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DOE/Sandia National Laboratories LNG Safety Research

Behavior of Large-Scale LNG Pool Fires on Water and Recommendations on Thermal Hazard Analysis

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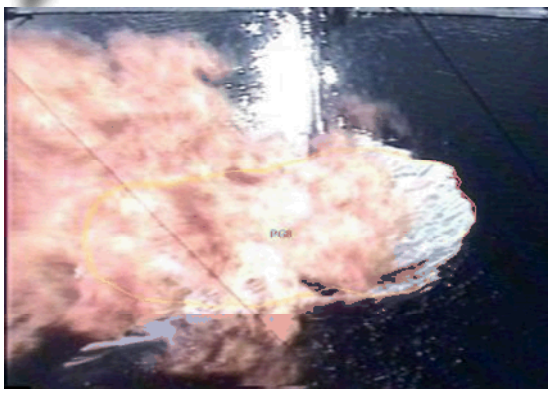
Spill Region vs. Burning Region

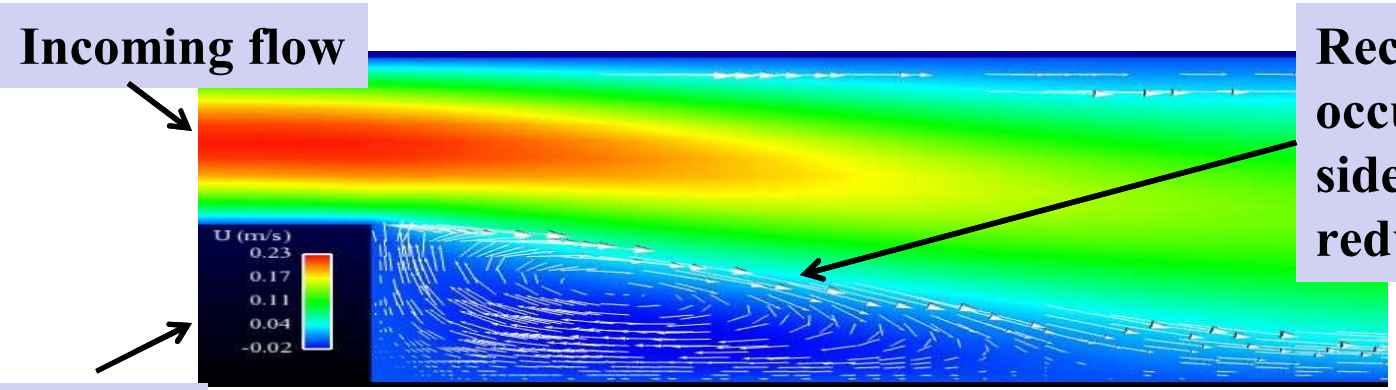


- Upwind regions of pool did not have sustained burning.
- Rate of fuel/air mixing is affected by surrounding flow which is induced by entrainment and wind.
- A critical flow velocity can be reached were chemical reaction cannot keep up with the supply of fuel and oxidant resulting in extinction.
- Recommend for hazard analysis that burning region encompasses entire pool region.

Flame Anchoring

- Regions of reduced flow on downwind side of berm which prevents extinction.
- Anticipated that in an actual scenario the LNG ship would be the anchor.
- The scenario affording the most potential regarding fire size would be a spill on the downwind side.

Flame tended to anchor around berm (slight wind of ~ 1 m/s).



Recirculation zones occur on downwind side of object and reduces flow.

Hydrate Formation




- Methane hydrates ($CH_4 \cdot nH_2O$, $n \geq 5.75$) typically found to occur in high-pressure low-temperature environments, but can be metastable at 1 atm.
- The very cold hydrate layer provided a suitable environment for a thick layer of water vapor to condense and form.
- Melting was prevented due to entrained water vapor attenuating the radiation from the flame.
- Difficult to achieve stability for water temperatures above freezing, with high salinity, and greater turbulent mixing.

Smoke Production

35 m diameter LNG pool fire on land (Montoir Tests - British Gas/Shell)

56 m diameter LNG pool fire on water (SNL)

- LNG 35 m fire on land produced more smoke than the 56 m fire on water.
- Not anticipated trend.

Effect of Water Addition

- Water addition is a plausible explanation for the discrepancy seen between the SNL and Montoir (British Gas/Shell) tests.
- Methane counter-flow diffusion flame studies have shown addition of water vapor either on the oxidizer or fuel side reduces soot volume fraction values by a factor of about 2 .
- Believed to be mainly due to the reaction $H_2O + H \rightarrow OH\cdot + H_2$.
- $OH\cdot$ lowers soot precursor concentrations and oxidizes soot.

Simulation Experiments

Simulation results with and without water addition compared to experimental data obtained by:

1. Brookes on a turbulent methane jet (4.07 mm diameter).

Five simulation cases

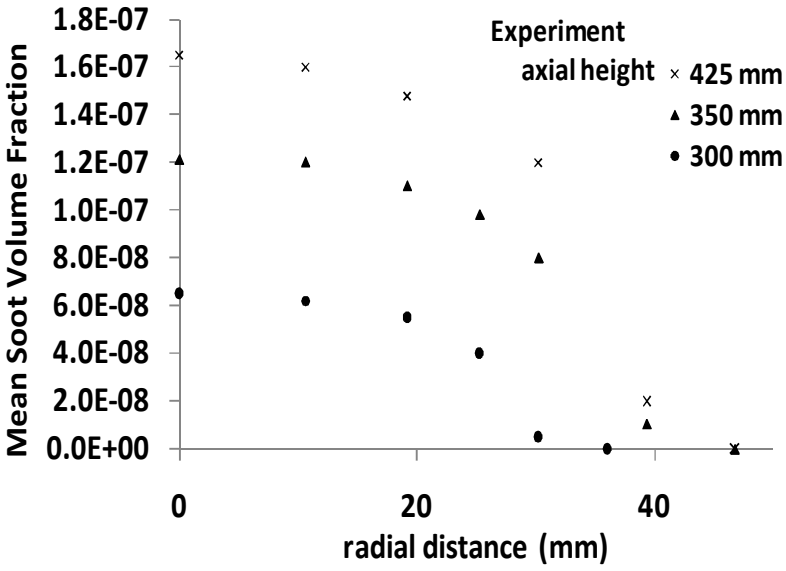
- **no water addition**
- **5% and 10% in air**
- **5% and 10% in fuel**

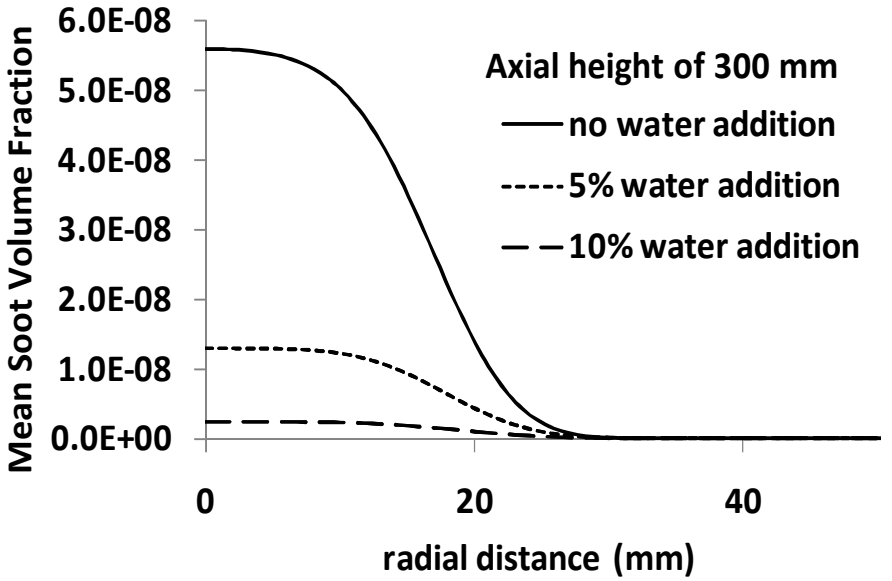
2. Montoir LNG pool fire experiment on land (35 m diameter).

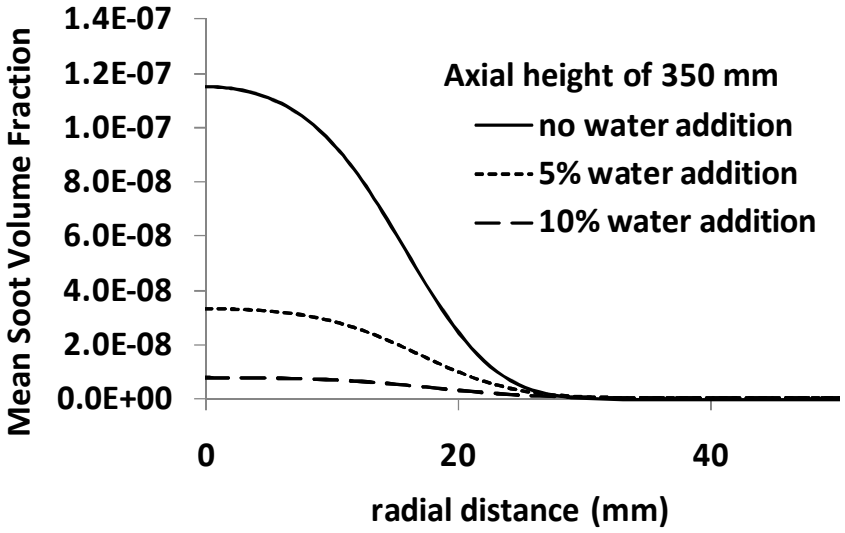
Three simulation cases

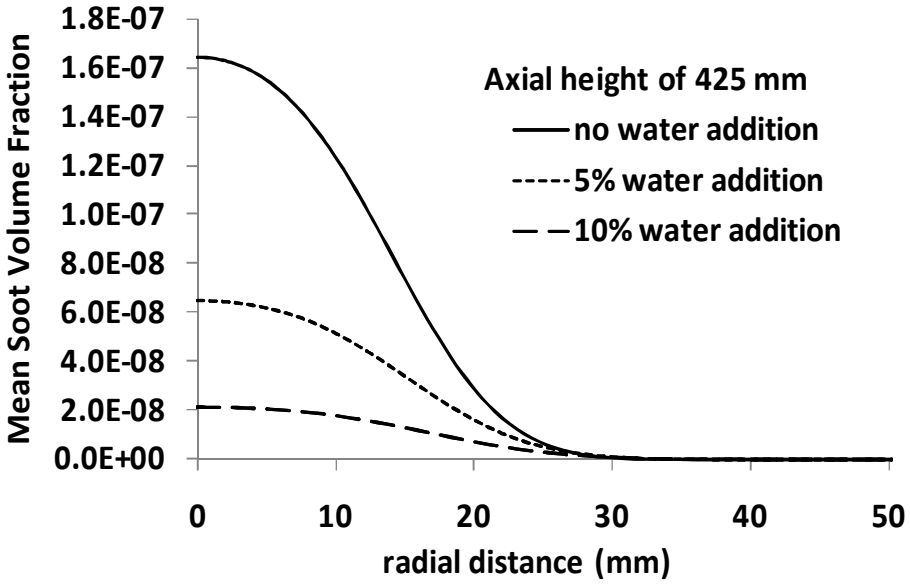
- **no water addition**
- **2.5% in fuel, 5% in air**
- **5% in fuel, 10% in air**

Simulation Results for Methane Jet Water Addition on Air Side



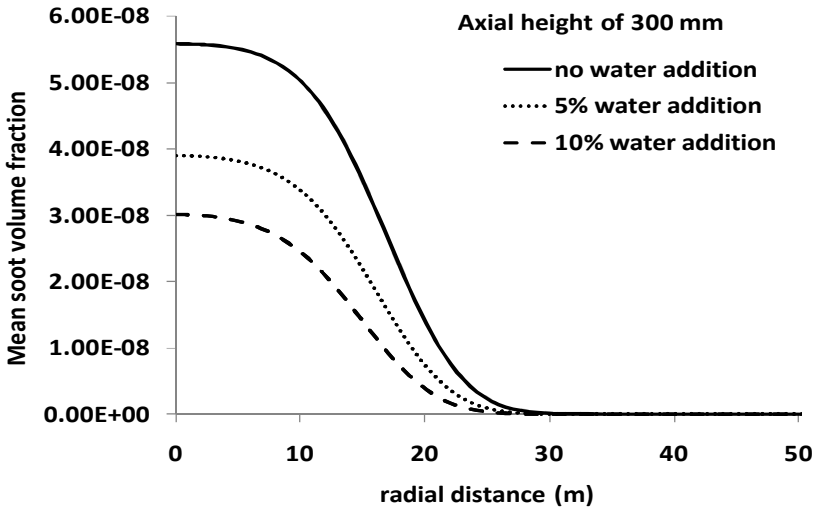


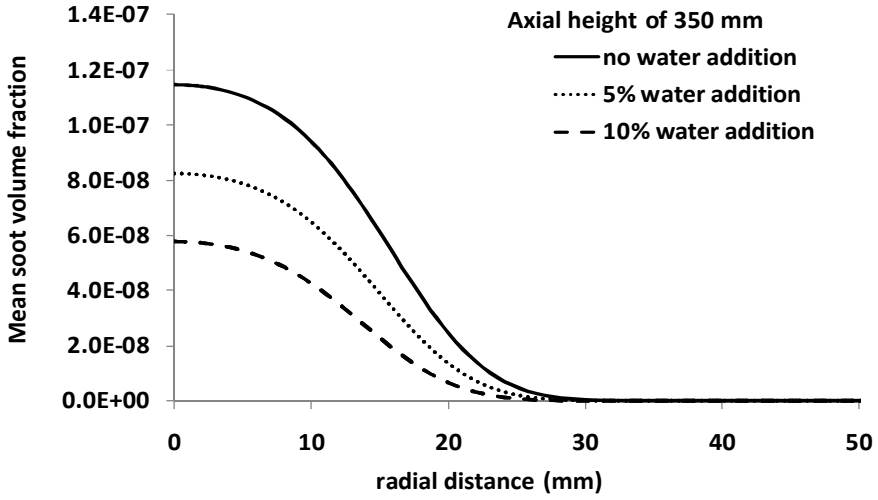


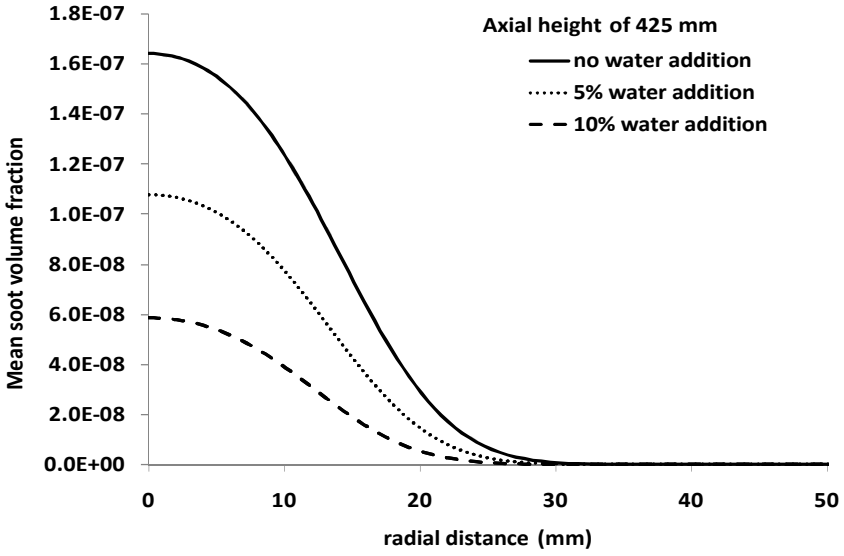


Simulation Results for Methane Jet Water Addition on Fuel Side

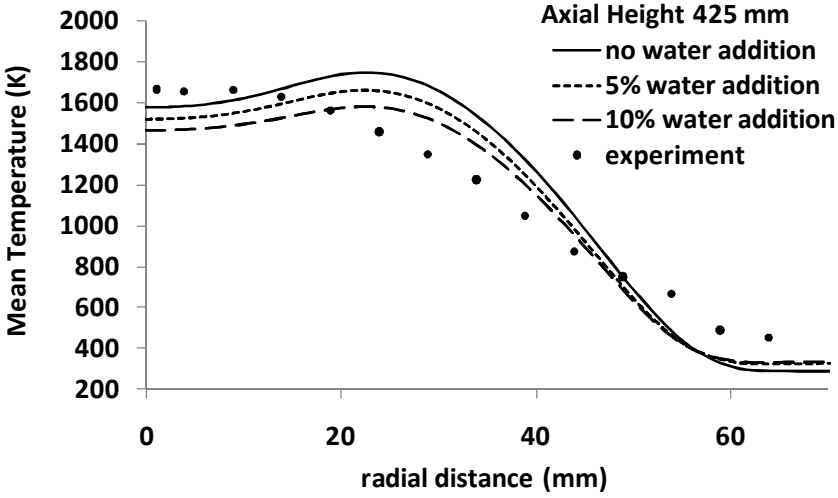
10% water addition on fuel side reduces soot less than when added on air side - factor of 2 versus 10.

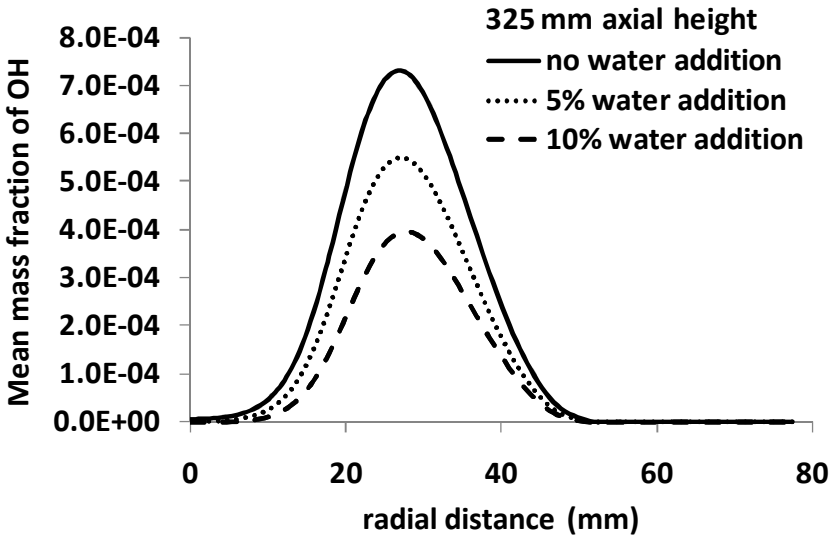


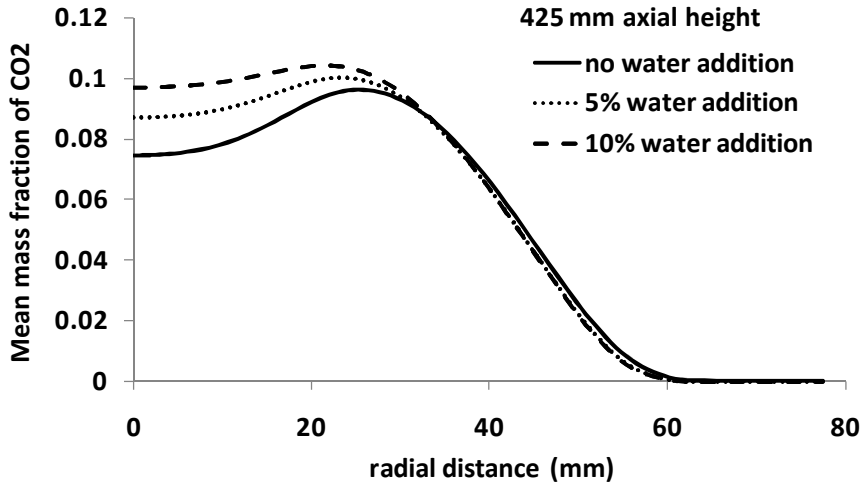


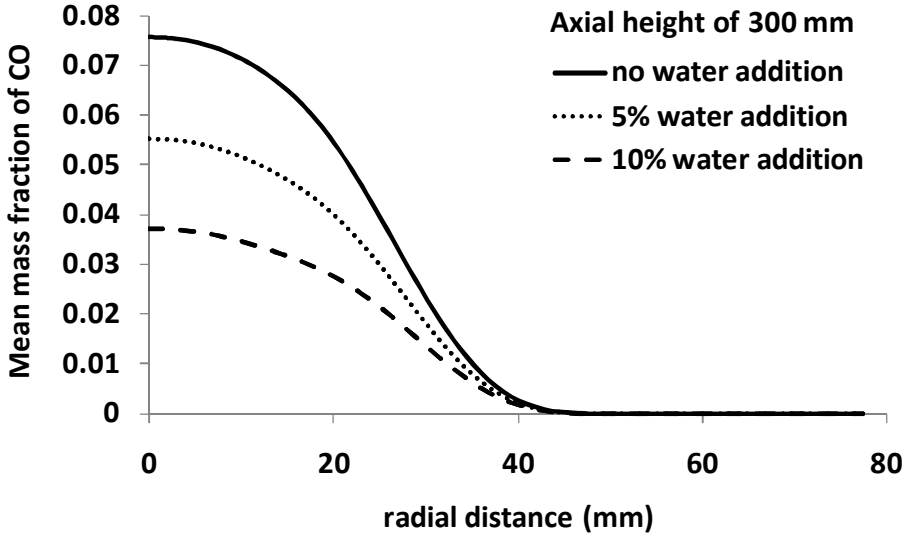


Simulation Results for Methane Jet Water Addition on Air Side









Simulation Results for Montoir

Time averaged results with and without water addition

		Water Addition by mass	
	No Water	5% air, 2.5% fuel	10% air, 5% fuel
soot volume fraction	2.36E-04	1.33E-04	3.14E-04
maximum local temperature (K)	1985	1519	1746
CO_2 mass fraction	297	737	312
CO mass fraction	117	91	63
OH mass fraction	0.57	0.39	0.21

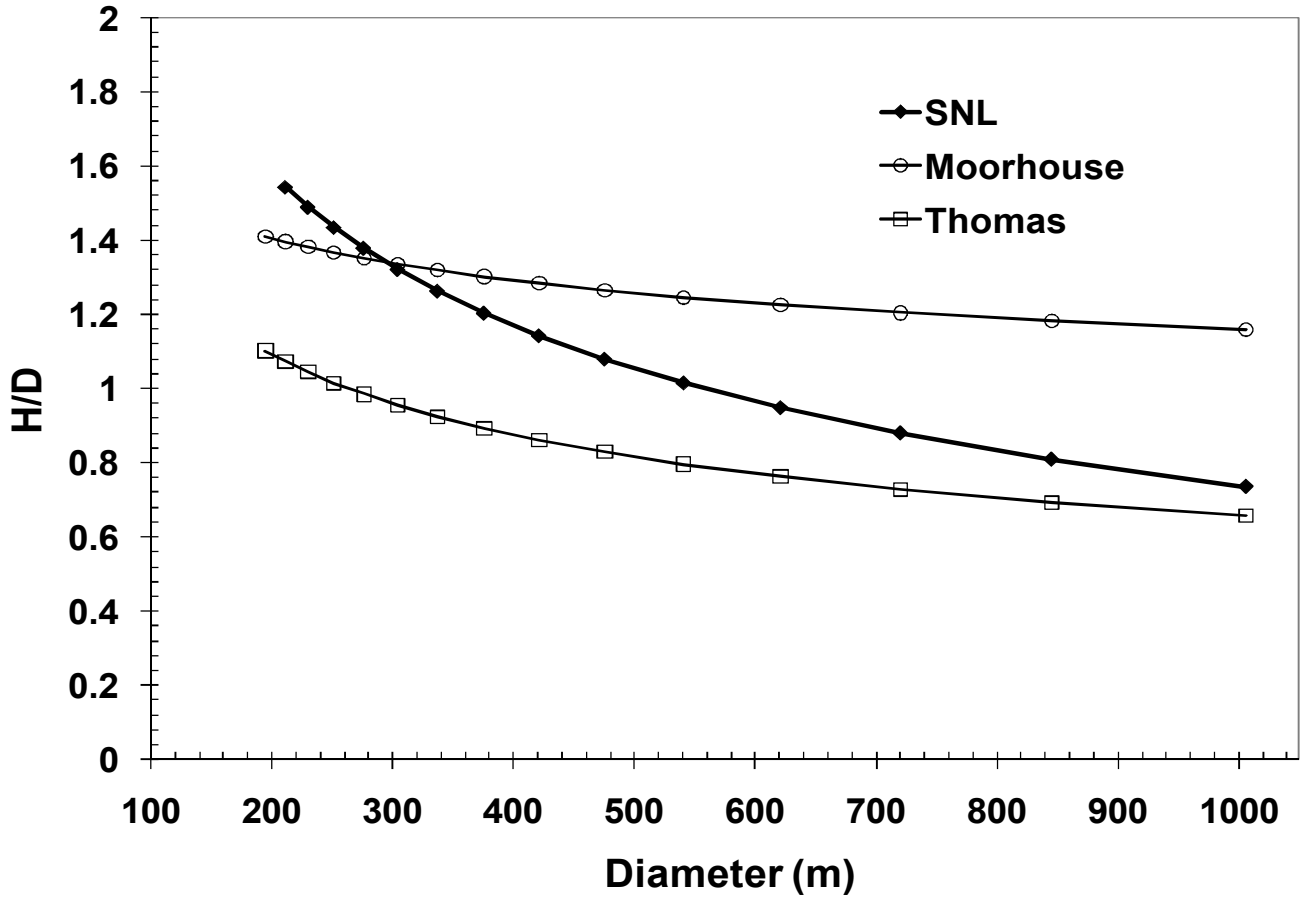
Recommendations on the Prediction of Thermal Hazard Distances from Large Liquefied Natural Gas Pool Fires on Water for Solid Flame Models

Parameter	Recommended Nominal Value	
	2004 Sandia Report	**Current**
Burn Rate (m/s)	3.0×10^{-4} $(2.0 – 8.0 \times 10^{-4})$*	3.3×10^{-4} $(2.6 – 4.5 \times 10^{-4})$*
Flame Height (m)	Moorhouse Correlation	SNL Correlation (eqns. for uncertainty)*
SEP (kW/m^2)	220 (175 - 350)*	286 (239 - 337)*
Transmissivity	0.8 (0.5)	Wayne formula (±10%)*

*range considered for parametric variation

Differences in Parameters Between Previous Sandia Reports and Current Recommendations

- **Burn rate has not changed significantly.**
- **The flame height has decreased for D>300 m.**



Differences in Parameters Between Previous Sandia Reports and Current Recommendations

- SEP has increased
- Transmissivity decreases for high humidity and/or temperatures
- Overall change in parameters tend to balance each other