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Suggestions on Modeling LNG Releases from a Ship

Mike Hightower
Sandia National Laboratories

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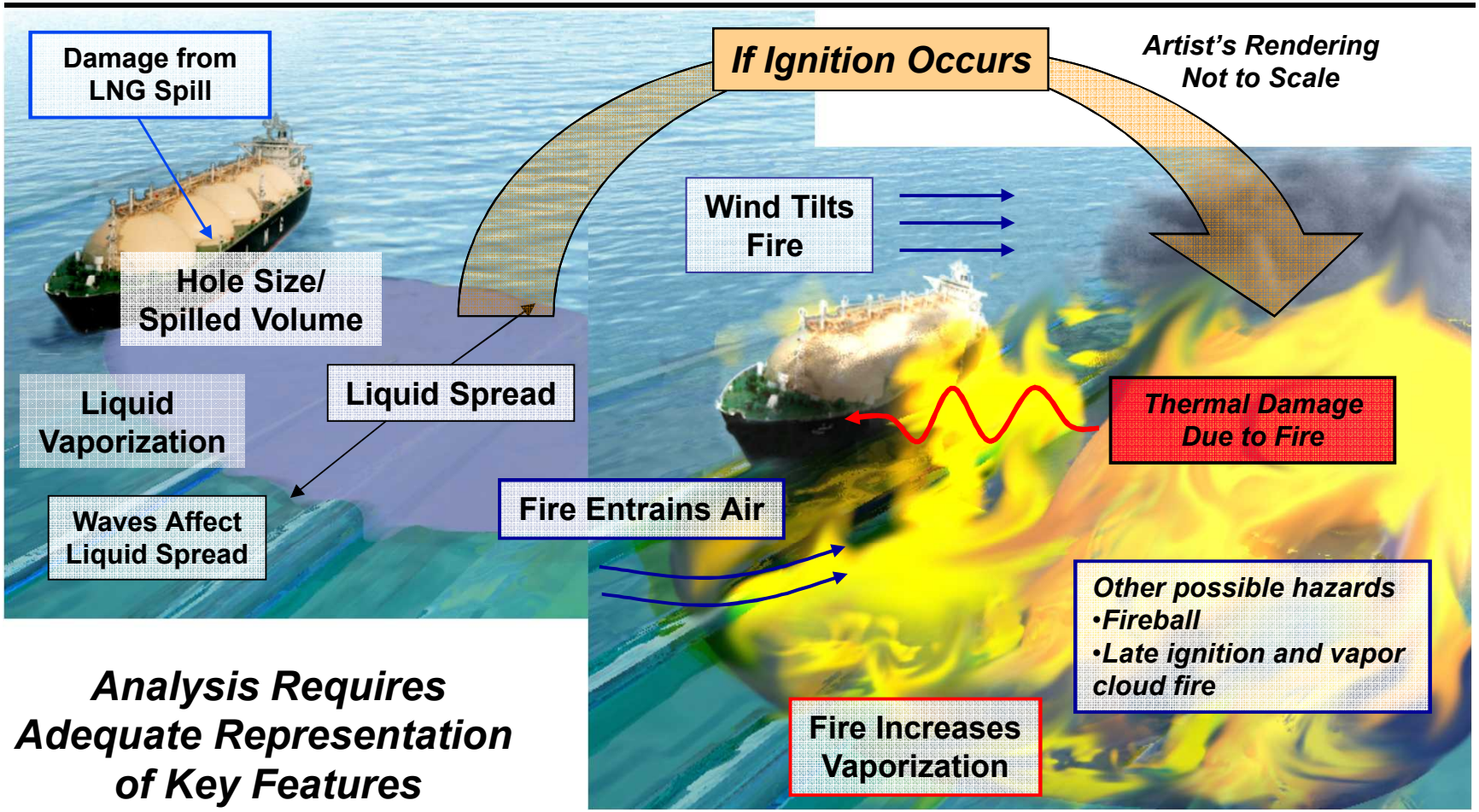
Key Features of an LNG Ship Spill and Associated Pool Fire



Analysis Requires Adequate Representation of Key Features

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LNG Spill Discussion Overview

- Threat considerations, uncertainties, and impacts on LNG spill analysis
- LNG cargo tank breach analysis and impacts on spill considerations
- Cascading damage considerations for a spill analysis
- Suggested LNG spill analysis approach:
  - Incorporate site-specific conditions
  - Incorporate uncertainties in threats and breach sizes
  - Assess spill rate and spill volume “ranges” to capture the “appropriate scale” of potential spills

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Site-specific LNG Spill Considerations

- **On-shore or near-shore**
  - Traffic control, safety zones, escorts
  - Smaller and fewer threats
  - Closer to infrastructure, people, critical facilities
  - Spills in congested areas can complicate hazards analyses
- **Off-shore**
  - Limited traffic control and enforcement capabilities
  - Larger and more threats
  - Further from public and infrastructure
  - Simple models are often appropriate to assess hazards from a spill

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Breach and Spill Analysis Issues and Challenges

- **Threat evaluations are inexact**
  - Difficult to predict future events or capabilities
  - Focus on credible threats identified by intelligence agencies
- **Breach analyses are difficult**
  - Multiple accidental and intentional events to consider
  - Breach sizes depend on the threat, location, and ship and cargo tank response
  - Little validated data on double hull ship breaches
- **Spill analyses are complicated**
  - Mechanics of a spill depend on the location and size of the breach and response of the ship and cargo tank
  - Latent effects of fire of cryogenic damage on ship and additional cargo tanks are difficult to quantify and validate

LNG Ship Breaching and Spill Events

Collision of Baltic Carrier Oil Tanker

USS Cole Attack

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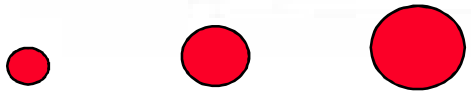
LNG Breach and Spill Categories

Category 1

Category 2

Category 3



2 m^2 5 m^2 12 m^2

Relative Breach Sizes to Scale

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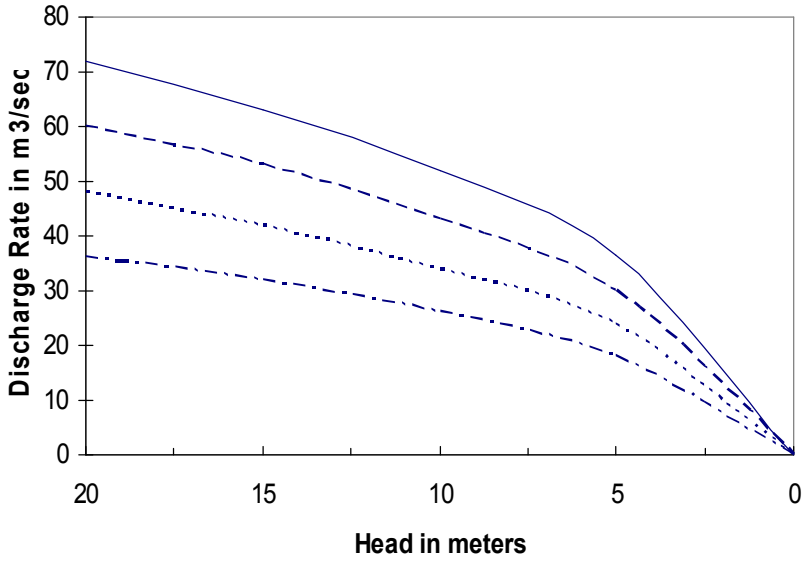
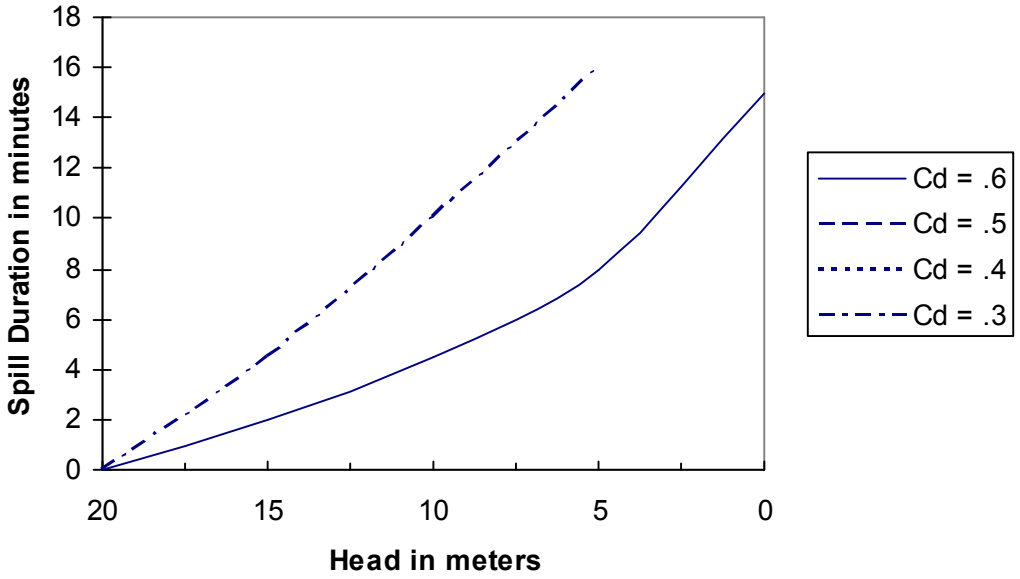
LNG Spill Analysis Approach

- **Category 2 related spills often provide largest initial spill rates**
  - **Can assess spill rates using Bernoulli's Equation (Torricelli's Theorem) for orifice flow or fluid dynamics models depending on structure complexity**
  - **For orifice models vary Cd from 0.6 to 0.3 to account for variations in hole roughness, ice formation, vacuum formation, etc.**
  - **Approach is compatible with current experimental data and uncertainties**
- **Multiple breach events should be considered, including cascading damage, for spill analyses**
  - **Assuming spills from up to three tanks at a time using nominal hole sizes is appropriate for current threat and cascading damage data and uncertainties**

Example LNG Spill Sensitivity Analysis

LNG spill rates for a single 6m^2 hole in a 200,000 m^3 Class LNG vessel Cargo Tank





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