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Breach and Hazard Analysis of Large LNG Carrier Spills

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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.

Background

- Emerging market for larger capacity LNG ships

- A 2007 GAO report identified the need to assess hazards

- DOE requested Sandia use the 2004 Sandia/DOE report approach

- Analyses were conducted for both near-shore and offshore terminals

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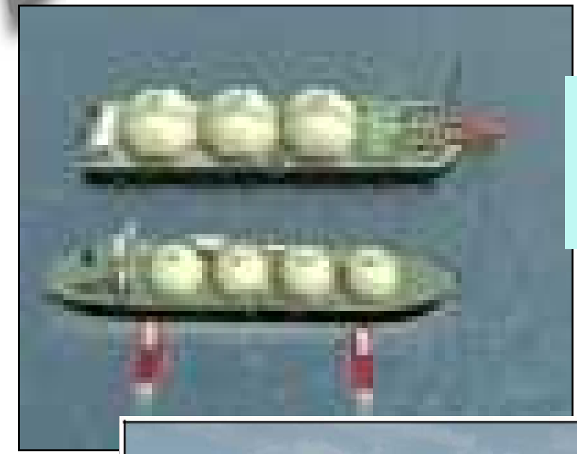
Emerging LNG Carrier Sizes

CLASS	MEMBRANE DESIGNS			
	145,000 m^3	155,000 m^3	215,000 m^3	265,000 m^3
Tanks	4	4	5	5
Length (m)	283	288	315	345
Width (m)	44	44	50	55
Draft (m)	11.4	11.5	12	12
CLASS	MOSS DESIGNS			
	138,000 m^3	145,000 m^3	200,000 m^3	255,000 m^3
Tanks	5	4	5	5
Length (m)	287	290	315	345
Width (m)	46	49	50	55
Draft (m)	11	11.4	12	12.5

(Poten and Partners, 2006)

Emerging Off-Shore Systems



Many different designs with 260,000 m³ capacities typical

Regasification capabilities

Off-shore floating LNG carrier-like terminals for storage and regasification with capacities to 300,000 m³

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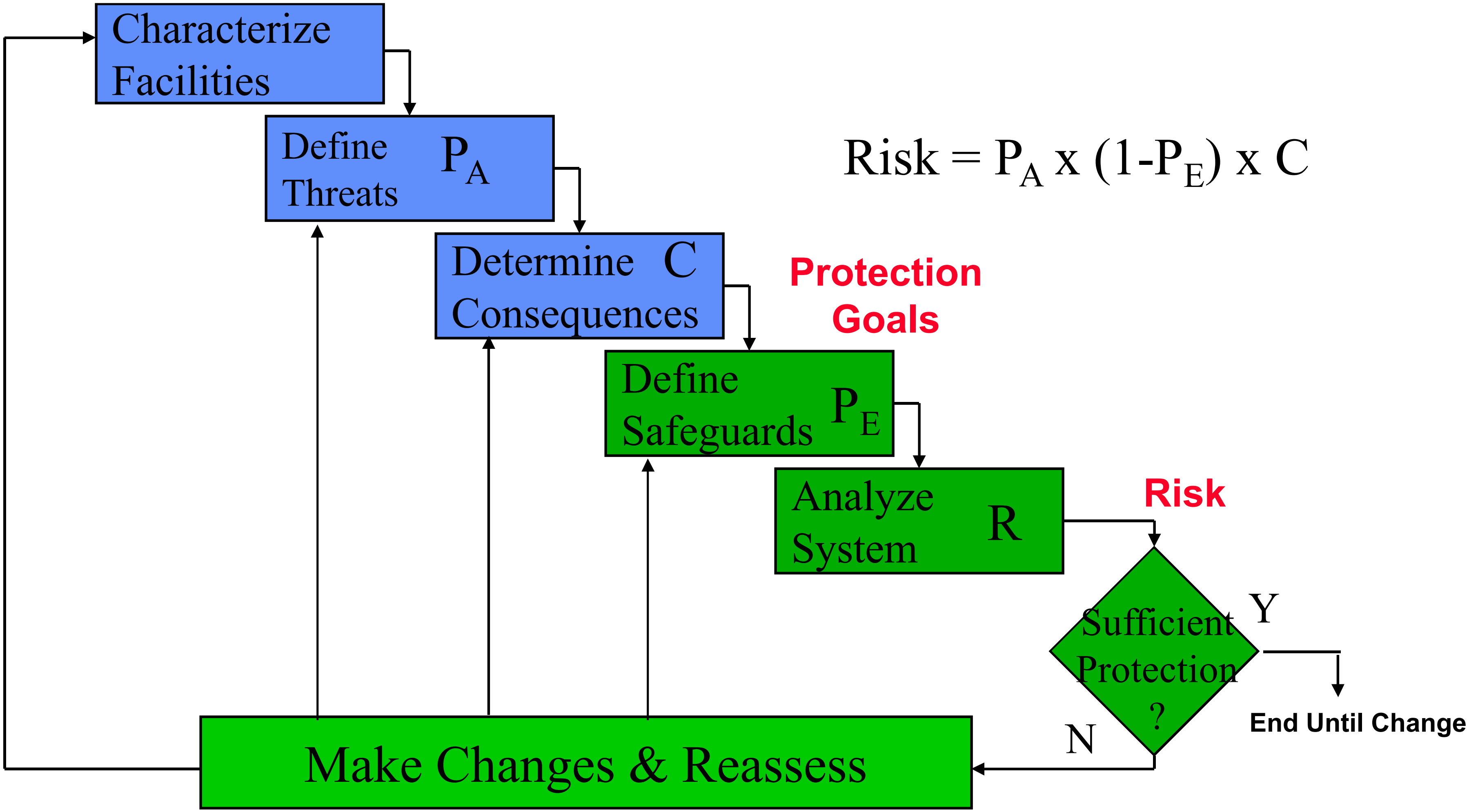
Application of Analysis Information and Results

- The results are not intended to be used prescriptively, but rather as guidance for conducting site-specific hazard and risk analyses

- Performance-based approaches should be used to analyze and responsibly manage risks to the public and property from potential LNG spills over water

Performance-based Risk Assessment Approach for LNG Spills



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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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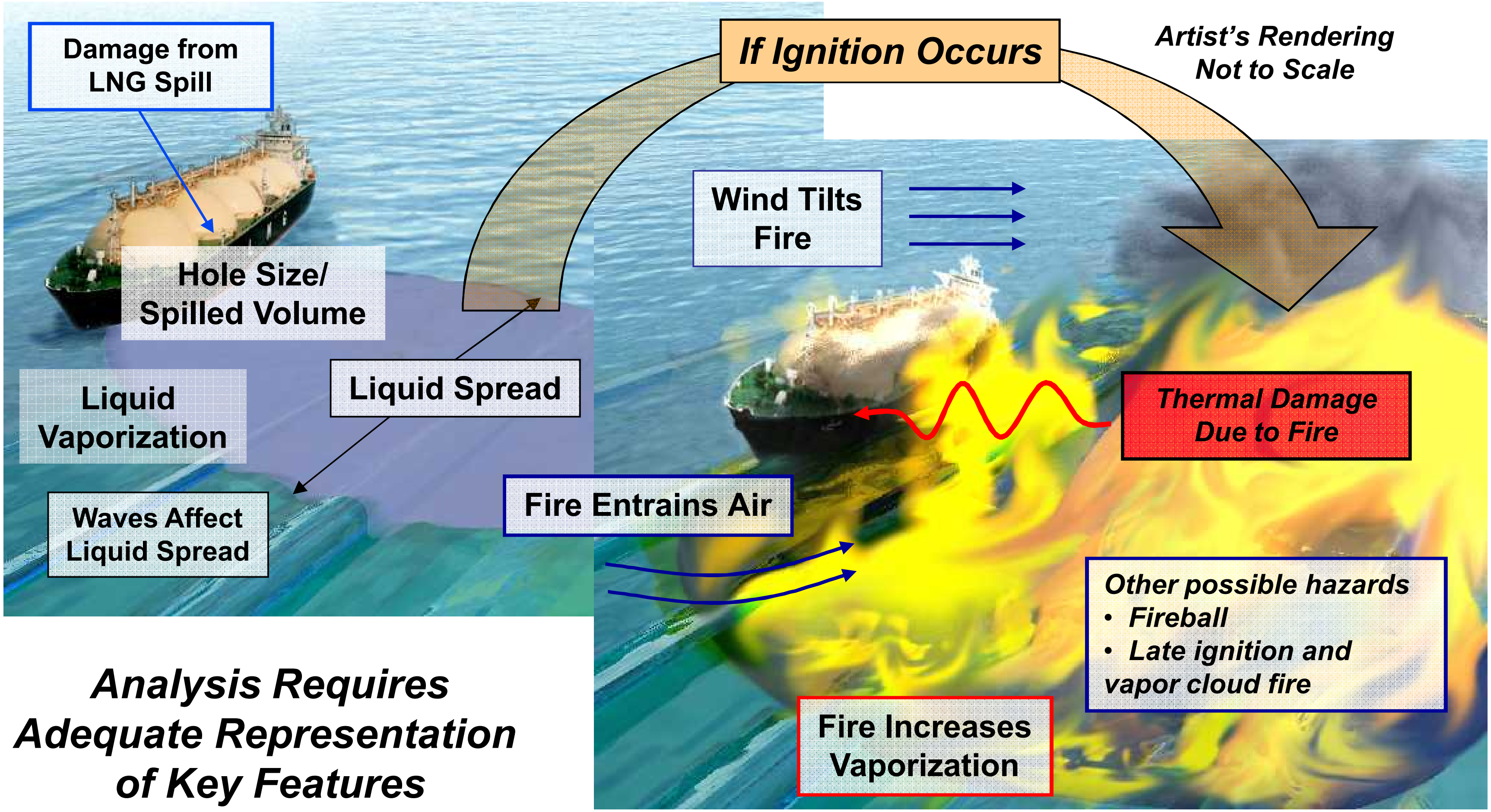
Key Features of LNG Spills Over Water



Analysis Requires Adequate Representation of Key Features

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Large Capacity LNG Carrier Breach Analyses

- Threats provided by the intelligence community
- Used 3-D shock physics code, CTH, for structural/explosive interactions
- Different cases were analyzed, exploring different charge size and placement, as well as standoff distance

Hazards Assessment

- Intent is to identify the scale of the hazards
- Pool fire most likely outcome due to immediate ignition from event
- Much smaller possibility of large scale dispersion event
- Determined distances for:
  - Pool fire heat flux levels
    - » 37.5 kW/m^2 – structural damage to steel within 10 minutes
    - » 5 kW/m^2 – 2nd degree burns to bare skin within 20 – 30 seconds
  - dispersion to the lower flammability limit

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Uncertainty Quantification Approach

Range of parameters explored due to uncertainty of:

- Large-scale LNG pool fire behavior:
  - » Burn rate - controls pool area and flame height
  - » Flame height – increasing height implies larger hazard distance
  - » Smoke production – increase in production will decrease hazard distance on average

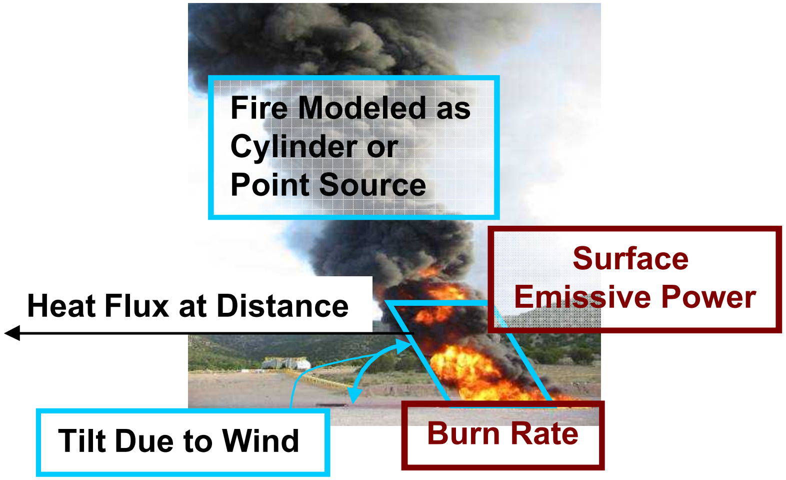
Montoir - 35 m LNG pool fire

- Cascading damage due to thermal load from fire or cryogenic brittle fracture
- Spill and pool spread dynamics

Pool Fire Modeling

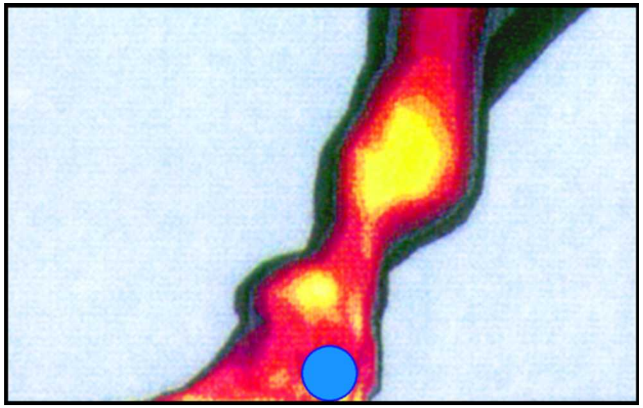
Integral or Similarity Models

- Treats fire as a global emitter with typically assumed cylindrical shape
- Input parameters based on data
- Heat flux (kW/m^2) calculated at distance
- Good for long distances, simple geometries



Computational Fluid Dynamics (CFD) Models

- Invokes more first principles
- Flow, reactions, heat transfer modeled
- Calculates heat flux distributions for specified scenario including complex geometries and irregular shaped pools



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Potential Thermal Hazards for Spills from Common LNG Carriers Near-shore

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 based on credible threats and available experimental data for a common LNG vessel**

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Potential Thermal Hazards for Spills from Large Capacity LNG Carriers Near-shore

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	225	57	382	881
5	3	.6	3×10^{-4}	220	0.8	615	23	774	2197
5*	1	.6	3×10^{-4}	220	0.8	355	23	446	1344
5	1	.3	3×10^{-4}	220	0.8	251	46	315	975
5	1	.6	2×10^{-4}	220	0.8	435	23	547	1487
5	1	.6	8×10^{-4}	220	0.8	217	23	273	1042
5	1	.6	3×10^{-4}	220	0.5	355	23	305	1050
5	1	.6	3×10^{-4}	175	0.8	355	23	373	1188
12	1	.6	3×10^{-4}	220	0.8	550	10	692	1981

***Nominal case: Expected outcomes based on credible threats and available experimental data for a large capacity LNG vessel**

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Potential Thermal Hazards for Spills from Large Capacity LNG Carriers Offshore

								DISTANCE TO	
HOLE SIZE (m^2)	TANKS BREACHED	DISCHARGE COEFFICIENT	BURN RATE (m/s)	SURFACE EMISSIVE POWER (kW/m^2)	τ	POOL DIAMETER (m)	BURN TIME (min)	37.5 kW/m^2 (m)	5 kW/m^2 (m)
5	3	0.6	3×10^{-4}	220	0.8	615	23	774	2196
12	3	0.6	3×10^{-4}	220	0.8	953	9.6	1090	3168
12*	1	0.6	3×10^{-4}	220	0.8	550	9.6	692	1980
12	1	0.3	3×10^{-4}	220	0.8	389	19	466	1429
12	1	0.6	2×10^{-4}	220	0.8	674	9.6	786	2335
12	1	0.6	8×10^{-4}	220	0.8	337	9.6	407	1261
12	1	0.6	3×10^{-4}	220	0.5	550	9.6	462	1539
12	1	0.6	3×10^{-4}	175	0.8	550	9.6	553	1738
16	1	0.6	3×10^{-4}	220	0.8	635	7.2	741	2202

***Nominal case: Expected outcomes based on credible threats and available experimental data for a large capacity LNG vessel**

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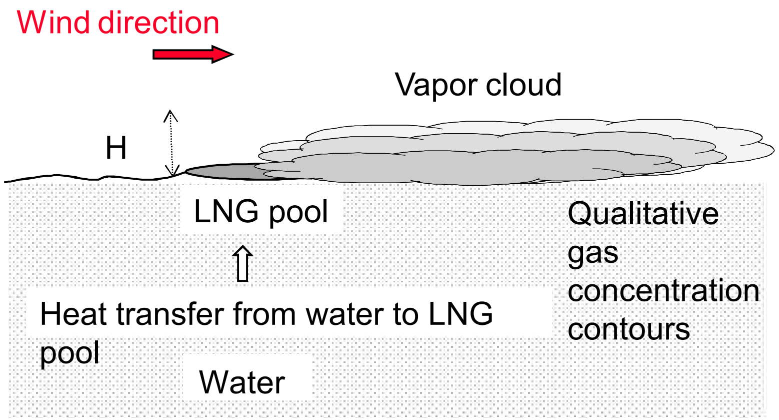
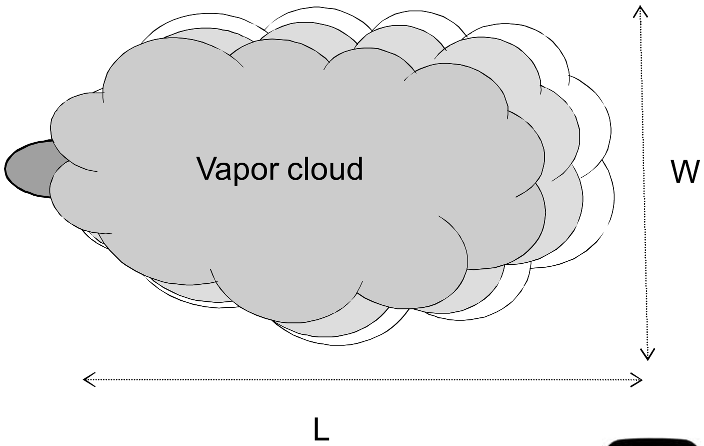
Potential Dispersion Hazards for Spills from Common LNG Carriers

Dispersion distances are limited by closest ignition source

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



Side View



Top View

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Potential Dispersion Hazards for Spills from Large Capacity LNG Carriers

Distance to the LFL for vapor dispersion

Near-shore operations

POOL DIAMETER (m)	HOLE SIZE (m^2)	NUMBER OF TANKS	MASS FLUX (m/s)	DISTANCE TO LFL (m)*
290	5	1	4.5×10^{-4}	2800
917	5	1	4.5×10^{-5}	3300

Offshore operations

POOL DIAMETER (m)	HOLE SIZE (m^2)	NUMBER OF TANKS	MASS FLUX (m/s)	DISTANCE TO LFL (m)*
450	12	1	4.5×10^{-4}	4000
1420	12	1	4.5×10^{-5}	5200

***Assumes no ignition source along path**

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Summary of Hazard Analyses

Near-Shore Operations:

- For larger ships, distances increased by 7 – 8% compared to current class of ships
- Fire duration triples due to greater volume
- Most significant impact to public safety and property are within approximately 500 m of a spill
- Lower public health and safety impacts at distances beyond approximately 1600 m
- For larger ships, distance to LFL increased by about 20% for a single-tank spill compared to current class of ships

Summary of Hazard Analyses

Offshore Operations:

- **Most significant impact public safety and property are within approximately 700 m of a spill**
- **Lower public health and safety impacts at distances beyond approximately 2000 m**

Summary of Hazard for Spills from Large Capacity LNG Carriers

- **Performance-based approaches should be used to analyze and responsibly manage risks**
- **Where impacts to the public and property could be high, or where a spill could interact with terrain or structures – use of validated, Computational Fluid Dynamics models can improve risk management**
- **Thermal and vapor dispersion hazard distances for offshore operations, generally 5 or more miles offshore, are unlikely to impact the onshore public or property**
- **The analyses suggest the "scale" of the hazards**
  - **Site-specific hazard analyses and risk management is necessary**

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