneous event, a BLEVE of the hypothetical 1,000,000-gal pressurized tank. The result would be two overpressure waves of roughly equal strength and equal effect zones separated by the short period of time required for a projectile to impact the second tank rather than a single overpressure wave with two times the strength and a larger effect zone. The second blast could cause some additional damage within the same effect zone due to structural weakening of buildings caused by the first blast.

## Projecting Fragments

The mechanical explosion from a BLEVE can also result in tank fragments projecting a distance from the source. The most common method for estimating the range of the distance is based on observations from BLEVE events. A rough factor is applied to the radius of the fireball to get an estimate of the size of the impact zone of projecting fragments (5):

- 80-90% of projectiles fall within 4 times the radius of the fireball from the tank
- Severe rockets can go 15 times the radius of the fireball
- In very severe, very rare cases it may be possible to see fragments travel 22-30 times the radius of the fireball The NWCSI report shows the contour associated with the 30 times the radius of the fireball.

## Radiation

Radiation from the initiating fire would last the duration of the event. Radiation from each fireball occurs for roughly 20 seconds if each 125,000-gal tank is full (6). The radiation from the fireballs are additive with the radiation from the initiating fire and each other only if the subsequent BLEVE occurs within 20 seconds of the first at a particular location. The result would be more intense radiation flux close to the source and larger radiation flux zones when compared to consequences of just the initiating fire but smaller radiation zones than modelling the hypothetical 1,000,000-gal pressurized tank BLEVE.

## Vapor Cloud Explosion (VCE)

Should the overpressure or a projectile from a BLEVE event breach the wall of the refrigerated storage tank or cause a catastrophic failure, liquid propane and the portion that vaporizes as the propane warms would be released. A vapor cloud explosion (VCE) requires both time for the cloud to form prior to ignition and some form of confinement or congestion. If not ignited immediately from the mechanical impact of the projectile with the tank structure, propane released from such a scenario could only form a vapor cloud until it reached the fire that initiated the BLEVE or another source of ignition. Once ignition occurs, the vapor cloud stops growing and starts combusting. The ignition would most likely cause a flash fire that would burn back to the source of the release and result in a large pool fire at the refrigerated tank. The facility does, however, have small areas of congestion such as the areas around the refrigeration equipment that could produce some overpressure in a deflagration-type VCE.

The difference between a detonation-type VCE and a deflagration-type VCE is the speed at which the flame front moves through the cloud of a propane-air mixture. For a propane-air mixture to undergo the deflagration to detonation transition (DDT), the proper ratio of air and propane needs to be present in either a confined or highly-congested region. Confinement refers to the degree to which the cloud is enclosed. Confinement prevents the mixture from expanding as it combusts and thus builds pressure that is released when the confinement fails increasing the subsequent speed of the flame front. Congestion refers to the degree to which the cloud surrounds solid obstacles. As the mixture expands during combustion, these obstacles create turbulence which further mixes the cloud, and increases the speed of the flame front. For detonation of propane to occur, the cloud needs to pass through an extended region where these obstacles are close together.

A catastrophic failure of a refrigerated tank with a resulting vapor cloud is included in the Facility QRA Report (3), as a potential independent event rather than a cascading-type event. That event in a cascading scenario is more likely to be ignited early, with limited development of the vapor cloud, than the independent event included in the Facility QRA Report (3).

## Earthquakes

DNV GL are not geotechnical experts and cannot comment on the movement of the ground given a major earthquake in the Portland area. However, the Pembina facility is designed to exceed the 2014 Oregon Structural Specialty Code and is built to handle all predicted seismic events in the Portland and Oregon region. The targeted risk level of 1% in 50 years is derived from the probabilistic Maximum Considered Earthquake in the 2014 code, (7) and is equivalent to 1 tank failure in 5000 years of terminal operation due to an earthquake. There would statistically need to be 200 identical terminals, each operating for 25 years, to experience one earthquake-initiated tank failure.

An earthquake that exceeds the design criteria could cause a catastrophic rupture of one of the refrigerated tanks and result in a large release of liquefied propane, which would begin to vaporize, mix with air and form a vapor cloud that moves with the wind. For a vapor cloud to reach this largest possible size, the flammable portion of the cloud cannot come into contact with any ignition sources until the full dispersion is achieved. In a populated area, especially if the event is initiated by an earthquake, uncontrolled ignition sources are abundant. Once ignition occurs, the vapor cloud stops growing and starts combusting and the full possible extent of the cloud is never reached.

A more likely scenario initiated by an earthquake is the misalignment of a connection point to the refrigerated tank resulting in a much slower vapor release. Given ignition and the resulting prolonged heat exposure to the pressurized tanks, a cascading series of events could occur as described in the previous section.

## Consequence and Risk

With the exception of a brief discussion about earthquake frequency, the NWCSI report strictly focuses on consequences. Consequences can be particularly helpful in emergency planning for both intentional and accidental releases but are only a portion of the picture. Cascading event scenarios are possible and should be modeled from a consequence perspective based on realistic potential scenarios to identify security-specific protections.

However, to fully understand the impact to workers onsite and the community at-large, the frequency of accidental releases should be considered along with the potential consequences. Consequences discussed in the NWCSI report are among the largest in the full range of possible consequences. The largest events occur at the lowest frequencies. A BLEVE scenario is estimated to occur less than one time in every 8000 years of terminal operation, even without accounting for fire protection or water deluge. The combination of the consequences and frequency for the full range of scenarios is available in the DNV GL report (3).

## References

1. **NOAA Technical Memorandum NOS OR&R 43.** *ALOHA® (AREAL LOCATIONS OF HAZARDOUSATMOSPHERES) 5.4.4 Technical Documentation.* November 2013.

2. **CENTER FOR CHEMICAL PROCESS SAFETY of the American Institute of Chemical Engineers.** *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs.* 1994.

3. **DNV GL.** *Pembina Propane Export Terminal Facility QRA Report PP124992 Rev 1.* 16 March 201.

4. **Khan, F. I. e Abbasi, S. A.** *Risk Assessment in the Chemical Process Industries.* s.l. : Discovery Publishing House, Jan 1, 1998 .

5. **Birk, Dr. A. M.** *"BLEVE Response and Prevention, Technical Documentation" prepared for Transport Canada, Department of Mechanical Engineering, Queen's University, Kingston Ontario, Canada .* September 1995.

6. **Roberts, Michael; EQE International, Inc.** *Analysis of Boiling Liquid Expanding Vapor Explosion (BLEVE) Events at DOE Sites.* 2000.

7. **Bureau of Planning and Sustainability, City of Portland, Oregon.** *Terminal 6 Environmental Overlay Zone Code Amendment and Environmental Overlay Zone Map Amendment. Part 1: Environmental Overlay Zone Code Amendment.* December 12, 2014.