Overview of LNG Facilities and Regulatory Approval and Oversight

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Federal Energy Regulatory Commission

Bio

- Over 15 years at Federal Energy Regulatory Commission (FERC) and Senior Executive Service since 2020 as first Director of Division of LNG Facility Reviews and Inspections;
- Oversees two branches in Washington D.C. and one in Houston responsible for the safety, reliability, and engineering reviews and inspections of LNG facilities throughout the life of LNG facilities, including application, detailed/final design, construction, commissioning/startup, and operation;
- Voting member of the National Fire Protection Association (NFPA) LNG Technical Committee responsible for NFPA 59A, *Standard for the Production, Storage, and Handling of LNG*, member of International Society of Automation (ISA) committees responsible for over 25 standards, and volunteer for American Society of Civil Engineers (ASCE) Technical Panel for Passive Fire Protection for Petrochemical Facilities;
- Served on several steering committees and research panels and responsible for several presentations and papers in professional conferences and journals on LNG safety, security, and oversight;
- Previously co-created and guest lectured Industrial Fire Protection Engineering and Process Safety Management graduate course for five years at University of Maryland, Department of Fire Protection Engineering,
- Previously supervisor at a security operations center responsible for 250+ CCTVs, all access controls and alarms, and liaison with police during active pursuits and investigations;
- B.S. Mechanical Engineering, B.S. Fire Protection Engineering, M.S. Fire Protection Engineering; licensed professional engineer in Maryland.

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Outline

- Recap (how FERC staff evaluates risk in terms of consequence and likelihood to inform effectiveness and reliability of layers of protection).

- Example of Stratification and Rollover Risk and Mitigation as it relates to pressure relief valve design capacity requirements and preventative measures.

- Example of Risk Informed Emergency Response Plan and Safety and Security Measures along LNG marine vessel transit routes.

Federal Regulation (Recap)

LNG Safety Regulatory Oversight (Recap)

FAA Aeronautical Studies

FERC Engineering Review

1) Identifying Hazards
2) Evaluating Risks
 -consequences
 -likelihood
3) Reducing Risks to Tolerable/Acceptable, ALARA/ALARP Levels

State Safety Advisory Reports

DoD MOU Correspondence

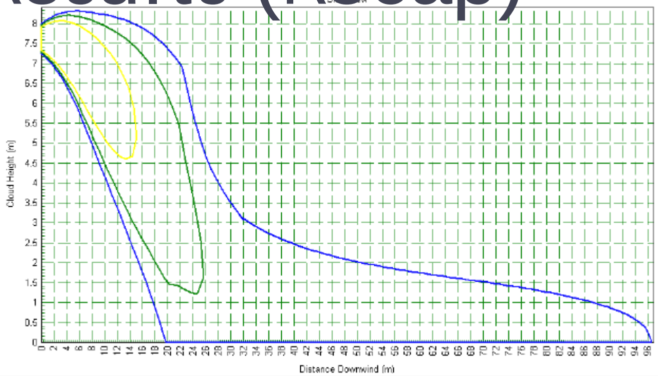
NRC Correspondence

OSHA and EPA Regulations and Worst Case and Alternative Scenarios

PHMSA Regulations (Letter of Determination and Potential

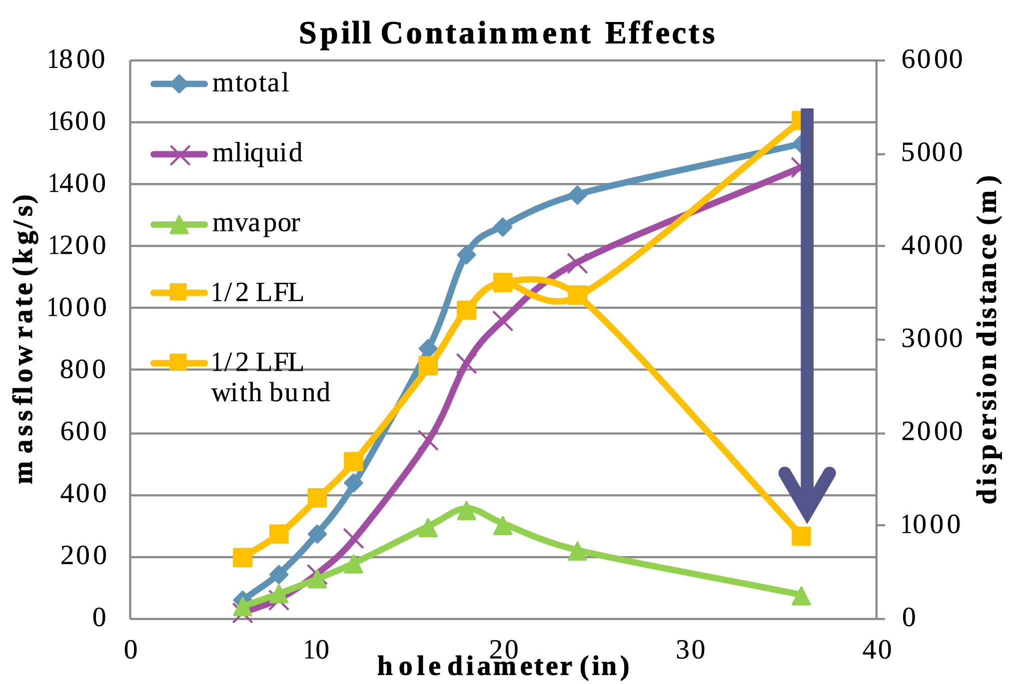
USCG Regulations, Zones of Concern and Letter of Recommendation

Unmitigated/Mitigated Consequence Modeling & Results (Recap)

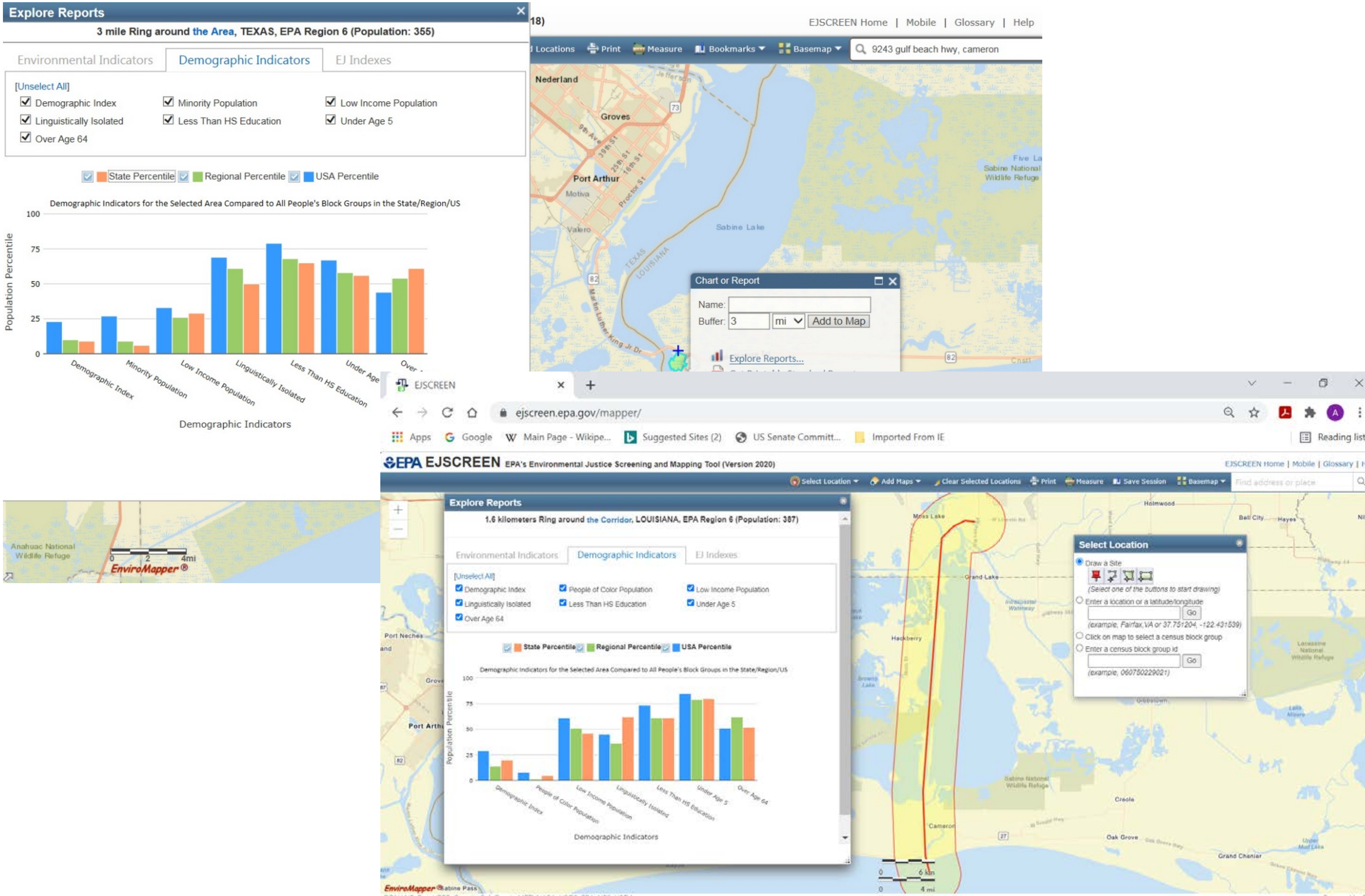


Pool Fire Spacing Table, 5kW/m2											
9/D	Hole Diameter [in]										
	1	2	4	6	8	12	16	24	30	36	42
Pressure [psig]	Minimum Distance from Edge of Impoundment or Container Drainage System to Property Lines That Can Be Built Upon [ft]										
1	141	289	536	747	887	1073	1214	1426	1581	1645	1669
1.5	140	297	563	790	919	1114	1260	1487	1625	1665	1681
2	118	284	573	801	939	1143	1294	1543	1646	1676	1689
2.5	73	251	571	806	951	1163	1319	1582	1658	1684	1695
3	n/a	214	566	807	958	1178	1339	1603	1667	1689	1701
3.5	n/a	186	562	805	963	1190	1354	1617	1672	1694	1705
		58	555	802	965	1197	1365	1625	1677	1697	1709
		/a	207	606	836	1145	1365	1613	1670	1707	1734
		/a	n/a	n/a	n/a	674	1018	1397	1523	1611	1678
		/a	n/a	n/a	n/a	n/a	n/a	906	1227	1407	1534

Jet Fire Spacing Table, 5kW/m2											
9/D	Hole Diameter [in]										
	1	2	4	6	8	12	16	24	30	36	42
Pressure [psig]											
1	45	86	152	210	261	353	434	57			
1.5	62	120	201	267	325	424	510	65			
2	67	128	243	320	381	485	574	7			
2.5	70	135	256	367	431	541	636	80			
3	73	140	267	392	478	596	698	87			
3.5	76	145	276	406	520	648	759	95			
4	79	149	285	418	550	700	819	10			
10	142	262	484	692	891	1274	1642	23			
20	158	294	542	776	1001	1431	1845	26			
30	168	312	577	826	1065	1524	1965	28			
40	175	325	601	861	1111	1591	2051	29			
50	180	335	620	889	1148	1644	2119	30			
60	185	344	636	912	1178	1687	2176	31			
70	189	351	650	932	1203	1724	2223	31			
80	192	357	662	949	1226	1756	2265	32			
90	195	363	673	965	1246	1785	2303	32			
100	198	368	682	979	1264	1811	2336	33			
200	216	402	747	1073	1386	1988	2566	36			
300	227	424	789	1134	1466	2103	2715	38			
400	238	444	828	1190	1538	2208	2851	40			
500	228	425	793	1140	1474	2117	2734	39			
600	228	427	796	1145	1480	2125	2746	39			



Potential Public Impact Results (Recap)



FERC Safety, Reliability, and Engineering Review (Recap)

FEDERAL ENERGY REGULATORY COMMISSION

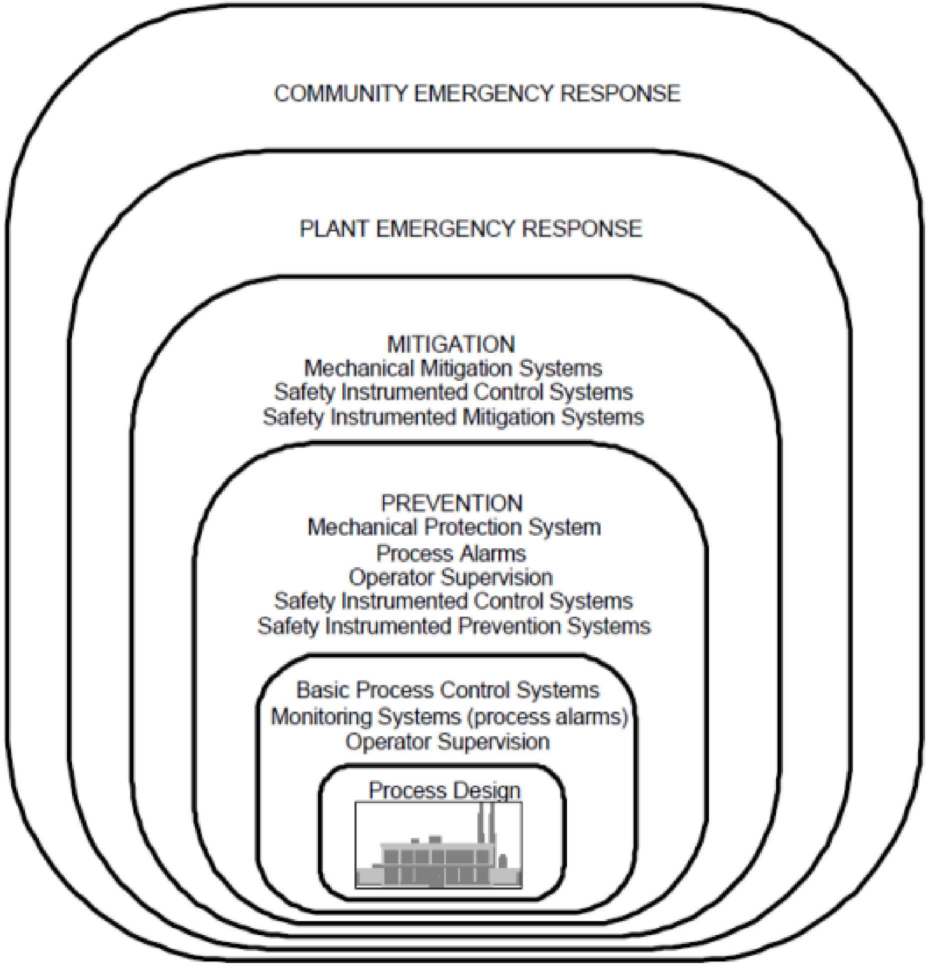
Office of Energy Projects

GUIDANCE MANUAL
FOR
ENVIRONMENTAL REPORT
PREPARATION
For Applications Filed Under the
Natural Gas Act

Volume II

Liquefied Natural Gas Project Resource Reports 11 & 13
Supplemental Guidance

February 2017

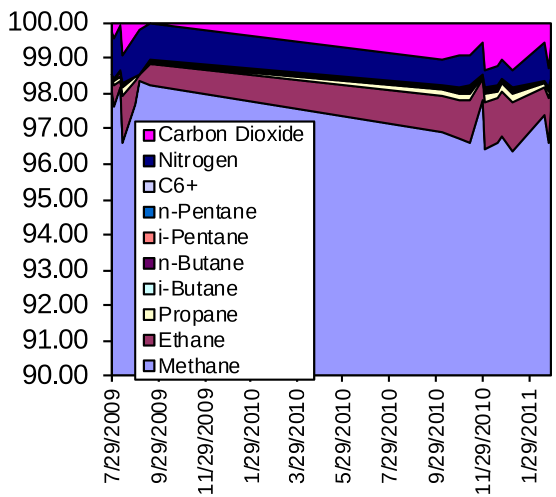


https://www.ferc.gov/sites/default/files/2020-04/guidance-manual-volume-2.pdf

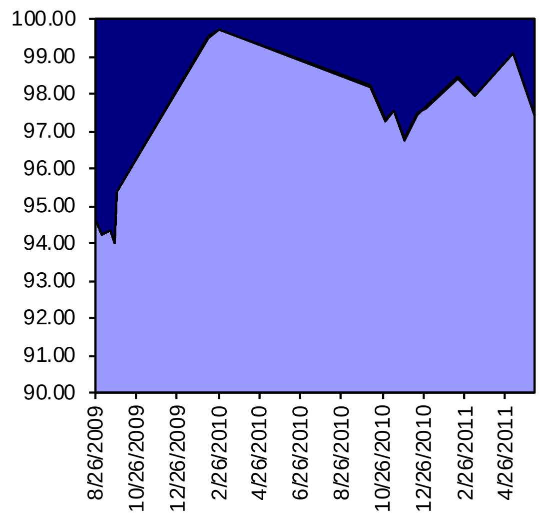
Example - Stratification and Rollover

- When shale gas became more prevalent, some of the LNG facilities began receiving natural gas supplies with heavier hydrocarbons. In some cases, it approached or exceeded the pre-treatment design basis and additional pre-treatment was needed to prevent issues with freezing/plugging in the liquefaction process and maintaining a consistent sendout composition. Note hydrogen blending could pose a different set of challenges that need to be mitigated through composition limits or design.
- Preferential boiloff (i.e., weathering) can exacerbate the density differences within the LNG tanks with nitrogen boiling off first and then methane. The vaporization of the lighter components causes the top layer to become denser at the same time that the bottom layer can become less dense from heat input to the bottom.

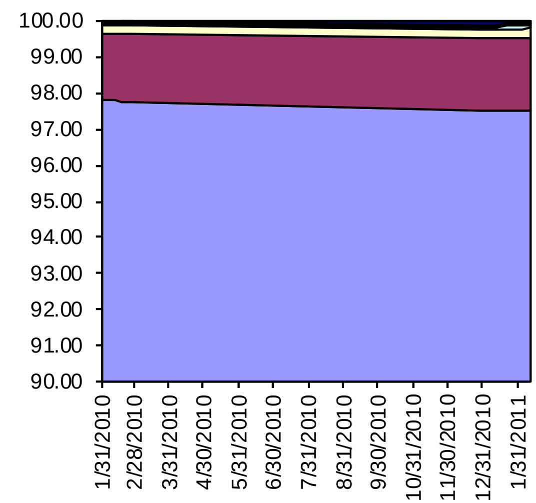
Feed Composition



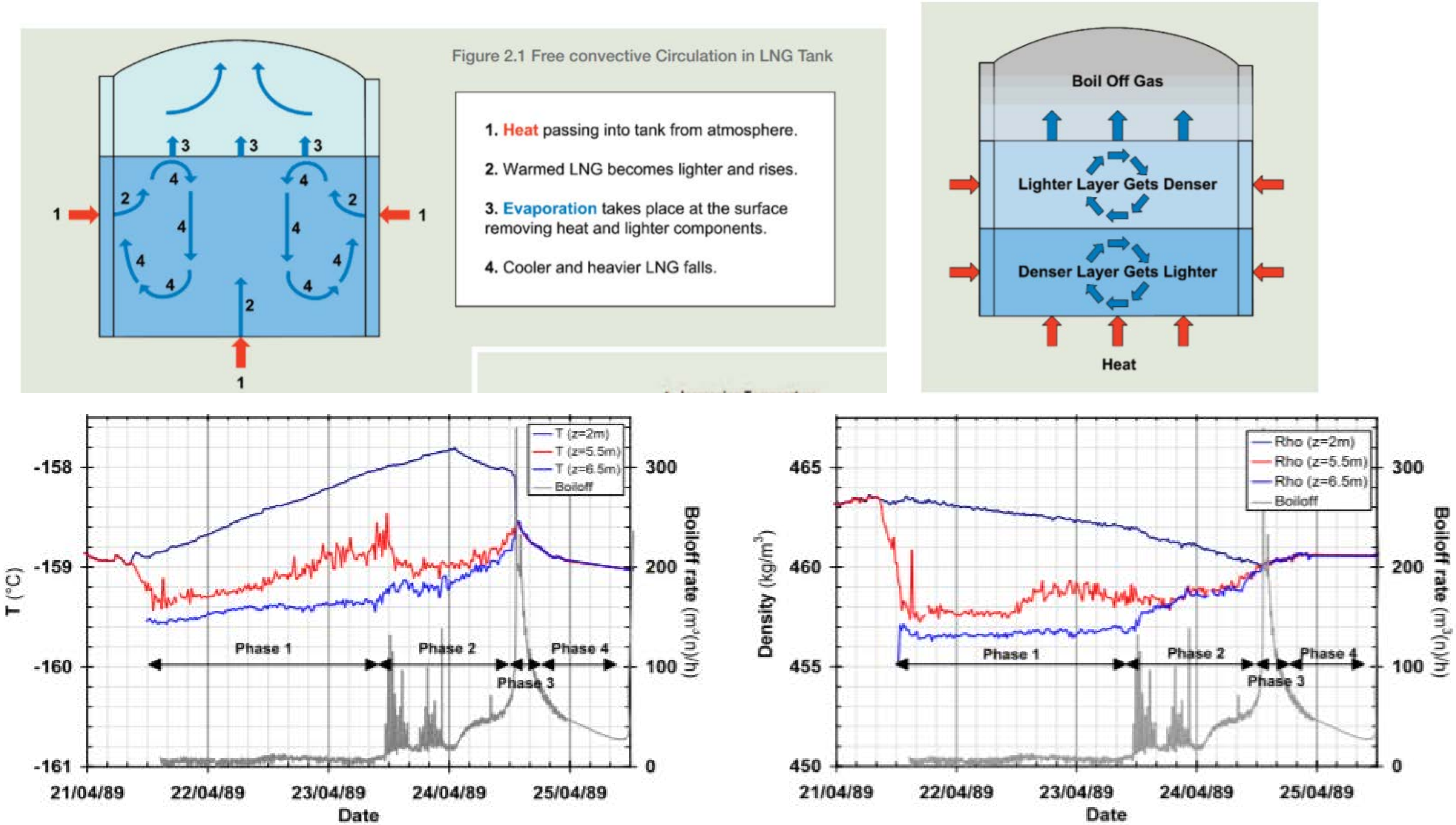
Boiloff Composition



Sendout Composition



Example - Stratification and Rollover



International Group of Liquefied Natural Gas Importers (GIIGNL), Rollover in LNG storage Tanks,
https://giignl.org/sites/default/files/PUBLIC_AREA/Publications/rollover_in_lng_storage_tanks_public_document_low-res.pdf

Example - Stratification and Rollover

- Low pressure tank design pressure and pressure relief valve set pressure and capacity typically lower than potential rollover vaporization and overpressure that can be generated (this may or may not be case for pressure vessels with smaller volumetric capacities and higher design pressures)
  - Therefore, prevention of rollover for larger low-pressure tanks is essential through:
    - level, temperature and density profile measurements
    - inter-tank and intra-tank transfer capabilities and procedures upon detection
    - bulk transfer procedures that monitor and account for differences in temperatures and densities
    - top and bottom fill capabilities and procedures

8.4.3* All LNG tank systems shall be designed for both top and bottom filling unless other process means are provided to mitigate stratification.

A.8.4.3 Operating requirements for prevention of stratification are located in Section 18.8. Additional details on rollover and rollover prevention can be found in the AGA publication *Introduction to LNG for Personnel Safety*.

Rollover exists when the density of the upper layer increases and/or the density of the lower level decreases such that the more dense upper layer sinks and/or the less dense lower layer rises, causing the two layers to rapidly mix or roll over. This becomes problematic when there also exists a significant temperature difference between the two layers as the rapid mixing will result in a rapid heat transfer and vaporization, which can overwhelm pressure relief valves. This density stratification can occur in a couple of ways.

One mechanism is when the bottom layer experiences relatively higher heat transfer near the base of the tank from the foundation and becomes warmer and less dense compared to the upper layer but cannot evaporate due the hydrostatic head exerted by the top layer.

In this case, the buoyancy force eventually causes the lower warmer and less dense fluid to rise and heat up and vaporize the upper colder layer and any residual superheated product flashes as the hydrostatic head is liberated on its ascent. The relative temperature difference of the layers and subsequent heat transfer can be compounded if filling LNG with different densities than what is stored such that heavier product is bottom filled or lighter product is top filled because the heavier denser product will need more heat to cause the density to lessen to a point where it becomes buoyant enough to rise.

Another mechanism is when the upper layer experiences preferential boil-off of lighter end fluids (i.e., nitrogen) and the liquid in the upper layer becomes warmer and more dense compared to the bottom layer until the density difference becomes large enough that the gravitational force causes the upper warmer layer to sink and heat and vaporize the lower colder fluid.

Both of these phenomena take time to develop and are dependent on a number of factors. Worse heat leak at the bottom of the tank will increase the differential warming and potential for this event. Increased storage time and less cycling will also increase the weathering of the upper layer and warming of the bottom layer and potential for this event. Increased storage volume will also increase the vaporization of the stratified layers and consequence from such an event. Flat bottom storage tanks with less uniform heating and higher head are often specified with level/temperature/density (LTD) gauges, top and bottom fill lines, and inter- and/or intra-tank transfers to monitor and mix the contents of the tank and prevent stratification. Pressure vessels are not typically specified with the same features because pressure vessels have more uniform insulation around the entire tank, shorter cycle times, less head, and smaller volumes that decreases the potential for large density and temperature stratifications to occur and also decreases the vaporization from a rollover.

8.4.10.5 Pressure Relief Device Sizing.

8.4.10.5.1 The capacity of pressure relief devices shall be based on the following:

(1) Fire exposure
(2) Operational upset, such as failure of a control device
(3) Other circumstances resulting from equipment failures and operating errors
(4) Vapor displacement during filling
(5) Flash vaporization during filling, as a result of filling or as a consequence of mixing of products of different compositions
(6) Loss of refrigeration
(7) Heat input from pump recirculation
(8) Drop in barometric pressure

8.4.10.5.2 Pressure relief devices shall be sized to relieve the flow capacity determined for the largest single relief flow or any reasonable and probable combination of relief flows.

8.4.10.5.3* The minimum pressure-relieving capacity in pounds per hour (kilograms per hour) shall not be less than 3 percent of the full tank system contents in 24 hours.

8.4.10.6 Vacuum Relief Sizing.

8.4.10.6.1 The capacity of vacuum relief devices shall be based on the following:

(1) Withdrawal of liquid or vapor at the maximum rate
(2) Rise in barometric pressure
(3) Reduction in vapor space pressure as a result of filling with subcooled liquid

8.4.10.6.2 The vacuum relief devices shall be sized to relieve the flow capacity determined for the largest single contingency or any reasonable and probable combination of contingencies, less the vaporization rate that is produced from the minimum normal heat gain to the container contents.

8.4.10.6.3 No vacuum relief capacity credit shall be allowed for gas-repressuring systems or vapor makeup systems.

8.4.10.7 Fire Exposure.

8.4.10.7.1 The pressure-relieving capacity required for fire exposure shall be computed by the following formulas:

For U.S. customary units:

$$H = 34{,}500\ FA^{0.82} + H_n \quad [8.4.10.7.1a]$$

For SI units:

$$H = 71{,}000\ FA^{0.82} + H_n \quad [8.4.10.7.1b]$$

where:
H = total heat influx [Btu/hr (watt)]
F = environmental factor from Table 8.4.10.7.1
A = exposed wetted surface area of the container [ft^2 (m^2)]
H_n = normal heat leak in refrigerated tanks [Btu/hr (watt)]

National Fire Protection Association (NFPA) 59A, Standard for Production, Storage and Handling of LNG

Example - Emergency Response Review

- Safety layers of protection effectiveness and reliability based on risk to public and nearby infrastructure (e.g., three independent liquid level transmitters for LNG tanks vs two for refrigerant vessels vs one for process vessels, passive fire protection requirements, etc.)
- Security layers of protection effectiveness and reliability based on risk to public and nearby infrastructure (e.g., vehicle barrier rating vs risk of scenarios, security escorts, etc.)
- Residual risks mitigated by last layer of protection emergency response capabilities and plans
    - Based on onset of hazard to public based on risk to public from various safety and security scenarios (e.g., LFL, 5 kW/m^2, 31.5kW/m^2), including:
        - public and emergency responder education and training (e.g., shelter in place locations, visual condensation of flammable vapor cloud vs relative humidity and temperature, firewater for exposure cooling not suppression of LNG fires, etc.)
        - time to notify public and emergency responders for action(s) and response (e.g., evacuation vs shelter in place)

Example - Emergency Response Review

- FERC responsible under Energy Policy Act of 2005 to review and approve emergency response plans for LNG terminals and associated LNG shipping activities.
- LNG spills can emit more radiant heat than most flammable fluids (i.e. higher surface emissive power with less smoke shielding)
- LNG plants have tanks that hold more total flammable liquid than most other hydrocarbon storage and LNG carriers may hold more total flammable liquid than most other bulk flammable carriers
  - 85% of LNG carrier capacities 125,000-185,000 m^3, and up to 267,000 m^3
  - Very large gas carriers (VLGCs) for LPG 70,000-85,000 m^3 and up to 101,000 m^3
- Sandia 2004/2008 LNG and 2018 LPG reports indicate LNG vessels have larger radiant heat impacts than LPG vessel release scenarios (below)

Marine Vessel Release Scenario	Hole Sizes	Pool Radius	Hazard Duration	Zone 1 (37.5 kW/m	Zone 2 (5 kW/m2)	Zone 3 (LFL)
2004 Nearshore LNG Accidental	11-43ft^2 (<43ft^2)	180-590ft (340ft)	20-40min (20min)	490-820ft (820ft)	1600-2500ft (2500ft)	4900-5600ft (5200ft)
2004* Nearshore LNG Intentional	**43-130ft^2 (50-75ft^2)**	**300-1000ft (500ft)**	**3-20min (8min)**	**820-2100ft (1600ft)**	**2600-6900ft (5200ft)**	**8200-12000ft (11000ft)**
2008 Offshore LNG Intentional	50-170ft^2 (130ft^2)	560-2300ft (900ft)	7-20min (10min)	1300-3600ft (2300ft)	4300-10000ft (6500ft)	13000-17000ft (16000ft)
2018 LPG Accidental	30ft^2 (30ft^2)	NR	NR	NR	NR	NR
2018 LPG Intentional	**75-170ft^2 (75ft^2)**	**360-770ft (510-640ft)**	**3-46min (6-46min)**	**360-770ft (510-640ft)**	**980-2400ft (1750ft)**	**8500-15000ft (NR)**

Example - Emergency Response Review

- FERC staff as part of its review process has evaluated 30,000 gal and 10,000 gal pressure vessel failure consequences for LNG, LPG, and Ethylene under various scenarios, representative of conditions that may be found in rail and tanker trucks, some of which are shown below, with general agreement with ERPG.
- FERC staff as part of its review process has also evaluated potential cascading (BLEVE) failures and consequences for LNG, LPG, and Ethylene, as shown below, with general agreement with ERPG.

Rail Car Release Scenario	Hole Sizes	Pool Radius	Hazard Duration	Zone 1 (37.5 kW/m^2)	Zone 2 (5 kW/m^2)	Zone 3 (LFL)	Projectiles (90-99.9%)
LNG Accidental (-220F @ 50psig)	0.8-3in^2 (3in^2)	none	60-65min (60min)	90-150ft (120ft)	150-180ft (180ft)	200-800ft (800ft)	0.62-1.8mi (1.2 mi)
LNG Catastrophic (-220F @ 50psig)	Catastrophic	none-130ft (none)	4-14min (11min)	270-480ft (290ft)	420-530ft (440ft)	940-1900ft (1100ft)	0.62-1.8mi (1.2 mi)
LPG Accidental (100F @ 175psig)	0.8-3in^2 (3in^2)	none	45-60 min (60 min)	40-110ft (100ft)	70-140ft (140ft)	130-170ft (150ft)	0.66-1.9mi (1.3 mi)
LPG Catastrophic (100F @ 175psig)	Catastrophic	none-110ft (none)	10-30min (11min)	260-370ft (300ft)	460-780ft (470ft)	800-1900ft (960ft)	0.66-1.9mi (1.3 mi)

*range taken as min and max across hole sizes and 2/F, 5/D, and 9/D results; nominal range taken as 5/D of entire contents from 2 inch hole and as 5/D of entire contents released over 10 min in line with EPA RMP worst case scenario and 99% projectiles

The Zone 1 and 2 cases for the conditions shown were commonly bounded by jet fires, for which the hazard model used does not have the same level of formal evaluation, but validation studies indicate the flame length is generally overpredicted, the surface emissive power is generally underpredicted, and the resultant radiant heats at different locations are overpredicted on average for natural gas, propane, butane, and other jet fires. While Zone 3 impacts for smaller LNG releases could exceed 330 ft, we do not expect Zone 1 and 2 jet fire radiant heat impacts to exceed the 330 ft for smaller LNG releases or Zone 3 dispersion distances to exceed the ½ mi for larger LNG releases or Projectile distances to exceed the 1 mi distances for projectiles used in the DOT ERG.

EVACUATION

Immediate precautionary measure

- Isolate spill or leak area for at least 100 meters (330 feet) in all directions.

Large Spill

- Consider initial downwind evacuation for at least 800 meters (1/2 mile).

Fire

- If tank, rail car or tank truck is involved in a fire, ISOLATE for 1600 meters (1 mile) in all directions; also, consider initial evacuation for 1600 meters (1 mile) in all directions.
- In fires involving Liquefied Petroleum Gases (LPG) (UN1075), Butane (UN1011), Butylene (UN1012), Isobutylene (UN1055), Propylene (UN1077), Isobutane (UN1969), and Propane (UN1978), also refer to BLEVE – SAFETY PRECAUTIONS (Page 366).

In Canada, an Emergency Response Assistance Plan (ERAP) may be required for this product. Please consult the shipping paper and/or the ERAP Program Section (page 390).

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LNG Hazard Onset and Duration for Zones 1 & 2

- FERC staff uses the information from these consequence models to inform its review and approval of Emergency Response Plans as each potential consequence may have different emergency response preparedness, planning, and response procedures in order to be effective.
  - Zone 3 outer most portions near LFL; innermost portions near 5kW/m
    - Evacuation feasible to mitigate impacts as time for onset of hazard is order of several minutes or longer to further distance from hazard. Preparedness, pre-planning and response needs should still be evaluated. Higher or sensitive population impacts or compromised or limited evacuation routes may warrant additional preparedness, pre-planning and response needs;
    - Shelter in place may not be advisable to protect from flammable vapors because larger overpressures would exist if ignited within a confined volume (e.g., inside a home); however, shelter in place may be advisable in this zone if the flammable vapors are ignited as the inner most portion of zone is below critical heat flux for common building materials.
  - Zone 2 outermost portions near 5kW/m^2; innermost portions near 37.5kW/m^2
    - Shelter in place feasible in outermost portion of zone where below critical heat flux for common building materials and failure of process equipment, but near innermost portion of zone it may be more difficult without special pre-planning and infrastructure in place (e.g., special construction);
    - Evacuation can be more difficult because second degree (irreversible) burns can occur for those with skin directly exposed to radiant heats in 2 seconds to 40 seconds, 1% fatalities in 10 seconds to 2 minutes; 100% fatalities in 30 seconds to 7 minutes. May be desirable to have public education outreach and pre-planned prompt actions (e.g., sirens or other quick acting public notification devices) to facilitate evacuation to maximize effectiveness. Higher or sensitive population impacts or compromised or limited evacuation routes may warrant additional preparedness, pre-planning and response needs and/or preventative measures.
  - Zone 1 outermost portions near 37.5kW/m^2; innermost center within incident location of release or fire
    - Shelter in place and evacuation can be very difficult without special pre-planning and infrastructure in place (e.g., specially designed shelters in place, etc.). Preparedness, pre-planning, and response may not be effective in mitigating impacts and may warrant additional preventative measures. Higher or sensitive population impacts may warrant additional preventative measures (e.g., exclusion zones for LNG plants from single accidental sources, positive control measures for LNG ship transits, higher wall thickness and maintenance requirements for pipelines, etc.).

Questions?