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Experimental development of propane burners for fast cook off testing

2013 Insensitive Munitions and Energetic Materials Symposium

San Diego, California

October 5-8 2013

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Current Propane Test Beds

Liquid Injection

Meppen, Germany

China Lake, USA

Pre-Mixed Injection

‘t Harde, Netherlands

Bofors, Sweden

Gaseous Injection

Dahlgren, USA

Status of Gas Fired Fast Cook Off Testing Initiative

Until 2010: Skeptical community

2010 FFE Meeting in Meppen: Dr .Eich paper showing *temperatures and heating rates* were actually higher in a propane fire than a comparable kerosene fire

2010 IM/EM Symposium in Munich: Toreheim paper showing very *similar reactions* in propane and liquid fuel for 40mm gun ammunition and shoulder fired anti-tank rocket launcher

2012 IM/EM Meeting in Las Vegas: Dahgren /China Lake paper showing nearly *equivalent temperatures and heating* rates in a large JP-5 fire and Meppen propane fire

2012 FFE Meeting in Bordeaux: Propane and liquid fuel produce ***comparable HF data*** and ***uniformity of spatial heating***. *100-150 kW/m*^{2} heat flux is a mandatory requirement for calibration testing.

2013 FFE 't Harde: Reaffirmed 100-150 kW/m2 heat flux, developed a specification for testing with propane & requirement for facility calibration

Agenda

Requirements definition

Discussion of heat flux

Instrumentation overview

Show through measurements and computer simulation how requirements are met

Summarize and conclude

Sources for Requirements

AOP-39: "Where environmental concerns dictate, alternate fuel such as *propane* or natural gas *may be used if testing verifies that the overall heat load to the test item matches* what would be achieved from *a liquid fuel fire* at the established ramp and average temperature. For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the *radiative conditions should match that of a liquid fuel fire*"

STANAG 4240: "In the standard liquid fuel/external fire test, the test specimen is surrounded by fuel rich flames from a large open hearth containing liquid fuel. The large horizontal dimensions of the hearth ensure that the flames are fuel rich and hence *heat transfer to the test specimen is approximately 90% radiative.*"

2010 Fuel Fire Experts Meeting: The concerns of the international community are *uniformity of heating, proportionality between radiation and convection, and the importance of soot*

Define Thermal Requirements

From the above we derived a requirements statement to guide the design of a propane burner for fast cook off testing:

The overall heat load to the test item matches what would be achieved from a liquid fuel fire

The heating must be uniform

The heating should be approximately 90% radiative

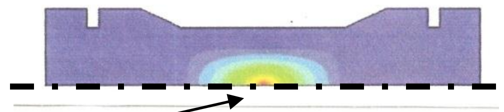
The above must be verified by testing

Heat Flux

Heat flux

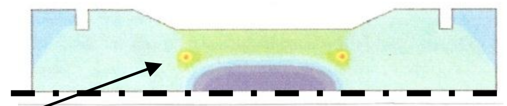
$$\frac{\text{heat}}{\text{area}} = \text{kW/m}^2$$

Fast cook, slow cook, and heat flux



Thermal Runaway
on Centerline

3 deg C / ***hour***



Thermal Runaway at
Interior Points

3 deg C / ***minute***

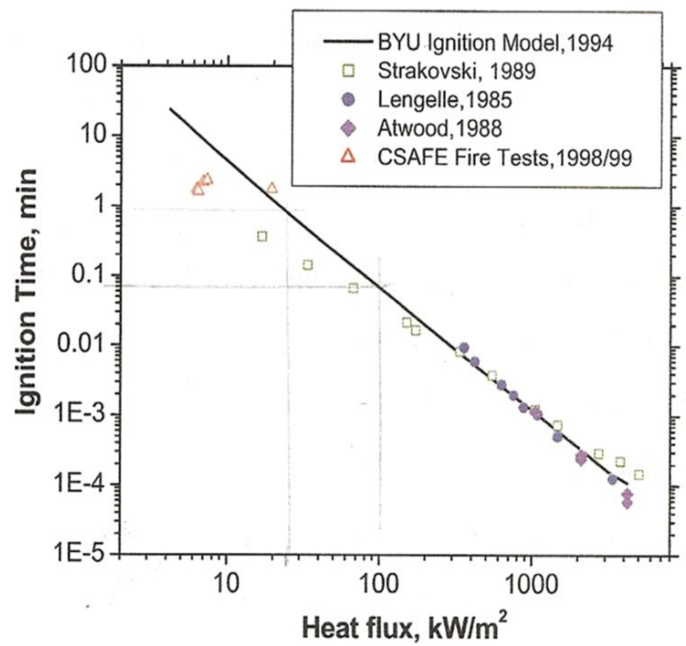
For high heat flux the ignition
is at the outer surface

The time to cook off varies inversely
with the heat flux

This shows

$T_{ignition} \doteq 100 \text{ min} / \text{Heat Flux}$

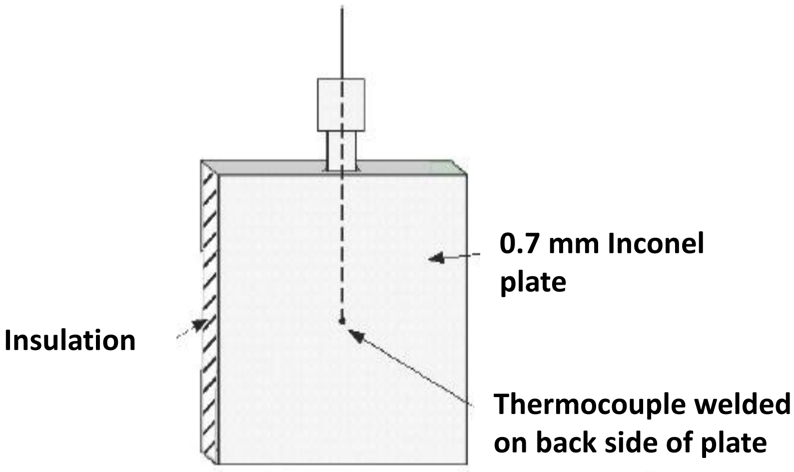
(A casing and insulation can reduce the heat flux
at the explosive below the incident value)



Heat Flux Instrumentation – PTs and DFTs

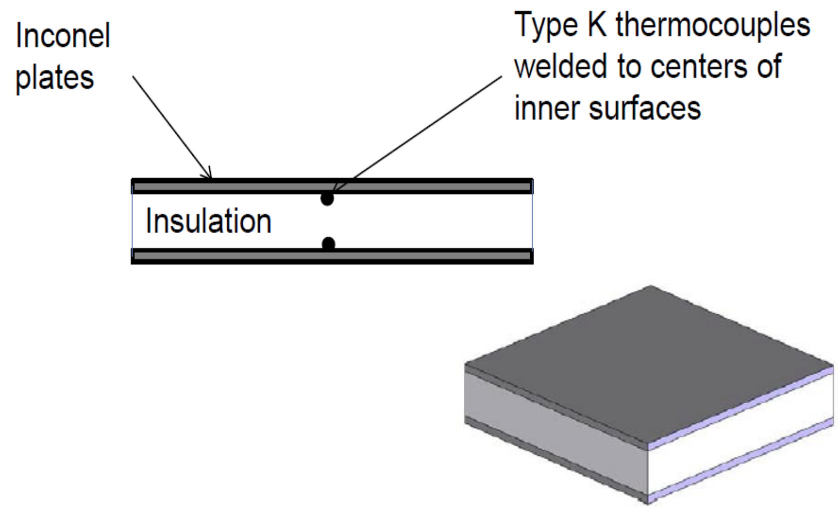
Plate Thermometer – PT

ISO 834-1:199(E)



Directional Flame Thermometer – DFT

ASTM E-1529



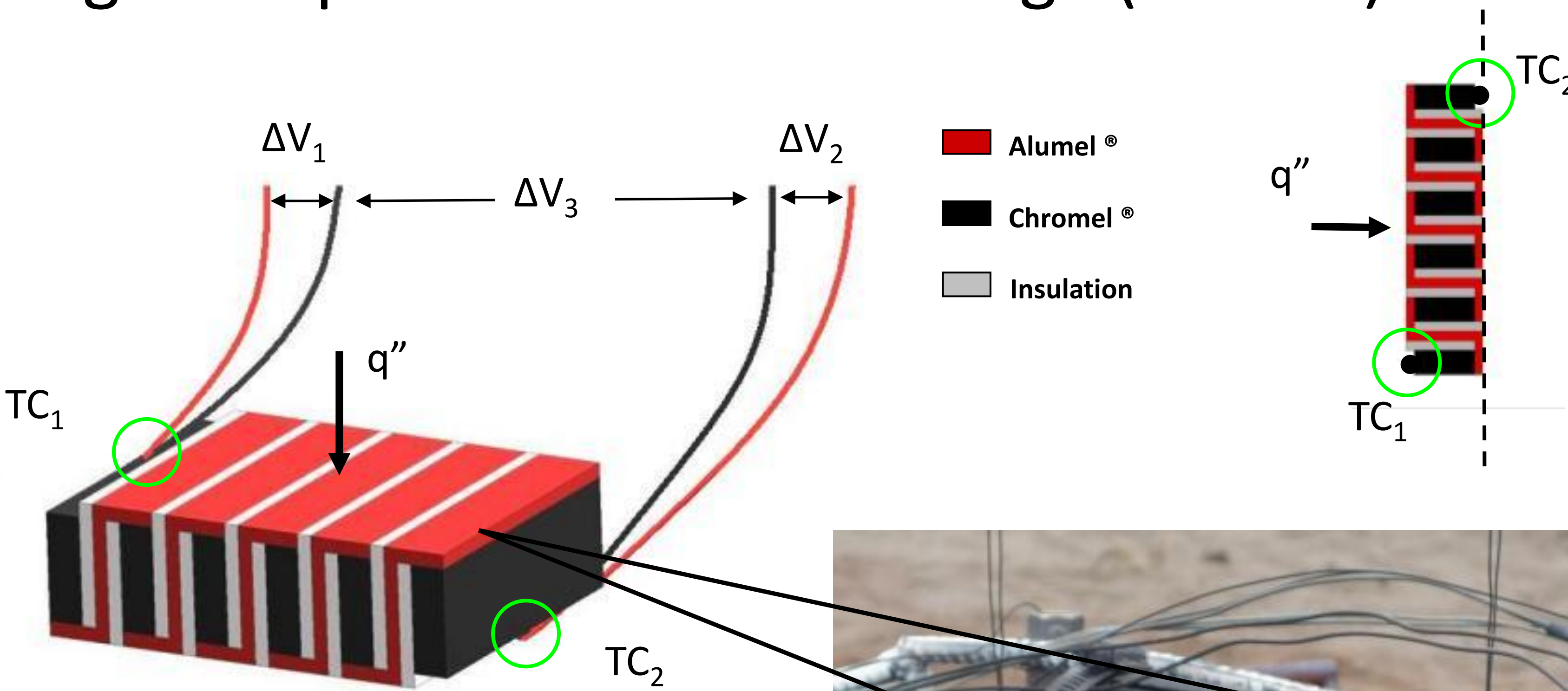
Pros

- Standard, accepted method
- Robust and relatively cheap

Cons

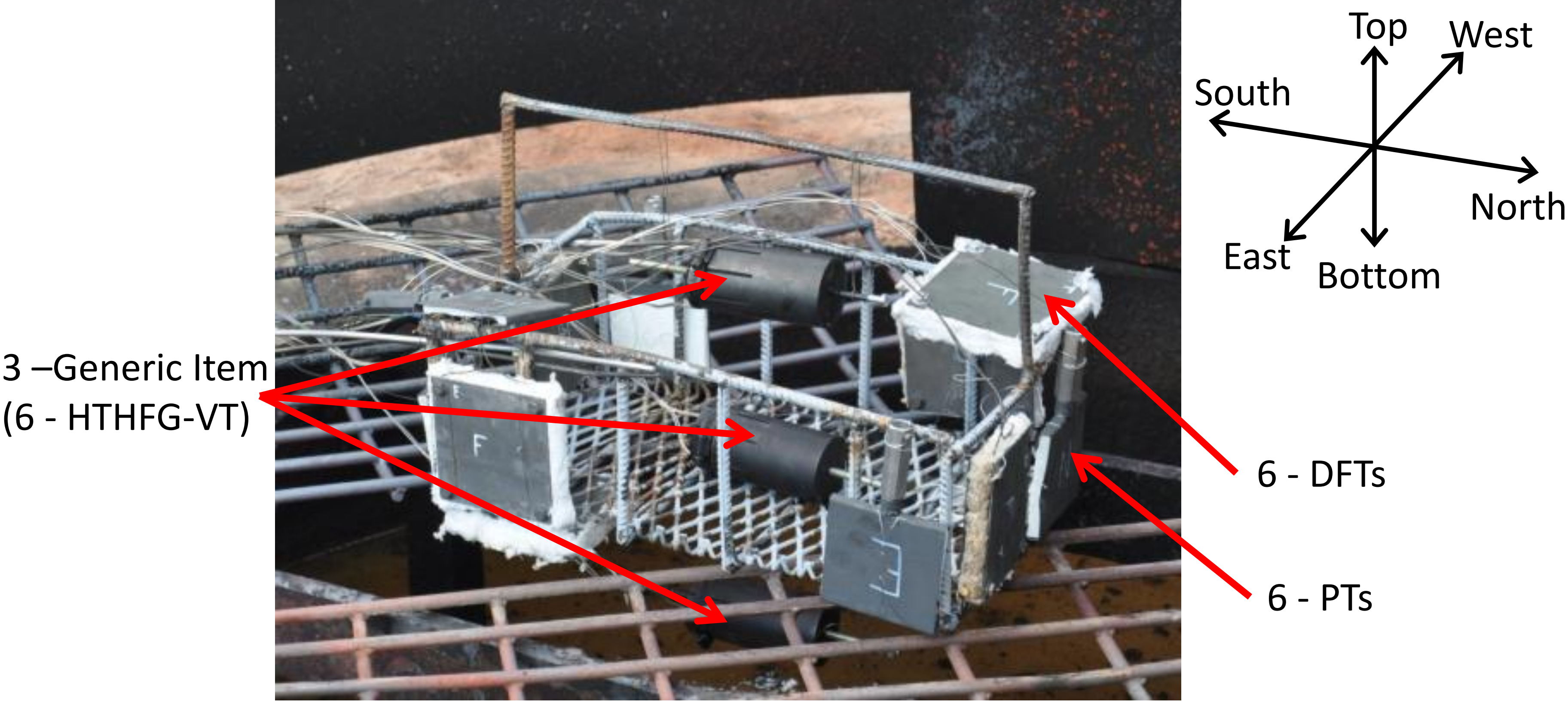
- Complicated post processing
- Sensitive to noise

High Temperature Heat Flux Gage (HTHFG) - VT



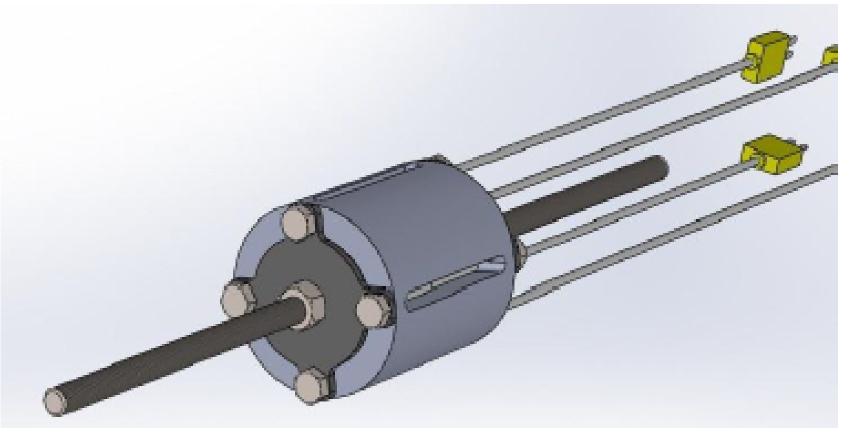
- Thermopile measures temperature drop
- Temperature drop is proportional to heat flux

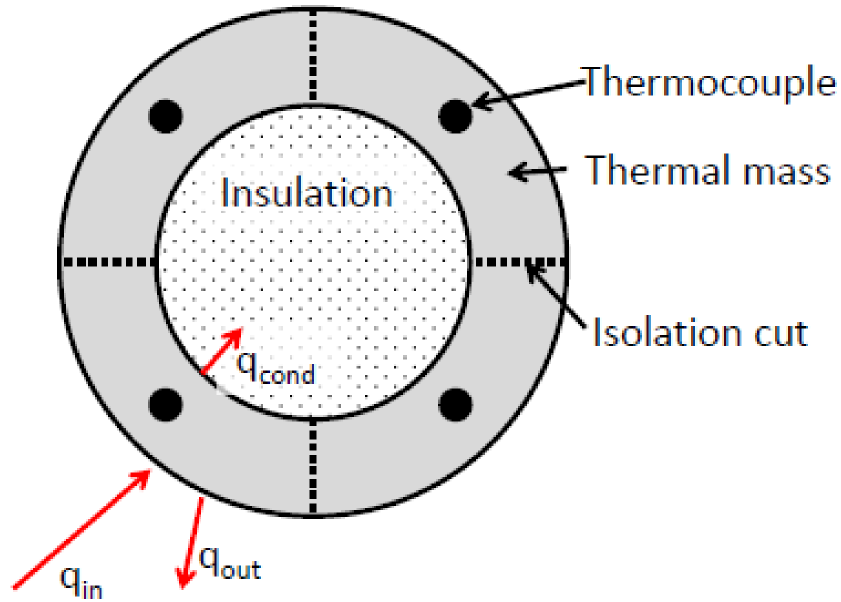
Instrumentation Arrangement



- 19” x 11” x 7”
- Used in Dahlgren JP5 fire, Meppen propane fire, Dutch liquid fuel fire, and Dutch propane fire

Directional Slug Calorimeter



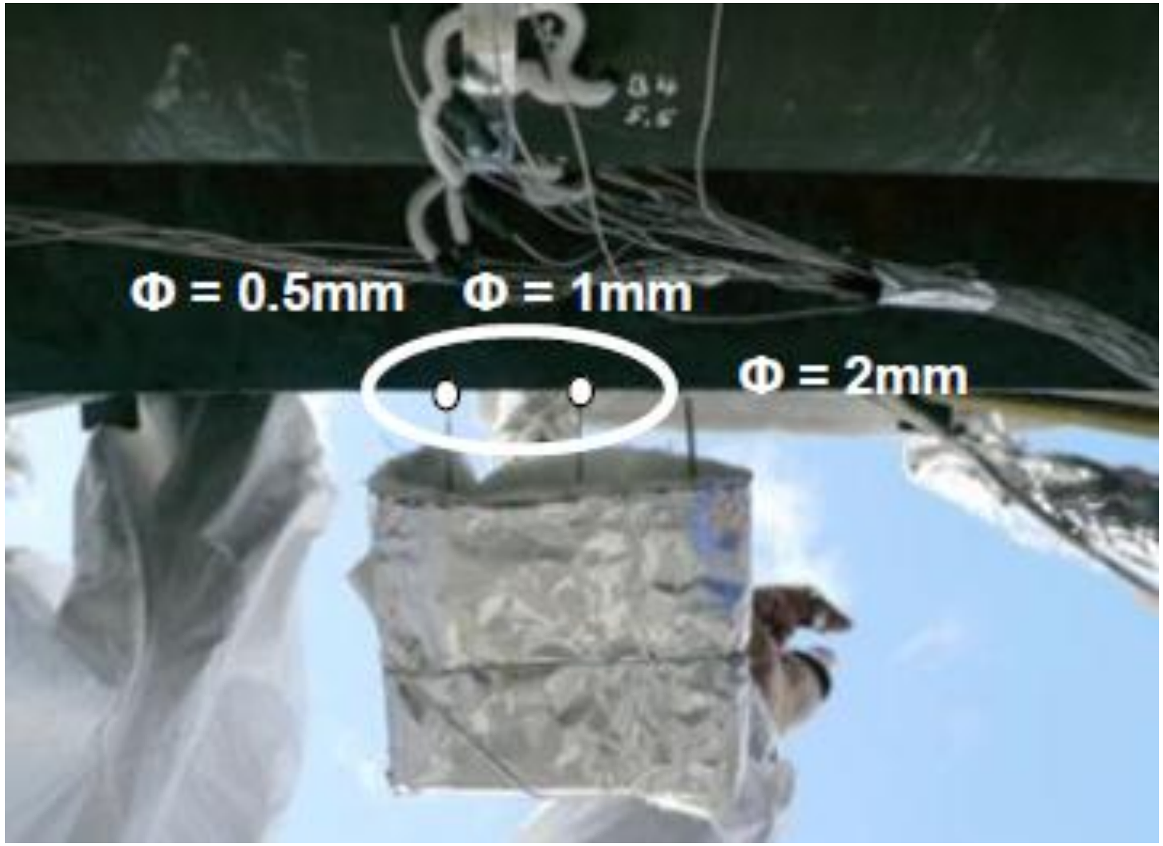


- Developed in G65
- Heat flux from temperature measurements
- Robust and easily repaired
- Patent application submitted

Net heating rate; Small, insulated; Measured by TC

$$\underbrace{q_{in} - q_{out}}_{\text{Net heating rate}} - \underbrace{q_{cond}}_{\text{Small, insulated}} = mC\underbrace{\frac{\partial T}{\partial t}}_{\text{Measured by TC}}$$

French Heat Flux Measurement Technique



Paired thermocouples of different diameters were used to calculate the heat flux incident on a rocket motor

Fabien Chassagne, "Fast Cook Off Test: Liquid Propane Gas vs Kerosene Pool Fire," DGA/DT/CAEPE,

Test Objective

Verify by testing the thermal requirements are met:

- *The overall heat load to the test item matches what would be achieved from a liquid fuel fire*

- *The heating is uniform*

- *The proportionality between radiation and convection is approximately 90% radiative*

Standardized Instruments in a Fire

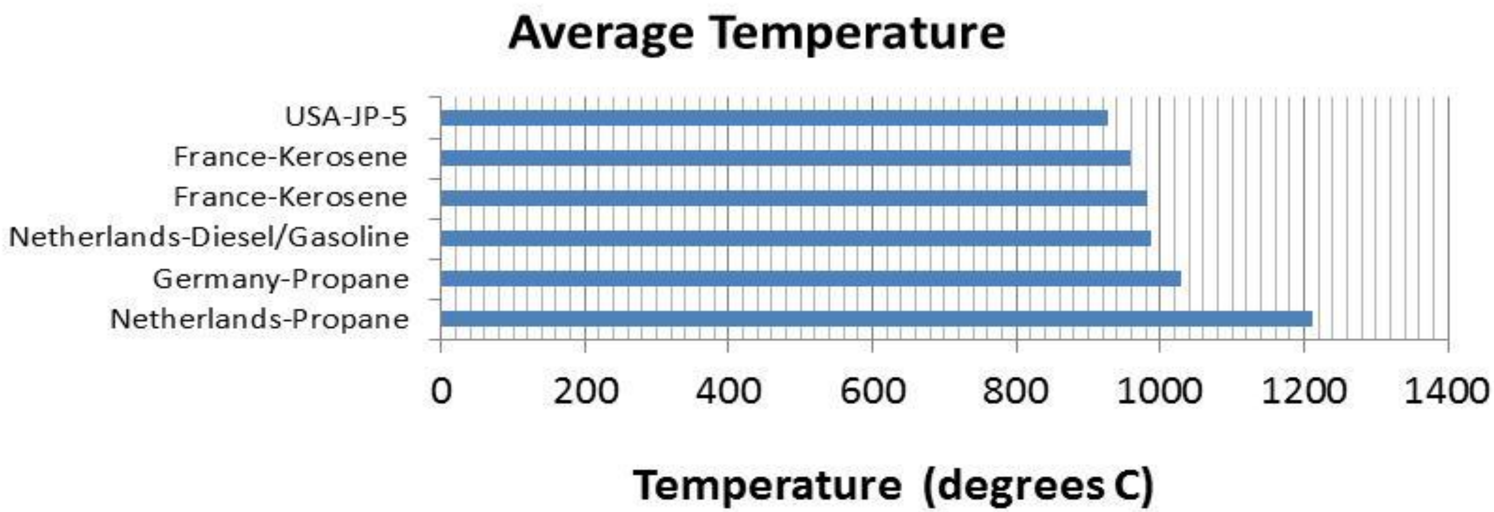
Instrumentation in a gasoline / diesel fuel fire in, ‘t Harte, The Netherlands

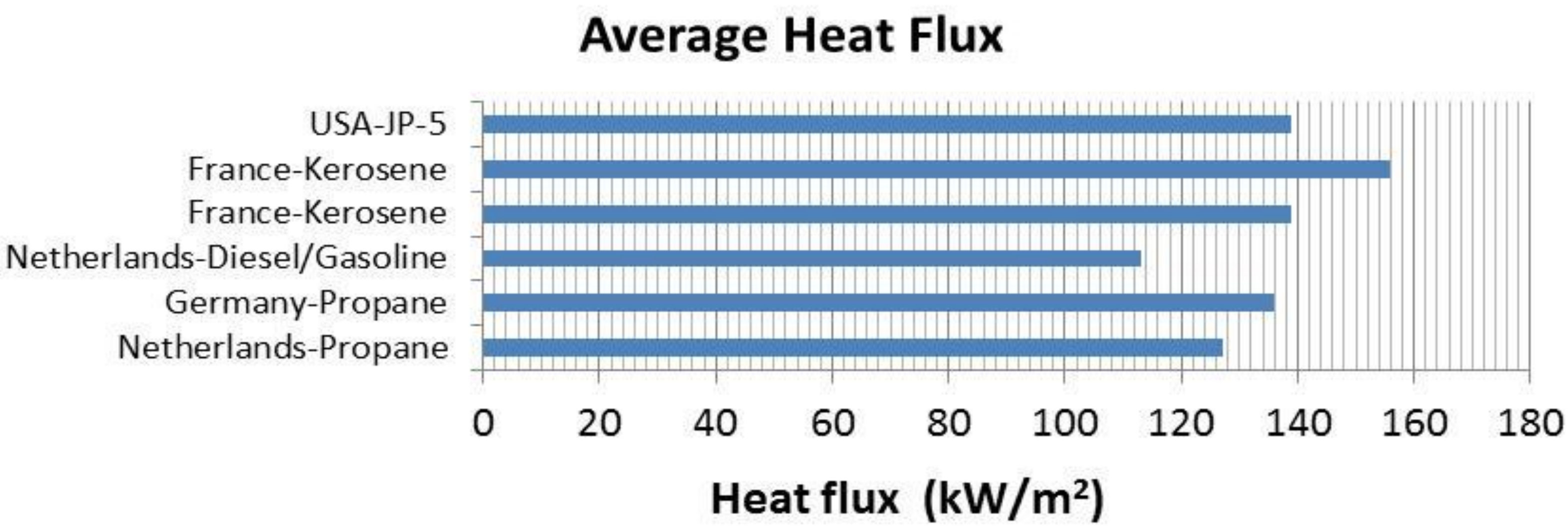
Basket of instruments

Summary of data from six fires

Fire	Fuel	Average Temperature	Temp s.d.	Average Heat Flux	Heat Flux s.d.
		degrees C	degrees C	kW/m^2	kW/m^2
USA	JP-5	927	32	139	5
France	Kerosene	959	13	139	16
France	Kerosene	981	35	156	5
Netherlands	Diesel/Gasoline	987	15	113	20
Germany	Propane	1028	131	136	5
Netherlands	Propane	1211	19	127	25

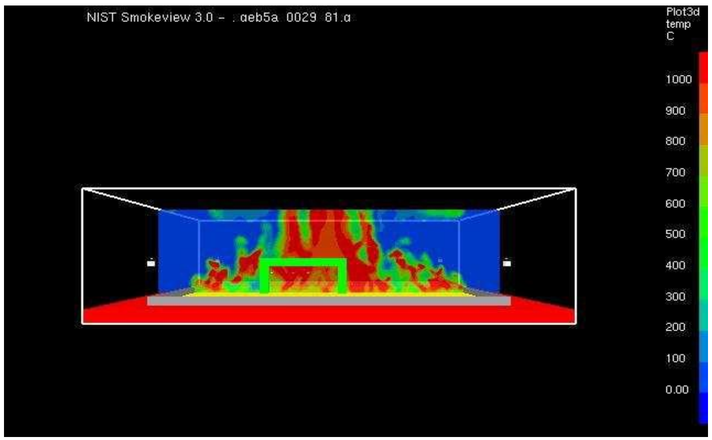
Average temperature and heat flux



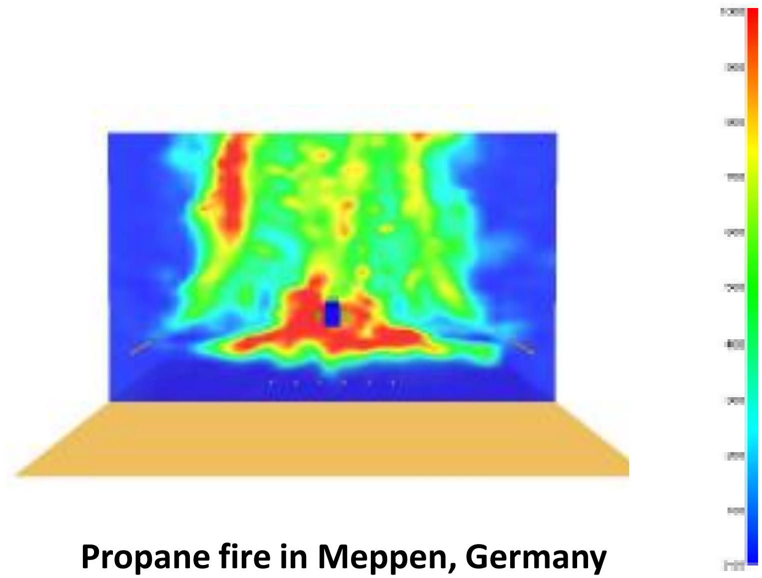


The heat flux is in the range 100 – 150 kW/m^2

Computer Model of Propane Fire



Liquid fuel fire in DGA, France

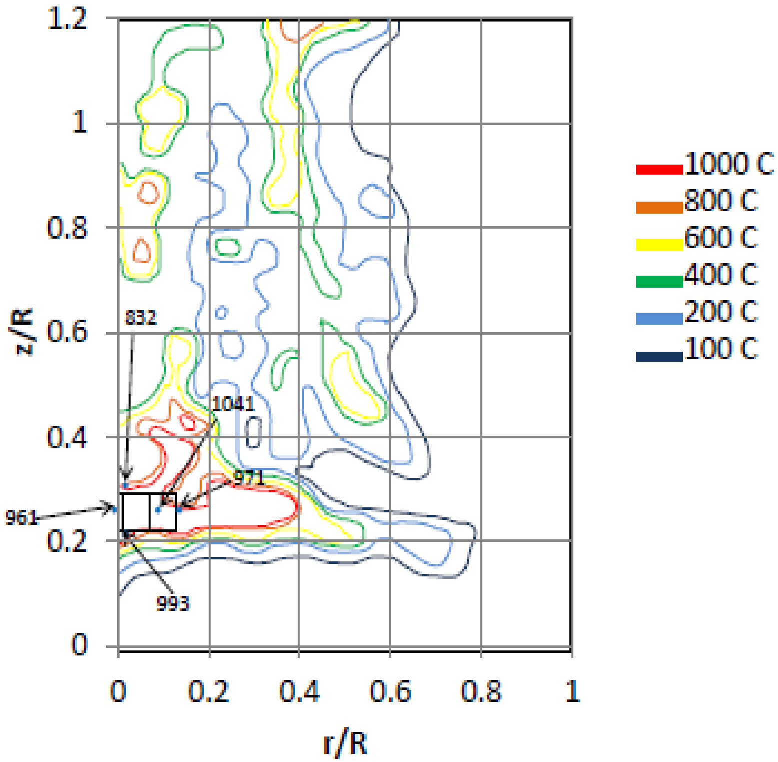


Propane fire in Meppen, Germany

National Institute of Standards and Technology "Fire Dynamics Simulator" computer simulations

Fabien Chassagne, "Fast Cook Off Test: Liquid Propane Gas vs Kerosene Pool Fire," DGA/DT/CAEPE,

Computer Simulation Results



Computer results with data from standard instrumentation in basket in Meppen fire

Time-Averaged Gas Temperature (°C)	LPG Fire
Tright 1	915
Tright 2	881
Tleft 1	887
Tleft 2	877
Tback	823
Tfront	817

(Fabien Chassagne, DGA)

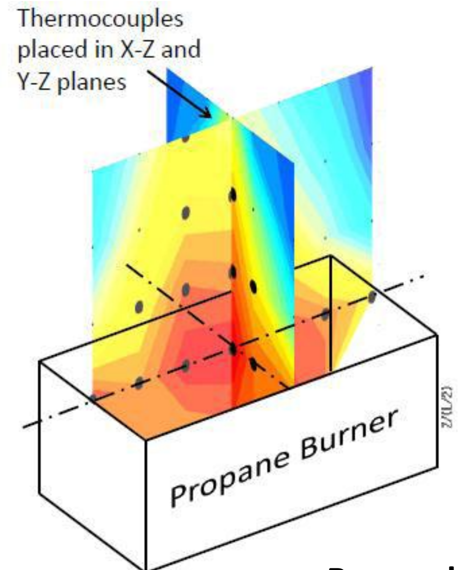
Time-Averaged Heat Flux (kW/m^2)	LPG Fire	
Incident Heat Flux Φ_{inc}	104,1	
Radiative Heat Flux Φ_{rad}	84,2	89,7%
Convective Heat Flux Φ_{conv}	9,6	10,2%
Net Heat Flux Φ_{net}	93,9	

(Fabien Chassagne, DGA)

The heat flux is 90% radiative

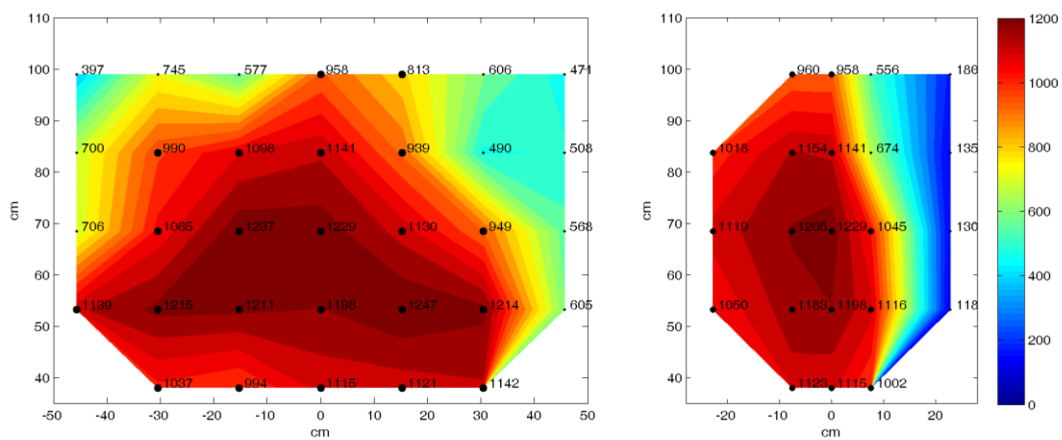
Thermocouple Grid and Temperature Fields

Grid with 50 thermocouples



Comparable to liquid fuel fire

Research fire, Dahlgren



Temperature field in ‘t Harde propane fire

The heating is uniform

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Summary and Conclusions

- Propane burners meet STANAG temperature rise and average requirements
- Propane burners meet the new heat flux requirements
- Propane burners provide mostly radiative heating as in liquid pool fires
- Burners must be analyzed to determine volume within the fire meeting requirements