SAND2009-2053P

Liquefied Natural Gas Research Activities

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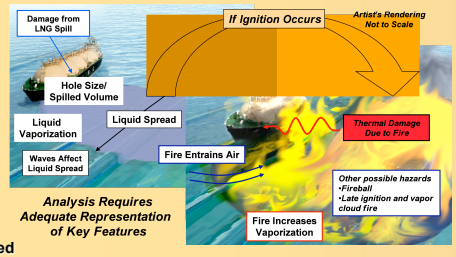
Moss-Type LNG Vessel

Background:

- At the request of DOE, Sandia is currently conducting large-scale LNG pool fire experiments and assessing cascading damage potential to an LNG vessel in the event of a spill.
- These pool fire experiments for diameters up to 100 m are the largest ever performed in the world and are being conducted at Sandia National Laboratories, New Mexico.
- This study is expected to provide the United States Coast Guard with information on the potential range of thermal hazards to identify exclusion zones.

Key Features of LNG Spills Over Water

- Forms a pool
- Vaporizes rapidly, faster on water than on land
- Forms a heavy vapor cloud that moves downwind
- If vapor cloud encounters an ignition source, it will burn back to it's source and to burn as a pool fire
- An LNG vapor cloud within flammable limits can explode if confined
- On water, it can undergo rapid phase transition (RPT) explosions
- These physical explosions cause damage but do not involve combustion
- It can cause brittle fracture of carbon steel ship hulls and tanks



Analysis Requires Adequate Representation of Key Features

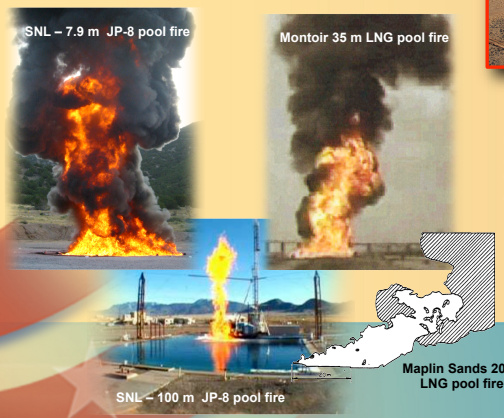
A pool fire is the most likely outcome in the event of an intentional breach, however, it is difficult to predict the thermal hazards for anticipated pool diameters of 100 to 500 m due to uncertainties in:

- Surface Emissive Power and Smoke Shielding
- Flame height
- Burn rate

These parameters are of interest for integral-based models which are used in industry. These are the controlling parameters in integral-based models for predicting the range of thermal hazards. The use of Computational Fluid Dynamics models are not used routinely, except for non-ignited LNG vapor clouds. This is due to the more intensive resources required.

LNG Pool Fires

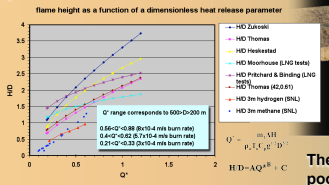
- LNG fires do not smoke like typical hydrocarbons at scales tested to date (35 m diameter or less).
- Some smoke production evident in largest LNG fires at vertical locations high above the ground.
- We expect smoke shielding to occur in LNG spill fires of very large diameter (100's of meters), but no data at these scales.
- Emissive power data inconclusive - $q'' \sim 170 - 270$ kW/m^2 for LNG;
- $q'' \sim 20 - 40$ kW/m^2 for other fuels.
- Radiative fraction data inconclusive - 0.16 versus 0.36 for essentially identical LNG pools.

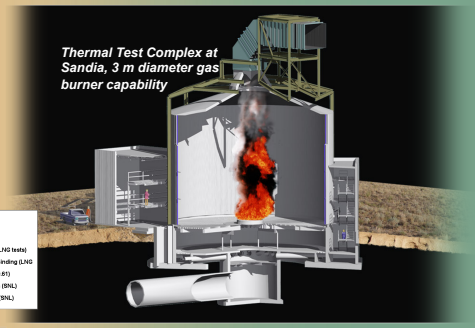


Current Research on Reduced-Scale Experiments:

To determine flame height for LNG pool fires on the order of 100 m, the Fire and Aerosol Science Department (1532) conducted experiments using the 3 meter gas burner at the Thermal Test Complex.

Several flame height correlations already exist, but none have been performed for a turbulent pool fire using a controllable gas burner in a well-characterized environment. It is important to test for a fire in the turbulent regime since it shares similar physics of large-scale pool fires. Also, well-characterized environments are vital for validation.





The reduced-scale test data suggests that for the anticipated pool diameters from an LNG spill on water the flame height to diameter ratio will be between 0.5 and 1. Note that this assumes a quiescent environment and does not include the affect of wind on flame structure.

Current Research on Large-Scale LNG Pool Fires

Research on large-scale LNG pool fires up to 100 m in diameter is currently being performed at Sandia by the Fire and Aerosol Science Department (1532). The data collected will provide information on the surface emissive power, burn rate, and flame height. The first test was conducted February 19, 2009 and the next is expected to be performed in June, 2009.

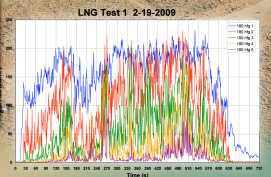
Test Series

Fire Diameter (m)	LNG volume (gallons)	LNG flow rate (gpm)
35	40,000	7,000
70	150,000	31,000
100	310,000	63,000

Instrumentation

- Instrument towers (12) 110 m, 160 m, and 210 m (from pool centerline)
- Data Acquisition Systems (5)
- Reservoir
  - Liquid level (1 pressure, 1 floats)
  - Temperature (8 TCs)
- Pool
  - Spill Area (overhead video (2)
  - Heat flux to surface (13 DFTs)
  - Water temperature (36 TCs)
- Plume
  - Height (12 cameras) (4 high speed, 2 infrared)
  - Spectrometers (4) (400-800 nm, 1300-4800 nm)
  - Heat flux (radiometers: narrow-angle (2R), wide-angle (1Q)
- Meteorology
  - 3D ultrasonic wind speed/direction (4)
  - ambient pressure/temperature/RH (1)

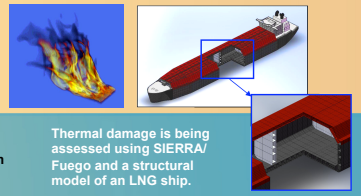
First LNG Test, February 19, 2009



Narrow-angle radiative heat flux 110 m from pool centerline

Current Research on Cascading Damage

Research on the potential for cascading damage to an LNG vessel is also being conducted. Cascading damage refers to multiple tanks rupturing due to either brittle fracture from an LNG spill or to thermal damage from an LNG pool fire. Thus, in the event of a breach of one tank the questions to be answered are: Will multiple tanks breach due to the initial event? If so, what are the time and length scales? Thus, this effort entails obtaining small-scale experimental data for development and validation of cryogenic failure and structural models. The cascading damage from a fire is being assessed with the Sandia Fire Code, SIERRA/Fuego.


Thermal damage is being assessed using SIERRA/ Fuego and a structural model of an LNG ship.

Evidence from actual spills on LNG ships has shown that brittle fracture and crack propagation occurs.

30-40 m^3 LNG spill on deck results in brittle fracture
Source: A. Valudolon (2000)

National Nuclear Security Administration

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

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