

Development and Characterization of a Propane Fueled Fast Cook-off Burner



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Background



- Fast Cook-Off is a standard safety test required for all explosive ordnance
 - Test initiated after multiple carrier fires in the 1960's
 - Test item immersed in a flame produced by a pool of burning liquid fuel





The Push for an Alternative Fuel



- Issues with current method
 - Environmental concerns
 - Atmospheric emissions
 - Public relations
 - Soil contamination
 - Safety and technical risks
 - Transfer of fuel to basin
 - Insufficient fire duration
 - Immersion of unreacted explosive components in fuel basin
 - Costs
 - Typical test at Dahlgren requires 1500-3000 gal
 - Additional cost to repeat invalid tests
- Increasing interest across NATO to develop an alternative





Designing a Propane Facility

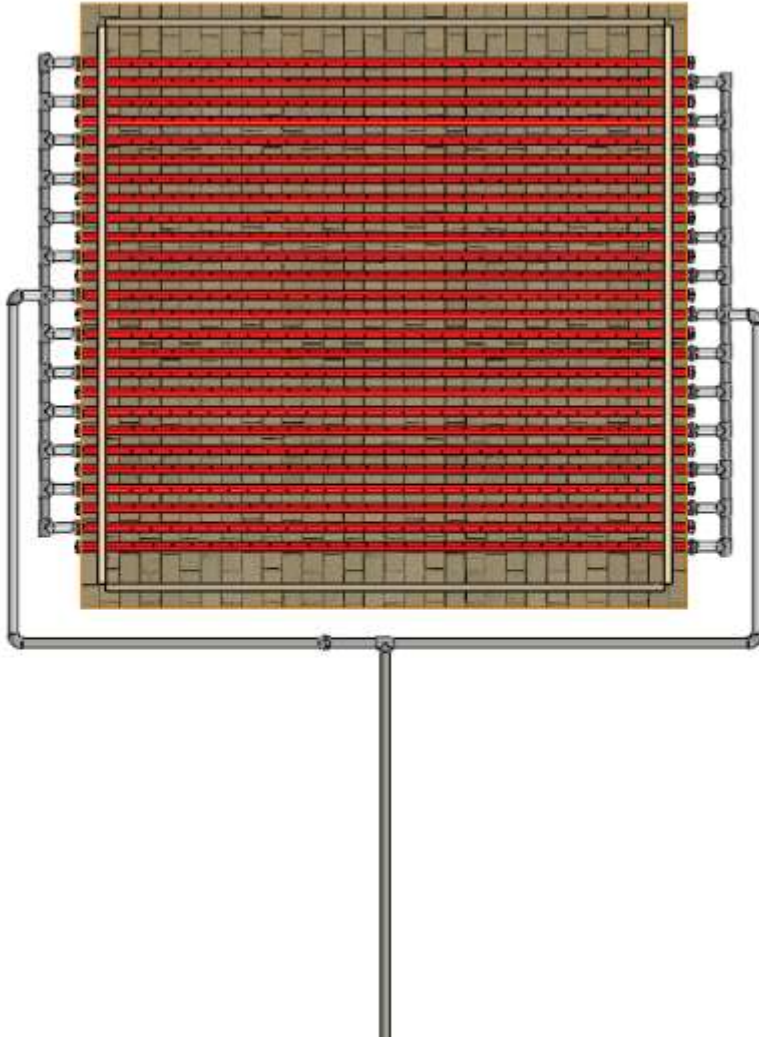


Thermal constraints imparted by the testing standards were condensed into the following thermal requirements:

- The flame temperature must be at least 800°C – (must also reach 550°C within 30 seconds)*
- The heating must be uniform*
- The average heat flux over the first 20 seconds after the 800°C temperature is met must be greater than 80 kW/m²*
- The heating should be primarily radiative*



Design Overview



- 12' (3.6m) square
- 26 burner tubes
- 676 gas ports





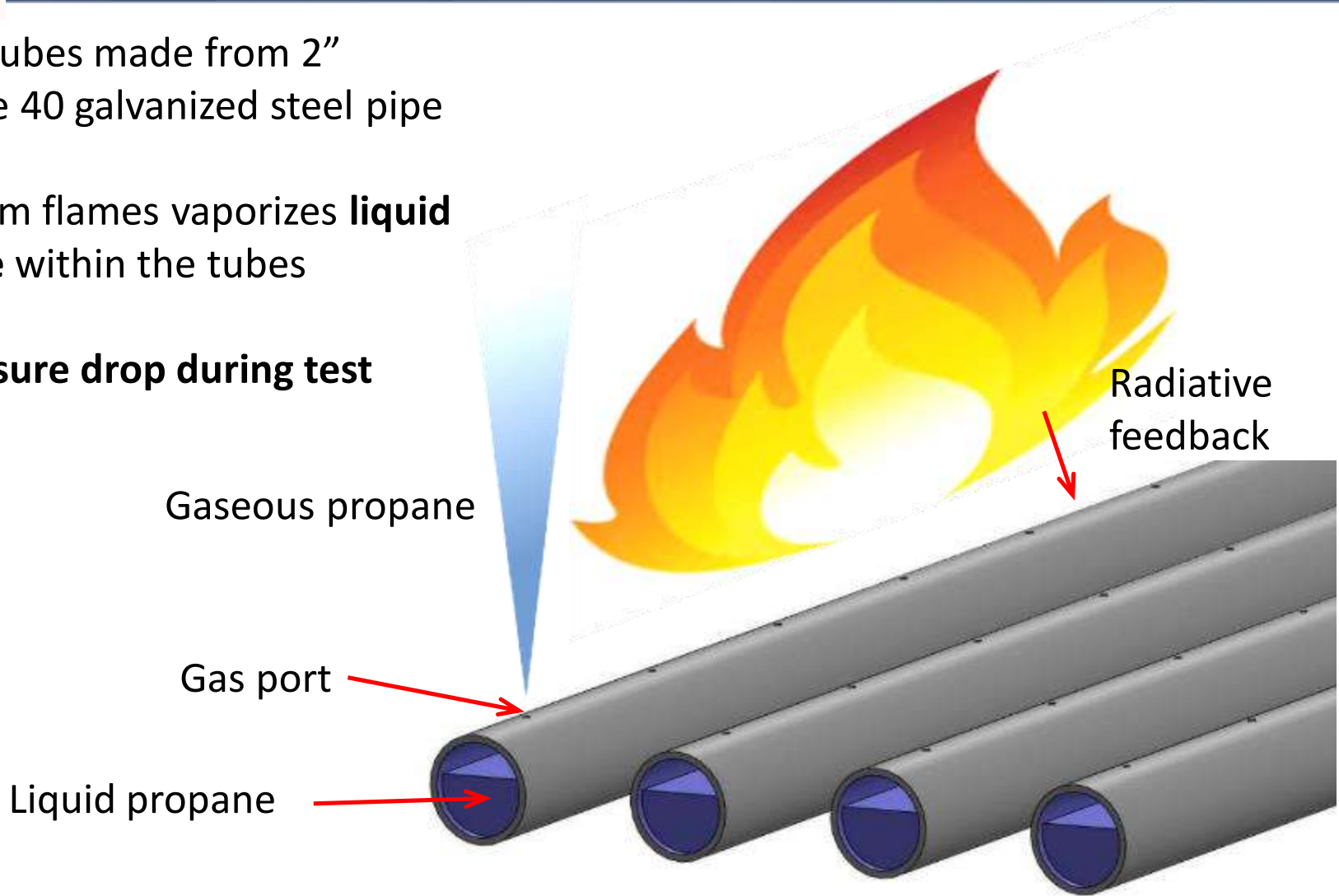
Design Details



Burner tubes made from 2" schedule 40 galvanized steel pipe

Heat from flames vaporizes **liquid propane** within the tubes

No pressure drop during test





Video of Burner Operation

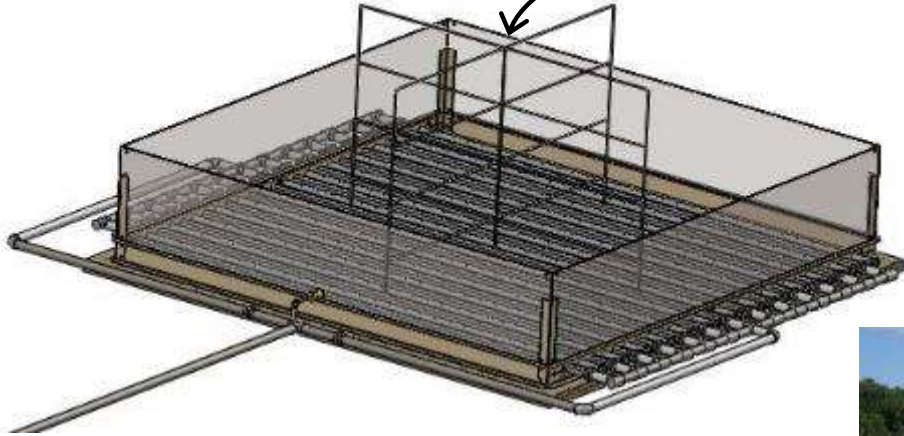




Testing Overview - Temperature



8' cross 6' tall for instrumentation

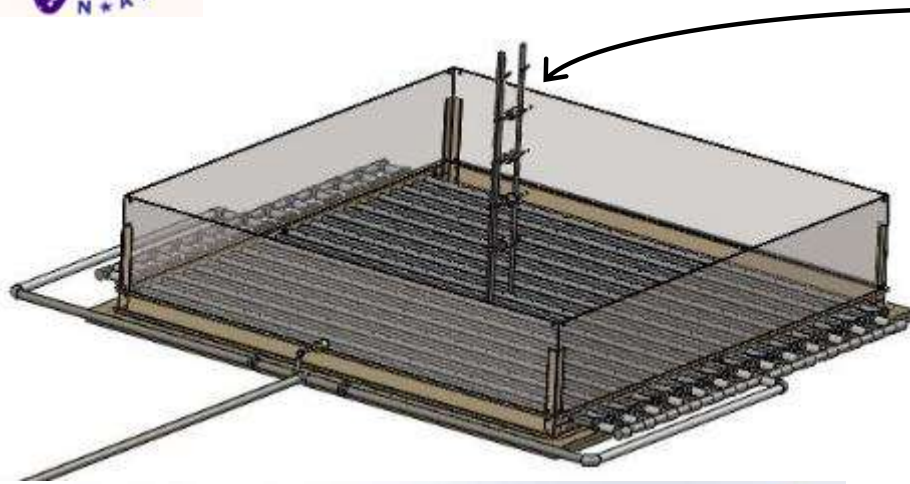


Determine the region within burner that meets 800°C Requirement

48 thermocouples on cross produce **orthogonal measurement planes of 26 temperature measurements**

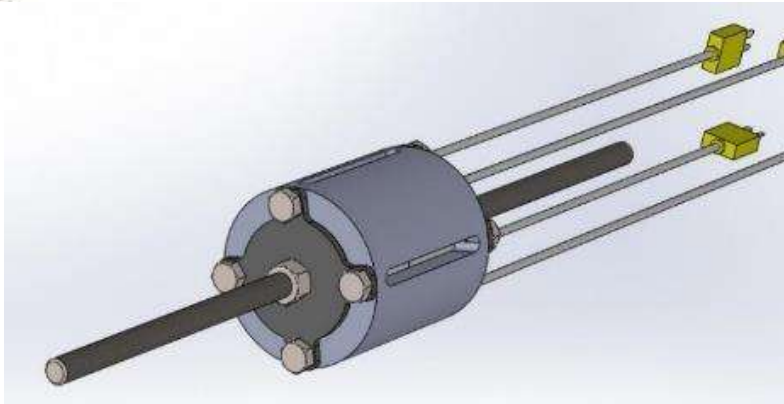
Temperatures averaged for test duration





Stand for heat flux measurements up to 6' above burner

Determine the region within burner that meets $80\text{kW}/\text{m}^2$ Requirement



Measure heat flux in four directions to cylindrical item 68.6mm in diameter



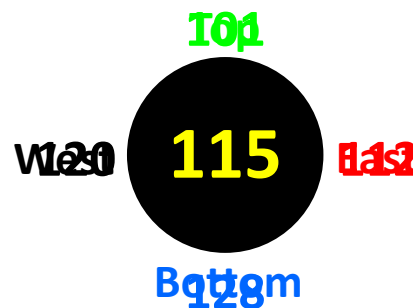
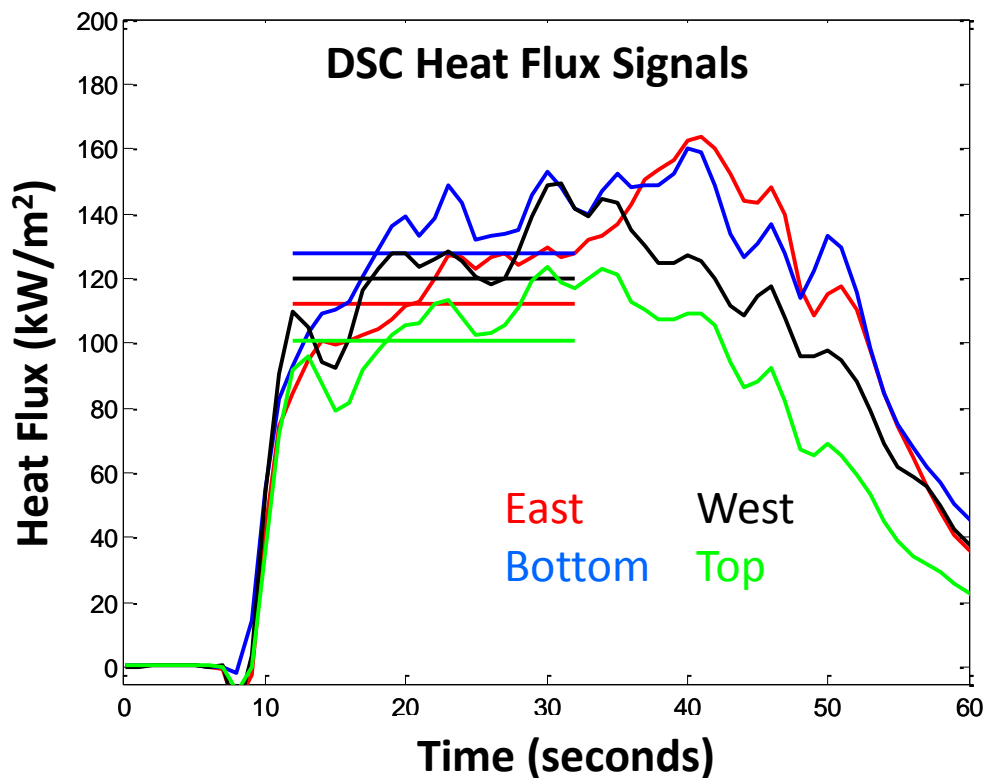


How Heat Flux Data is Displayed



DSC provides heat flux signals in four directions

- Heat flux signal is averaged for 20 seconds after 800°C requirement is met
- Overall average
- Directional uniformity



$$\% \text{ Uniformity} = 100 \times \left(1 - \frac{\sigma}{\mu} \right)$$

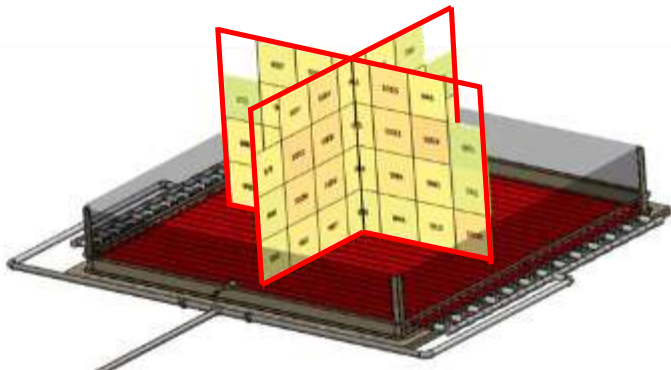
= 90%

≥75% considered good

Coefficient of variation: standard deviation normalized by the mean



Temperature Measurements (°C)



Average	907°C
Maximum	1047°C
Co. Var.	8%



Square meter for reference

	801	894	897	938	938	
749	842	906	928	951	882	817
899	936	933	900	956	923	847
944	940	911	827	834	932	967

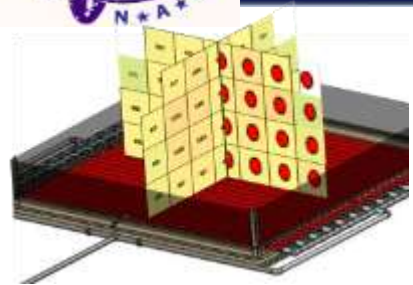
← 8' →

	870	920	897	997	1047	
658	929	990	928	961	987	952
910	1003	955	900	962	988	897
1012	871	903	827	850	859	814

↑ 6' ↓

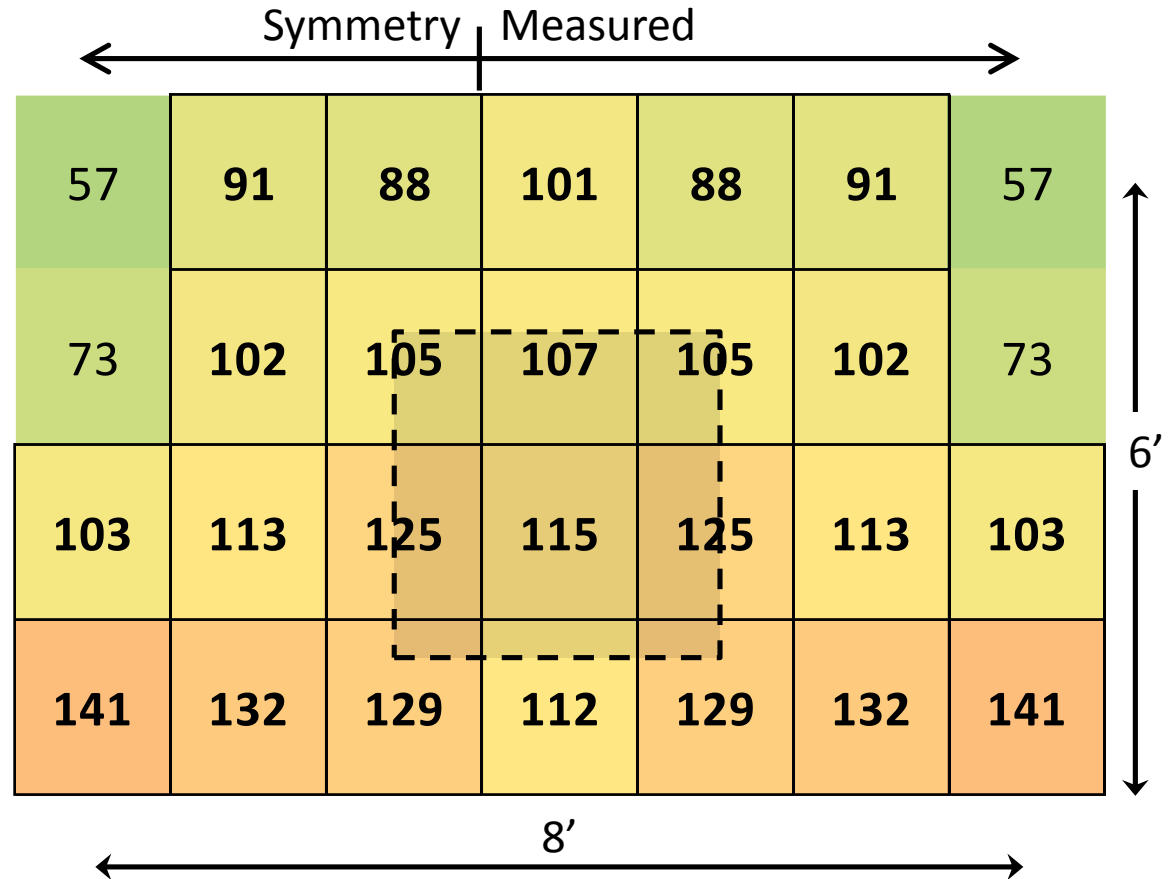


Heat Flux Measurements



Average heat flux exceeds 80 kW/m^2 over large percentage of volume

Large values combined with low velocities imply a **high radiation percentage**

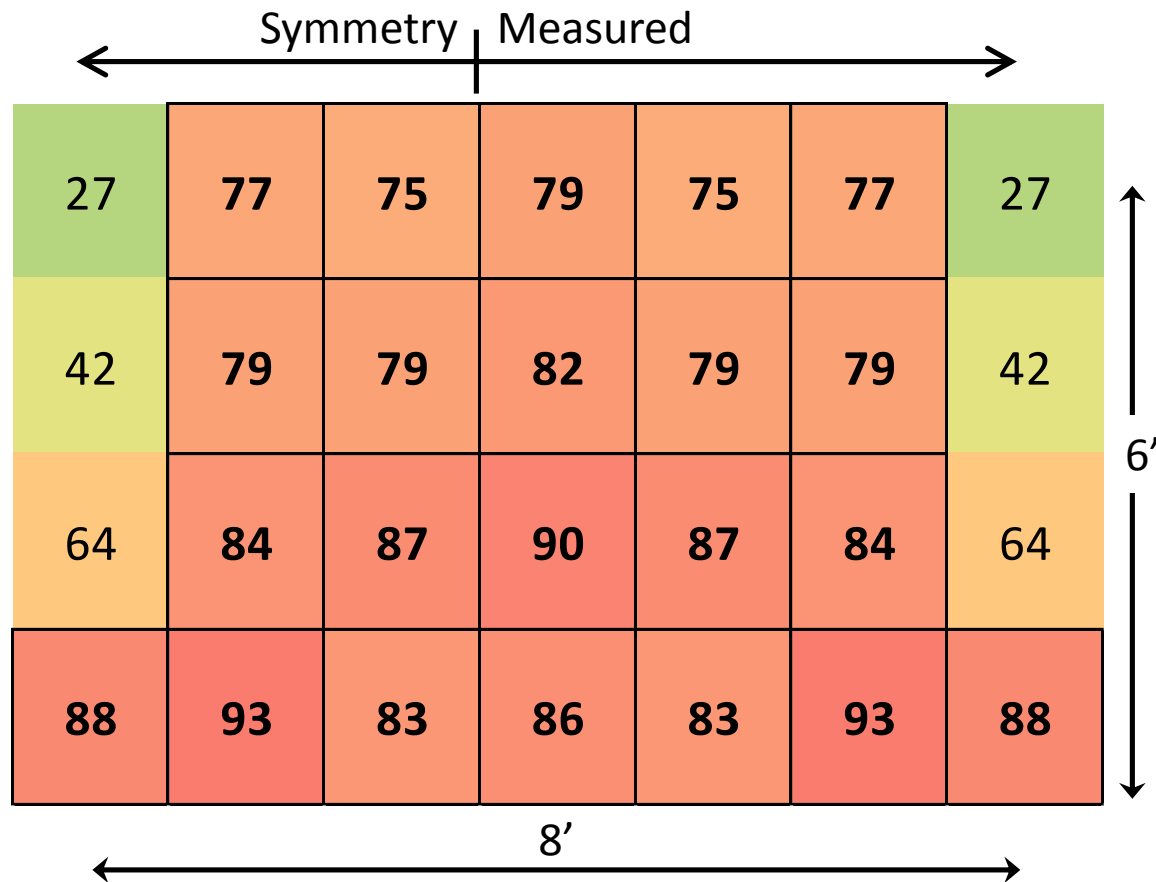




Directional Uniformity



- $\geq 75\%$ considered good
- High percentages within the hearth indicate that heating is nearly equal from all sides
- This also implies a high radiation percentage





Summary of Results



The following thermal characteristics of the burner were measured

- ✓ *The flame temperature must be at least 800 degrees C – (also has a rise time requirement)*
- ✓ *The heating must be uniform*
- ✓ *The average heat flux over the first 20 seconds after the 800 degree temperature is met must be greater than 80 kW/m²*
- ✓ *The heating should be primarily radiative*

The Navy's propane burner has met all of the thermal design requirements



Acknowledgements



Funded provided by:

The Environmental Security Technology
Certification Program (ESTCP)

The Inertive Munitions Advanced
Development (IMAD) Program



Extra Material



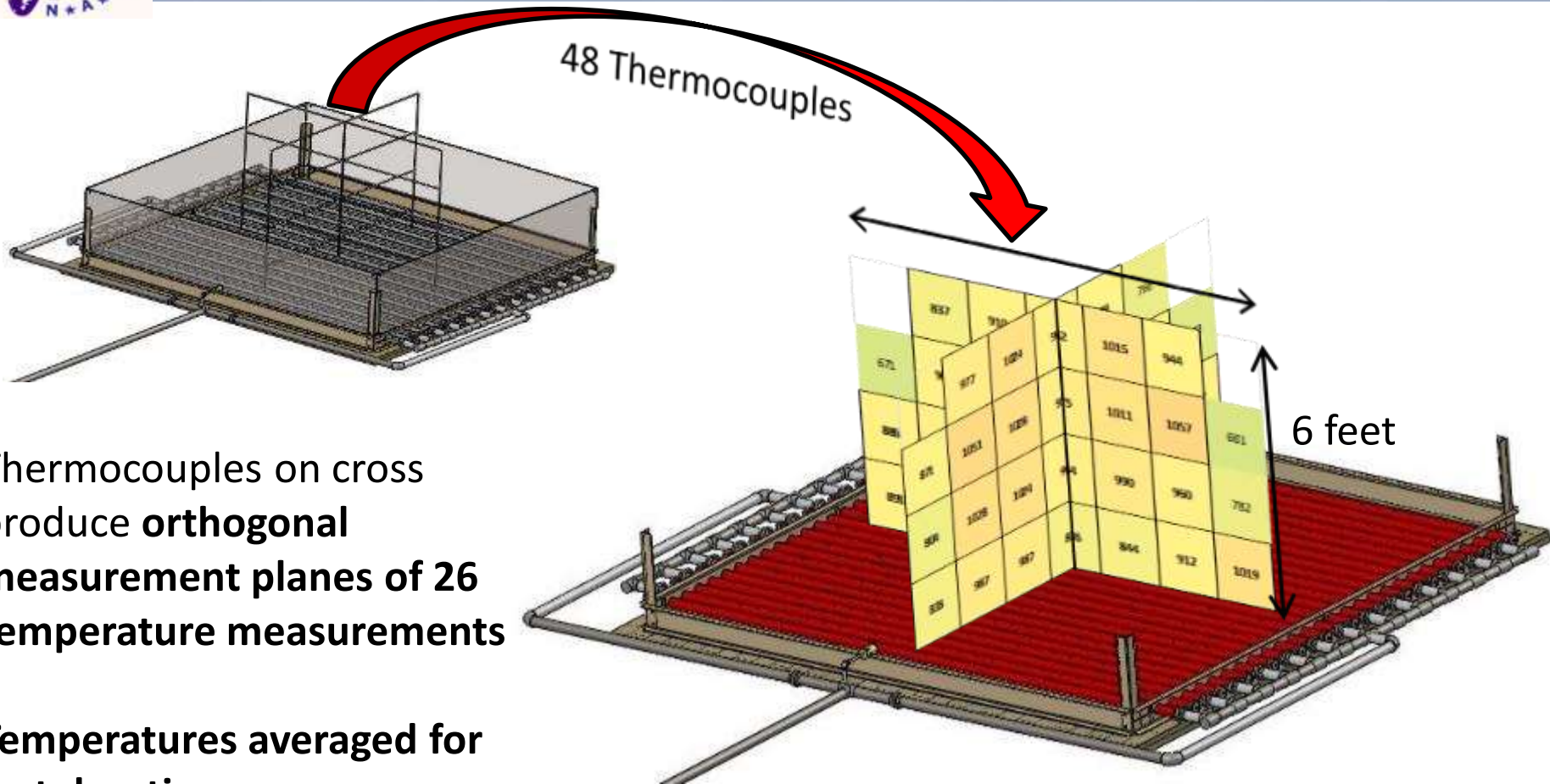
Goal: Propane burner used to score munitions

- September 2014: Presented to at the Fuel Fire Experts meeting in Sweden
- November 2014: Presented to JSIMTP
- November 2014: JSIMTP presented to the IM IPT

- May 2015: Final draft of the new AOP completed
- May 2015: Final Fuel Fire Experts meeting, Italy
- November 2015: Progress report to JSIMPT
- November 2016: Final report to JSIMPT
- FY 2017: Joint Services and OSD submission to JROC for US acceptance of propane burner for FCO testing



Temperature Measurements



Thermocouples on cross produce **orthogonal measurement planes of 26 temperature measurements**

Temperatures averaged for test duration

Thermocouple located 18" vertically and 16" horizontally



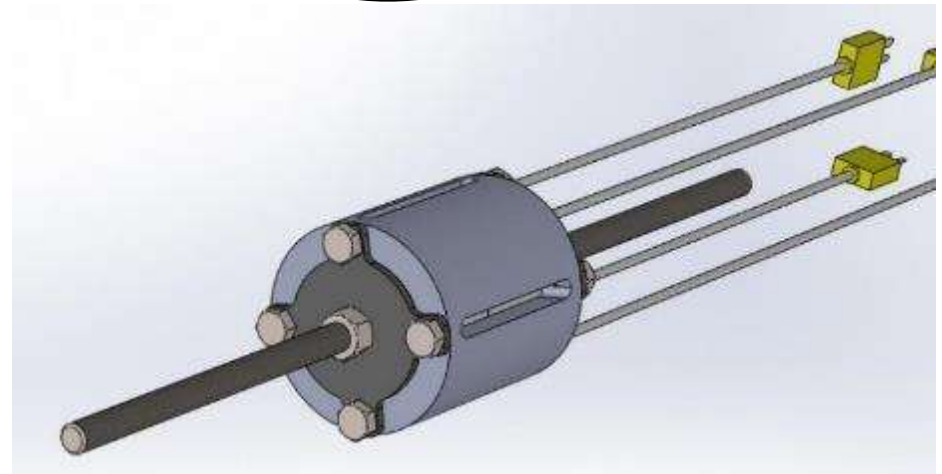
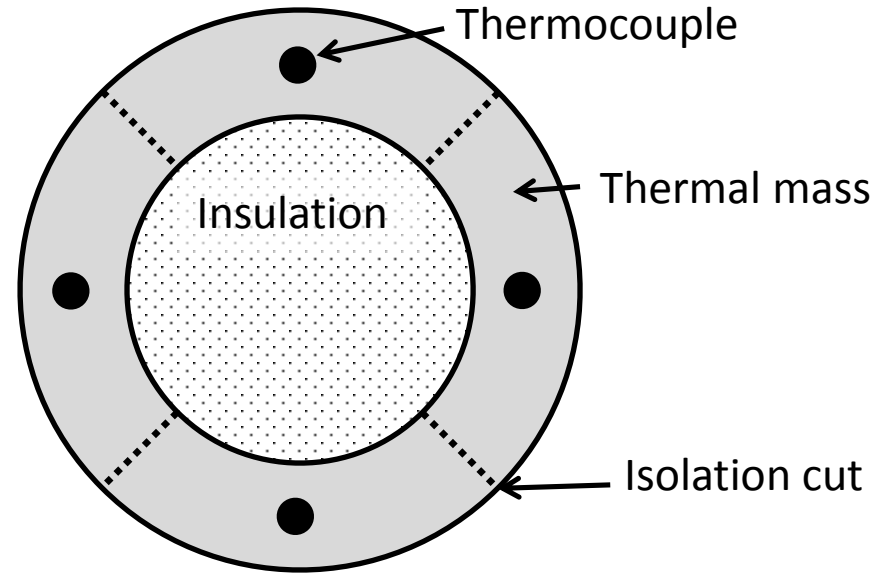
Heat Flux Instrumentation



Directional Slug Calorimeter

Total heat flux measurement on top, bottom, left, and right of cylinder

Measurements presented in kW/m^2



$$q_{in} \approx \underbrace{\varepsilon\sigma T^4}_{\text{rad + conv}} + \underbrace{mC \frac{\partial T}{\partial t}}_{\substack{q_{out} \\ q_{stored}}}$$



Heat Flux Measurements



Directional Slug Calorimeter used to measure heat flux at 16 locations indicated by **red circles** in figure

Symmetry of temperature field implies symmetry in heat flux as well, **only one quadrant tested**

Each vertical rake represents a separate test

