Extent of Thermal Hazards Predicted in Four Recent LNG Carrier Spill Studies

(Lehr/Simecek)
- Not Reported
- 500m Radius 5kw/m²

(Quest)
- 110m Diameter
- 280m Radius ~25kw/m²
- 490m Radius 5kw/m²

(Vallejo)
- 1290m Radius 5kw/m²
- 660m Radius
- 195m Radius

(Fay)
- 343m Radius
- 930 m Radius ~25kw/m²
- 1900m Radius 5kw/m²

Distance Scale

900m

= Fuel Spill Area
Suggested Risk-based Assessment Approach for LNG Carrier Spills

1. Characterize Facilities
2. Define Threats $P_A$
3. Determine Consequences
4. Define Safeguards $P_E$
5. Analyze System $R$
6. Risk = $P_A \times (1 - P_E) \times C$
7. Sufficient Protection?
   - Y: Make Changes & Reassess
   - N: End Until Change
Safety and Consequence Analyses

• Evaluated several breaching events
  – Collisions, groundings, impacts
  – Sabotage and possible attacks

• Evaluated consequences from LNG spills
  – Fire, vapor dispersion, explosions

• Evaluated possibility of cascading damage
  – Cryogenic damage from a spill
  – Thermal damage to structures and LNG vessel from a fire

• Identified high, medium, and low consequence zones for range of possible spills
Analysis of Accidental Breaching of Double Hull Tanker

• LNG tankers designs are robust
• Breaching conditions vary by site
• An LNG container breach can have various results
  – Spill onto water, spill between double hulls, etc.
• Analysis was based on large, 3-D, finite element model results
Analysis of Intentional Breaching of LNG Cargo Tanks

• Assessed “credible threats”
  • Plausible with knowledge and resources
  • Historically observed
• Coordinated analysis with government agencies
• Analysis conducted using modern modeling tools
Summary of Accidental and Intentional LNG Cargo Tank Breach Analyses

- **Accidental breach hole sizes of up to 1.5 m² (1.3 m diameter) possible**
  - No breach for collisions with small boats
  - Conditions for accidental breach unlikely at many sites
  - Current accident safety measures appropriate and effective

- **Intentional breach hole sizes of <2 m² up to 12 m² (<1.6 m to 4 m diameter) possible**
  - Nominal breach size ~5 m² (2.5 m diameter), smaller than used in many studies
  - Cryogenic damage to ship possible for large spills

- **Most events are expected to have an ignition source**
Nominal Conditions Used for Spill, Thermal, and Dispersion Analyses

- Spill of 12,500 m$^3$ per cargo tank
- Liquid height of 15 m above the breach
- Used nominal spill conditions
  - Nominal wind and wind speed
  - General discharge and orifice flow parameters
  - Common data for burn rates, surface emissive power, etc.
- Nominal sensitivity analysis of experimental data variation on hazard results
- Cascading damage hazards considered
Thermal Damage and Consequence Considerations

- Two thermal hazard evaluation criteria were considered
  - 35 kW/m² (major structural damage in 10 minutes)
  - 5 kW/m² (2nd degree burns in 30 seconds, NFPA Standard for land-based LNG)
- LNG Foam insulation degradation
  - Some LNG insulation materials (foams) degrade and decompose around 600-800°F
  - Without safety systems operating, top-side foam insulation decomposition on the order of 5 minutes during a fire
- Fires longer than 5 minutes assessed and sequential, cascading cargo tank failures evaluated
Thermal Hazard Analysis Results for Accidental LNG Breaches and Spills

<table>
<thead>
<tr>
<th>HOLE SIZE (m²)</th>
<th>TANKS BREACHED</th>
<th>DISCHARGE COEFFICIENT</th>
<th>BURN RATE (m/s)</th>
<th>SURFACE EMISSIVE POWER (kW/m²)</th>
<th>POOL DIAMETER (m)</th>
<th>BURN TIME (min)</th>
<th>DISTANCE TO 37.5 kW/m² (m)</th>
<th>DISTANCE TO 5 kW/m² (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>.6</td>
<td>3X10⁻⁴</td>
<td>220</td>
<td>148</td>
<td>40</td>
<td>177</td>
<td>554</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>.6</td>
<td>3X10⁻⁴</td>
<td>220</td>
<td>209</td>
<td>20</td>
<td>250</td>
<td>784</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>.6</td>
<td>3X10⁻⁴</td>
<td>220</td>
<td>362</td>
<td>20</td>
<td>398</td>
<td>1358</td>
</tr>
</tbody>
</table>

Uses nominal input parameters from existing data
Simultaneous, multiple tank damage highly unlikely
## Estimated Impacts to Public Health and Safety from Accidental Spills

<table>
<thead>
<tr>
<th>EVENT</th>
<th>POTENTIAL SHIP DAMAGE AND SPILL</th>
<th>POTENTIAL HAZARD</th>
<th>POTENTIAL IMPACT ON PUBLIC SAFETY³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>~250 m</td>
<td>~250 – 750 m</td>
</tr>
<tr>
<td>Collisions: Low speed</td>
<td>Minor ship damage, no breach</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Collisions: High Speed</td>
<td>LNG cargo tank breach from 0.5 to 1.5 m² spill area</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td></td>
<td>▪ Small fire</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>▪ Damage to ship</td>
<td>High</td>
<td>High - Med</td>
</tr>
<tr>
<td></td>
<td>▪ Vapor Cloud</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grounding: &lt;3 m high object</td>
<td>Minor ship damage, no breach</td>
<td>Low</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

### POTENTIAL IMPACT ON PUBLIC SAFETY³

- **Very low** – little or no property damage or injuries
- **Low** – minor property damage and minor injuries
- **Medium** – potential for injuries and property damage
- **High** – major injuries and significant damage to property
# Thermal Hazard Analysis Results for Intentional LNG Breaches and Spills

<table>
<thead>
<tr>
<th>HOLE SIZE (m²)</th>
<th>TANKS BREACH</th>
<th>DISCHARGE COEFF.</th>
<th>BURN RATE (m/s)</th>
<th>SURFACE EMISSIVE POWER (kW/m²)</th>
<th>TRANSMISSIVITY</th>
<th>POOL DIA. (m)</th>
<th>BURN TIME (min)</th>
<th>DISTANCE TO 37.5 kW/m² (m)</th>
<th>DISTANCE TO 5 kW/m² (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>209</td>
<td>20</td>
<td>250</td>
<td>784</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>572</td>
<td>8.1</td>
<td>630</td>
<td>2118</td>
</tr>
<tr>
<td>5*</td>
<td>1</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>330</td>
<td>8.1</td>
<td>391</td>
<td>1305</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.9</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>405</td>
<td>5.4</td>
<td>478</td>
<td>1579</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.3</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>233</td>
<td>16</td>
<td>263</td>
<td>911</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.6</td>
<td>2 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>395</td>
<td>8.1</td>
<td>454</td>
<td>1538</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.6</td>
<td>8 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>202</td>
<td>8.1</td>
<td>253</td>
<td>810</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>175</td>
<td>0.8</td>
<td>330</td>
<td>8.1</td>
<td>314</td>
<td>1156</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>350</td>
<td>0.8</td>
<td>330</td>
<td>8.1</td>
<td>529</td>
<td>1652</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.8</td>
<td>512</td>
<td>3.4</td>
<td>602</td>
<td>1920</td>
</tr>
</tbody>
</table>

*Nominal case: Expected outcomes of a potential breach and thermal hazards based on credible threats and best available experimental data*
## Estimated Impacts to Public Health and Safety from Intentional Spills

<table>
<thead>
<tr>
<th>EVENT</th>
<th>POTENTIAL SHIP DAMAGE AND SPILL</th>
<th>POTENTIAL HAZARD</th>
<th>POTENTIAL IMPACT ON PUBLIC SAFETY&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>~500 m</td>
<td>~500 – 1600 m</td>
</tr>
<tr>
<td>Insider Threat or Hijacking</td>
<td>Intentional, 2-7 m&lt;sup&gt;2&lt;/sup&gt; breach and medium to large spill</td>
<td>▪ Large fire</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Damage to ship</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Fireball</td>
<td>Med</td>
</tr>
<tr>
<td></td>
<td>Intentional, large release of LNG</td>
<td>▪ Large fire</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Damage to ship</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Vapor cloud fire</td>
<td>High</td>
</tr>
<tr>
<td>Attack on Ship</td>
<td>Intentional, 2-12 m&lt;sup&gt;2&lt;/sup&gt; breach and medium to large spill</td>
<td>▪ Large fire</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Damage to ship</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Fireball</td>
<td>Med</td>
</tr>
</tbody>
</table>

<sup>a</sup> Impacts to public health and safety vary significantly with distance from the spill.

- **Very low** – little or no property damage or injuries
- **Low** – minor property damage and minor injuries
- **Medium** – potential for injuries and property damage
- **High** – major injuries and significant damage to property

*Sandia National Laboratories*
Suggested Risk-based Assessment Approach for LNG Carrier Spills

1. Characterize Facilities
2. Define Threats
3. Determine Consequences
4. Define Safeguards
5. Analyze System
6. Make Changes & Reassess

Risk = \( P_A \times (1-P_E) \times C \)

Risk = Protection Goals

Sufficient Protection?

Y: End Until Change
N: Make Changes & Reassess

\( P_A \): Probability of Accident
\( P_E \): Probability of Equipment Failure
\( C \): Consequence of Accident

Risk = Risk x Protection Goals x Sufficient Protection

End Until Change
LNG Spill Risk Management Analysis

Risks can be responsibly managed through a combination of approaches:

• **Improve risk prevention measures**
  - Earlier ship interdiction, boardings, and searches; positive vessel control during transit; port traffic control measures; safety and security zones and surveillance; or operational changes

• **Locate LNG terminals where risks to public safety, infrastructures, and energy security are minimized**

• **Improve LNG safety and security systems**

• **Improve emergency response, evacuation, and mitigation strategies**
LNG Spill Safety and Risk Analysis Conclusions

- Though limitations in data and modeling exist for LNG spills, current tools, used as identified in the guidance, can help identify and mitigate hazards to the public from a possible spill. As better models and data become available, they can be incorporated into the guidance.
- Consequences from accidental spills using current safety and security practices are generally low.
- Consequences of an intentional breach, absent aggressive prevention strategies, can be more severe than from accidents. The most significant impacts exist within about 500 m of a spill, with much lower impacts at distances beyond 1600 m, even for very large spills.
- Risk-based approaches should be developed in cooperation with stakeholders to reduce risks to public safety and property and compatible with site-specific protection goals.
LNG Spill Analysis and Risk Management Guidance

Zone 1 (High hazard areas)

• Use appropriate and validated analytical models as necessary, especially where interaction with critical infrastructures, terrain, etc. is possible
• Risk prevention and mitigation and emergency response strategies are very important and should be closely coordinated

Zone 2 (Intermediate hazard areas)

• Similar to Zone 1 but less rigorous modeling and risk management operations and strategies required

Zone 3 (Low hazard areas)

• Use of simpler models generally appropriate and nominal risk management operations needed
Report Guidance Designed to Help Sites Evaluate LNG Import Issues

Report provides guidance on assessing site-specific LNG terminal safety and security concerns:

• Site-specific issues
  • location, closeness to critical infrastructures or residential or commercial areas, and available resources

• Assessing potential threats and issues

• Cooperating with stakeholders, public safety, and public officials to identify site “protection goals”

• Modeling and analysis approaches appropriate for a given site, location, or operations

• Assessing system safeguards and protective measures

• Managing risks through cooperative prevention and mitigation to ensure a reliable energy supply while being protective of public safety and property