Incorporating Asphyxiation and Cryogenic Hazards into Risk Analysis

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Overview

Risk Assessment – Hidden Dangers of LNG
- Summary
- Introduction to LNG Hazards
- Asphyxiation Hazards & Modeling Parameters
- Cryogenic Hazards & Modeling Parameters
- Consequence Modeling
- Application in Design
- Guidelines and Mitigations
- Conclusions
- Questions
Introduction to LNG Hazards

Basic LNG factoids:

- Imported LNG is commonly 89% – 97% C1
- LNG is transported at ambient pressures and stored in low pressure cryogenic tanks. ~ 60 - 100 psi
- Liquefying natural gas vapor, which reduces the gas into a practical size for transportation and storage, reduces the volume that the gas occupies more than 600 times
- LFL approx. 5% and UFL approx. 15% at 77°F
- A visible white cloud upon vaporization
- Vapor is heavier than air at vapor temperatures below about –113°C (-171°F)
- Vapor is non-toxic, colorless, odorless and, asphyxiant
- liquid is cryogenic, requiring special materials of construction
Introduction to LNG Risk Analysis

1) Consequence Analysis typically covered for accidental release risk analysis
   - Heat radiation, and/or direct flame contact
     - jet fire
     - pool fire
     - flash fire
   - Overpressure from a vapor cloud explosion or an explosion in confined or highly congested space.
   - Overpressure from a rapid phase transition.

2) Consider other “hidden dangers” of LNG in Consequence Analysis
   - Although non-toxic, LNG (vapor) has the potential to cause asphyxiation, particularly if exposure occurs in a confined space
   - Cryogenic/low temperature hazards
     liquid (e.g. skin contact)
     vapor (e.g. skin contact and vapor inhalation)
Asphyxiation Hazards & Effects

An atmosphere with marginally less than 21% oxygen can be breathed without noticeable effects.

At the minimum oxygen concentration (MOC) of 19.5%

OSHA's lower limit for confined space entry in 29 CFR 1915.12, there is a rapid onset of impairment of mental activity.
# Asphyxiation Hazards & Effects

## Summary of asphyxiant effects

<table>
<thead>
<tr>
<th>MOC by Volume in Air (at Sea Level)</th>
<th>Physiological Symptoms or Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.9%</td>
<td>Normal</td>
</tr>
<tr>
<td><strong>20.9 to 19.5%</strong></td>
<td>Some adverse physiological effects, but they are unnoticeable.</td>
</tr>
<tr>
<td><strong>19.5% - 16%</strong></td>
<td>Increased pulse and increased breathing rate with disturbed muscular coordination.</td>
</tr>
<tr>
<td><strong>16 – 15 %</strong></td>
<td>Impaired thinking and attention. Reduced coordination.</td>
</tr>
<tr>
<td><strong>15% - 10%</strong></td>
<td>Faulty judgment, rapid fatigue, insensitivity to pain. Impaired respiration that might cause permanent heart damage. Nausea and vomiting.</td>
</tr>
<tr>
<td><strong>10% - 6%</strong></td>
<td>Inability to perform vigorous movement. Nausea, vomiting, collapse, permanent brain damage</td>
</tr>
<tr>
<td><strong>Less than 6%</strong></td>
<td>Convulsions, cessation of breathing, death</td>
</tr>
</tbody>
</table>
## Asphyxiation Modeling Parameters

### Proposed Asphyxiation Quantitative Risk Criteria

<table>
<thead>
<tr>
<th>Flash fire Range</th>
<th>Parameter</th>
<th>Endpoint</th>
<th>Escape Impairment</th>
<th>Fatality Probability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LFL</td>
<td>5 %</td>
<td>No</td>
<td>50 to 99%</td>
<td>Within a uniform flammable flash fire radius. Increased probability of fatality or severe burns</td>
</tr>
<tr>
<td></td>
<td>½ LFL</td>
<td>2.5 %</td>
<td>No</td>
<td>0 to 50%</td>
<td>Within a flammable flash fire radius with pockets of LFL concentration. Increased probability of injury or burns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Asphyxiation Range</th>
<th>Parameter</th>
<th>Proposed Endpoint</th>
<th>Escape Impairment</th>
<th>Fatality Probability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 % MOC</td>
<td>33.3 %</td>
<td>Yes</td>
<td>70 to 99%</td>
<td>Faulty judgment, rapid fatigue</td>
</tr>
<tr>
<td></td>
<td>16 % MOC</td>
<td>23.8 %</td>
<td>Yes</td>
<td>10 to 50%</td>
<td>Impaired thinking/attention may result in faulty impairment decision</td>
</tr>
<tr>
<td></td>
<td>19.5 % MOC</td>
<td>7.1 %</td>
<td>No</td>
<td>1 to 10%</td>
<td>Some adverse physiological effects, but they are unnoticeable</td>
</tr>
</tbody>
</table>
Cryogenic Hazards & Effects

LNG can cause severe cryogenic burns to exposed skin.

Cryogenic burns are more severe for liquid exposure than for vapor exposure.

On contact with skin, the liquid removes more sensible heat and latent heat of vaporization from the skin.

The potential for fatality can be considered for the following:

- Direct exposure to a liquid release, i.e. for persons caught within a pool of LNG liquid.
- Direct skin and inhalation exposure to cryogenic vapors, i.e. for person caught within a cloud or during escape.
Cryogenic Modeling Parameters

LNG liquid and vapor in the evaporation zone is constantly at -260ºF.

Impairment minimum = -171ºF  (LNG vapor is lighter than air)

Cryogenics as a minimum affect human skin extreme low temperature, generally below -100ºF.

- Basis: The damage to skin tissue considered here is based on small exposure duration (i.e. few seconds for escape) and exposure to a small area of affected/exposed skin tissue.
Cryogenic Modeling Parameters

Cryogenic exposure is a function of exposed area and duration of exposure.

Ladders, handrails, door handles, and platforms

- For aluminum and steel, skin temperatures of 0°C occur within 6 seconds at surface temperatures of 5°F.
- For non-metallic surfaces, onset of numbness occurs within ~ 60 seconds of contact at -31°F and onset of cold pain occurs within 5 seconds of contact at 4°F.

Physiological criteria for onset of pain (15°C), onset of numbness (7°C) and onset of frostbite risk (0°C)
# Cryogenic Modeling Parameters

## Proposed Cryogenic Quantitative Risk Criteria

<table>
<thead>
<tr>
<th>Cryogenic Range</th>
<th>Temp Effect</th>
<th>Phase</th>
<th>Escape Impairment</th>
<th>Impairment Probability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>-260°F</td>
<td>Liquid (pool)</td>
<td>Yes</td>
<td>99%</td>
<td>Immediate liquid cryogenic burns. Permanent damage to skin</td>
</tr>
<tr>
<td></td>
<td>-260°F</td>
<td>Vapor</td>
<td>Yes</td>
<td>50 to 70%</td>
<td>Cryogenic inhalation and damage to skin possible in short duration exposure</td>
</tr>
<tr>
<td></td>
<td>-166°F</td>
<td>Vapor</td>
<td>No</td>
<td>Less than 10%</td>
<td>Cryogenic inhalation may be possible with long exposure duration</td>
</tr>
<tr>
<td></td>
<td>-100°F</td>
<td>Vapor</td>
<td>No</td>
<td>Less than 10%</td>
<td>Some cryogenic inhalation</td>
</tr>
<tr>
<td>Support Structures</td>
<td>-260°F</td>
<td>Liquid (pool)</td>
<td>Yes</td>
<td>99%</td>
<td>Steel structure brittle failure possible with long exposure and without cryogenic passive protection</td>
</tr>
<tr>
<td>Escape handrails / Ladders</td>
<td>-35°F</td>
<td>Vapor</td>
<td>No</td>
<td>Less than 10%</td>
<td>Onset of numbness on non-metallic surfaces</td>
</tr>
<tr>
<td></td>
<td>5°F</td>
<td>Vapor</td>
<td>No</td>
<td>Less than 10%</td>
<td>Onset of numbness on aluminum or steel surfaces</td>
</tr>
</tbody>
</table>
Consequence Analysis

Four LNG scenarios and one Natural Gas scenario are modeled for small accidental releases assuming typical low wind meteorological conditions.

• Loading Arm
• Boil-off Condenser
• Low Pressure Pump
• High Pressure Pump
• Natural Gas (for comparison)

LNG release scenarios are modeled using PHAST 6.53®.
Consequence Analysis

<table>
<thead>
<tr>
<th>Scenarios Based on 25 mm Release Diameters</th>
<th>Asphyxiation</th>
<th>Cryogenic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOC 19.5%</td>
<td>MOC 16%</td>
</tr>
<tr>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>Low pressure LNG from a loading or unloading arm</td>
<td>70</td>
<td>16</td>
</tr>
<tr>
<td>Low pressure Boil-off LNG vessel</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>Low pressure LNG pump</td>
<td>89</td>
<td>31</td>
</tr>
<tr>
<td>High pressure LNG pump</td>
<td>48</td>
<td>17</td>
</tr>
<tr>
<td>High pressure Natural Gas</td>
<td>16</td>
<td>4</td>
</tr>
</tbody>
</table>
Consequence Analysis

Results
Anyone in the vicinity of any release would be at risk of asphyxiation hazard.

- Low pressure LNG release is the most significant hazard for 16% MOC.
- Pool liquid spread is a function of containment.
- The vapor temperatures have similar results in the cryogenic region
  - -171ºF for escape impairment.
  - -100ºF for damage to skin with small exposure duration.

Example = 32 m (100 ft) is a criterion for safe distance to escape routes

Impact of asphyxiation and cryogenic hazards:
- LNG scenarios = Impact on Risk Analysis
- Natural gas = Can be ignored
Incorporating Asphyxiation and Cryogenic Hazards into Risk Analysis

Application in Design

Inherently safer design application

- Minimizing or eliminating hazardous inventories
- Minimizing process facilities and pipe run length where practicable and therefore potential leak sources
- Ensuring that hazardous materials, process and habitation areas are located such that risks to personnel and essential safety systems are ALARP
- Minimizing the potential release of gas and liquids by appropriate provisions of isolation, emergency shutdown and de-pressuring
- Ensuring that the layout and configuration of facilities minimizes the effects of hazardous events.
- Design and channeling of spill containment away from escape routes and manned areas.
General Asphyxiation Guidelines

- Consideration should be given to providing air packs or escape packs where people may be walking in clouds of 19.5% MOC or less.

- Utilizing 16% MOC as a criterion for impairment due to asphyxiation. Literature suggests that impaired judgment due to oxygen deficiency can occur between 16% and 14% MOC. Because each person responds differently, 16% MOC is proposed in order to adequately protect all individuals.
General Cryogenic Guidelines

- Utilizing -171 °F as a criterion for impairment due to cryogenic vapors. Cryogenic temperature of -100°F is utilized as a minimum cut-off for damage to skin with small exposed skin area and exposure duration.

- For long exposure duration, 0°F may be considered for adverse effects on skin.

- Minimize cryogenic impact on liquefied gas on deck or upper part of installation to avoid brittle fractures or spalling in concrete by use of appropriately rated and validated materials, containment of spills, and application of passive fire protection to vulnerable structures.

- In all cases where the temperature is reduced by localized cryogenic storage or other cooling conditions, such factors shall be taken into account in establishing the service temperatures for considered structural parts.
**Spill Containment Guidelines**

Spill containment is a major hazard mitigation measure to control cryogenic fluids.

Stainless steel or aluminum preferred with insulating layer and concrete outer/secondary containment.

Stationary equipment - installation on skids.

The open drain system will collect any rainwater, other wash fluids.

Leaks in LNG welded piping systems will be contained in troughs.

Sufficient deck curbing, barriers should be provided around the perimeter of the deck.
Active Fire Protection Guidelines

Ensure emergency procedures are appropriate and do not increase the risk e.g.:

• Special consideration should be given to design of water sprays as it may increase the rate of evaporation thereby increasing the size of the gas cloud and hence the risk of asphyxiation.

• water sprays, if aimed directly at the liquefied gas, may deflect it to other areas;

• contact between liquefied gas and water may result in a rapid phase transfer which can be violent and present a risk to people nearby;

• water may freeze, producing a slippery surface and impeding escape.

• Fire fighting foam deluge systems mitigate LNG spills by keeping the vapors down.
Conclusions

Typical risk assessments

• Focus on toxic, thermal and explosion consequence events.
• Other hazards have less of an impact
• Other hazards assumed to be less probable events

For LNG processing, this paper shows that potential hazards due to exposure to the cryogenic liquid and vapor, and asphyxiation for personnel can be hidden dangers that need to be addressed in the design by:

• Developing design guidelines and criteria for asphyxiation and cryogenic exposure
• Incorporating this criteria into the design - evaluating in both qualitative and quantitative risk assessments.
• Paying special attention to mitigation, containment, and escape impairment against the developed design criteria.
Questions?