Guidance on Safety and Risk Management of Large Liquefied Natural Gas (LNG) Spills Over Water

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.
Motivation of Sandia Guidance Report for LNG Spills over Water

• Safety standards exist for LNG spills on land, however not for LNG spills over water

• Results of several previous studies differed greatly due to differences in assumptions and models used

• Previous studies provide little justification for accidental or intentional breach assumptions, cascading damage issues, or how an LNG spill could occur

• Previous studies were limited in scope with a focus on consequences, excluding modern risk management and risk mitigation considerations to improve safety and security
The information and results presented are intended to be used as guidance for conducting site-specific hazard and risk analyses.

The results are not intended to be used prescriptively, but rather as a guide for using performance-based approaches to analyze and responsibly manage risks to the public and property from potential LNG spills over water.
LNG Spill Safety Analysis and Risk Management Guidance

- Provides direction on hazards analyses
- Identifies “scale” of hazards from intentional events
- Provides direction on use of risk management to improve public safety
- Provides process for site-specific evaluations
- Study used many resources: experts on LNG vessel design and operations, explosion and fire modeling, intelligence and terrorism, and risk management from industry and academia
Key Features of LNG Spills Over Water

- **Hole Size/Spilled Volume**
- **Liquid Vaporization**
- **Liquid Spread**
- **Waves Affect Liquid Spread**
- **Fire Entrains Air**
- **Wind Tilts Fire**
- **Fire Increases Vaporization**
- **Thermal Damage Due to Fire**
- **Other possible hazards**
  - Fireball
  - Late ignition and vapor cloud fire

**Analysis Requires Adequate Representation of Key Features**
Extent of Thermal Hazards Predicted in Four Recent LNG Carrier Spill Studies

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

(Quest)
- 110m Diameter
- 190m Radius 5kw/m²
- 280m Radius ~25kw/m²

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

(Vallejo)
- 1290m Radius 5kw/m²
- 660m Radius
- 105m Radius
Behavior of Pool Fires

• Burn rate controls pool area and flame height
• Flame height to pool diameter ratio decreases as pool diameter increases, with transition at very large diameters
• Heavier hydrocarbons produce more smoke than methane for equal diameters, smoke production unknown for LNG pool fires >35 m diameter
• Smoke shielding on average reduces the radiative heat flux level at a distance
Potential Thermal Hazards for Spills from Common LNG Vessels

<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>
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<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>
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<tr>
<td>5*</td>
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<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>
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<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>
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<tr>
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<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>
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<tr>
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<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>
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<td>3 x 10⁻⁴</td>
<td>220</td>
<td>0.5</td>
<td>330</td>
<td>8.1</td>
<td>297</td>
<td>958</td>
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<tr>
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<td>.6</td>
<td>3 x 10⁻⁴</td>
<td>175</td>
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<td>314</td>
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<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, best available experimental data, and nominal environmental conditions for a common LNG vessel.
Potential Dispersion Hazards for Spills from Common LNG Vessels

<table>
<thead>
<tr>
<th>HOLE SIZE (m²)</th>
<th>TANKS BREACHED</th>
<th>POOL DIAMETER (m)</th>
<th>SPILL DURATION (min)</th>
<th>DISTANCE TO LFL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidental Events</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>256</td>
<td>20</td>
<td>1710</td>
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<tr>
<td>Intentional Events</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>405</td>
<td>8.1</td>
<td>2450</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>701</td>
<td>8.1</td>
<td>3614</td>
</tr>
</tbody>
</table>

Dispersion distances are limited by closest ignition source
Potential Thermal and Dispersion Hazards for Spills from Large LNG Vessels

<table>
<thead>
<tr>
<th>HOLE SIZE (m²)</th>
<th>TANKS BREACHED</th>
<th>POOL DIAMETER (m)</th>
<th>DISTANCE TO 37.5 kW/m² (m)</th>
<th>DISTANCE TO 5 kW/m² (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2</td>
<td>640</td>
<td>~750</td>
<td>~2500</td>
</tr>
</tbody>
</table>

**Thermal Distances for Potential Intentional Events**

<table>
<thead>
<tr>
<th>HOLE SIZE (m²)</th>
<th>TANKS BREACHED</th>
<th>WIND SPEED (m/sec)</th>
<th>DISTANCE TO LFL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2</td>
<td>2</td>
<td>~10,000</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>6</td>
<td>~7,000</td>
</tr>
</tbody>
</table>

**Dispersion Distances for Potential Intentional Events**

Example hazard distances are for intentional spills of ~200,000 m³ of LNG in open areas without risk management.
Performance-based Risk Assessment Approach for LNG Spills

1. Characterize Facilities
2. Define Threats
   - \( P_A \)
3. Determine Consequences
4. Define Safeguards
   - \( P_E \)
5. Analyze System
   - \( R \)
   - Risk
6. Sufficient Protection
   - Y
   - N
   - End Until Change

Risk = \( P_A \times (1-P_E) \times C \)
Risk Management Process to Help Sites Evaluate Potential LNG Spills

Chapter 6 of Sandia report provides guidance on a process for assessing and responsibly managing risks of a LNG spill:

- **Site-specific conditions to consider**
  - location, environmental conditions, proximity to infrastructures or residential or commercial areas, ship size, and available resources

- **Site-specific threats to evaluate**

- **Cooperating with stakeholders, public safety, and public officials to identify site-specific “protection goals”**

- **Appropriate modeling and analysis approaches for a given site, conditions, and operations**

- **Identification of approaches to manage risks, through prevention and mitigation, enhancing energy reliability and the safety of people and property**
LNG Spill Risk Management Elements

Risks can often be managed through a combination of approaches:

• Improved risk prevention measures to reduce the likelihood of possible scenarios
  - Earlier ship interdiction, boardings, and searches; positive vessel control during transit; port traffic control measures; safety and security zones and surveillance; or operational changes
• Locating LNG terminals where risks to public safety, other infrastructures, and energy security are minimized
• Improved LNG transportation safety and security systems
• Improved hazard analysis modeling and validation
• Improved emergency response, evacuation, and event mitigation strategies
Summary of Risk Management Guidance

• Use of effective security and protection operations can be used to reduce the hazards and risks from a possible breaching event

• Risk management strategies should be based on site-specific conditions, protection goals, and the expected impact of a spill
  – Less intensive strategies can often be sufficient in areas where the impacts of a spill are low

• Where impacts to public safety and property could be high and where a spill could interact with terrain or structures – use of modern, validated Computational Fluid Dynamics models can improve hazard analyses