Summary of the Phoenix Series Large Scale LNG Pool Fire Experiments

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U.S. DEPARTMENT OF ENERGY

Oil and Natural Gas

Sandia National Laboratories

Congressionally Directed LNG Safety Research

- Based on recommendations contained in GAO Report 07-316 issued in February 2007, House Committee on Energy and Commerce announced on 3/14/2007 a hearing on LNG Tanker Security, Safety, and Licensing.
- From those hearings, Committee members recommended that DOE expand LNG safety research underway with Sandia to examine all of the top LNG safety issues identified by the GAO.
- In December 2007, Congress provided DOE with $8M in FY08 funding to expand LNG research at Sandia to address the top 10 safety issues and concerns identified in GAO Report 07-316.
- Sandia received funding from DOE in June 2008 to start a large, multi-year LNG safety research program. The research is focused on the major LNG safety issues identified by the GAO, with primary emphasis on vessel damage and the potential for cascading failure, and on fire testing, modeling, and analysis. USGS provided an additional $1M.

Rationale for Expanded LNG Safety Research Program

- Motivation originates from the breach of an LNG carrier, either from an intentional or accidental event, resulting in a large amount of LNG spilling into an LNG carrier or onto the water.
- The current range of LNG fire modeling parameters, due to lack of data at spills of interest (~500 m diameter), provide a significant variation in thermal hazard and consequence predictions for large LNG pool fires.
- The potential impact of a large LNG spill on the structural integrity and stability of an LNG carrier, either from cryogenic or fire damage, was not well understood.
- The emerging use of very large LNG carriers could compound potential existing hazard and consequence analysis deficiencies.

Expanded DOE/Sandia LNG Safety Research Program Objectives

- **Objective 1: Improve the understanding of the physics and hazards of large LNG pool fires resulting from spills over water for application in LNG risk analysis and mitigation planning for federal, state, and local decision makers.**
- **Objective 2: Improve the understanding of the thermal (cryogenic and fire) hazards of large LNG spills on the structural integrity and associated damage of LNG carriers and cargo tanks.**
- **Objective 3: Assess the potential for damage from an initial LNG spill to cause damage to other LNG cargo tanks, thus increasing the size of a spill and the hazards to the public and property.**

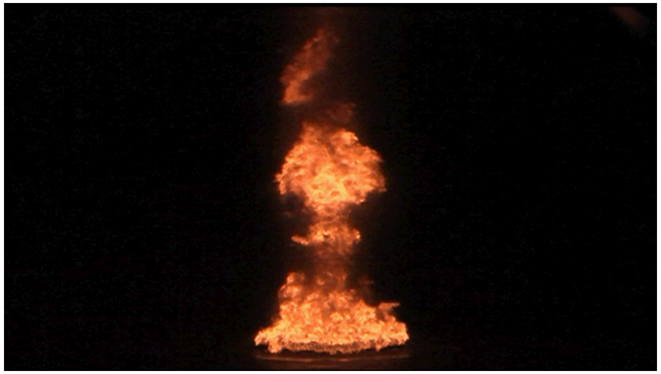
- **Today's talk focus is on Objective 1.**

Objective 1 – Large LNG Pool Fire Testing and Modeling Efforts

- Conduct scaled fire height to diameter tests in controlled conditions
- Construct a large experimental area to conduct up to 100m in diameter LNG pool fires on water
- Conduct large-scale LNG pool fire tests (30m, 70m, and 100m diameter) to determine large LNG pool fire hazards, including:
  - Large pool fire behavior, physics, and characteristics
  - Surface emissive power (flame radiant energy)
  - Fuel vaporization rate (pool size)
  - Flame height and diameter (view factor)
- From the test data obtained, update existing fire models to enable better estimates of LNG pool fire properties and behavior at scales of interest (up to 500 m diameter) with complicated conditions and geometries

Fire Dynamics at Large Scale

JP8 – 2 m (SNL)



JP8 – 3 m (SNL)

JP8 – 20 m (China Lake)

LNG - 10 m SNL 2005

LNG - 35 m 1989 Montoir 1989

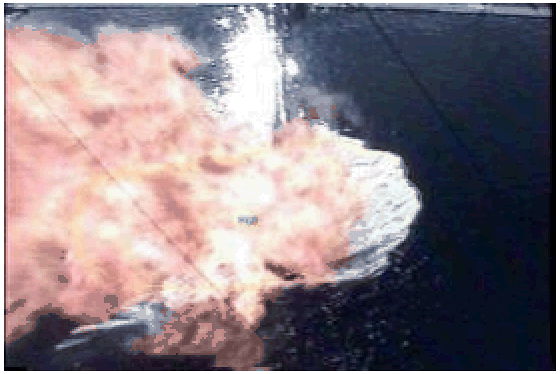
????

LNG ~200 m

Methane has unique chemistry that results in an order of magnitude less soot production and less smoke production/shielding.

LNG Fire Dynamics at Large Scale

LNG - 10 m SNL 2005



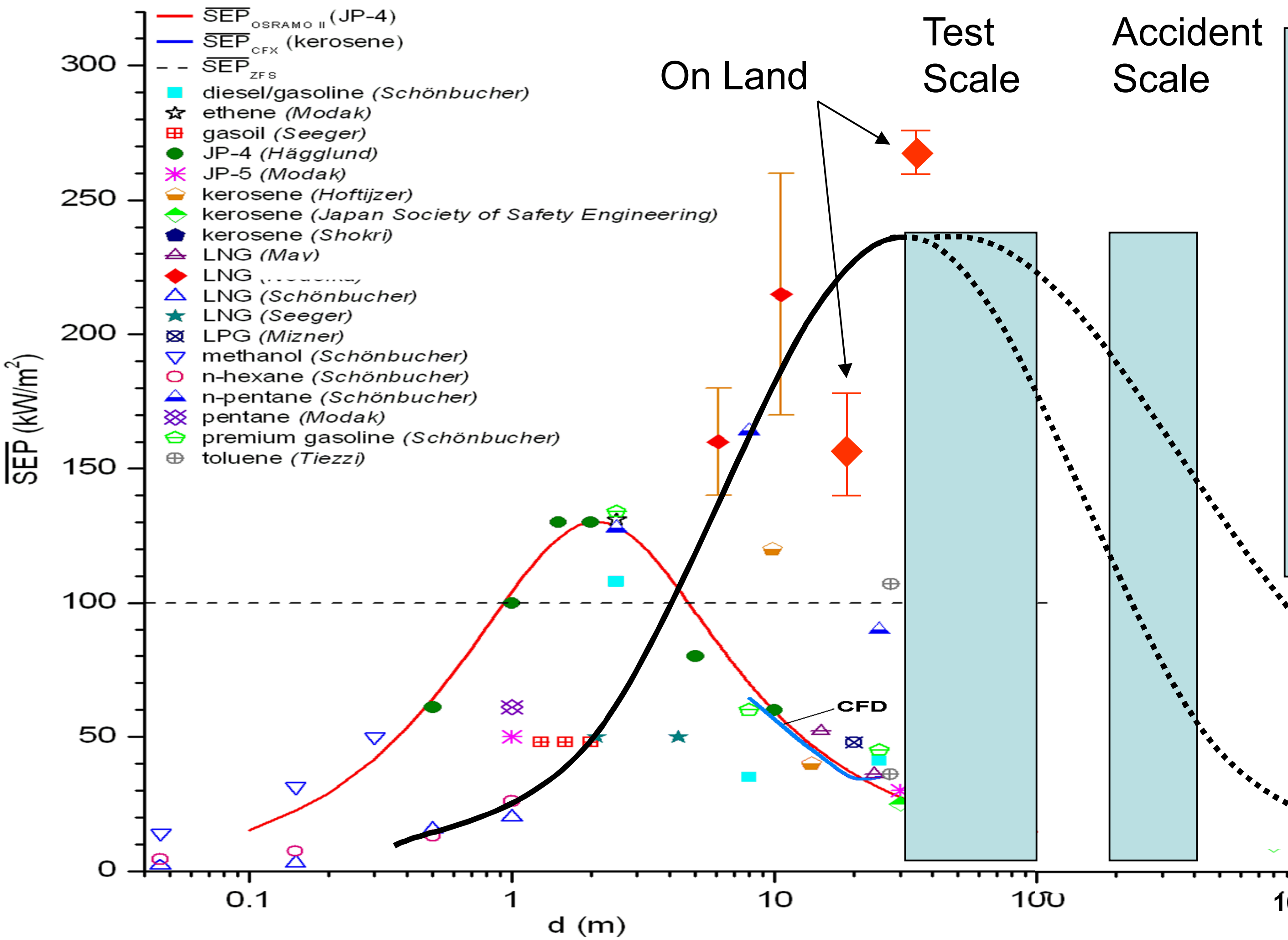
For the 10 m test:
Spot SEP_{ave} ~190 kW/m^2

LNG - 21 m SNL 2/2009

LNG - 83 m SNL 12/2009

Note the pool diameter does not determine the flame width on open water.

Surface Emissive Power as a Function of Pool Diameter Heavy Hydrocarbons Compared to LNG



Factors of ~ 2 uncertainty may exist in SEP at LNG accident scales without:

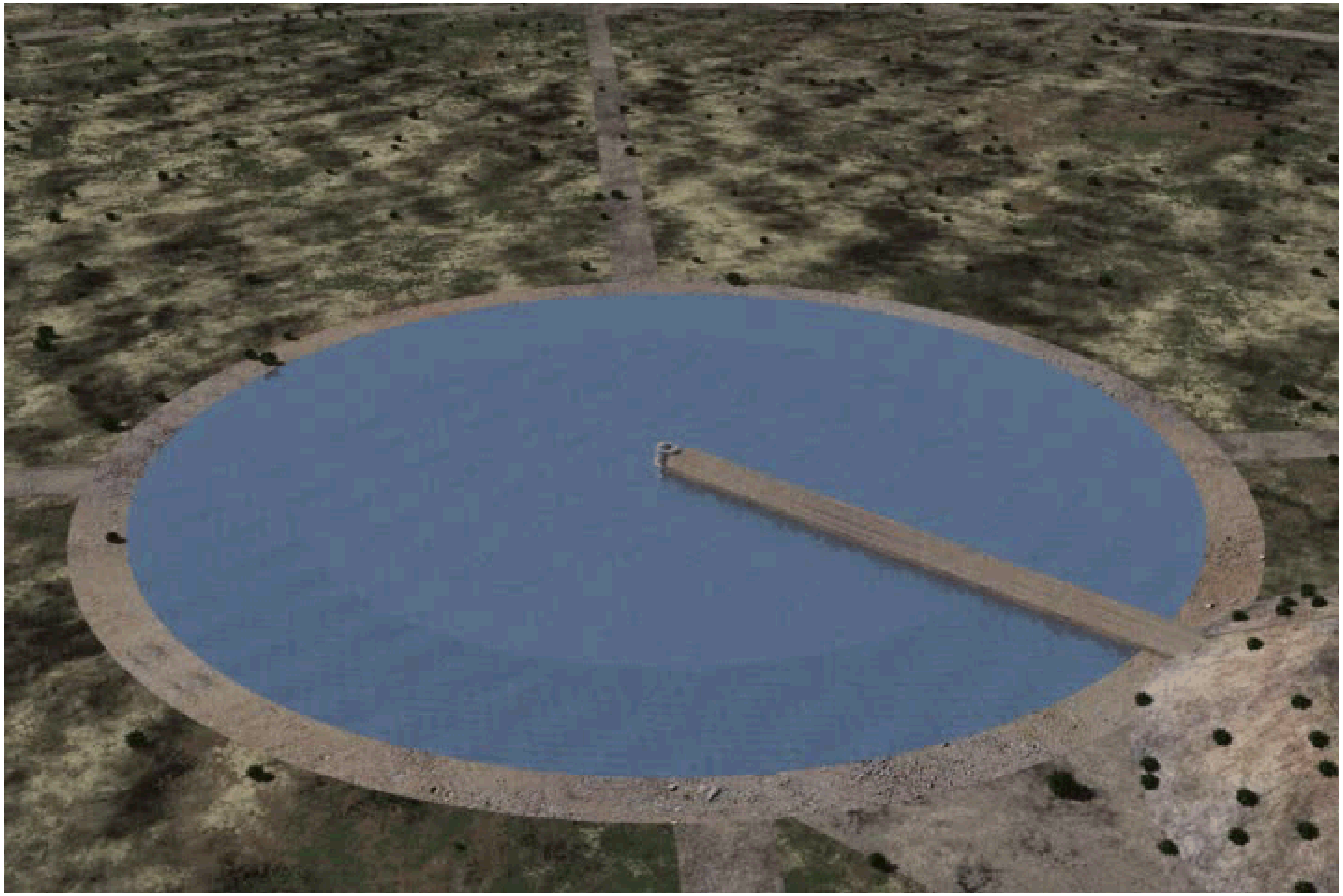
- Large-scale pool fire data, and
- Detailed, physics-based, fire modeling capability

The flame height/diameter ratio and the heat flux is expected to decrease with increasing scale for large LNG fires; however, the extent is unknown.

LNG Large Scale Pool Fire Testing and Modeling Summary

- LNG Pool construction July 2008 through November 2008
- Test 1
  - February 2009
  - 26m diameter spill, 23m diameter pool fire, 3 minute steady state pool fire
- Test 1a
  - Scheduled July 2009
  - During filling identified leak in LNG storage reservoir, test aborted, and reservoir repaired and modified over 5 month
- Test 2
  - December 2009
  - 83m diameter spill, 56m diameter pool fire, 1 minute steady state pool fire
- Pool Fire Test Report peer reviewed and complete
  - Blanchat, T., Helmick, P., Jensen, R., Luketa, A., Deola, R., Suo-Anttila, S., Mercier, J., Miller, T., Ricks, A., Simpson, R., Demosthenous, B., Tieszen, S., and Hightower, M., (2010). The Phoenix Series Large Scale LNG Pool Fire Experiments, SAND2010-8676, Sandia National Laboratories, Albuquerque, NM.
- Large Pool Fire Integral Model report peer reviewed and complete
  - Luketa, A. J. (2011), Recommendations on the Prediction of Thermal Hazard Distances from Large Liquefied Natural Gas Pool Fires on Water for Solid Flame Models, SAND2011-0495, Sandia National Laboratories, Albuquerque, NM.

Large-scale LNG Pool Fire
Test Setup and Operational Sequence

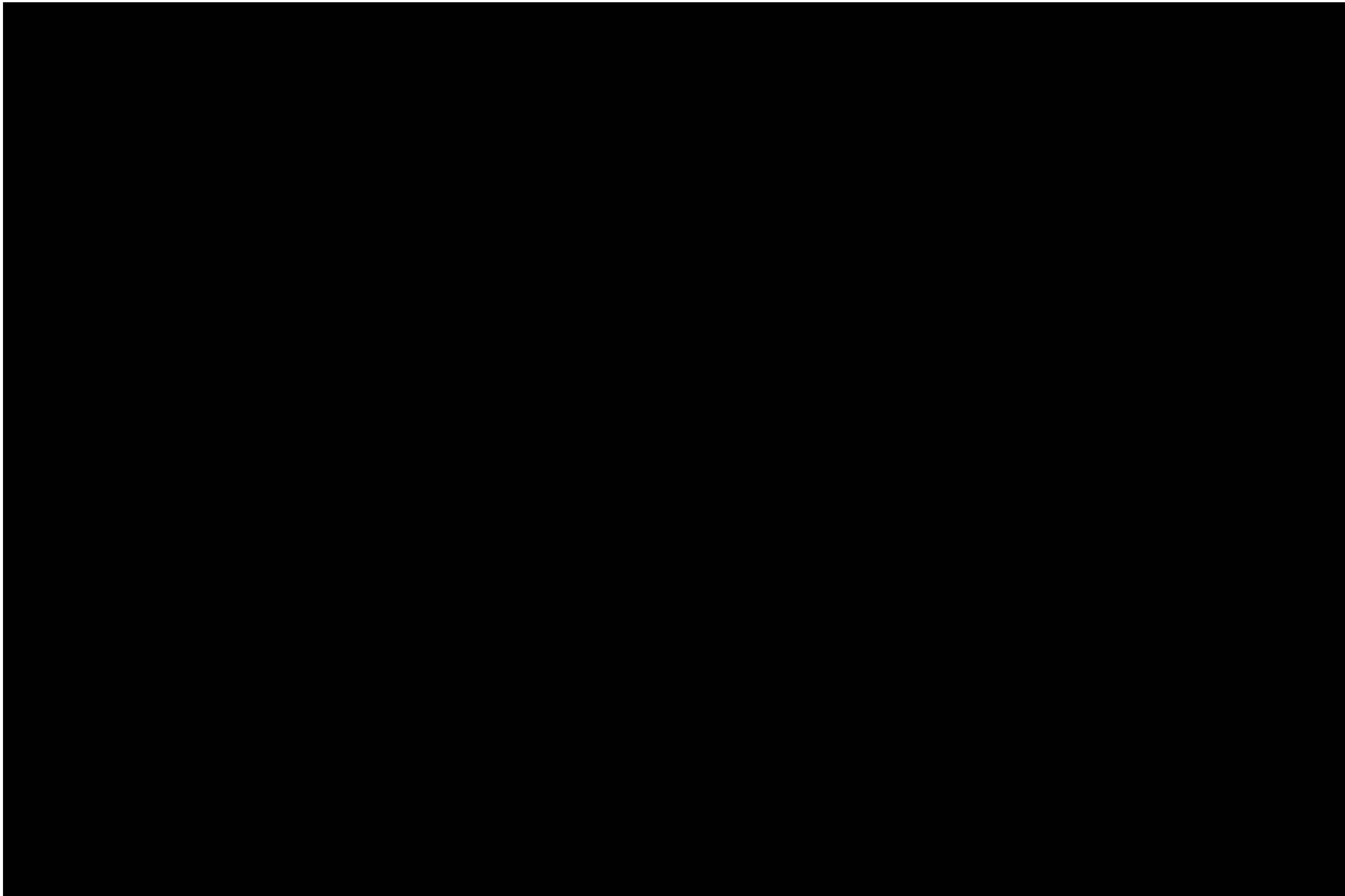


120 m diameter 2 m deep pool, 350,000 gal LNG storage reservoir

Over 50 separate thermal radiation monitoring and other instrumentation

Phoenix Series – 2nd LNG Pool Fire Test

Aerial and long range camera sequences at spill start, during steady-state fire, and end of test.

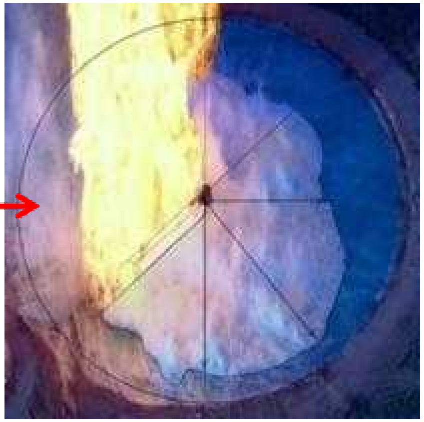


Phoenix Series – 2^{nd} LNG Pool Fire Test

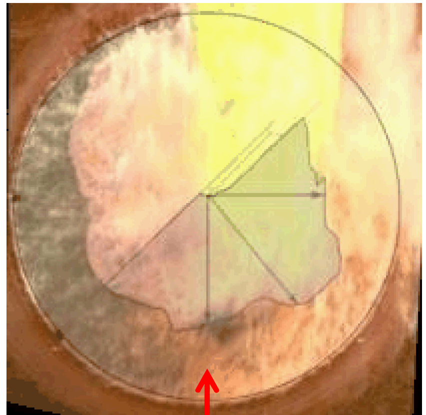
"Grasshopper" North Spoke Camera
Point Grey Research, 1200x400 pixels
1Hz acquisition, entire test (10 min), X20 playback, 30 s video

Water vapor entrainment on the oxidizer side of the flame is quite evident.
Water vapor is also most likely entrained on the fuel side due to vigorous boiling at the LNG/water interface.

LNG Pool Fire Test #2
Height and Diameter Data

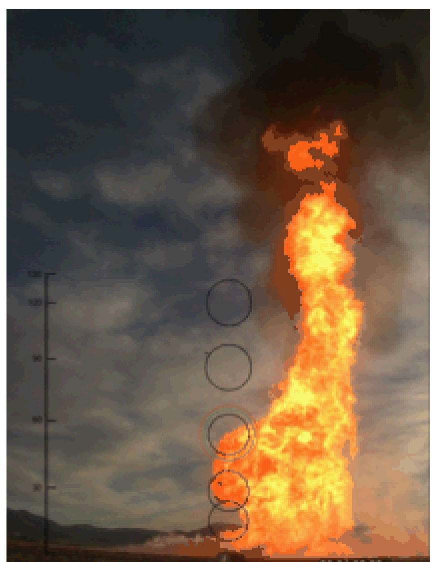


90º aerial at 270s

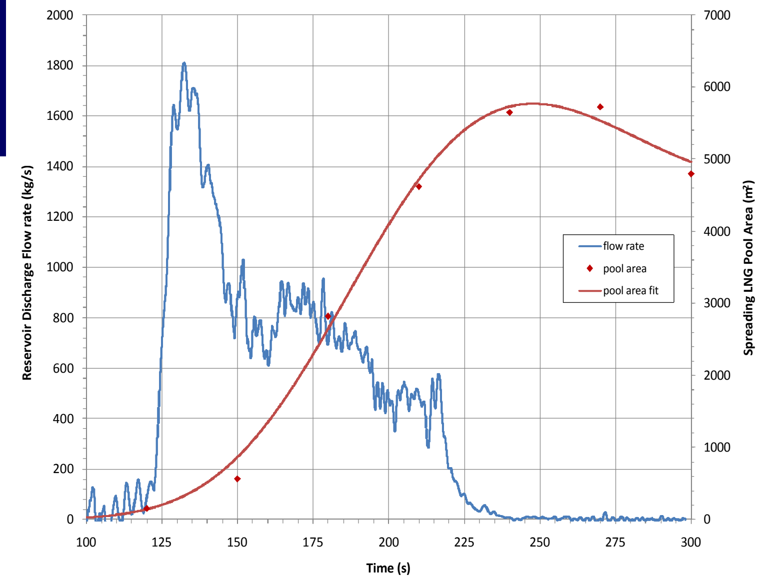


270º aerial at 270s

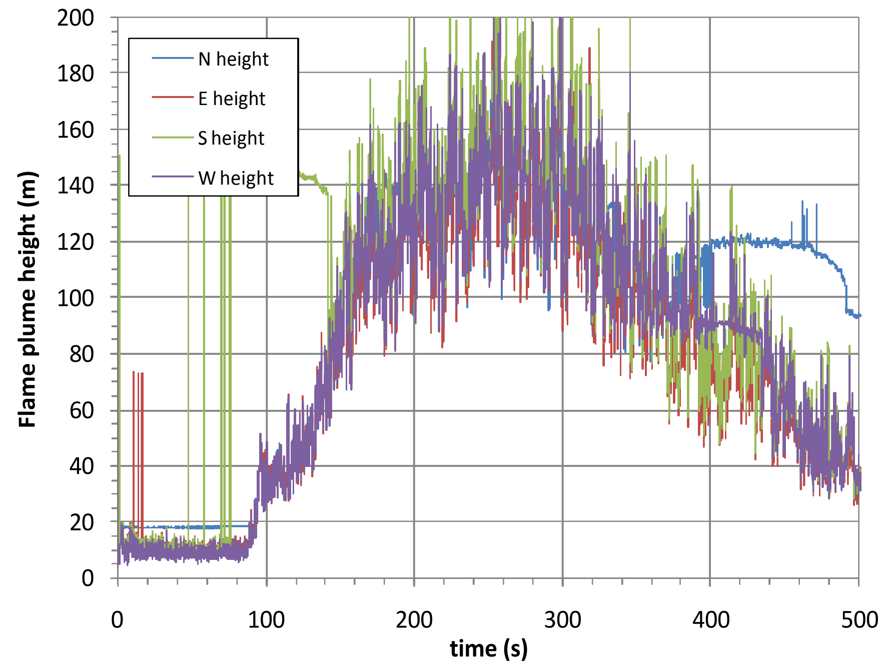
south cam at 270s



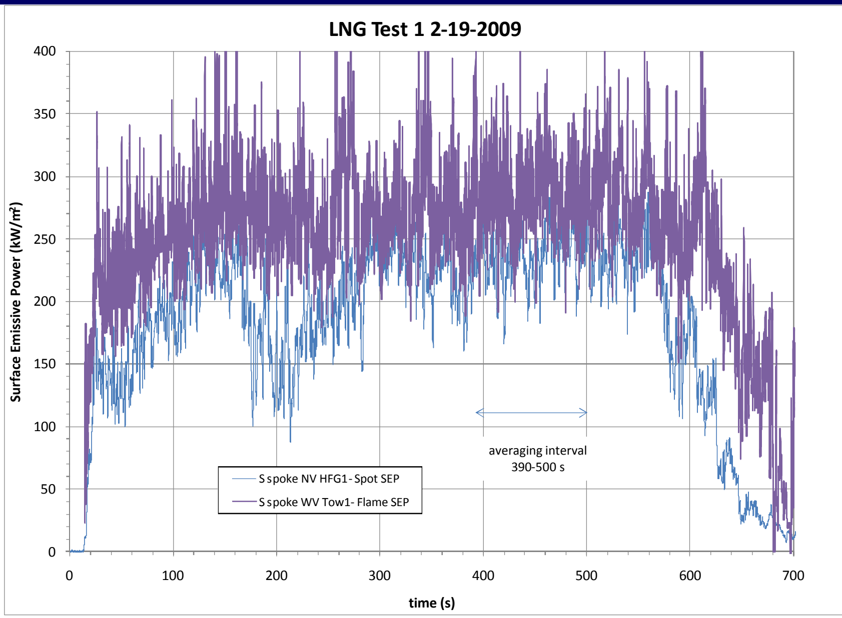
west cam at 270s

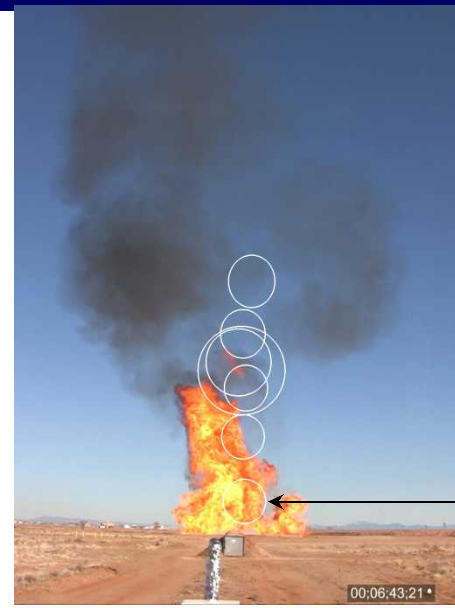


~100 s spill duration (~200 m^3 at 800 kg/s)
Pool Width 83 m
Flame Width 56 m
Flame Height 146 m



Surface Emissive Power
(narrow view and wide view heat flux radiometers)

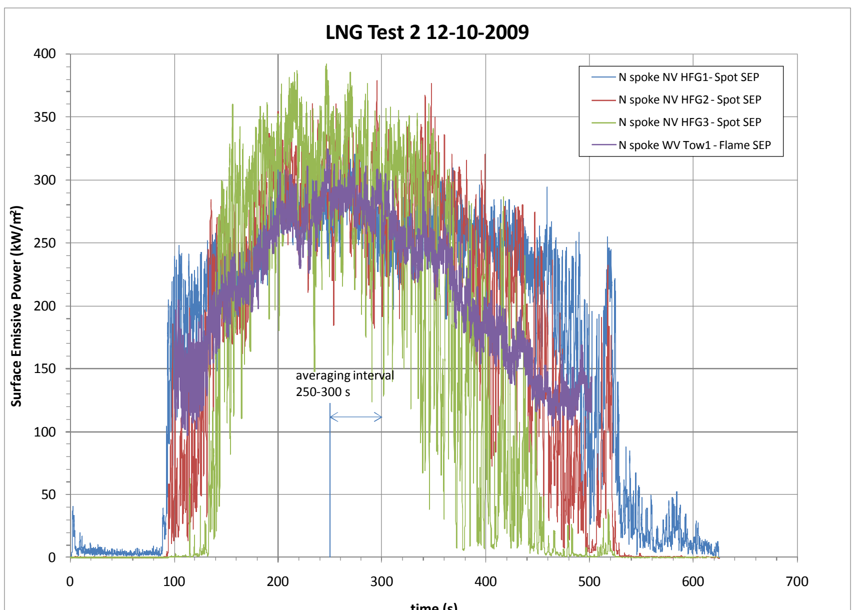


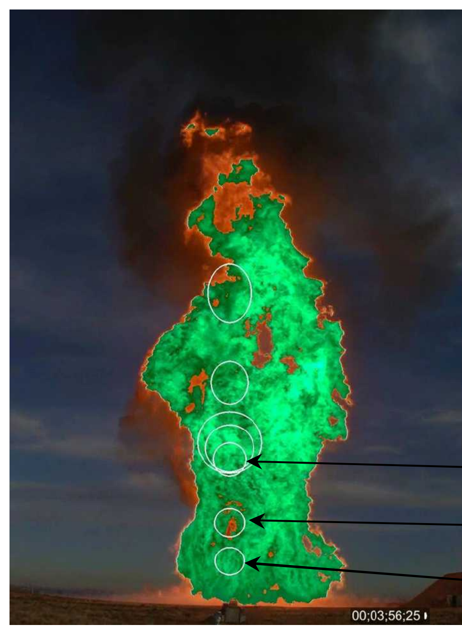


NV HFG1

Test 1 (~58 m^3 discharge)
Burn rate ~0.14 kg/m^2s

Flame SEP – wide view gauges
277 ± 60 kW/m^2 (2σ)
Spot SEP – narrow view gauges
238 ± 30 kW/m^2 (2σ)
(390s - 500s)



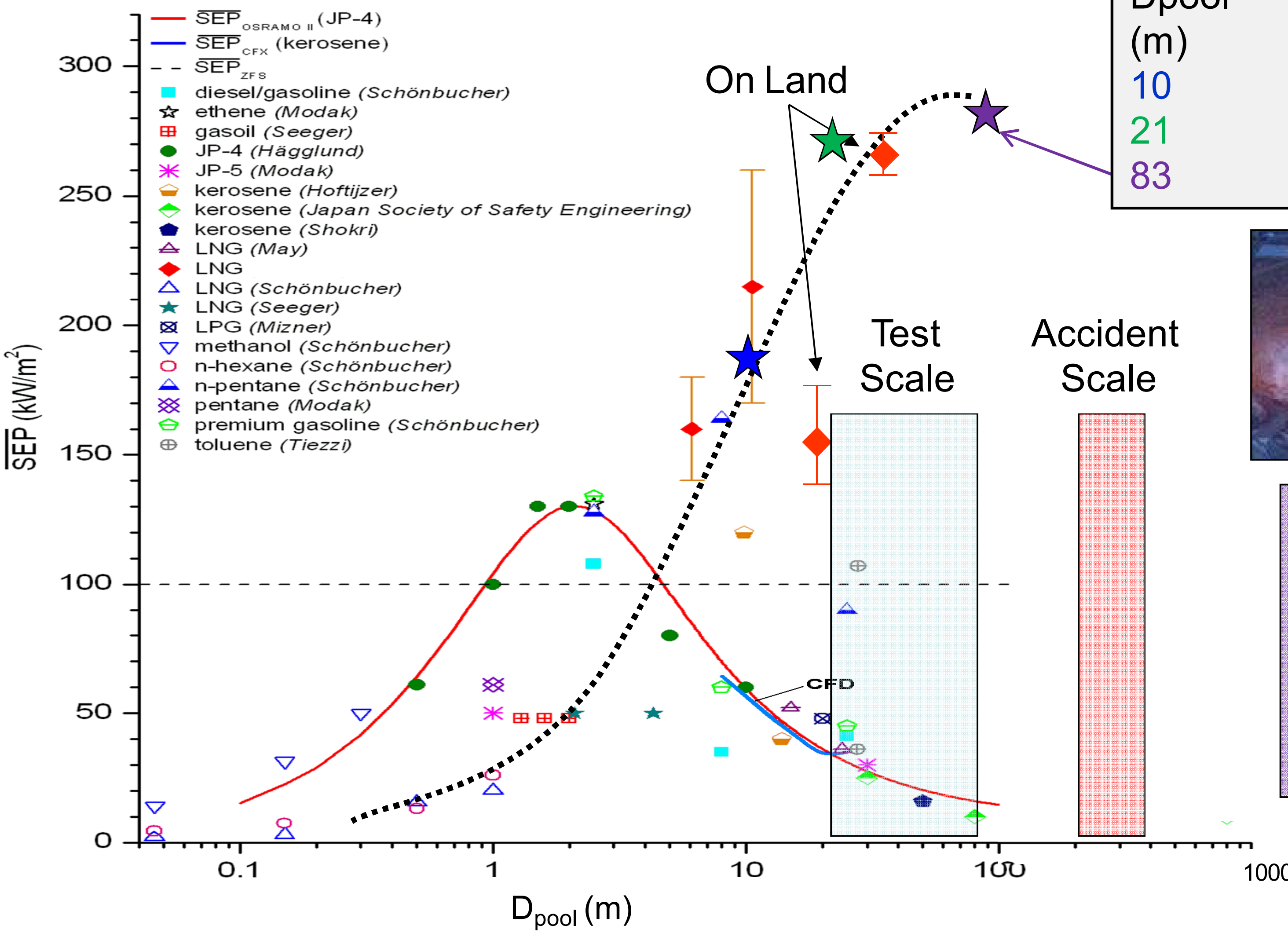


NV HFG3
NV HFG2
NV HFG1

Test 2 (~199 m^3 discharge)

Flame SEP – wide view gauges
286 ± 20 kW/m^2 (2σ)
Spot SEP – narrow view gauges
282 ± 101 kW/m^2 (2σ)
(250s - 300s)

Surface Emissive Power as a Function of Pool Diameter Heavy Hydrocarbons Compared to LNG (with large scale test data)



Dpool (m)	SEP (kW/m^2)
10	190
21	277
83	286

LNG Test #2

@270s

D_{pool} 83 ± 4 m

W_{flame} 56 ± 12 m

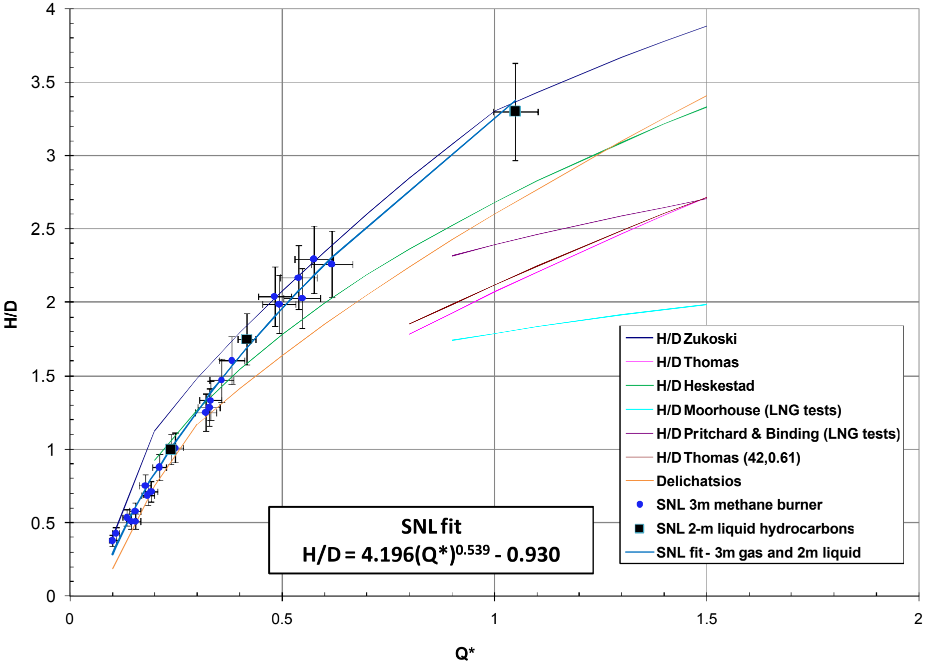
@250-300s

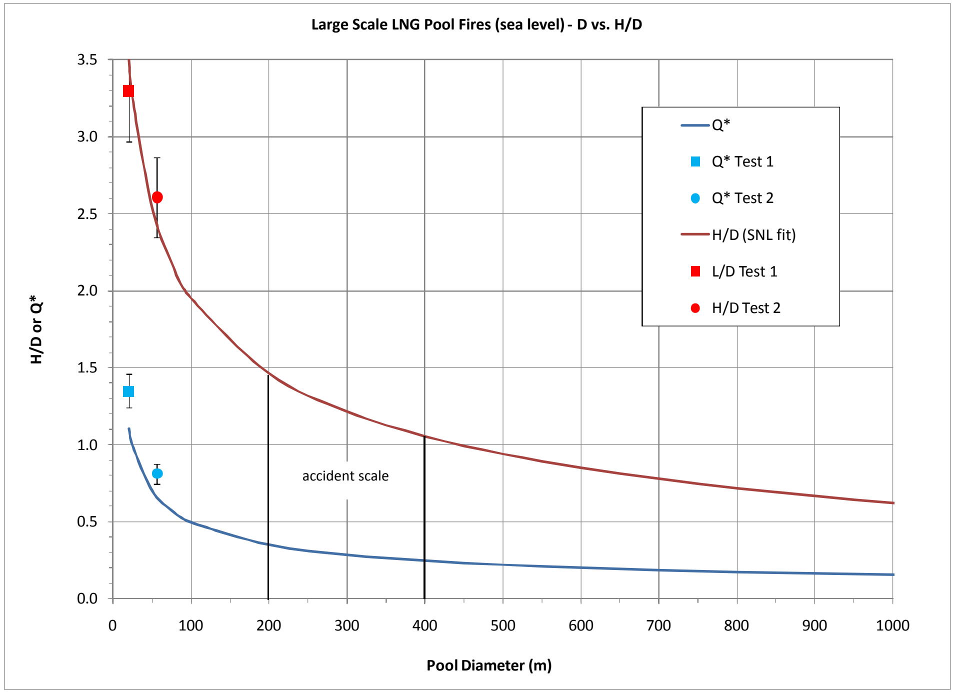
H_{flame} 146 ± 8 m

Methane Gas Burner Tests
H/D vs. Q*

The flame height and Q* (nondimensional heat release rate) are model parameters used for hazard assessment studies because they relate to the total area and power of the fire that irradiates the surroundings.

Thermal Test Complex
FLAME/RH Test Cell





A pool diameter of 200-400 m corresponds to a Q* values of 0.35 to 0.25 and the estimated H/D ratios would be ~1.5 to ~1.1.

LNG Safety Research
Large Scale Pool Fire General Results

- **Large-scale pool fire testing and analysis results**
  - No smoke shielding and water entrainment yield surface emissive powers in the range of 270-290 kW/m^2
  - Pool diameter is less than spill diameter, and fire height/diameter is less than past data suggested for large pool fires (since it is very difficult to predict the extent of non-burning regions across the pool it is recommended for safety purposes to assume the pool area is fully burning).
  - In both very light and significant cross-winds the flame will stabilize on objects projecting out of the fire, suggesting that the ship itself will act as a flame anchor.
  - Overall LNG pool fire hazard distances decrease by ~5-10% from 2004 and 2008 Sandia LNG reports (the reduced flame height results and transmission factors offset higher SEP values).
    - "For a nominal 1 tank breach with a 5 m^2 hole resulting in a 300 m diameter spill and 8 minute fire, the distance to the 5 kW/m^2 heat flux level is ~1300 m."
  - It must be emphasized as in the 2004 Sandia report that hazard distances will change depending on the surroundings conditions and the scenarios associated with the site. Thus, site-specific analyses should be performed.

Questions?

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