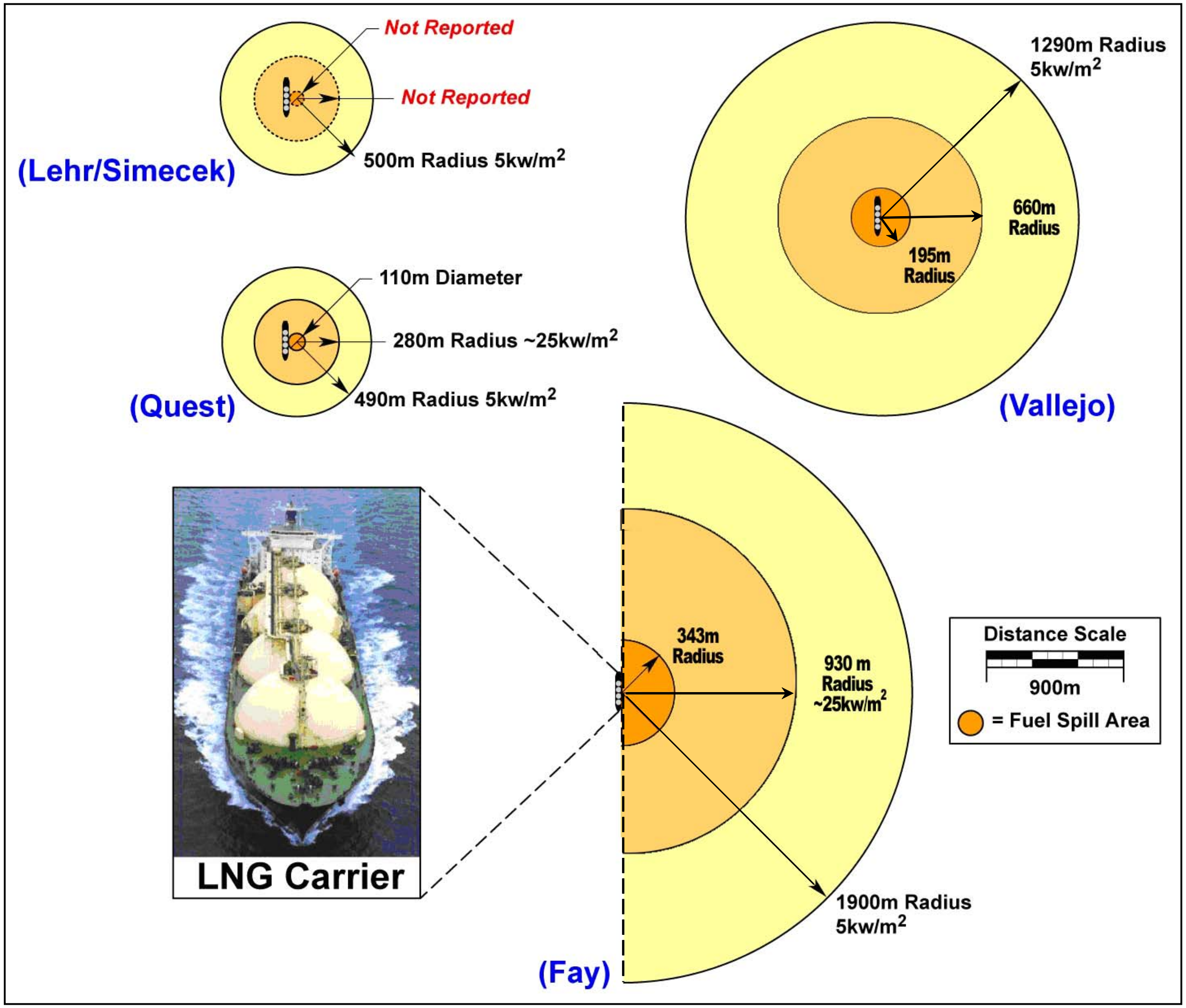
Extent of Thermal Hazards Predicted in Four Recent LNG Carrier Spill Studies



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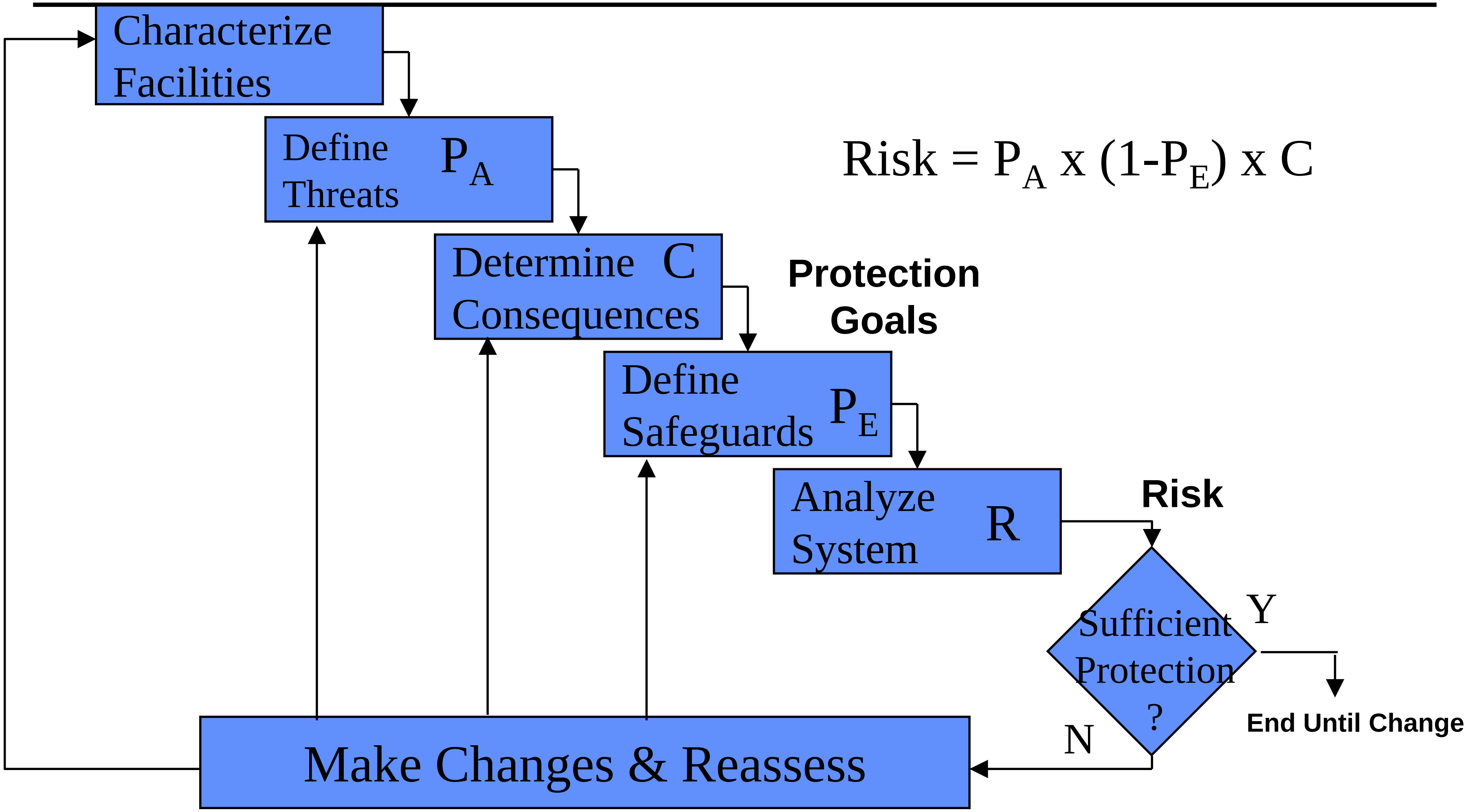
Suggested Risk-based Assessment Approach for LNG Carrier Spills

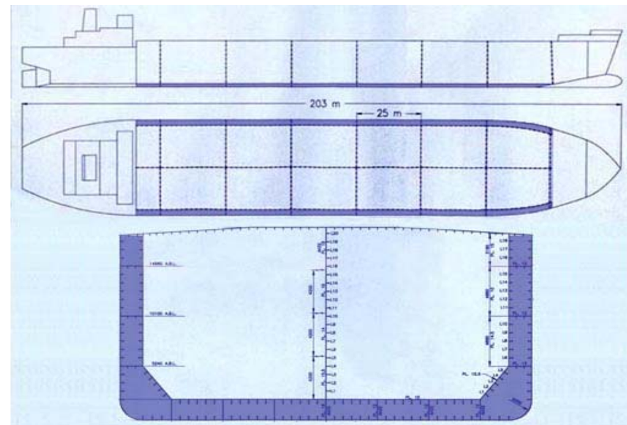


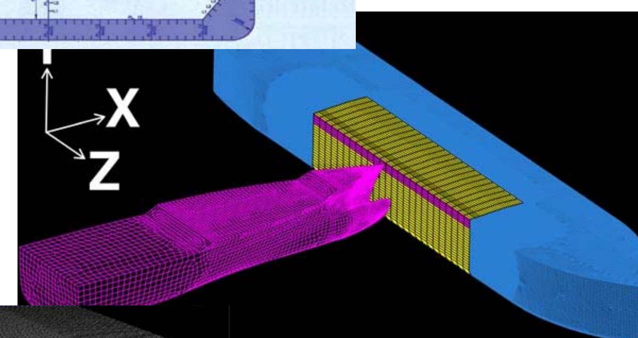
Safety and Consequence Analyses

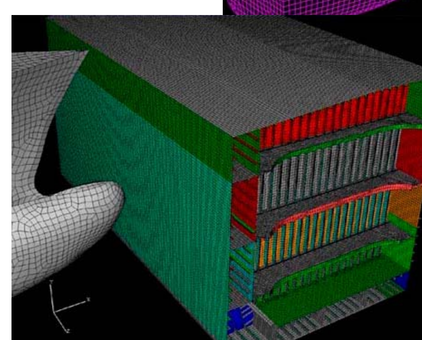
- Evaluated several breaching events
  - Collisions, groundings, impacts
  - Sabotage and possible attacks
- Evaluated consequences from LNG spills
  - Fire, vapor dispersion, explosions
- Evaluated possibility of cascading damage
  - Cryogenic damage from a spill
  - Thermal damage to structures and 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**







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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**

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Summary of Accidental and Intentional LNG Cargo Tank Breach Analyses

- **Accidental breach hole sizes of up to 1.5 m^2 (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 m^2 up to 12 m^2 (<1.6 m to 4 m diameter) possible**
  - Nominal breach size ~5 m^2 (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**

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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/m^2 (major structural damage in 10 minutes)
  - 5 kW/m^2 (2^{nd} 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**

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Thermal Hazard Analysis Results for Accidental LNG Breaches and Spills

HOLE SIZE (m^2)	TANKS BREACHED	DISCHARGE COEFFICIENT	BURN RATE (m/s)	SURFACE EMISSIVE POWER (kW/m^2)	POOL DIAMETER (m)	BURN TIME (min)	DISTANCE TO 37.5 kW/m^2 (m)	DISTANCE TO 5 kW/m^2 (m)
1	1	.6	$3X10^{-4}$	220	148	40	177	554
2	1	.6	$3X10^{-4}$	220	209	20	250	784
2	3	.6	$3X10^{-4}$	220	362	20	398	1358

Uses nominal input parameters from existing data

Simultaneous, multiple tank damage highly unlikely

Estimated Impacts to Public Health and Safety from Accidental Spills

EVENT	POTENTIAL SHIP DAMAGE AND SPILL	POTENTIAL HAZARD	POTENTIAL IMPACT ON PUBLIC SAFETY[a]		
			~250 m	~250 – 750 m	>750 m
Collisions: Low speed	Minor ship damage, no breach	Minor ship damage	Low	Very Low	Very Low
Collisions: High Speed	LNG cargo tank breach from 0.5 to 1.5 m^2 spill area	▪ Small fire ▪ Damage to ship ▪ Vapor Cloud	High Med High	Med Low High - Med	Low Very Low Med - Low
Grounding: <3 m high object	Minor ship damage, no breach	Minor ship damage	Low	Very Low	Very Low

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

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Thermal Hazard Analysis Results for Intentional LNG Breaches and Spills

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}	175	0.8	330	8.1	314	1156
5	1	.6	3×10^{-4}	350	0.8	330	8.1	529	1652
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 and best available experimental data

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Estimated Impacts to Public Health and Safety from Intentional Spills

EVENT	POTENTIAL SHIP DAMAGE AND SPILL	POTENTIAL HAZARD	POTENTIAL IMPACT ON PUBLIC SAFETY[a]		
			~500 m	~500 – 1600 m	>1600 m
Insider Threat or Hijacking	Intentional, 2-7 m^2 breach and medium to large spill	▪ Large fire	High	Med	Low
		▪ Damage to ship	High	Med	Low
		▪ Fireball	Med	Low	Very Low
	Intentional, large release of LNG	▪ Large fire	High	Med	Low
		▪ Damage to ship	High	Med	Low
		▪ Vapor cloud fire	High	High - Med	Med ium
Attack on Ship	Intentional, 2-12 m^2 breach and medium to large spill	▪ Large fire	High	Med	Low
		▪ Damage to ship	High	Med	Low
		▪ Fireball	Med	Low	Very Low

Very low – little or no property damage or injuries
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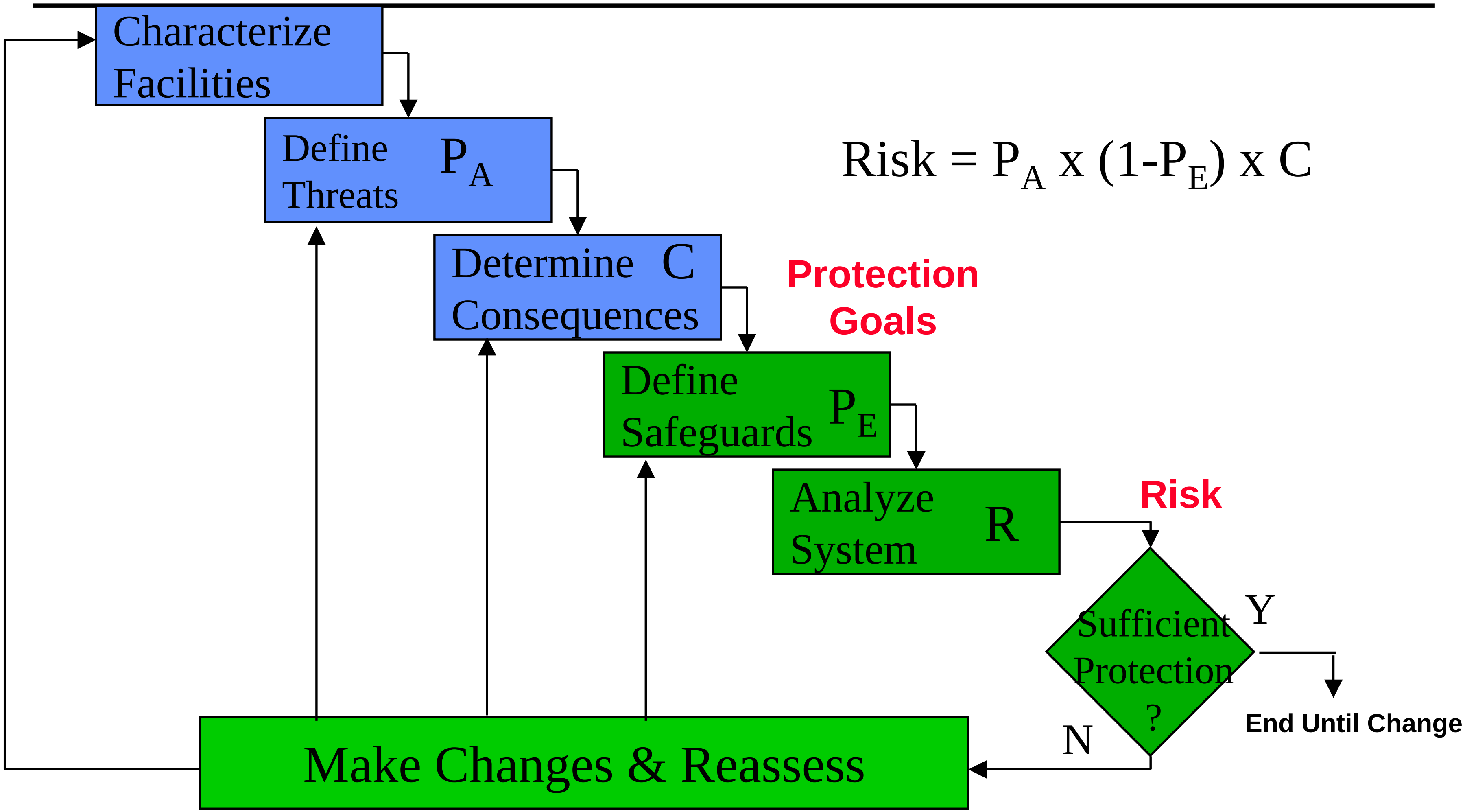
Suggested Risk-based Assessment Approach for LNG Carrier Spills



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**