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

U.S. Department of Energy LNG Forums 2006

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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**

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Application of Guidance Information and Results

- 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

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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**

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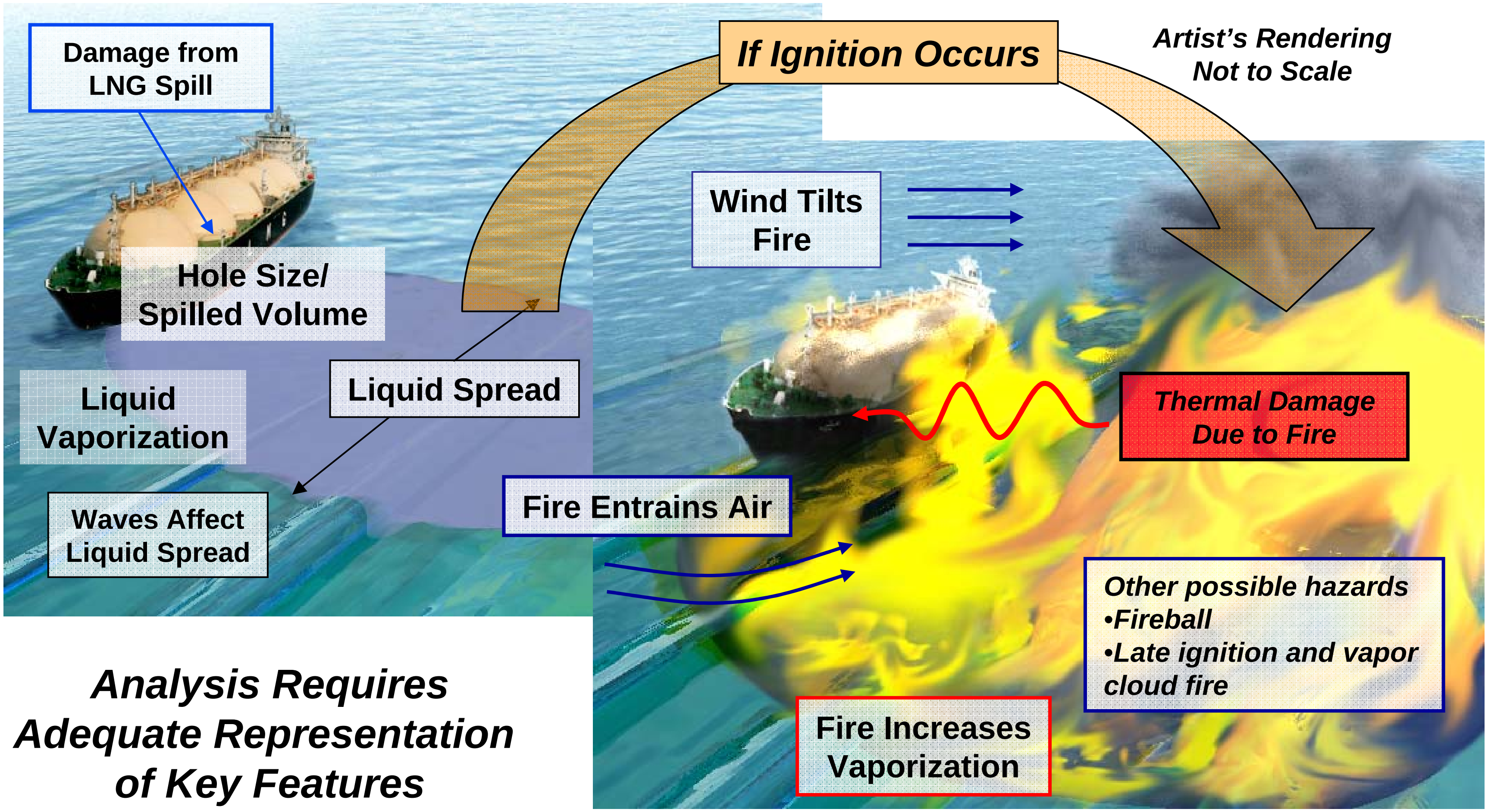
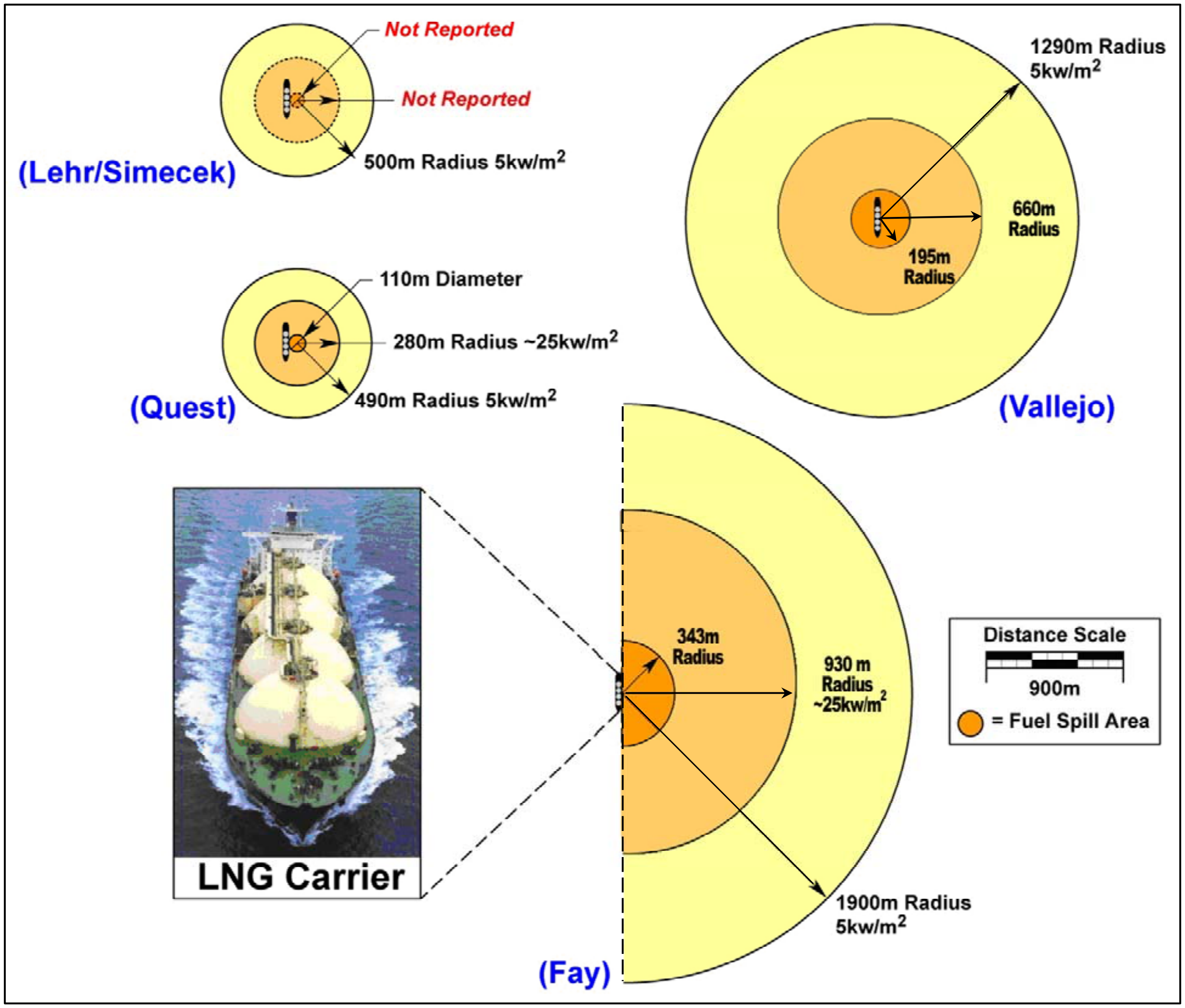
Key Features of LNG Spills Over Water



Analysis Requires Adequate Representation of Key Features

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



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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 <u>on average</u> reduces the radiative heat flux level at a distance**

Montoir - 35 m LNG pool fire

SNL - 8 m JP-8 pool fire

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Potential Thermal Hazards for Spills from Common LNG Vessels

HOLE SIZE (m^2)	TANKS BREACH	DISCHARGE COEFF.	BURN RATE (m/s)	SURFACE EMISSIVE POWER (kW/m^2)	TRANS-MISSIV-ITY	POOL DIA. (m)	BURN TIME (min)	DISTANCE TO 37.5 kW/m^2 (m)	DISTANCE TO 5 kW/m^2 (m)
2	3	.6	3×10^{-4}	220	0.8	209	20	250	784
5	3	.6	3×10^{-4}	220	0.8	572	8.1	630	2118
5*	1	.6	3×10^{-4}	220	0.8	330	8.1	391	1305
5	1	.9	3×10^{-4}	220	0.8	405	5.4	478	1579
5	1	.3	3×10^{-4}	220	0.8	233	16	263	911
5	1	.6	2×10^{-4}	220	0.8	395	8.1	454	1538
5	1	.6	8×10^{-4}	220	0.8	202	8.1	253	810
5	1	.6	3×10^{-4}	220	0.5	330	8.1	297	958
5	1	.6	3×10^{-4}	175	0.8	330	8.1	314	1156
12	1	.6	3×10^{-4}	220	0.8	512	3.4	602	1920

*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

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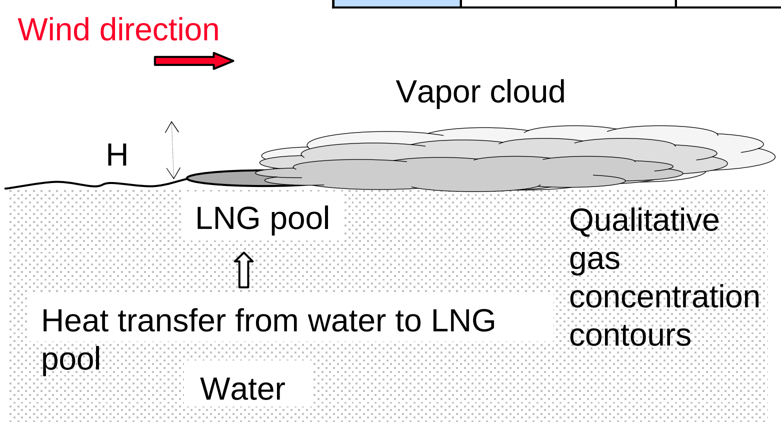
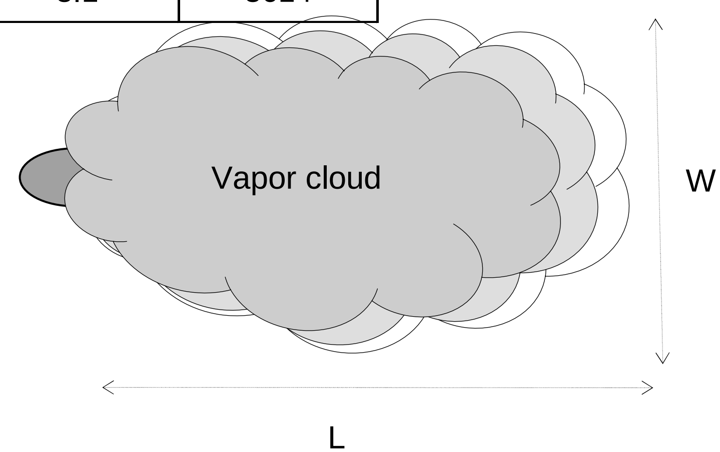
Potential Dispersion Hazards for Spills from Common LNG Vessels

HOLE SIZE (m^2)	TANKS BREACHED	POOL DIAMETER (m)	SPILL DURATION (min)	DISTANCE TO LFL (m)
Accidental Events				
2	1	256	20	1710
Intentional Events				
5	1	405	8.1	2450
5	3	701	8.1	3614



Side View



Top View

Dispersion distances are limited by closest ignition source

Potential Thermal and Dispersion Hazards for Spills from Large LNG Vessels

HOLE SIZE (m^2)	TANKS BREACHED	POOL DIAMETER (m)	DISTANCE TO 37.5 kW/m^2 (m)	DISTANCE TO 5 kW/m^2 (m)
Thermal Distances for Potential Intentional Events				
7	2	640	~750	~2500

HOLE SIZE (m^2)	TANKS BREACHED	WIND SPEED (m/sec)	DISTANCE TO LFL (m)
Dispersion Distances for Potential Intentional Events			
7	2	2	~10,000
7	2	6	~7,000

Example hazard distances are for intentional spills of ~200,000 m^3 of LNG in open areas without risk management

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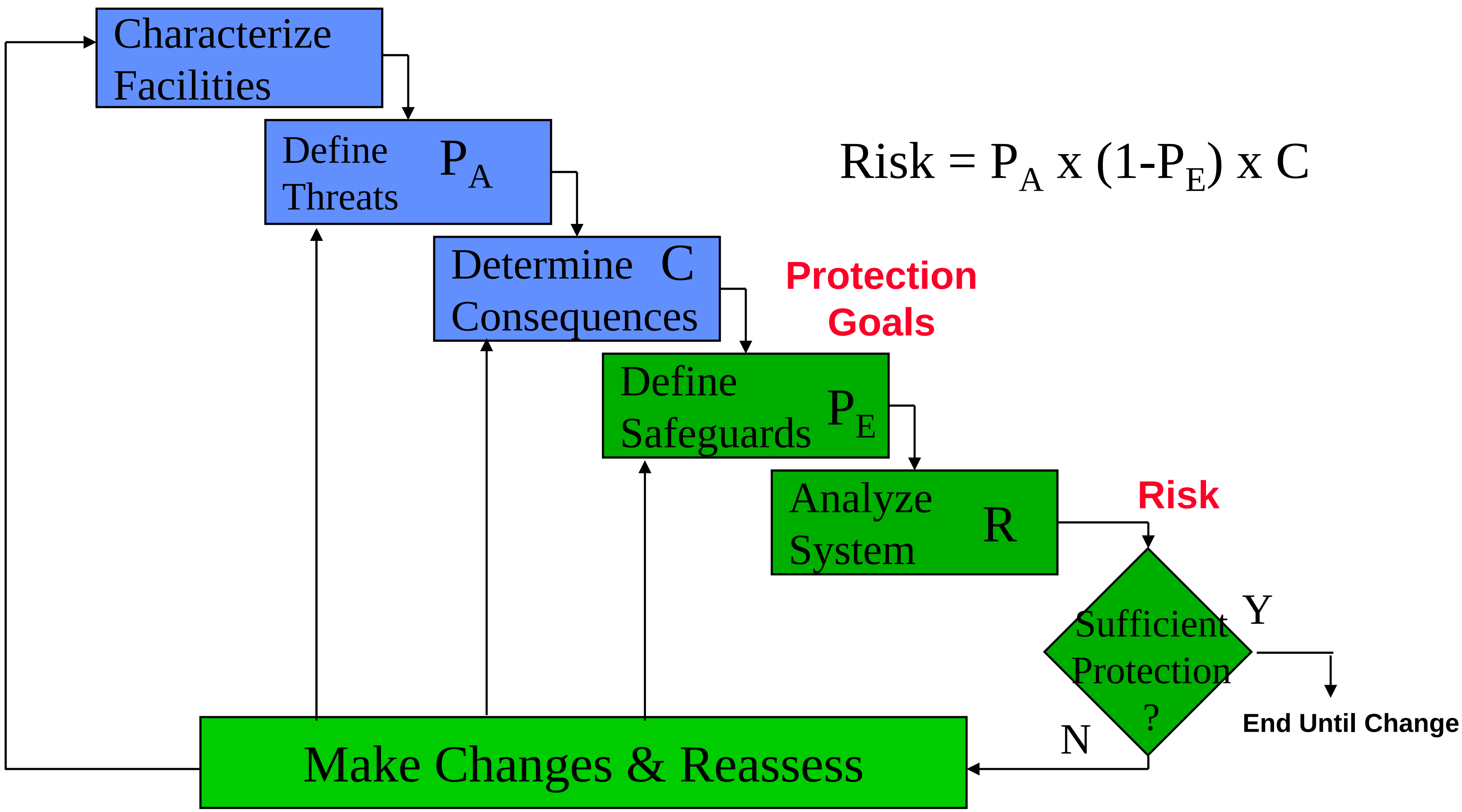
Performance-based Risk Assessment Approach for LNG Spills

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



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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**

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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**

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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

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