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DOE/Sandia National Laboratories Coordinated Approach for LNG Safety and Security Research

Large Scale LNG Pool Fire Experiments
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Background and Objective

- Motivation originates from the breach of a LNG ship, either from an intentional or accidental event, resulting in a large amount of product spilling onto the water.
- The current uncertainty of LNG fire modeling parameters due to lack of data for scales of interest (~500 m) drives large uncertainty in thermal hazard and consequence prediction for LNG pool fires.
- Objective: To improve the understanding of the physics and hazards of large LNG fires resulting from spills over water for application in LNG risk analysis and mitigation planning.

DOE/SNL Large Scale LNG Spill Fire Experiments

Anticipated Benefit, Historical Analogue

Dispersion Model Comparison for 25,000 m^3 LNG spill on water from 1980 Report* (BEFORE Burro experiments, 1982)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Predicted Distance to LFL (km)	28	18	26	40	1.2	8.3

Distance is around 3 km based upon validated computational fluid dynamics (CFD) simulations

Burro (LLNL), LNG dispersion experiment

*Safety Aspects of Liquefied Natural Gas in the Marine Environment, National Materials Advisory Board

DOE/SNL Large Scale LNG Spill Fire Experiments

Anticipated Benefit

- LLNL Dispersion Experiments greatly enhanced understanding of LNG dispersion and allowed data for validation
- SNL Pool Fire Experiments are anticipated to be the analogue to the LLNL Dispersion Experiments
- Will facilitate progress in siting ports by allowing federal and state agencies to make informed decisions

Objective and Approach

Obtain data to allow best estimate prediction of thermal hazard distances for large LNG pool fires

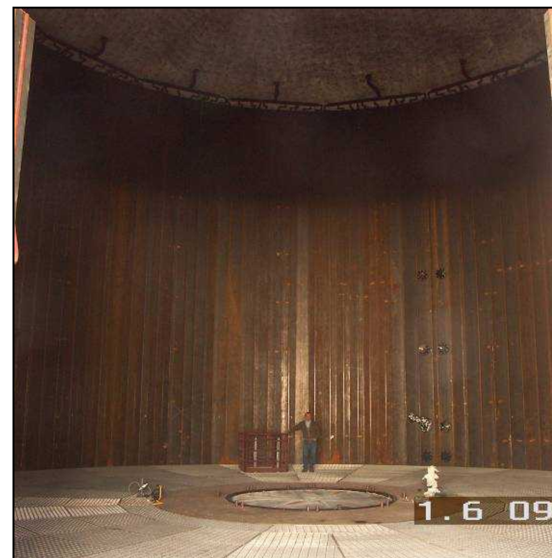
- Small-scale Tests using a 3 m diameter gas burner (Thermal Test Complex)
  - Tests in TTC using methane will provide data in support of **flame height prediction**.
  - Measure flame height as a function of a **dimensionless heat release parameter** (Q*) in order to develop flame height correlation.
  - Determine critical dimensionless parameter value at which transition to non-coherent fire plume **(mass fire) behavior** occurs.

- Large-scale LNG pool fire tests
  - **Surface emissive power**, **mass loss (burn) rate**, and **luminous flame height** measurements will be obtained for a minimum of three LNG spills on water for three different pool diameters up to 100 m.
  - Trend in these parameters will allow for development of correlations for pool diameters greater than 100 m.

Small Scale LNG Pool Fire Tests

Thermal Test Complex

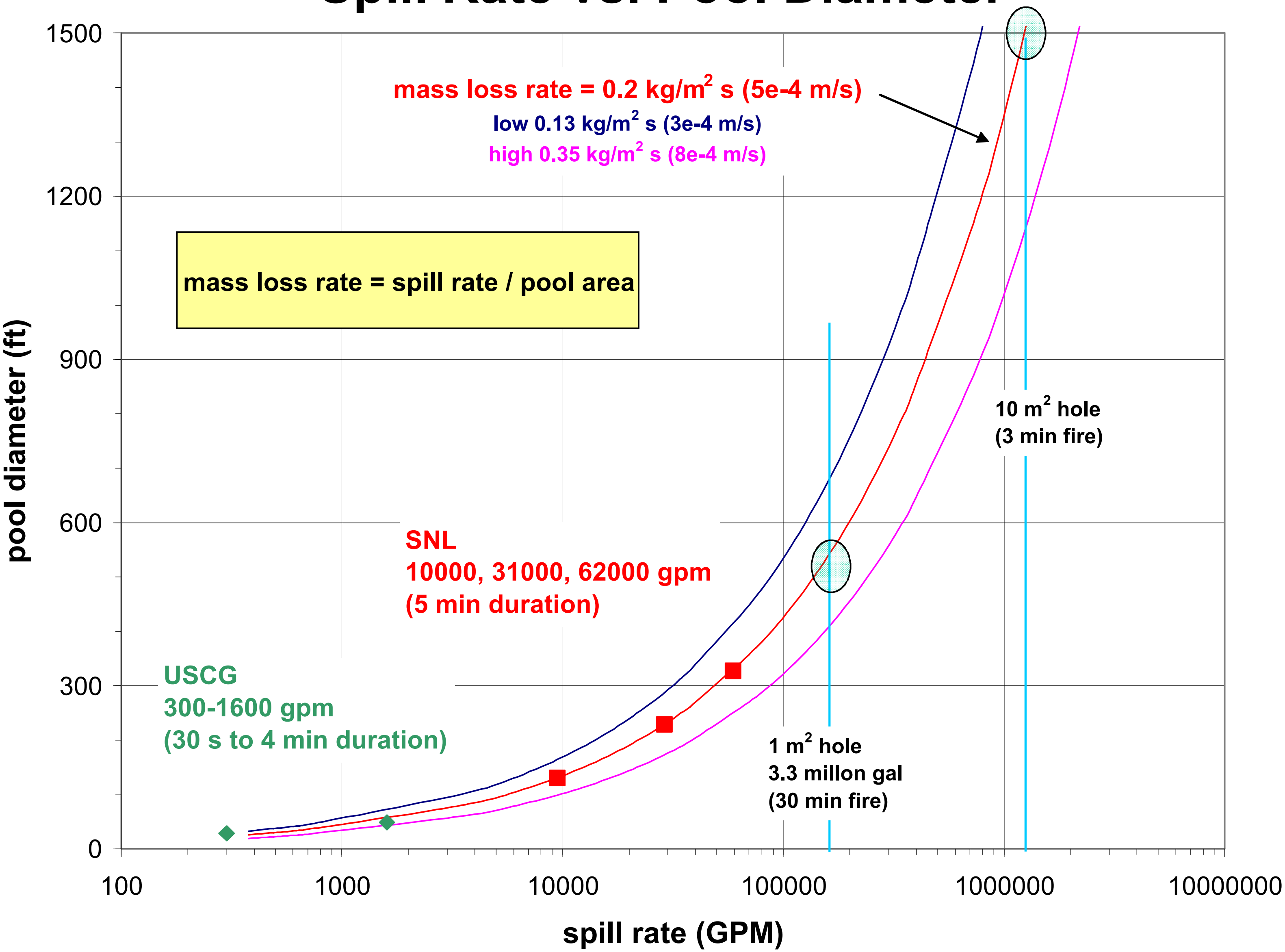
- Flame height for LNG pool fires (~100 m) is uncertain. Mass fire behavior is also unknown.
- Previous studies have not used burners which result in fully turbulent fires (i.e. different physics).
- Controlled fuel flow rate experiments.
  - **develop flame height correlation**
  - **investigate mass fire behavior**
- Will compare correlation to measured flame heights from large scale tests.



3-m diameter methane test

Large Scale LNG Pool Fire Tests

Spill Rate vs. Pool Diameter

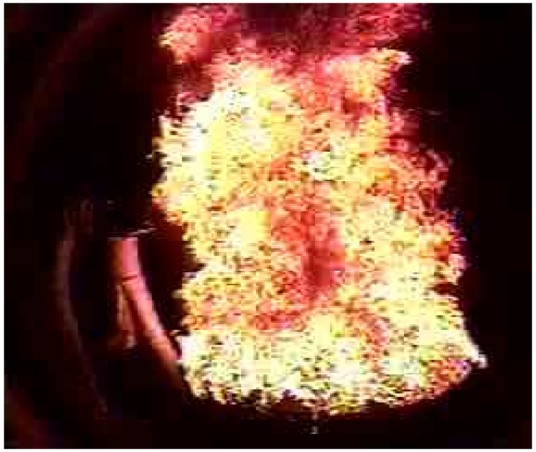


Smoke Shielding

LNG spill and pool fire, 300 gpm, 10 m diameter, SNL WIF (2005)

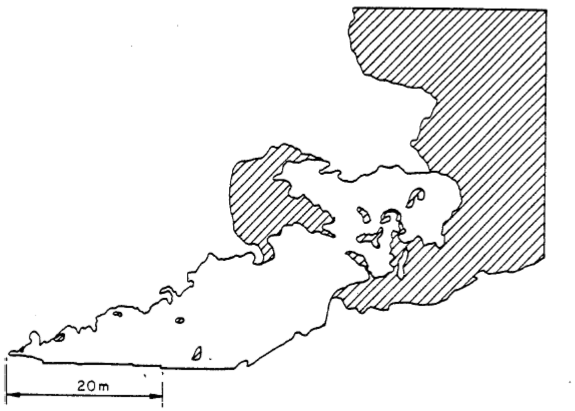
Smoke Shielding

JP8 – 2 m (SNL)



JP8 – 3 m (SNL)

JP8 – 20 m (China Lake)



LNG – 20 m

Maplin Sands Tests – 1982

LNG – 35 m

Montoir Tests – 1989

LNG ~ 200 m

- The smoke shielding is expected to increase for large LNG fires, however, the amount of smoke shielding is unknown.

Large-Scale LNG Pool Fire Test Concept and Methodology

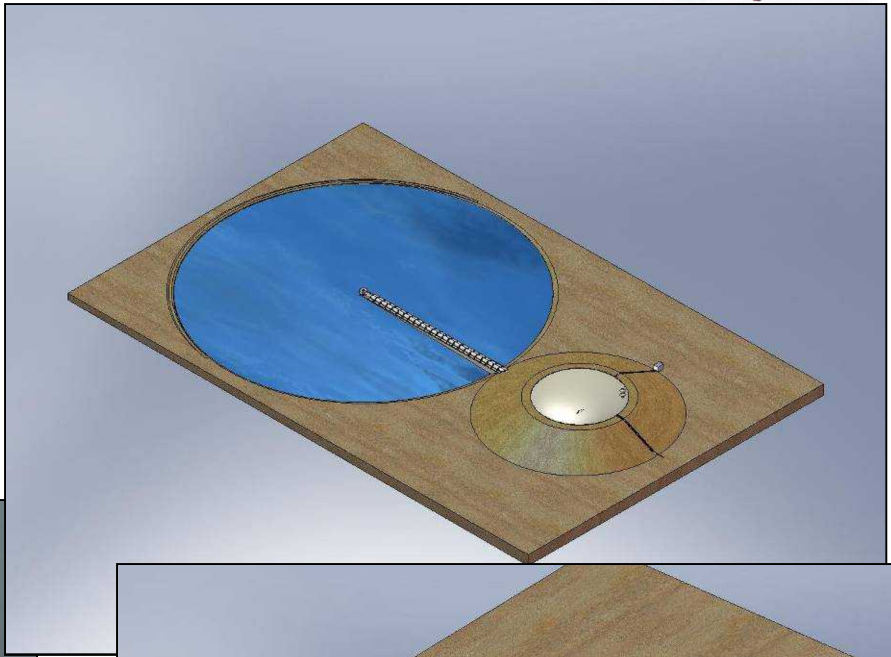
- Identify reservoir design criteria and appropriate test site
- Construct a 120 m diameter shallow water pool (1 m deep)
- Construct a reservoir to contain up to 310,000 gallons LNG
- Construct reservoir discharge systems and channel to discharge at pool center
- Construct LNG reservoir process fill piping
- Install reservoir, pool, and perimeter instrumentation
  - (flow rate, meteorology, video, IR, heat flux, etc.)

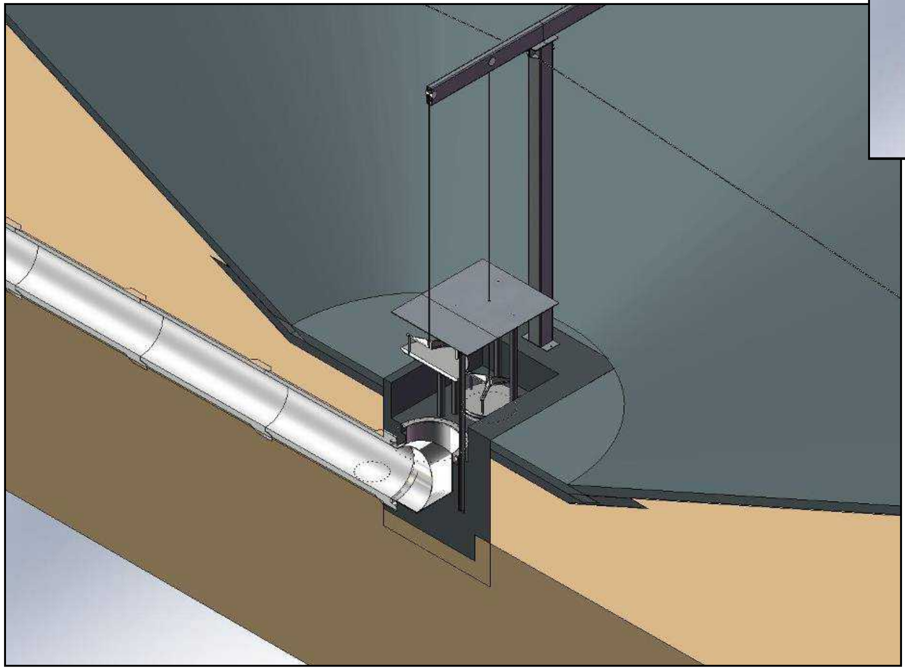
Design criteria: 1) Mass flux = 0.2 kg/m^2s (yielding a burn rate of 5×10^{-4} m/s), 2) Spread time = 3 minutes (for the 100 m diameter pool), and 3) Steady-state pool fire duration = 2 minutes. Determines a reservoir liquid capacity of 310,000 gallon (1175 m^3).

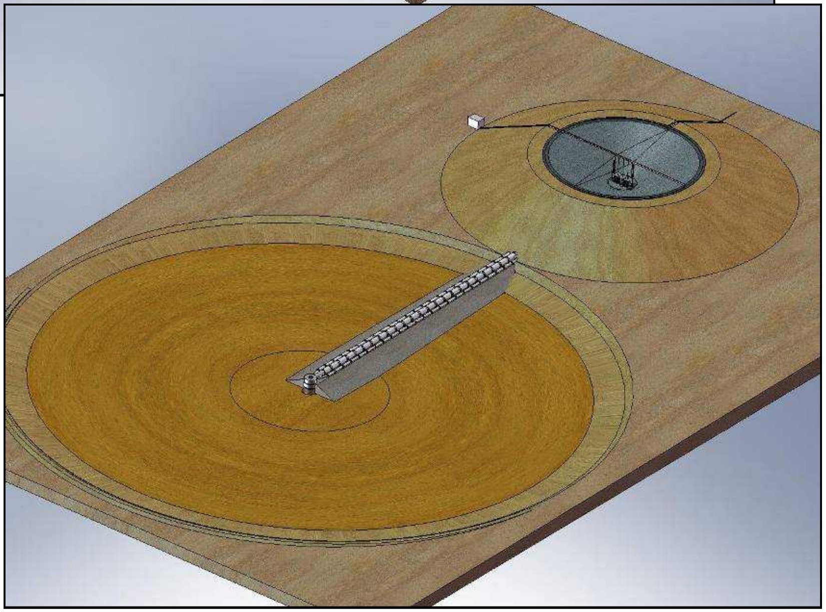
Fire Diameter (m)	LNG volume (gallons)	LNG flow rate (gpm)
40	51,000	10,000
70	154,000	31,000
100	310,000	62,000

Experiment Description

- LNG released onto a 120-m diameter lined water pool (1-m deep).
- Gravity release fed from a capped, soil-bermed (concrete lined) reservoir.
- LNG flows through concrete pipes to the center of the pool – immediate ignition at release.



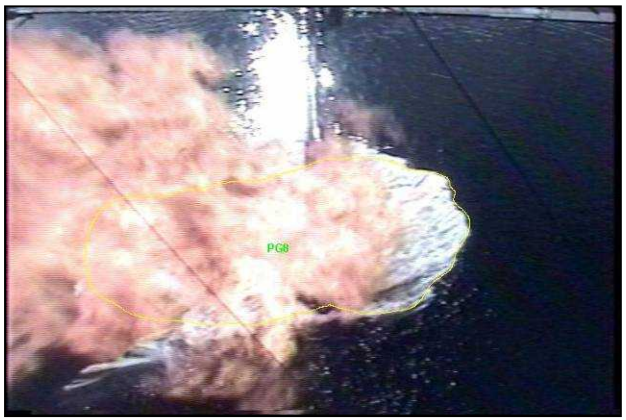


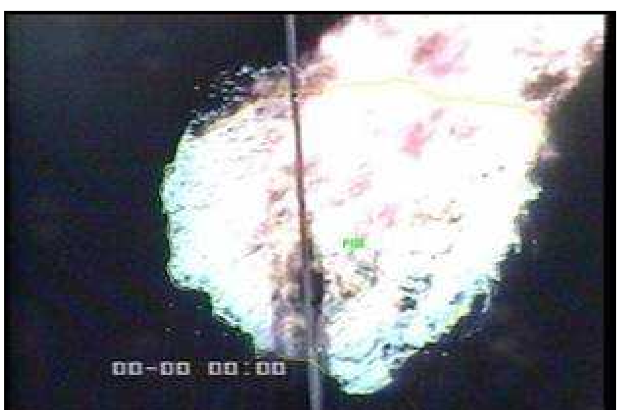


Photometric Coverage - Pool Area

- Overhead video (USAF helicopter) and SAR (GA Otter) to determine the real-time extent of the spreading pool fire - needed for burn rate measurement.

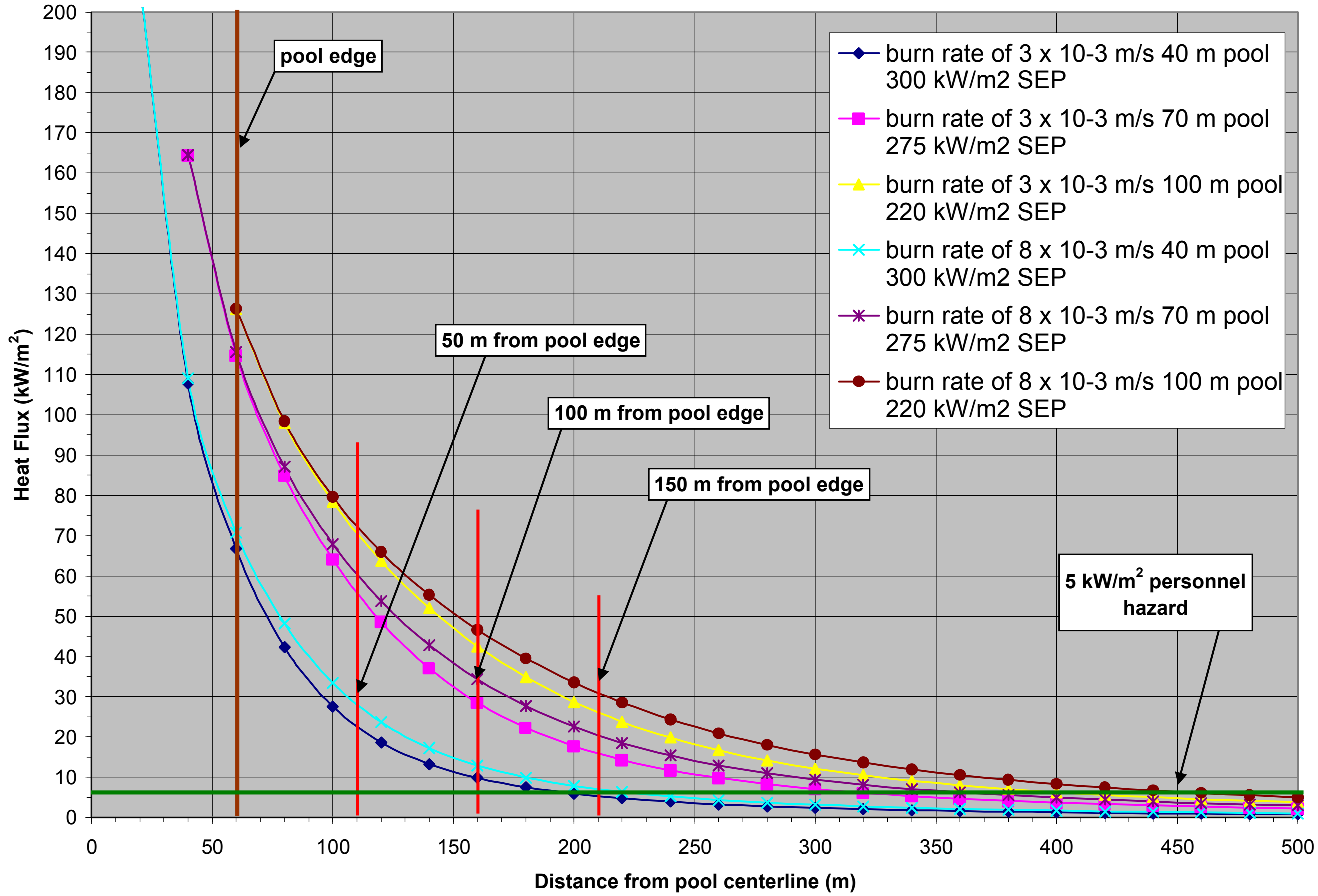
10 m diameter (300 gpm) LNG pool fire at SNL





Thermal Hazard Description

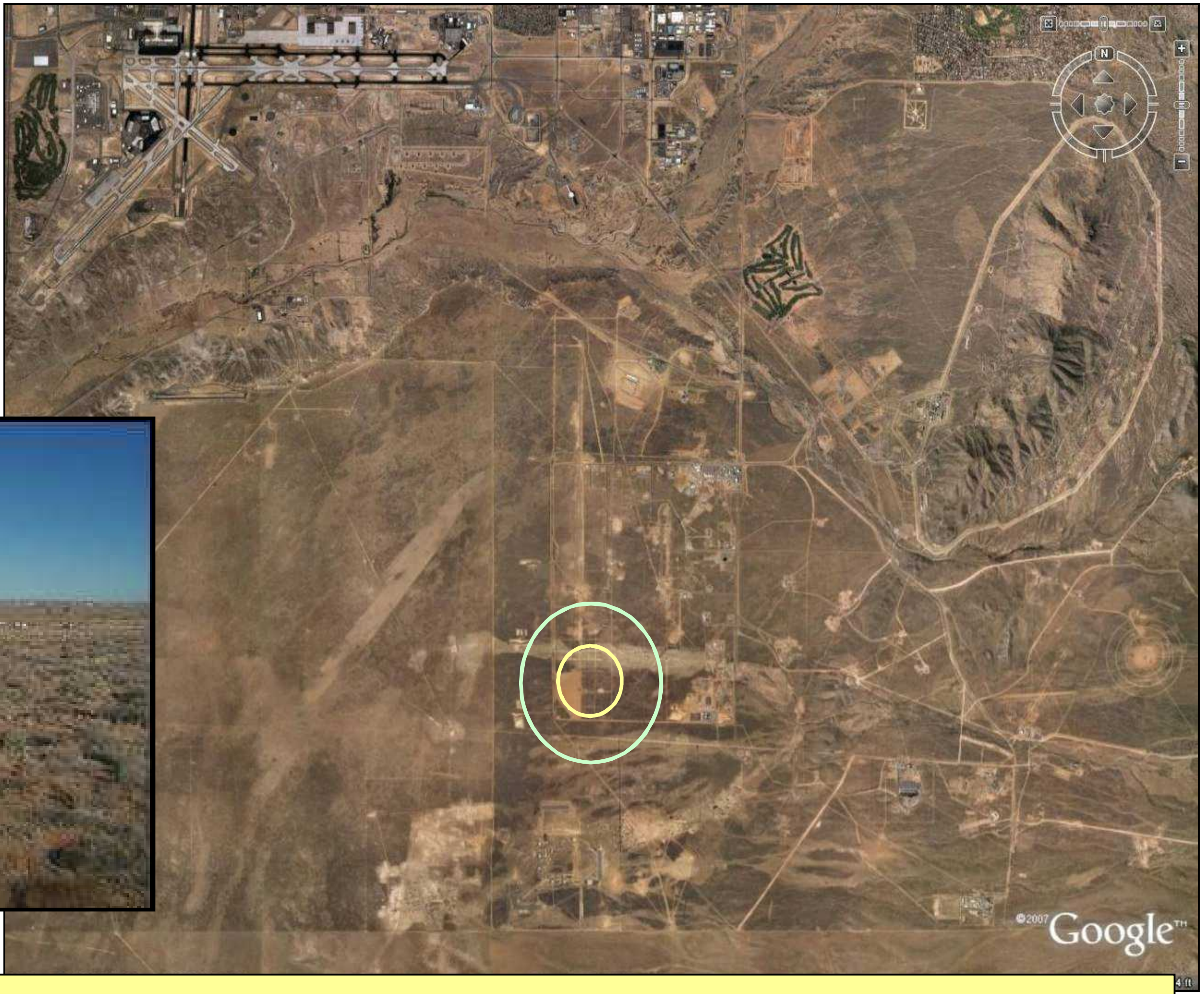
- Heat flux as a function of distance from the pool center for pool diameters of 40, 70 and 100 meters.
  - Conservative estimate for safety.
- SEP assumed to vary
  - 300 kw/m^2 for a 40 m pool
  - 220 kW/m^2 for a 100 pool fire.



Hazard Arc Identification

SNL/NM

D Explosive Test Site



Hazard zones:

- **450 m radius - largest fire heat flux.**
- **900 m radius - largest spill unignited dispersion and subsequent vapor cloud ignition.**

Permits and Approvals

Title	Status
NEPA – SNA07-0195 – Large Scale LNG Spill Tests	Complete – DOE determined CX
PHS - SNL07A00147-001 - Large Scale LNG Tests	Complete – Moderate Hazard Classification
Burn Permits: 07-0064 (51,000 gal-Sep08) 07-0065 (154,000 gal-Oct08) 07-0066 (310,000 gal-Nov08)	COA Approved
Biological Survey	Complete
Fugitive Dust Permit – 10090626-3732	Issued May 29, 2007, Expires Dec 31, 2008
Storm Water Pollution Prevention Plan	Complete
Excavation Permit	Complete
Aviation Operations - requests for aviation support and aviation safety plans	Submitted to SNL Aviation Support SME
COA Industrial Waste Engineering & NMED	Contacted for sanitary sewer discharge
DOE ISMS - IWP1662 - Large Scale LNG Pool Fire Experiments	Submitted – pending MOR
Meteorological Support	Requested
PrHA	Draft complete – Confirmed Moderate Hazard Classification
PSM Elements addressed	Draft Complete
PSM Pre-Startup Safety Review	Completed prior to test operations

Major Deliverables for LNG Fire Testing

Milestones	Date
•Complete Small Scale Tests	April 2008
•Large Test Planning/Construction Analyses/Documentation	April 2008
•Finalize Test Plan with Peer Review	May 2008
•Commence Construction – Pool and Reservoir	June 2008
•Complete Water Pool & Reservoir Construction	October 2008
•Operational Readiness Review/Check Tests	October 2008
•LNG Test 1 (51,000 gals)	November 2008*
•LNG Test 2 (154,000 gals)	December 2008*
•Interim Test Report	December 2008
•LNG Test 3 (310,000 gals)	January 2009*
•Preliminary Test and Data Summary Report	Summer 2009
•Site Remediation/Waste Disposal	Fall 2009
•Preliminary LNG Large-Fire Model	September 2009
•Complete Data Analyses/Final Test Report	December 2009
•Release LNG Large-Fire Model	March 2010

* Weather Permitting

Summary Costs for LNG Pool Fires Testing

Tasks	~Costs $K
•Reduced scale fire tests	$ 300K
•Experiment design (including design and safety reviews)	$ 300K
•Construction and instrumentation	$ 900K
•Procurement of LNG for 30m, 75m, and 100m fires	$1500K
•Experiment shakedown testing	$ 200K
•Multiple fire event testing	$1200K
•Interim data analyses and report	$ 100K
•Final data analyses and final report	$ 500K
•CFD fire modeling development	$ 500K
•Total	$5500K

Peer Review Group (PRG)

- Dr. JONATHAN S. PUTTOCK - Senior Consultant, HSE Consultancy, Shell International Petroleum Company Limited, Shell Global Solutions (UK). Ph.D. Cambridge University. Participant in the Maplin Sands and Montoir LNG experiments. Leads the research and development effort in the Major Hazards Management team (sponsored by Shell's LNG business). Produced a wide range of tools for the assessment of gas hazards and risk. These include prediction of release rate, evaporation, dispersion, jet fires, pool fires and explosions, as well as risk integration. Member of the Center for LNG.

- Dr. JOHN L. de RIS - Principle Research Scientist - Assistant Vice President FM Global, Ph.D. Harvard University. Physical and theoretical modeling of fires, flame heat transfer, fire spread, wall burning, pool fires, laminar and turbulent combustion, flame radiation, as well as soot formation and oxidation.

- Dr. RICHARD C. CORLETT - Professor Emeritus - Mechanical Engineering - University of Washington. Ph.D. Harvard University. Expert in heat transfer, thermodynamics, fluid dynamics. Research focused on fire flow and thermal modeling.

- Dr. CARLOS FERNANDEZ-PELLO - Professor - Mechanical Engineering, University of California, Berkeley. Ph.D. University of California, San Diego. Specializing in combustion, heat and mass transfer, and thermodynamics. Research focused on ignition, flame spread, and explosive burning of droplets and boiling of liquid hydrocarbon fuel pools.