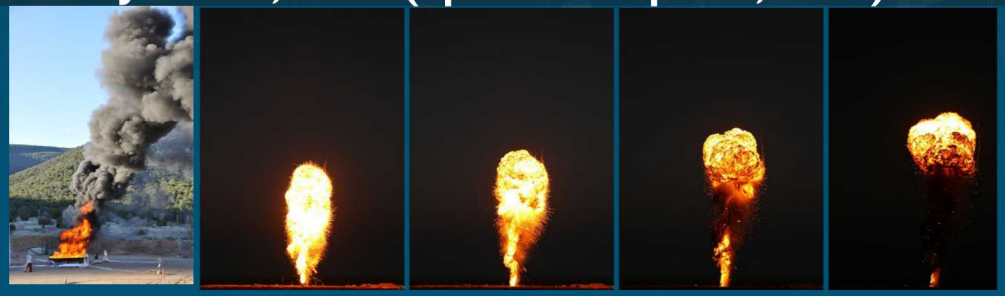
SAND2019-10783PE

Crude Oil Characterization Research Study Combustion Experiments

U.S. DOE Forrestal Building

June 13, 2019 (updated Sept 10, 2019)



PRESENTED BY

Anay Luketa, Ph.D. and David L. Lord, Ph.D.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Crude Oil Characterization Research Study

Objective:

Evaluate whether crude oils currently transported in North America, including those produced from "tight" formations, exhibit:

- physical or chemical properties that are distinct from conventional crudes, and
- how these properties affect parameters required to assess thermal hazard distances from radiant exposure associated with pool fires and fireballs

Motivation:

Crude transport by rail poses risks recognized by US and Canadian regulators and stakeholders

Casselton, ND, Dec 30, 2013

"Bakken crude may be more flammable than previously thought: U.S. regulator"
Reuters: January 2, 2014

Numerous high-profile train accidents in the US and Canada

Open debate whether type of crude (tight vs. conventional) contributes to accident severity

Project Structure

Task 1: Project Administration & Outreach (ongoing)

Task 2: Sampling & Analysis Methods Evaluation (complete)

Task 3: Combustion Experiments ← Today's focus

Task 4: Crude Characterization, Tight vs. Conventional (starting)

Task 3: Combustion Experiments

Key elements of approach:

Oils span a range of vapor pressures with light ends preserved

- Bakken
- Tx Shale

..and removed

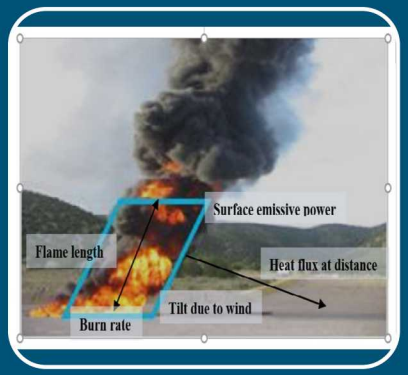
- SPR

Pool Fires

- 2-m indoor exploratory (SPR only)
- 5-m diameter outdoor (all oils)

Fireballs

- 100-gallon exploratory (Jet-A)
- 400-gallon (all oils)



Measure parameters that affect thermal hazard distances

- Pool fires: burn rate, flame height, surface emissive power
- Fireballs: diameter, height, duration, surface emissive power

Task 2 Results Informed Task 3 Methods

Crude oil sampling & analysis methods that met performance requirements in Task 2 were implemented in Task 3

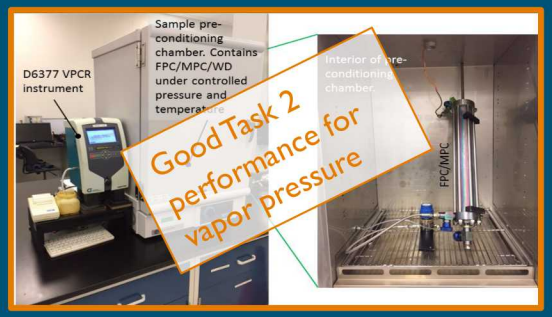
Oil sampling

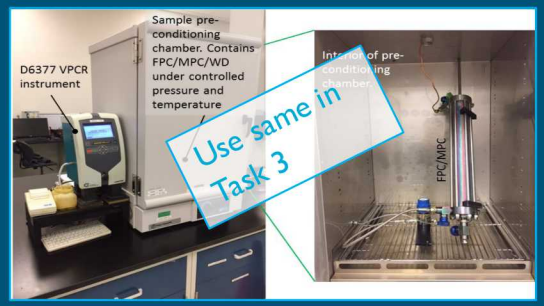
0.5 L water displacement oil cylinder

upscale

Custom 18,000 L water displacement oil tanker

Vapor pressure





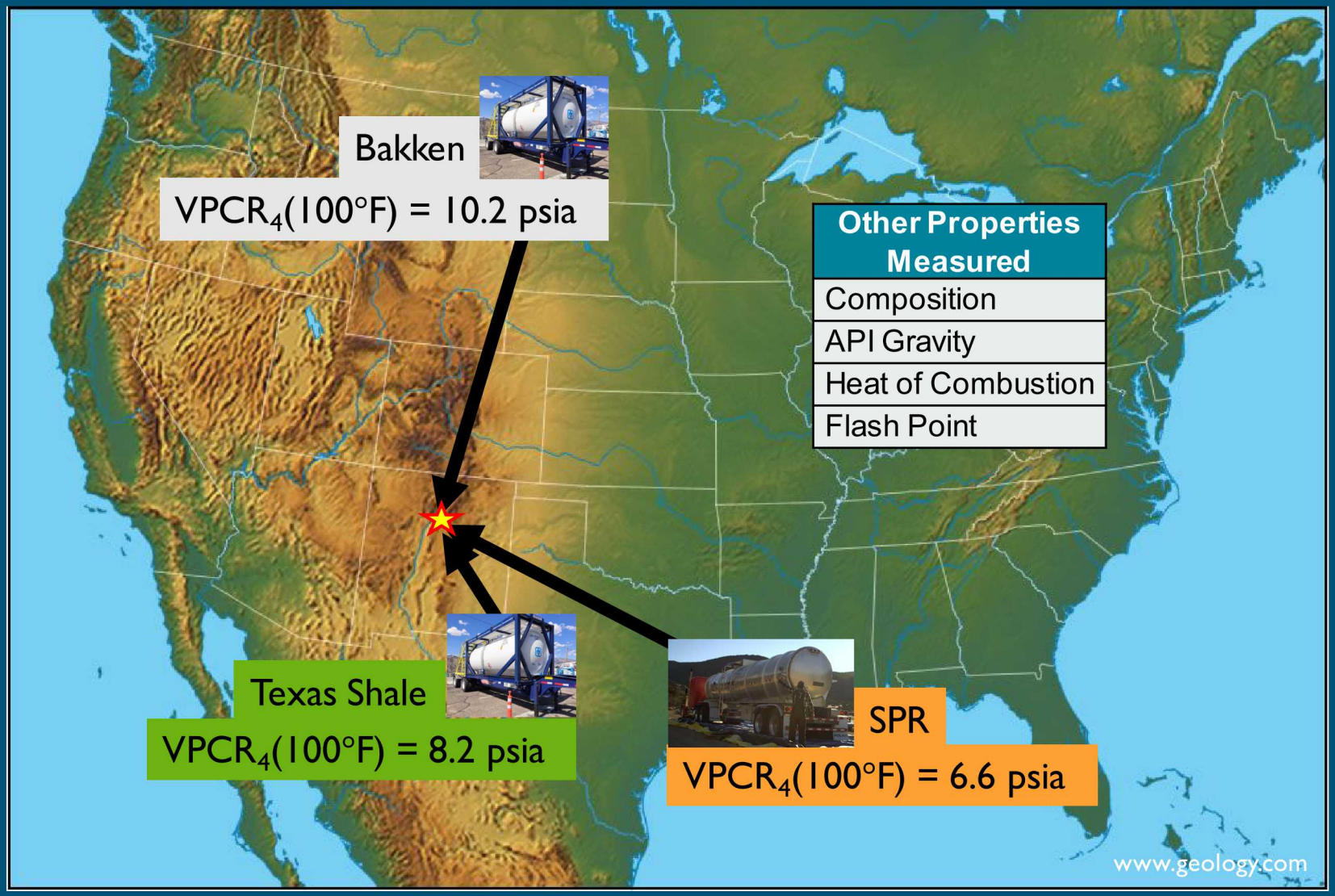
Compositional analysis

TVP-95 separator method
GPA 2103-M pressurized composition
Additional pressurized methods

Down-select for best technical performance, availability, cost

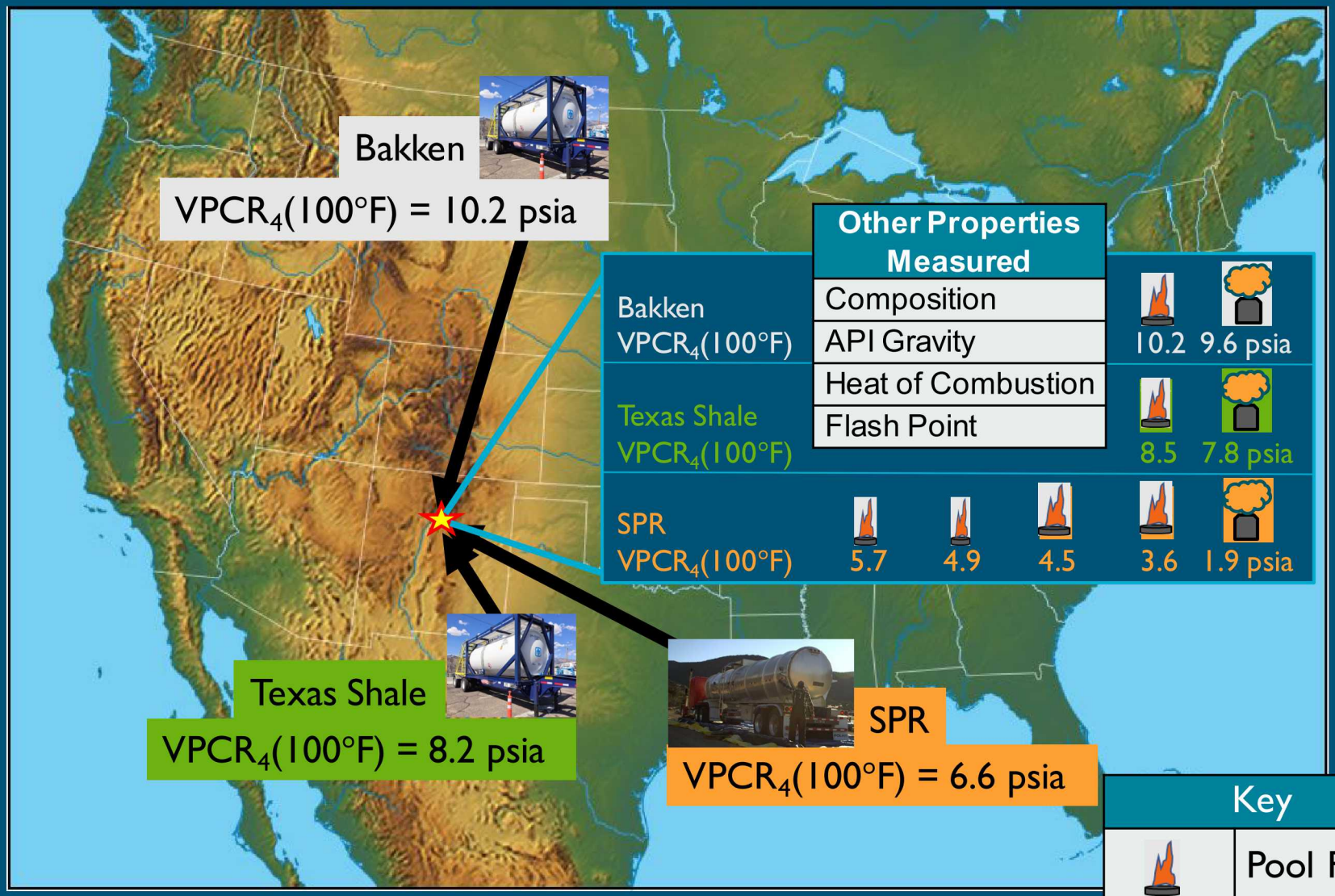
GPA 2103-M pressurized composition

Task 3: Oil Sampling & Property Measurement

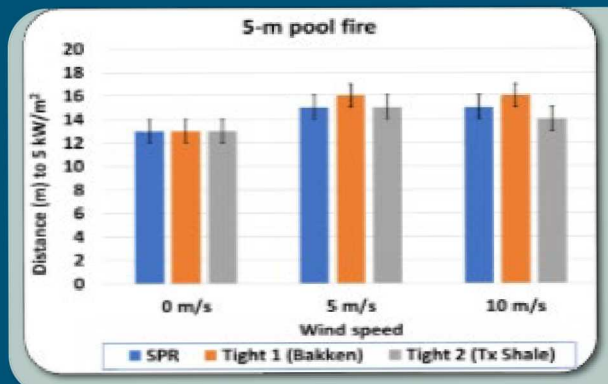


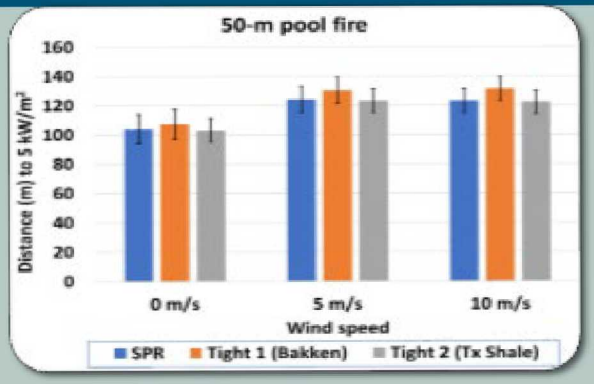
Other Properties Measured
Composition
API Gravity
Heat of Combustion
Flash Point

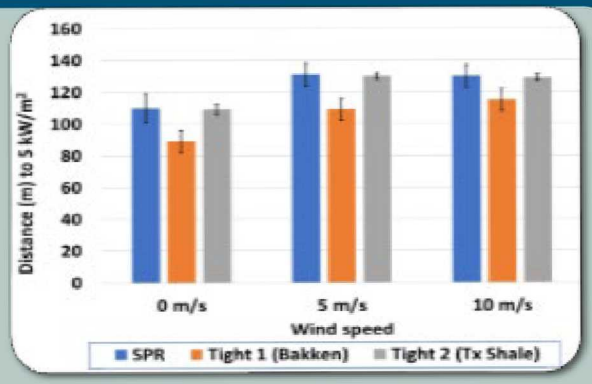
Task 3: Oil Sampling & Property Measurement



Pool Fire Thermal Hazard Calculations







5-m diameter pool fire

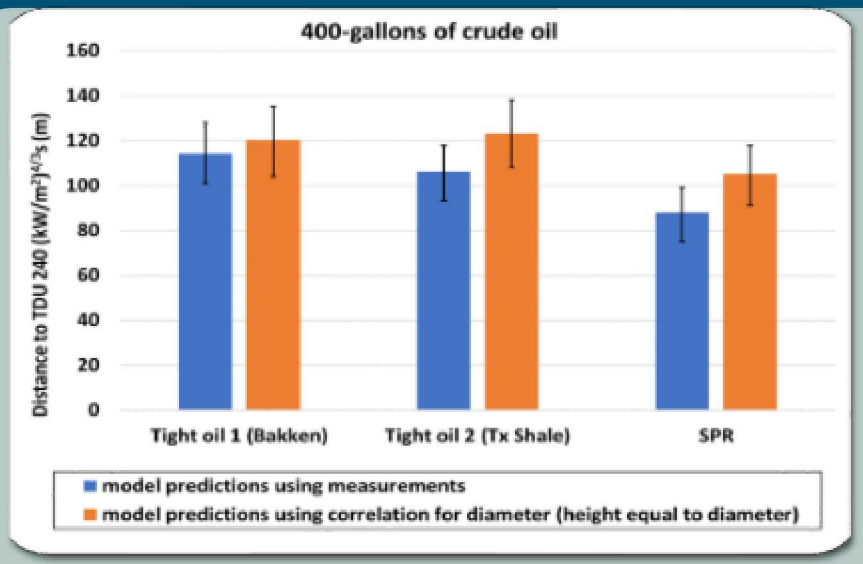
50-m diameter pool fire

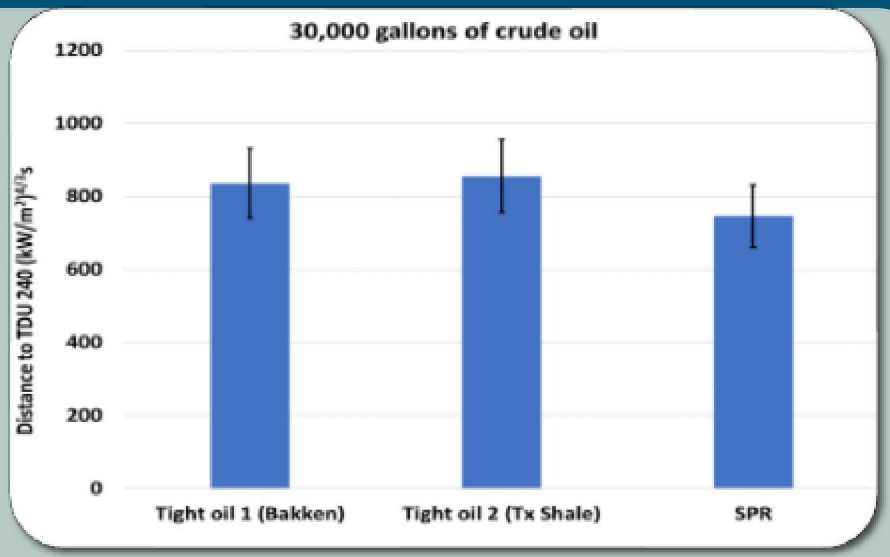
30,000-gallon release uncontained pool fire

Pool Fire calculations using measured parameters

Distance based on injury criterion of 2nd degree burns after 30-second exposure to a radiant heat flux of 5 kW/m^2

Fireball Thermal Hazard Calculations





400-gallon fireball

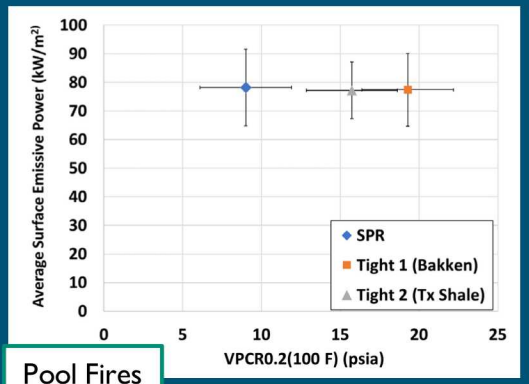
30,000-gallon fireball

Fireball calculations using measured parameters

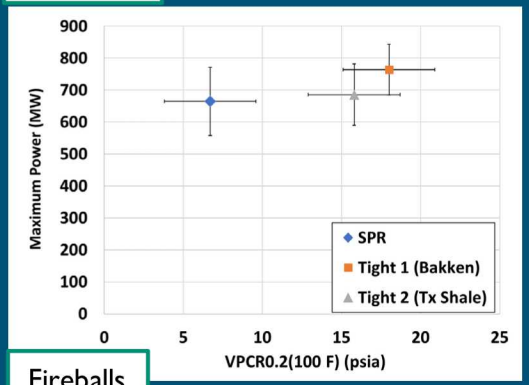
Distances based on injury criterion of 2nd degree burns. Corresponds to a thermal dose level of 240 $(kW/m^2)^{4/3}s$

General conclusion #1

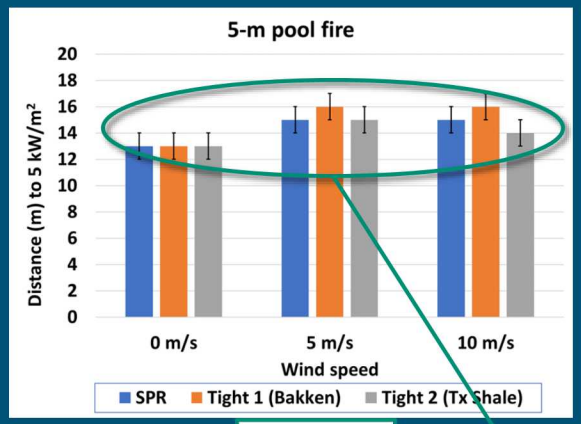
The similarity of pool fire and fireball burn characteristics pertinent to thermal hazard outcomes of the three oils studied indicate that vapor pressure is not a statistically significant factor in affecting these outcomes. Thus, the results from this work do not support creating a distinction for crude oils based on vapor pressure with regards to these combustion events.



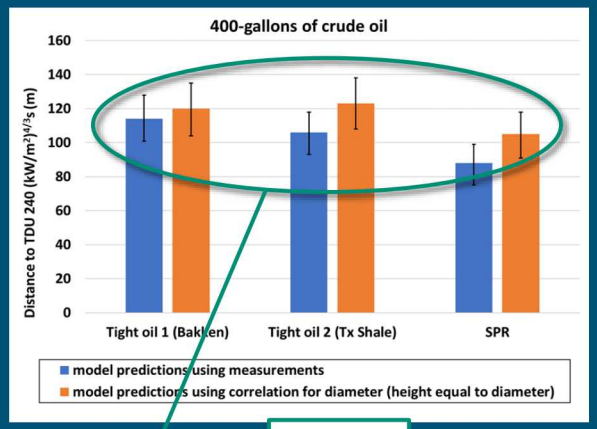
Pool Fires



Fireballs



Pool Fires

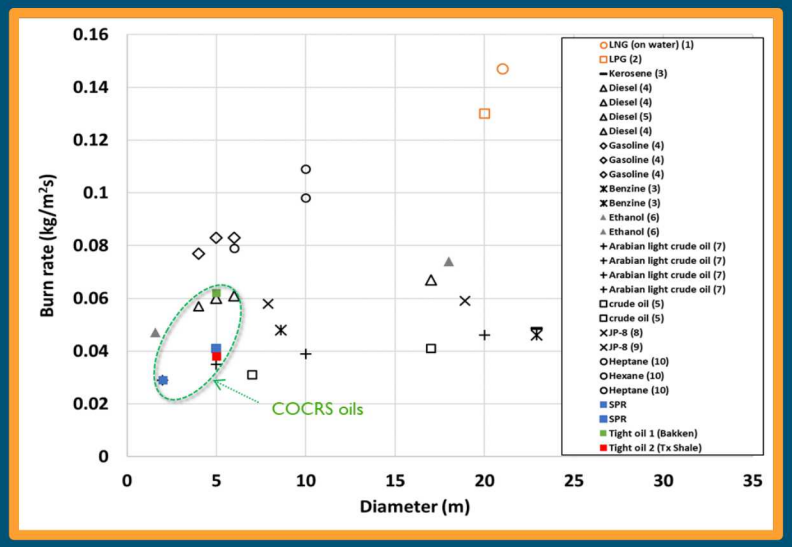


Fireballs

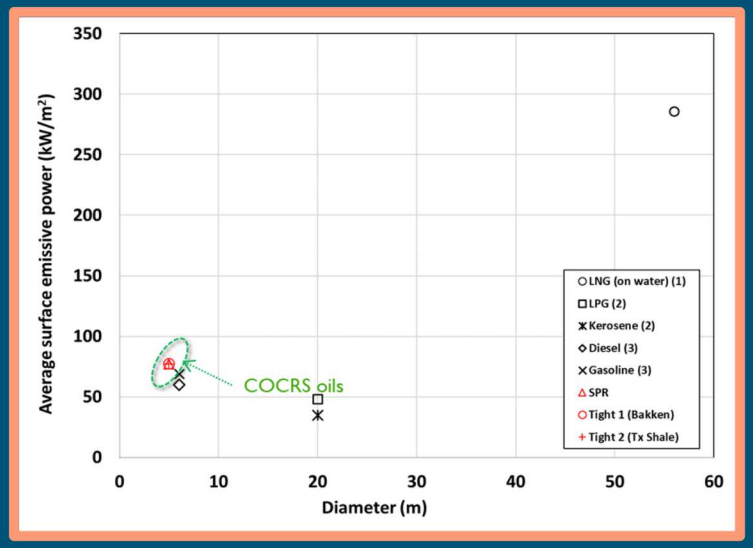
Distances not statistically different
Overlapping error bars

General conclusion #2 (pool fires)

Based on comparison to combustion data from public literature on common liquid fuels (primarily commercial grade propane and butane), the results of this study are considered to be pertinent to crude oils and most hydrocarbon liquids that exceed the vapor pressures of the crude oils tested here.



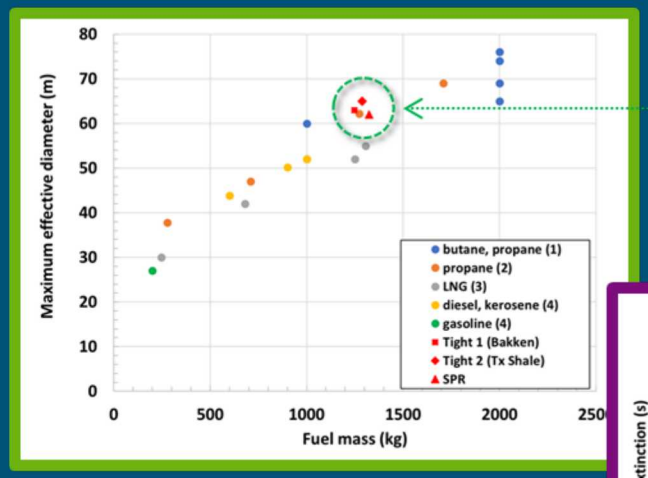
Burn rate



Surface emissive power

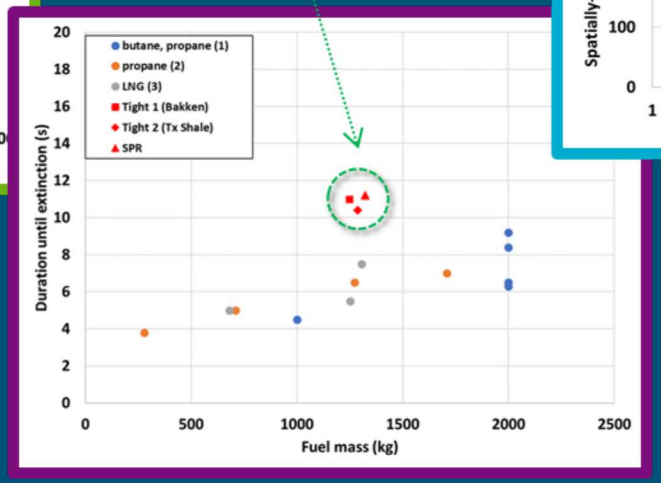
General conclusion #2 (fireballs)

Based on comparison to combustion data from public literature on common liquid fuels (primarily commercial grade propane and butane), the results of this study are considered to be pertinent to crude oils and most hydrocarbon liquids that exceed the vapor pressures of the crude oils tested here.

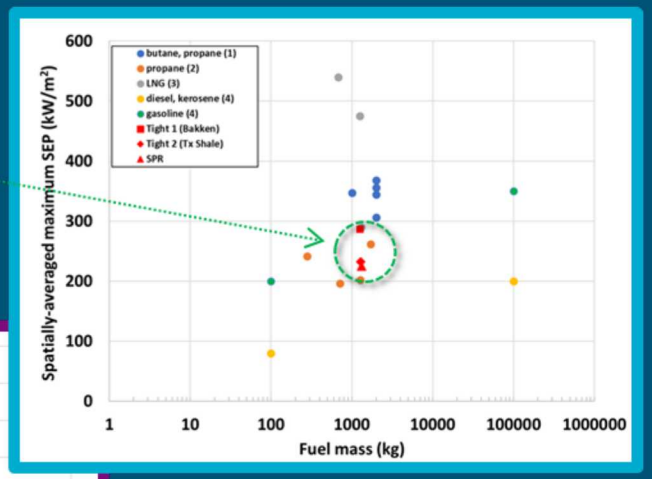


Diameter

COCRS oils



Duration



Surface emissive power

BACK UP SLIDES

Task 3: Participants

Sponsoring Agencies

- US Department of Energy
- US Department of Transportation
- Transport Canada

Technical Authors

- Anay Luketa
- Tom Blanchat (retired)
- David Lord
- Joe Hogge
- Alvaro Cruz Cabrera
- Ray Allen

Sandia Project Team

- Large interdisciplinary team acknowledged in the SAND report

Peer Reviewers

- Elizabeth Weckman, Ph.D.
- Michael Gollner, Ph.D.
- Robert Falkiner, MSc, P.E.
- Dr. Kesavalu Bagawandoss, Ph.D., J.D.

Executive Summary

Pool Fires

- The experimental results indicate that measured values of surface emissive power and flame height among the oils tested are within 1 % and 24% of each other, respectively, with standard deviation ranges overlapping. The burn rate for the Tight 1 (Bakken) oil is about a factor of 1.5 higher than that for other tested oils.
- The predicted thermal hazard distances are similar among the oils tested for contained pool fires and are within 14% of each other, with standard deviation ranges overlapping. Distances were evaluated using the measured parameters, an integral model, and the injury criterion of 2nd degree burns after 30-second exposure to a radiant heat flux of 5 kW/m^2 for both a 5-m and a 50-m diameter contained pool fire. A 50-m pool diameter is representative of a 114-m^3 (30,000-gallon) release. Predicted thermal hazard distances are for comparison purposes only and not intended to be applied to railcar accidents.

Executive Summary cont'd

Pool Fires

- The predicted thermal hazard distances using the measured parameters and a 2nd degree burn criterion for an uncontained or spreading pool resulting from a 114-m^3 (30,000-gallon) release indicate that the Tight 1 (Bakken) oil results in lower distances compared to the other oils by 16%-27%. It should not be concluded from this comparison that the Tight 1 oil (Bakken) is less hazardous than the other oils. Given potential variation in accident scenarios, atmospheric conditions, and parameter input uncertainty, what should be concluded is that thermal hazard distances do not differ greatly.
- Historic accidents have demonstrated that hazards can exceed the distances calculated in this work due to damage of numerous railcars leading to significant amounts of oil contributing to a fire which can then propagate to surrounding fuels sources, such as wooden structures, vegetation, and other hydrocarbons.
- The measurements of burn rate, flame height, surface emissive power, and heat flux to an engulfed object are consistent with other alkane-based liquid hydrocarbons for all oils tested.

Executive Summary cont'd

Fireballs

- The experimental results indicate that the average surface emissive power at maximum power for the two tight oils are about 30% higher than the SPR oil.
- The maximum fireball diameters measured were similar among the three oils (~62-65 m).
- The Tight 1 (Bakken) oil had a 10% lower height at fireball extinction than the other oils.
- The time to fireball extinction were similar among the oils (~10-11 s).
- The predicted thermal hazard distance using the injury criterion of 2nd degree burns after 30-second exposure to a thermal dose level of 240 $(kW/m^2)^{4/3}s$ was evaluated for a 400-gallon release for all oils tested. The results indicate the distances for the tight oils are similar but are about 20-30% higher than the distance predicted for the SPR oil.

Executive Summary cont'd

Fireballs

- Predicted thermal hazard distances, for a 30,000-gallon release, among the crude oils differ by about 12% with the range of uncertainties overlapping. Thus, the predicted thermal hazard distances among the oils are comparable.
- The observed measurements of diameter, duration, and surface emissive power for the tested crude oils are consistent with experiments performed by other researchers testing similar volumes for propane, butane, gasoline, and diesel as fuels.
- The average surface emissive power at maximum power for all oils are below the Center for Chemical Process Safety (CCPS) recommendation to use a value of 350 kW/m^2 for thermal hazard evaluation. It is anticipated that the oils will not exceed this value for larger releases. The CCPS is a non-regulatory organization within AIChE that addresses process safety of hazardous *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards* (Center for Process Safety). American Institute of Chemical Engineers, 2011

Evidence to Support Pool Fires

Key Finding #1:

The experimental results indicate that measured values of surface emissive power and flame height among the oils tested are within 1 % and 24% of each other, respectively, with standard deviation ranges overlapping. The burn rate for the Tight 1 (Bakken) oil is about a factor of 1.5 higher than that for other tested oils.

Oil	Average Burn Rate (mm/min)	Average Flame Height (m)	Average Surface Emissive Power (kW/m^2)
SPR	2.7 ±0.1	4.9 ±3.1	78.2 ±13.4
Tight 1 (Bakken)	4.6 ±0.1	4.5 ±3.9	77.4 ±12.7
Tight 2 (Tx Shale)	2.7 ±0.3	5.5 ±3.9	77.2 ±9.9

Evidence to Support Pool Fires

Key Finding #2:

The predicted thermal hazard distances are similar among the oils tested for 5-m and 50-m contained pool fires and are within 14% of each other, with standard deviation ranges overlapping.

- Injury criterion: radiant heat flux of 5 kW/m^2 resulting in 2nd degree burns after 30-second exposure

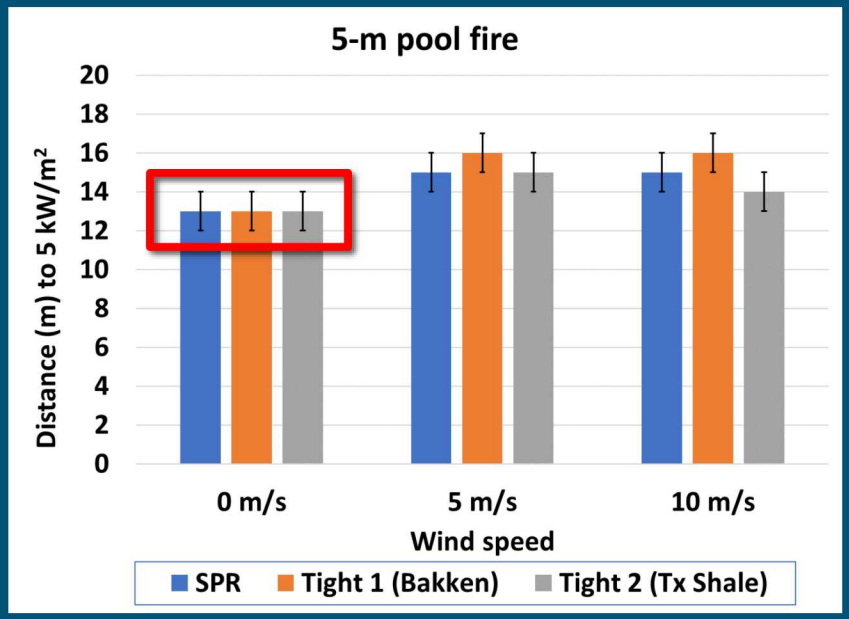


Figure 3-6: Comparison of distances to 5 kW/m^2 for a 5-m diameter pool fire for various wind speeds based on model predictions.

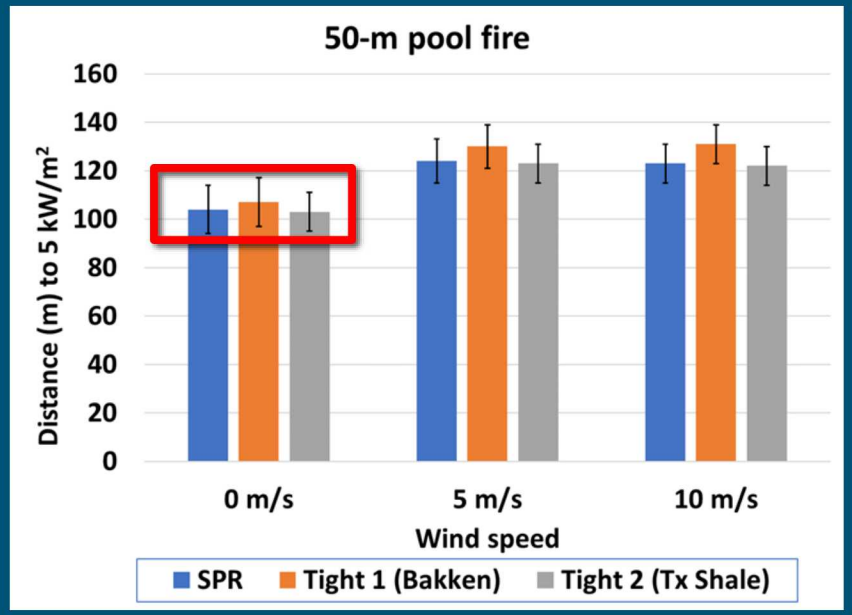


Figure 3-8: Comparison of distances to 5 kW/m^2 for a 50-m diameter pool fire for various wind speeds based on model predictions.

Evidence to Support Pool Fires

Key Finding #3:

The predicted thermal hazard distances using the measured parameters for 2nd degree burn criterion for an uncontained or spreading pool resulting from a 114 m^3 (30,000 gallon) release indicate that the Tight 1 (Bakken) oil results in lower distances compared to the other oils by 16%-27%.

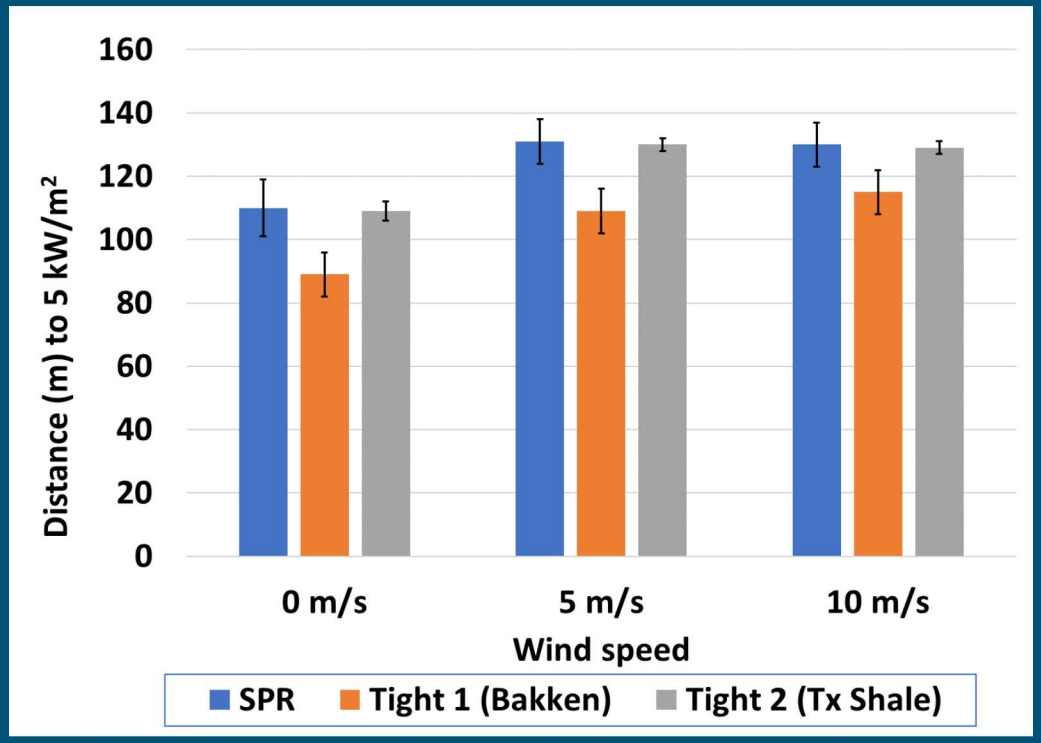


Figure 3-10: Comparison of distances to 5 kW/m^2 for spreading pool fire for various wind speeds based on model predictions, assuming a spill rate of 0.1 m^3/s.

Evidence to Support Pool Fires

Key Finding #4:

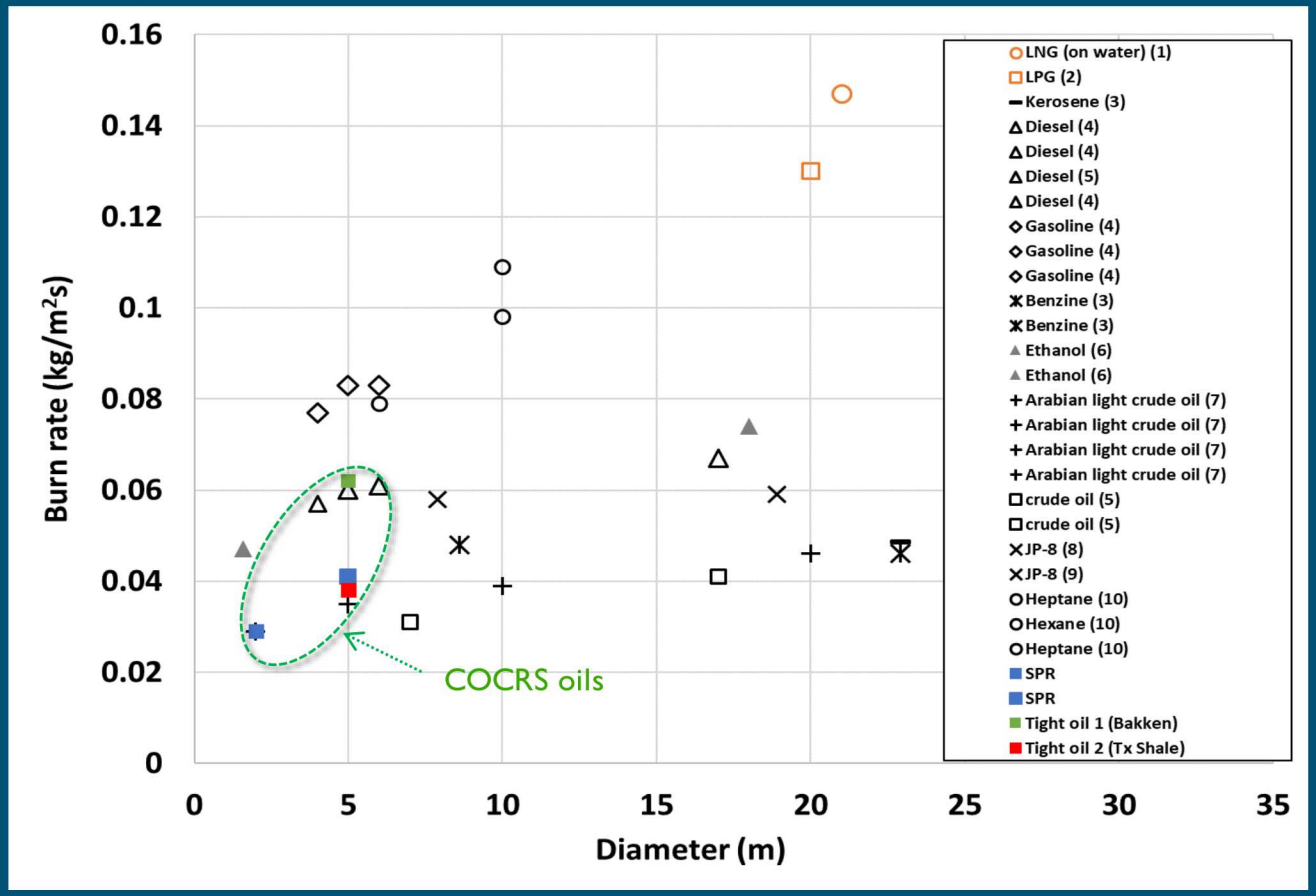
Historic accidents have demonstrated that hazards can exceed the distances calculated in this work due to damage of numerous railcars leading to significant amounts of oil contributing to a fire which can then propagate to surrounding fuels sources, such as wooden structures, vegetation, and other hydrocarbons.

Lac-Mégantic, Canada accident site
July 6, 2013

Evidence to Support Pool Fires

Key Finding #5:

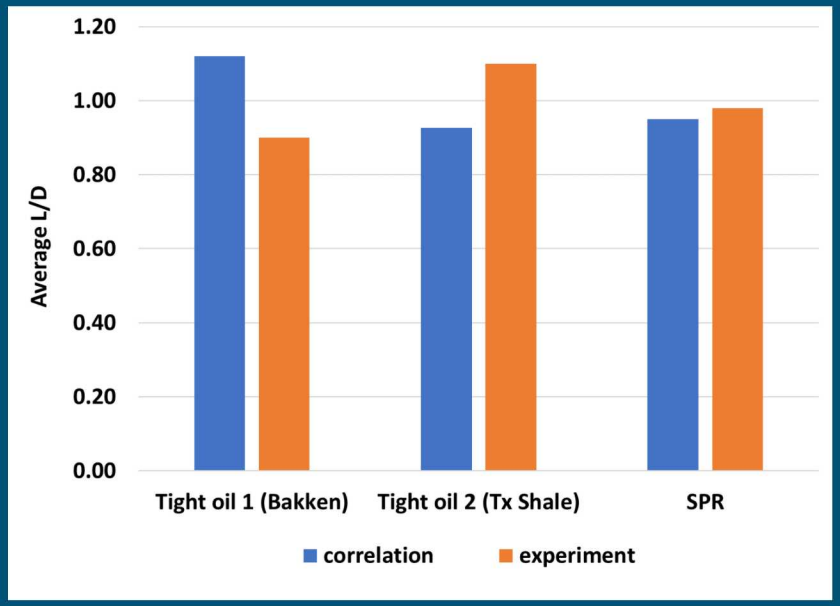
The measurements of **burn rate**, flame height, surface emissive power, and heat flux to an engulfed object are consistent with other alkane-based liquid hydrocarbons for all oils.

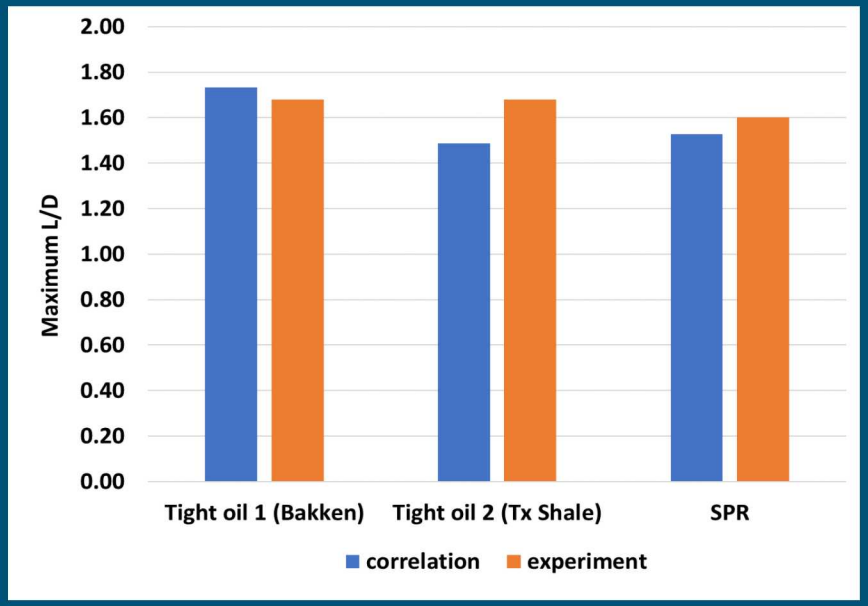


Evidence to Support Pool Fires

Key Finding #5 cont'd:

The measurements of burn rate, **flame height**, surface emissive power, and heat flux to an engulfed object are consistent with other alkane-based liquid hydrocarbons for all oils.



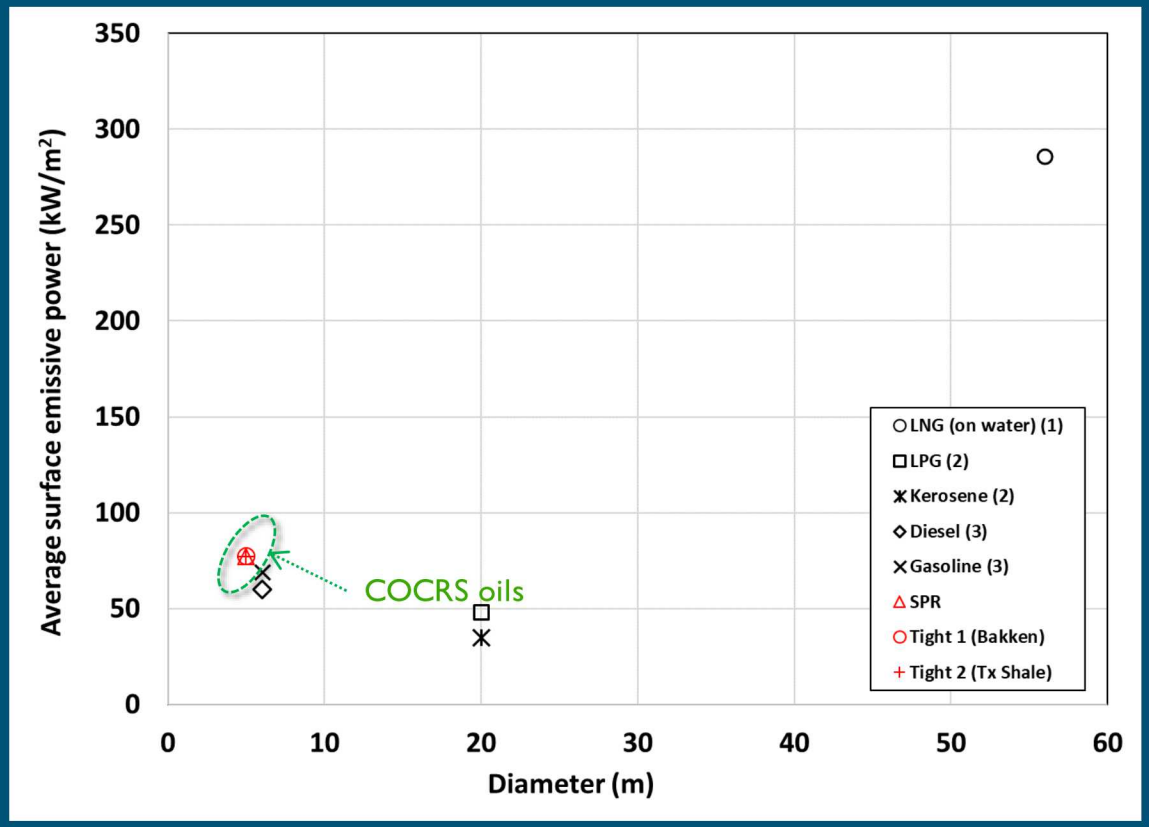


Average and maximum flame height comparison to correlation for diesel fuel and gasoline

Evidence to Support Pool Fires

Key Finding #5 cont'd:

The measurements of burn rate, flame height, **surface emissive power**, and heat flux to an engulfed object are consistent with other alkane-based liquid hydrocarbons for all oils.



Evidence to Support Fireballs

Key Finding #1:

The experimental results indicate that the average surface emissive at maximum power for the tight oils are about 30% higher than the SPR oil.

Oil	Average Surface Emissive Power (kW/m^2)
SPR	225 ±14
Tight 1 (Bakken)	293 ±22
Tight 2 (Tx Shale)	295 ±22

Evidence to Support Fireballs

Key Finding #2:

The maximum fireball diameters measured were similar among the oils (~62-65 m).

Oil	Maximum Diameter (m)
SPR	62
Tight 1 (Bakken)	63
Tight 2 (Tx Shale)	65

Evidence to Support Fireballs

Key Finding #3:

The Tight 1 (Bakken) oil had a 10% lower height to fireball extinction than the other oils.

Oil	Height to Extinction (m)
SPR	200 ±5
Tight 1 (Bakken)	180 ±4
Tight 2 (Tx Shale)	200 ±4

Evidence to Support Fireballs

Key Finding #4:

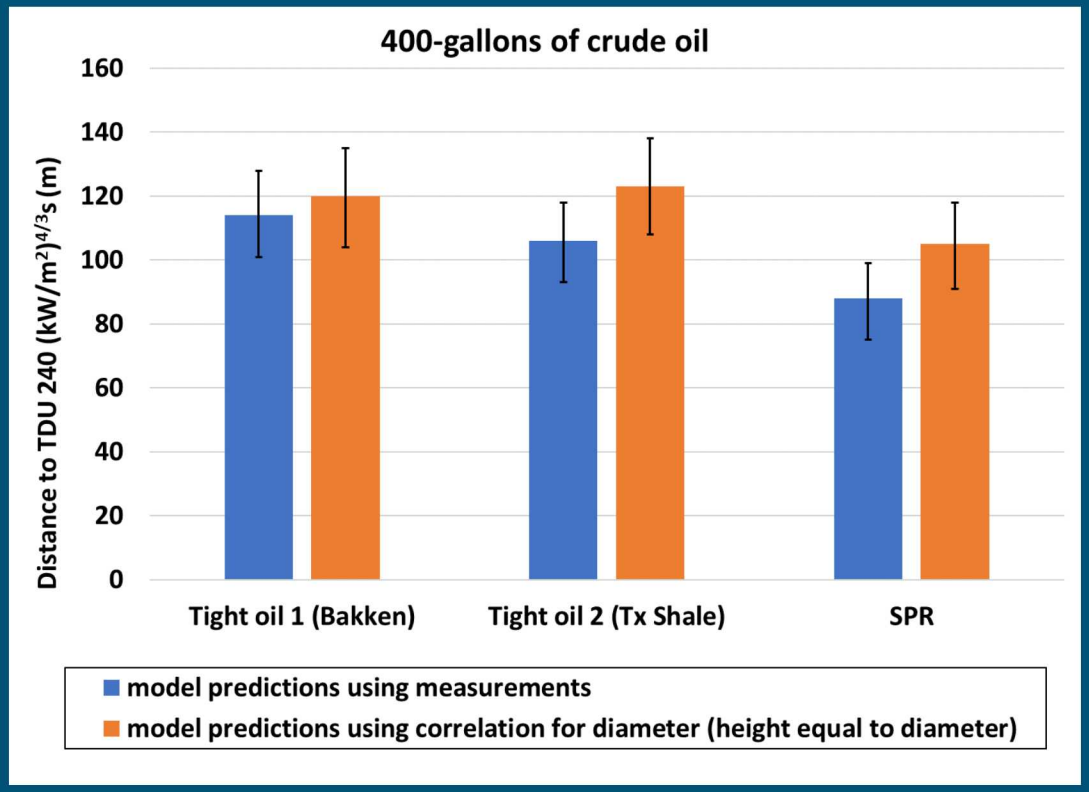
The time to fireball extinction were similar among the oils (~10-11 s).

Oil	Time to Extinction (s)
SPR	11.0 ± 1
Tight 1 (Bakken)	10.0 ± 1
Tight 2 (Tx Shale)	10.0 ± 1

Evidence to Support Fireballs

Key Finding #5:

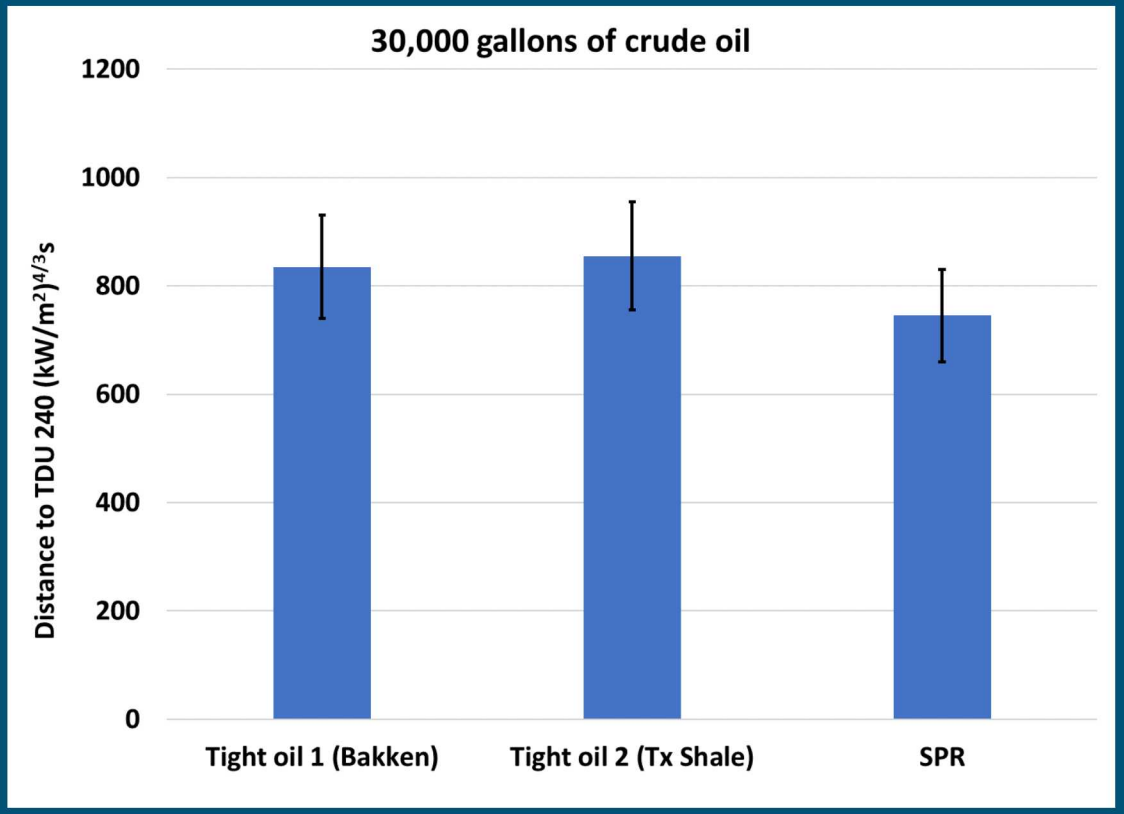
The predicted thermal hazard distance using the injury criterion of 2nd degree burns after 30-second exposure to a thermal dose level of 240 $(kW/m^2)^{4/3}s$ was evaluated for a 400-gallon release for all oils tested. The results indicate the distances for the tight oils are similar but are about 20-30% higher than the distance predicted for the SPR oil.



Evidence to Support Fireballs

Key Finding #6:

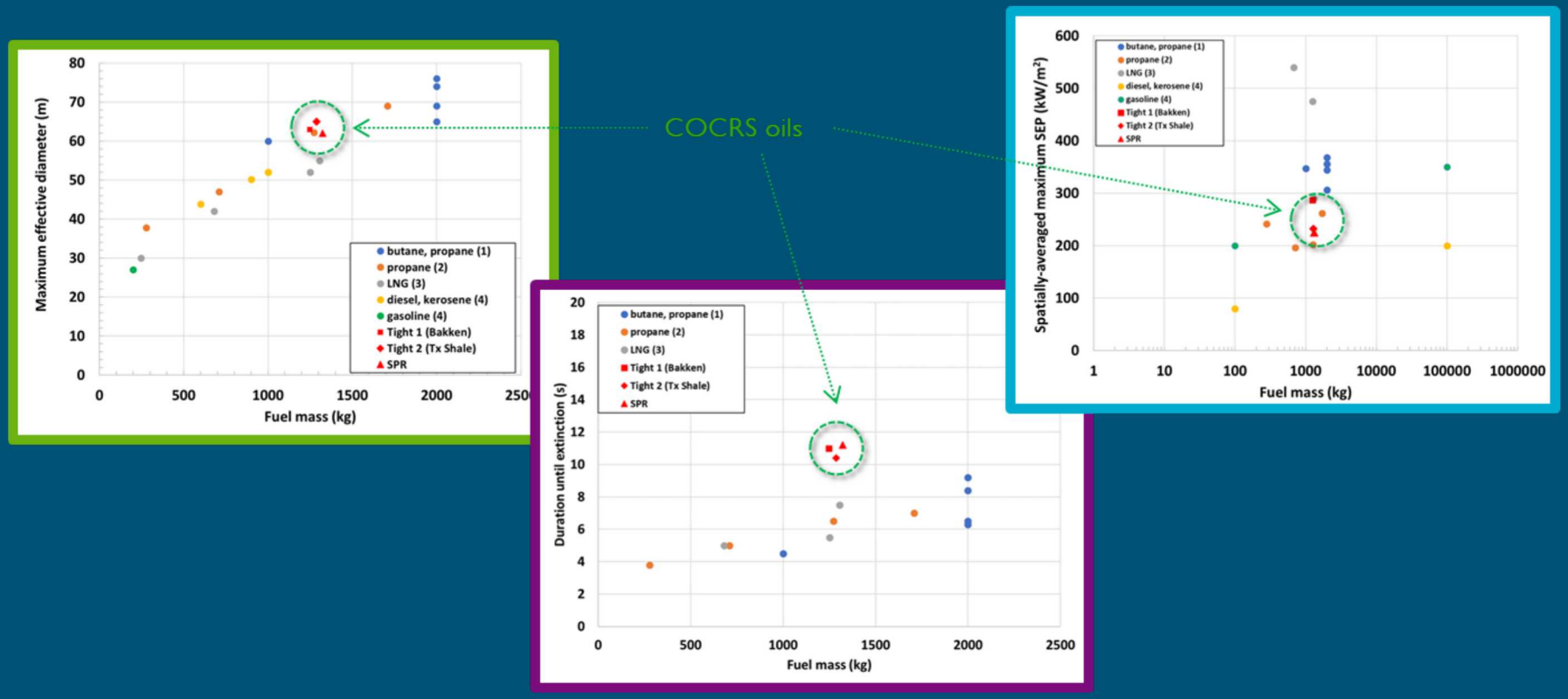
Predicted thermal hazard distances, for a 30,000-gallon release, among the crude oils differ by about 12% with the range of uncertainties overlapping. Thus, the predicted thermal hazard distances among the oils are comparable.



Evidence to Support Fireballs

Key Finding #7:

The observed measurements of diameter, duration, and surface emissive power for the COCRS tested crude oils are consistent with experiments performed by other researchers testing similar volumes for propane, butane, gasoline, and diesel as fuels.



Evidence to Support Fireballs

Key Finding #8:

The average surface emissive power at maximum power for all oils are below the Center for Chemical Process Safety (CCPS) recommendation to use a value of 350 kW/m^2 for thermal hazard evaluation. It is anticipated that the oils will not exceed this value for larger releases. The CCPS is a non-regulatory organization within AIChE that addresses process safety of hazardous *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards* (Center for Process Safety). American Institute of Chemical Engineers, 2011

Oil	Average Surface Emissive Power (kW/m^2)
SPR	225 ±14
Tight 1 (Bakken)	293 ±22
Tight 2 (Tx Shale)	295 ±22

Project Publications

- Lord, D. L., R. G. Allen and D. K. Rudeen (2017). "DOE/DOT Crude Oil Characterization Research Study, Task 2 Test Report on Evaluating Crude Oil Sampling and Analysis Methods." *in press*. Sandia National Laboratories, Albuquerque, NM.
- Lord, D., A. Luketa, C. Wocken, S. Schlasner, R. Allen and D. Rudeen (2015). "Literature Survey of Crude Properties Relevant to Handling and Fire Safety in Transport." *Unlimited Release SAND2015-1823*. Sandia National Laboratories, Albuquerque, NM.
- Lord, D. L., R. G. Allen and D. K. Rudeen (2017). "DOE/DOT Crude Oil Characterization Research Study, Task 2 Test Report on Evaluating Crude Oil Sampling and Analysis Methods." *SAND2017-12482*. Sandia National Laboratories, Albuquerque, NM.
- Lord, D., R. Allen, D. Rudeen, C. Wocken and T. Aulich (2018). "DOE/DOT Crude Oil Characterization Research Study, Task 2 Test Report on Evaluating Crude Oil Sampling and Analysis methods, Revision 1 - Winter Sampling." *Unclassified Unlimited Release SAND2018-5909*. Sandia National Laboratories, Albuquerque, NM.

End of prepared slides