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Modeling Challenges and Uncertainties Regarding Liquefied Natural Gas Hazard Predictions

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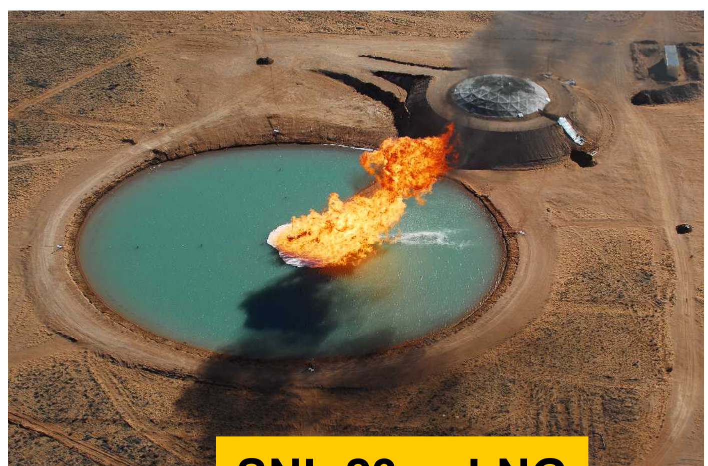
LNG Pool Fire Characteristics

- LNG fires do not produce smoke like typical hydrocarbons at scales tested to date (35 m diameter or less).
- 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 at large scale
- Flame height and burn rate uncertain

SNL 7.9 m JP-8 pool fire

SNL 10 m LNG pool fire



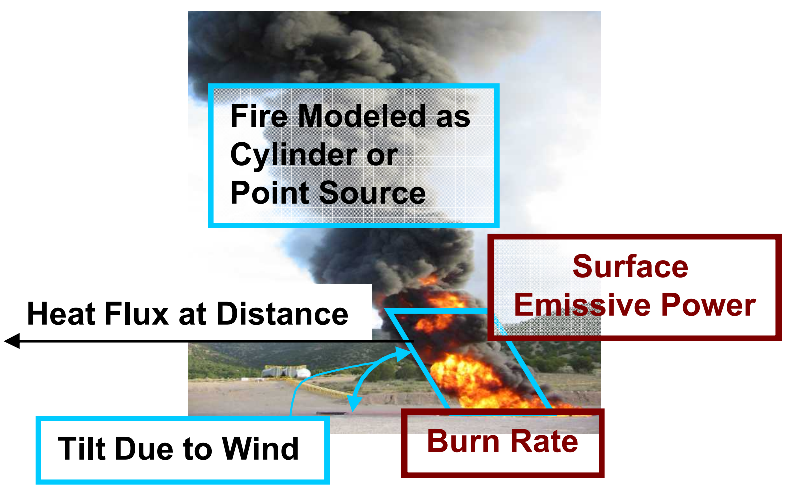
SNL 23 m LNG pool fire

Montoir 35 m LNG pool fire

LNG Pool Fire Modeling

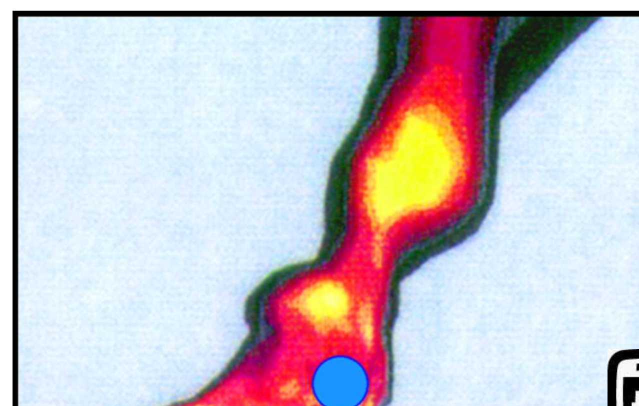
Integral or Similarity Models

- Treats fire as a global emitter with typically assumed cylindrical shape
- Input parameters based on data
- Heat flux (kW/m^2) calculated at distance
- Good for long distances, simple geometries



Computational Fluid Dynamics (CFD) Models

- Invokes more first principles
- Flow, reactions, heat transfer modeled
- Calculates heat flux distributions for specified scenario including complex geometries and irregular shaped pools



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Fire modeling considerations

- Reasonable approach using solid flame models for locations far from populations.
- In areas where thermal interactions occur with structures CFD models are necessary.
  - Assess building shielding on short-term hazards.
  - Assess latent effects of fire on structures and people and emergency management needs.
- Validation needed for smoke shielding, flame height/diameter ratio, and burn rate for any model.

Deepwater Port far from populations

Port near populations and with many structures

LNG pool fire data for validation at relatively small scale

Trench Fires up to 52 m:

Croce, P.A, Mudan, K. S., and Moorhouse, J. (1984) Thermal Radiation from LNG Trench Fires – Vol 1 and 2, Arthur D. Little, Inc., GRI Report No. 84/0151.1

Circular Pool Fires up to 35 m in diameter:

- Nedelka, D. et al., (1989) The Montoir 35 m diameter LNG pool fire experiments, Int. Conf. Liq. Nat. Gas, v. 2, 9th, 17-20 Oct 1989, Nice, France.

- Mizner, G. A., Eyre, J. A. (1982) Large-Scale LNG and LPG Pool Fires, EFCE Publication Series (European Federation of Chemical Engineering), no.25, p.147-163.

Pool Fire on Water up to 15 m in diameter:

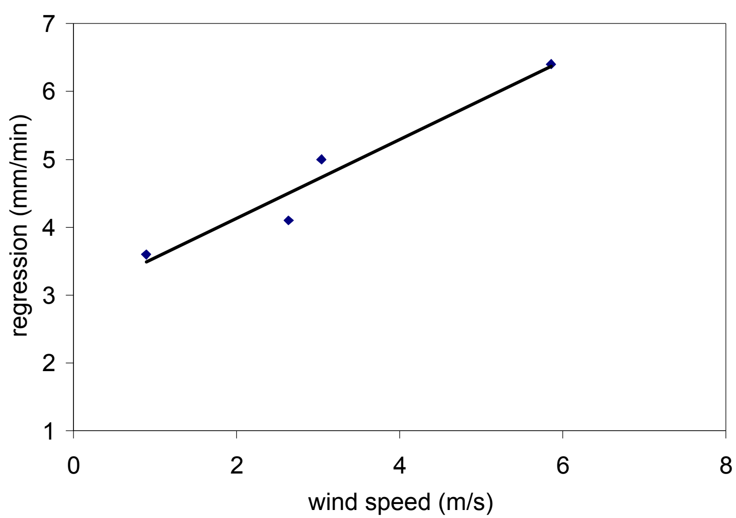
Raj, P. K., Mudan, K. S., Moussa, A. N. (1979) Experiments Involving Pool and Vapor Fires from Spills of LNG on Water. Report #CG-D-55-79, NTIS AD077073, U.S. Coast Guard.

Parameters for solid flame models

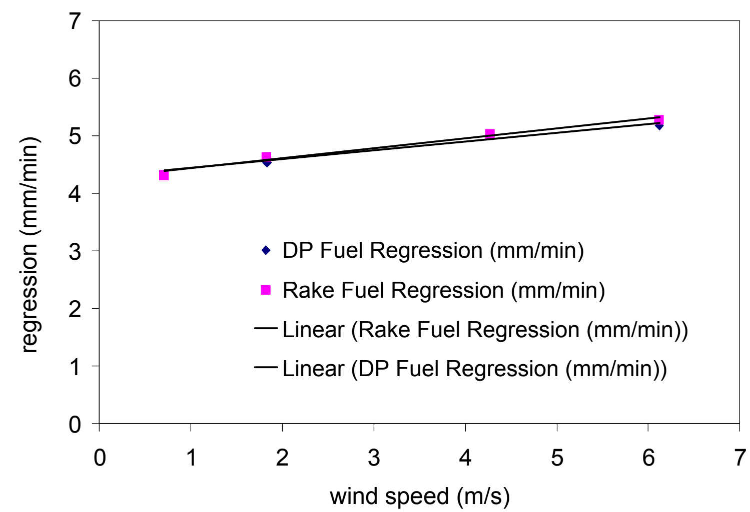
Burn rate: Data indicates,

- **2.6×10^{-4} – 9×10^{-4} m/s (fire tests on water)**
- **3.4×10^{-4} – 7.1×10^{-4} m/s (additive from fire tests on land and un-ignited pools)**
- **Recommend using a range of 3×10^{-4} – 8×10^{-4} m/s**

Variability could be due to the effect of wind:



18.9 m, JP-8 pool fire



7.9 m, JP-8 pool fire

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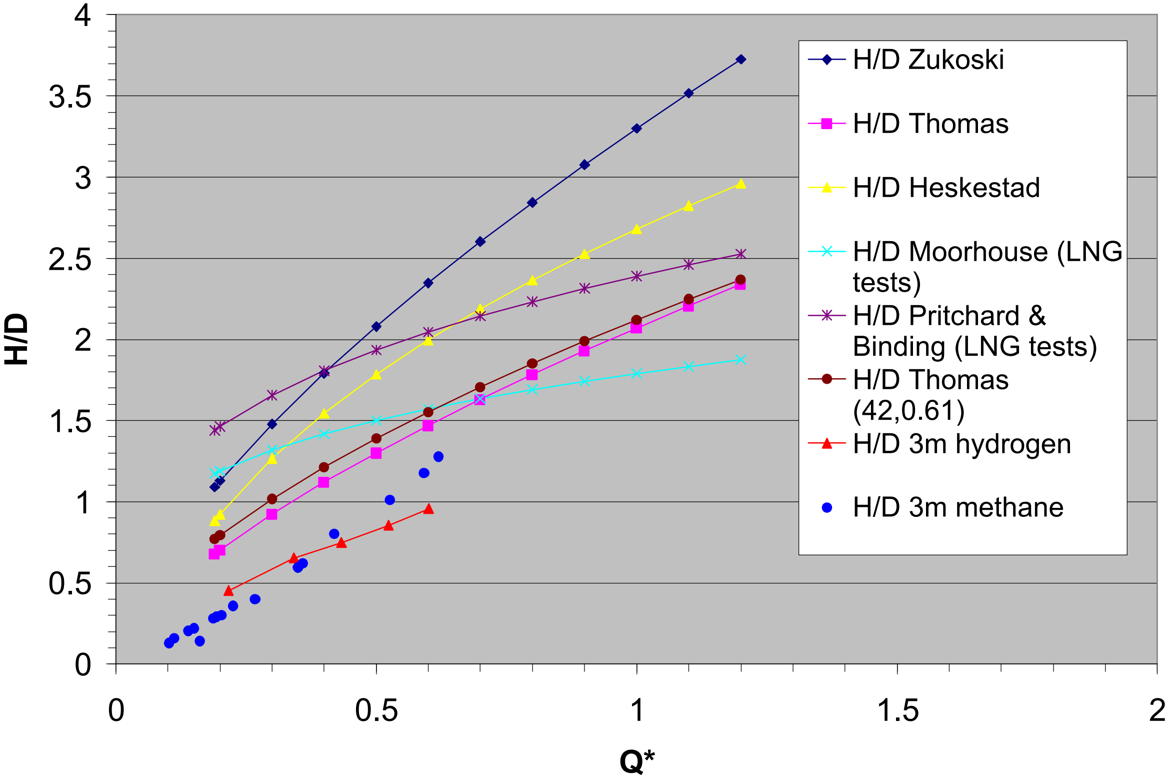
Flame height/diameter ratio from Reduced Scale Tests - 3 m burner



Test conducted in Flame Test Cell at Sandia using 3 m burner

100 m, Q* = 0.47
70 m, Q* = 0.57
35 m, Q* = 0.82
23 m, Q* = 1.0

- Note that smaller Q* values mean larger diameter
- H/D data falls below all of the correlations, suggesting a lower height to diameter ratio for large scale LNG pool fires
- H/D values are between 0.25 and 0.5 for anticipated pool diameters of 200 to 500 m.

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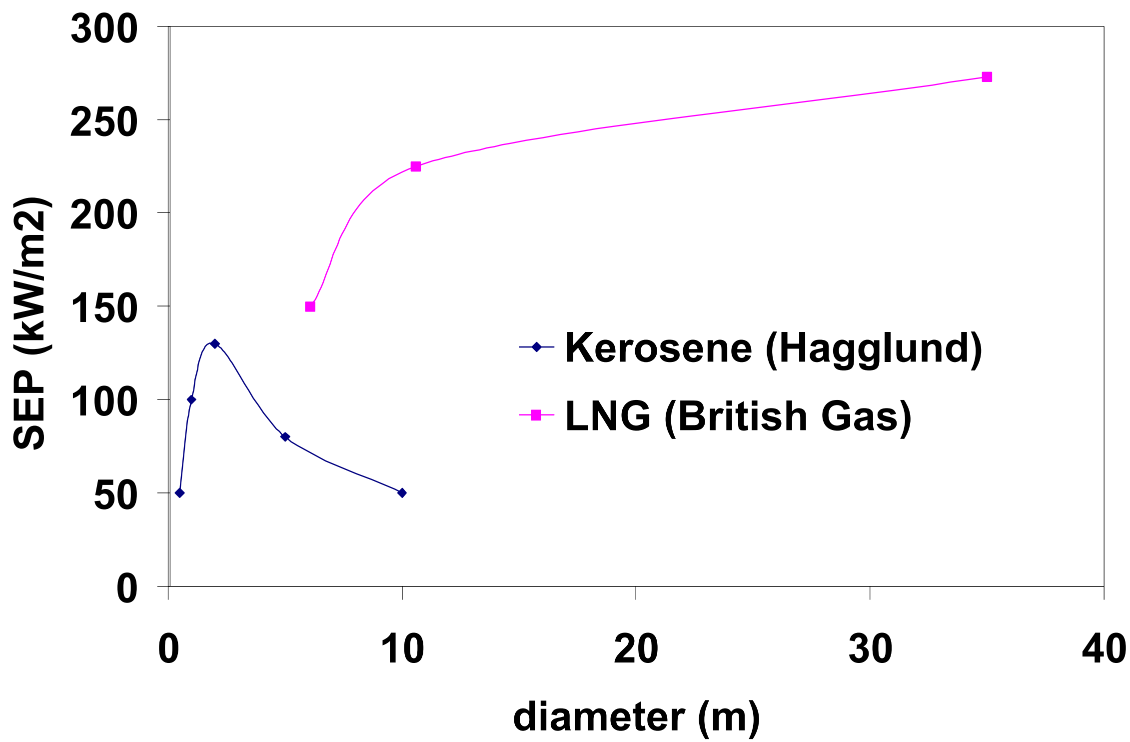
Parameters for solid flame models

Surface Emissive Power:

- Data indicates that SEP is beginning to reach a peak at 35 m
- SEP declines after reaching peak as observed with other hydrocarbons
- Conservative values to use for diameters ~100 m would be above 200 kW/m^2



LNG data based upon synchronized video recording of flame geometry

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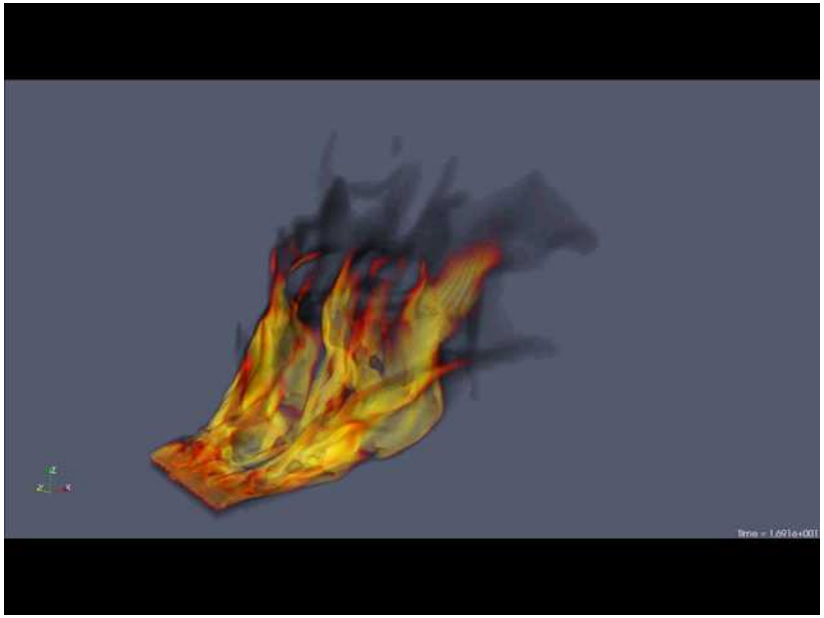
CFD Models

- Data needed at larger scales for validation
- Soot models are in need of the most development
- Provides greatest potential for prediction
- Necessary for scenarios involving object interaction



CFD simulation of object/fire interaction (cross-wind facility at Sandia)

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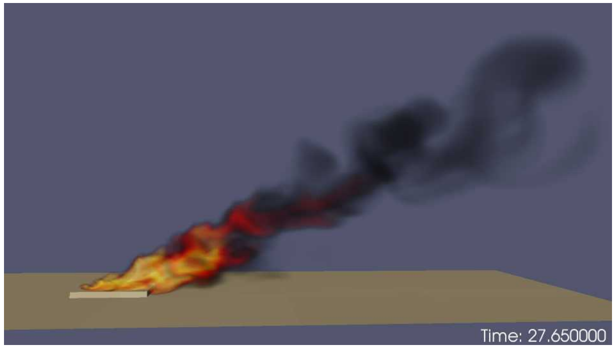
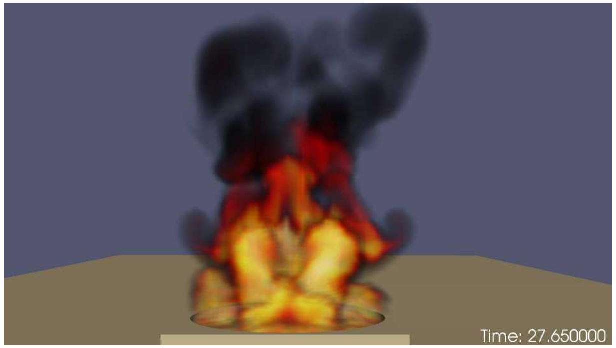
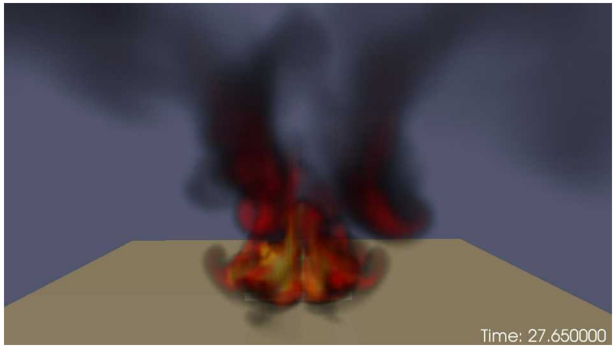
FUEGO Simulation of Montoir 35 m Land Test with Highest Average Wind Speed 9.6 m/s (20 mph)



Side



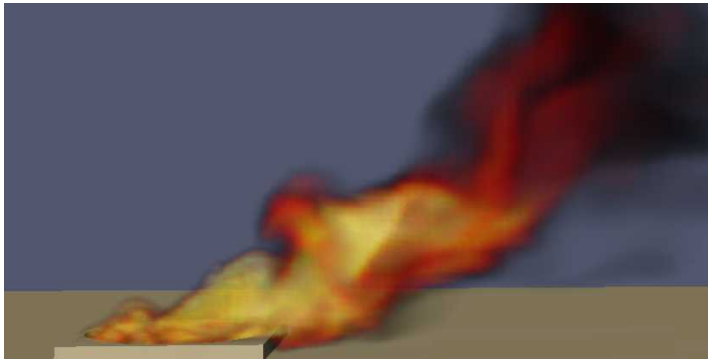
Upwind



Downwind

Experiment

SEP: 265 ± 30 kW/m^2



Simulation

SEP: 277 kW/m^2

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Verification and Validation

Verification: Purpose is to check if equations are being solved correctly and if any errors exist.

Validation: Purpose is to determine if models contain appropriate and sufficient physics to predict the metrics of interest for a particular application.

- Part of the validation process is uncertainty quantification and sensitivity analysis
- Comprehensive documentation of V&V also important, describing model, experimental data, and steps taken to carry out process.

Uncertainty Quantification

- Includes uncertainty arising from experimental measurement, as well as from model parameters
- The result will provide an estimate plus uncertainty for the metrics of interest
- Perform for comparison to existing data sets and extrapolated predictions
- Quantification can be performed by exploring range of parameters which provide bounding results

Sensitivity Analysis

- Provides understanding of model behavior and identifies parameters which contribute to the largest uncertainty in response quantities
- This allows identification of areas where improvements to the model and/or experimental measurement can be made to reduce uncertainty
- Linear regression analysis is one method to assess sensitivity along with scatter plots

Final Step

Must decide if model is adequate for intended use and what safety margin to apply

- **If model is not adequate it may be necessary to**
  - **improve the model**
  - **use a different model and/or**
  - **obtain additional experimental data to reduce input uncertainties to the model**

- **Given the upper bound of the uncertainty range provided, a regulator will have to decide what margin of safety to apply based on the model, location, and reported range.**

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