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"An Environmentally Acceptable Alternative for Fast Cook-Off Testing, Demonstration, Validation and Implementation Efforts"

August 11, 2016

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Welcome and Introductions

Michael Kavanaugh, Ph.D., P.E.
Webinar Facilitator

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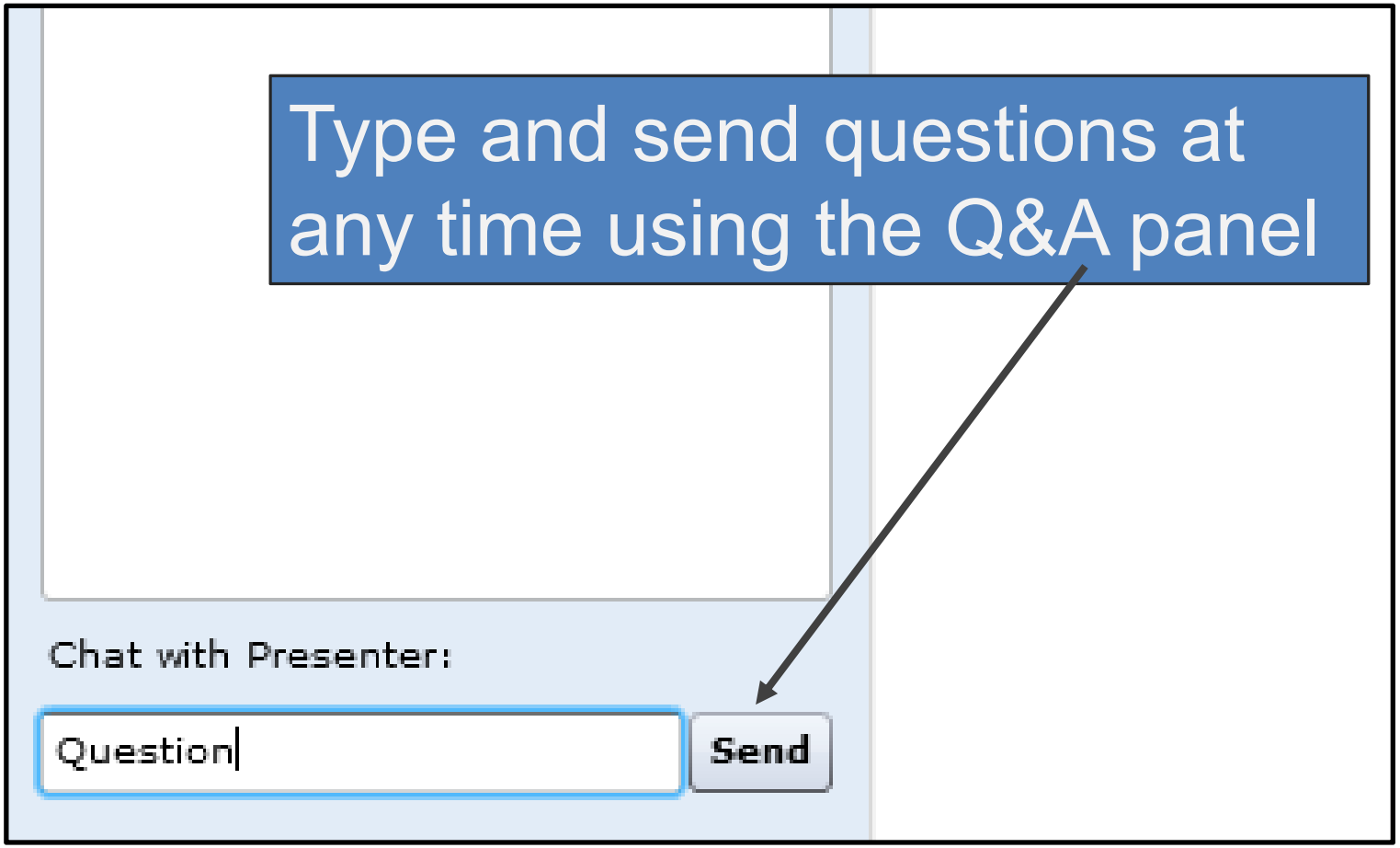
Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Michael Kavanaugh, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Robin Nissan, SERDP and ESTCP
- **An Environmentally Acceptable Alternative for Fast Cook-Off Testing, Demonstration, Validation and Implementation Efforts** (55 minutes)
  Dr. David Hubble, Naval Surface Warfare Center Dahlgren Division
  Dr. Ephraim Washburn, Naval Air Warfare Center Weapons Division
- **Final Q&A session**

How to Ask Questions



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SERDP and ESTCP Overview

Robin Nissan, Ph.D.

SERDP and ESTCP, Weapons Systems and Platforms Program Manager

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SERDP

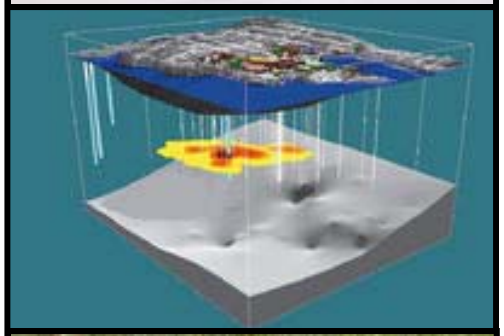
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

1. Energy and water
2. Environmental restoration
3. Munitions response
4. Resource conservation and climate change
5. Weapons systems and platforms



Weapons Systems and Platforms

- Major focus areas
  - Surface engineering and structural materials
  - Energetic materials and munitions
  - Noise and emissions
  - Waste reduction and treatment in DoD operations
  - Lead free electronics

SERDP and ESTCP Webinar Series

Date	Topic
September 8, 2016	Assessment of Redox-Based Groundwater Remediation Technologies
September 22, 2016	Managing the Brown Treesnake Headache: Assessment of the Aerial Acetaminophen Bait Drop on Guam
October 6, 2016	Cyber Security Requirements and Impacts on Installation Energy Systems
October 20, 2016	DoD Decision Making and Climate Change

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An Environmentally Acceptable Alternative for Fast Cook-off Testing, Demonstration, Validation and Implementation Efforts

David Hubble, Ph.D.
Naval Surface Warfare Center
Dahlgren Division

Ephraim Washburn, Ph.D.
Naval Air Warfare Center
Weapons Division

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Agenda

- Background
- Design and calibration of propane burner
- Q&A session
- Energetic and inert items test results
- Conclusions
- Final Q&A session

Acknowledgements

- The Environmental Security Technology Certification Program (ESTCP)

- The Insensitive Munitions Advanced Development (IMAD) Program

Background

- The fast cook-off test is a standard safety test required for all explosive ordnance
- In response to catastrophic fires aboard carriers in the 1960's
  - USS Oriskany - 1966
  - USS Forrestal - 1967
  - USS Enterprise - 1969

Background

- Technical requirements specified by STANAG 4240
  - Test item immersed in a flame produced by a pool of burning liquid hydrocarbon fuel
    - Typically jet fuel or kerosene
    - Average flame temperature >1472°F (800°C)
    - Fire duration >150% of expected time until reaction

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
  - Costs
    - Typical test at Dahlgren requires 1500-3000 gallons of jet fuel

Increasing interest across NATO to develop a cleaner alternative
Some European nations have already banned liquid fuel testing

The Benefits of Propane

- Environmental concerns
  - Significantly fewer emissions
  - No large soot cloud
  - Minimal chance of soil contamination
    - Low boiling point
- Safety and technical risks
  - No fuel at test site until after all personnel are in shelter
  - Fire duration only limited by size of fuel tank
  - No liquid fuel for components to fall into
  - No long delay between go decision and test initiation while fuel is pumped
- Costs
  - Uses approximately $^{1}/_{10}$ as much fuel as liquid pool tests

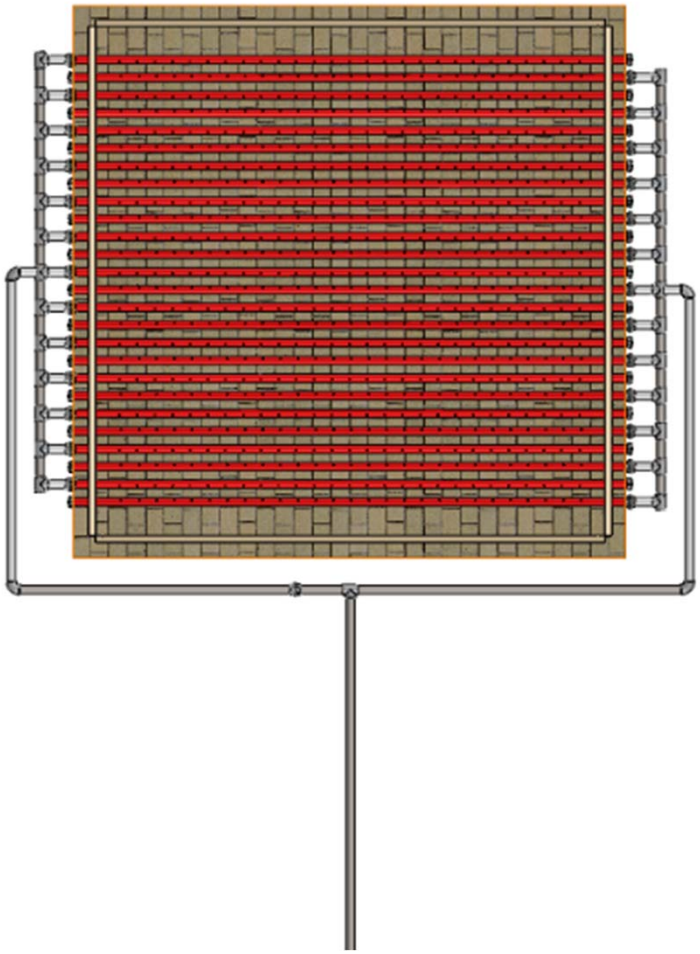
Designing a Propane Burner

- Thermal constraints imparted by the testing standards were condensed into the following thermal requirements
  - The flame temperature must be greater than 800°C
  - The average heat flux must be greater than 80 kW/m^2
  - The heating must be uniform
  - The heating should be approximately 90% radiative

Design Guidelines

- The following requirements were used to guide the design of the propane burner
  - Made from inexpensive, commercial off the shelf parts to make it affordable/expendable
  - Quick and simple to repair in the event that it is damaged during testing
  - Scalable or modular for testing of larger items

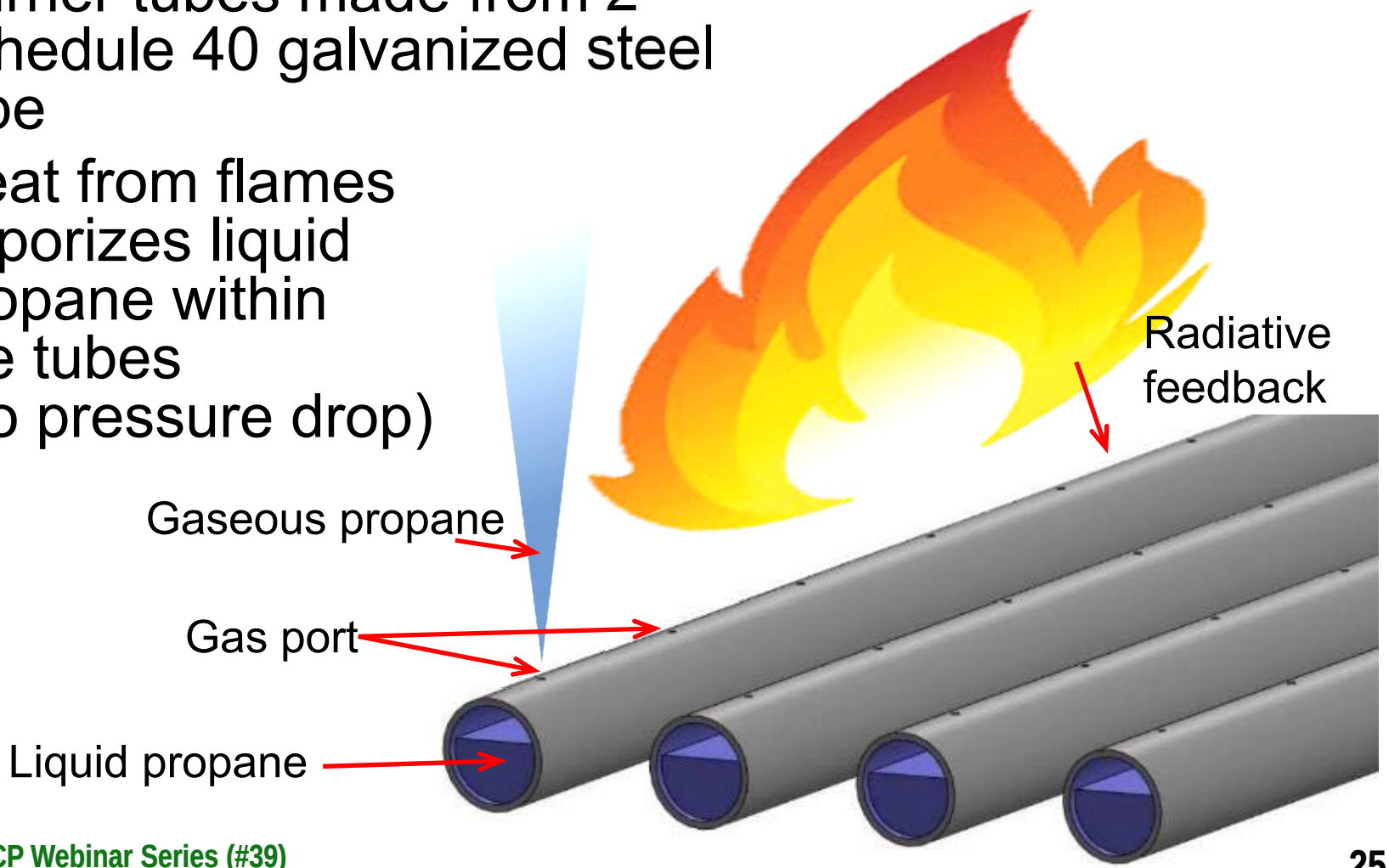
Design Overview



- 12’ (3.6 m) square
- 26 burner tubes
- 676 gas ports, Ø0.081” (Ø2mm)

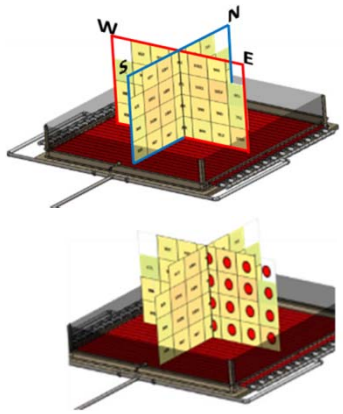
Design Details

- Burner tubes made from 2” schedule 40 galvanized steel pipe
- Heat from flames vaporizes liquid propane within the tubes (no pressure drop)



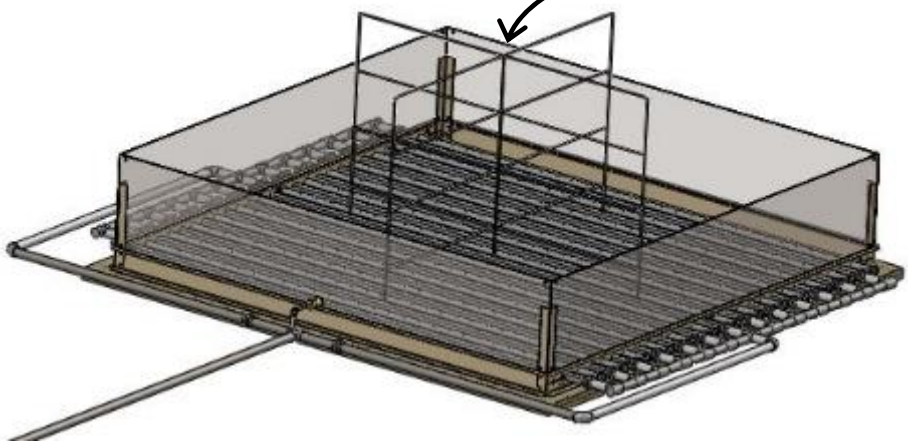
Video of Burner Operation

Thermal Characterization



- Temperature requirement
  - Where is the temperature requirement met?
  - Thermocouple array used to measure temperature field
- Heat flux requirement
  - Where is the heat flux requirement met?
  - Directional slug calorimeters used to measure heat flux field
- Heating uniformity
  - Is the heating uniform within the burner?
  - Look at both temperature and heat flux measurements
- Primarily radiative heating
  - Analyze temperature and heat flux data to determine if the heating is primarily by radiation

Testing Overview – Temperature

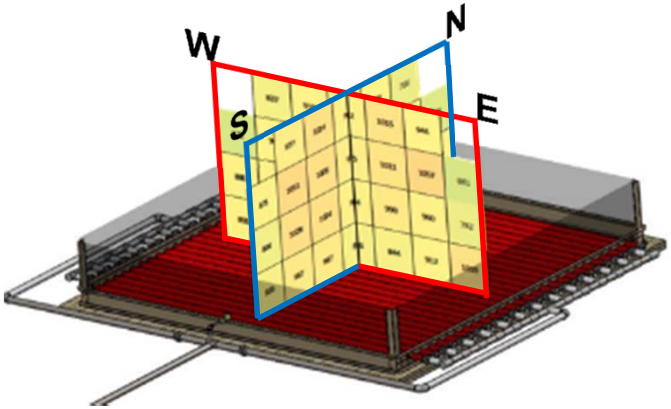


Cross 8’ wide and 6’ tall placed within burner

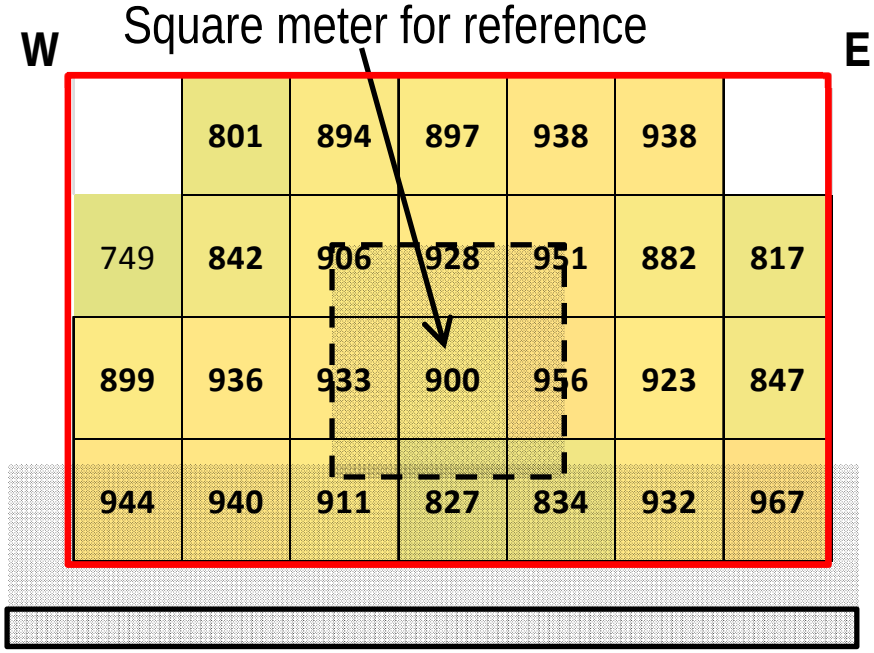
Determine the region within burner that meets 800°C requirement

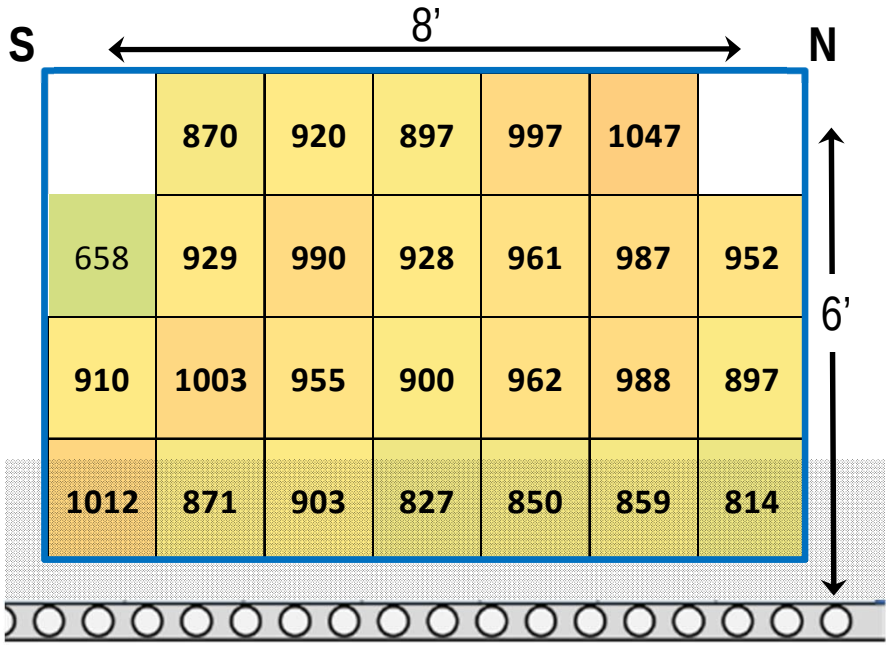
- Instrumentation cross placed within burner
- Allows for accurate positioning of 48 thermocouples for temperature measurements

Temperature Measurements (°C)



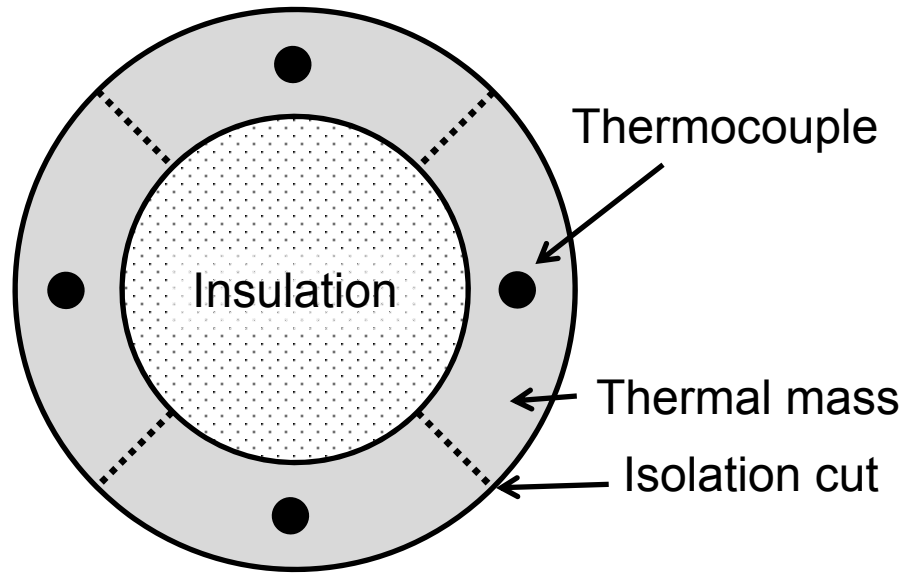
	Measured	Target
Average	907°C	>800°C
Max	1047°C	-
Co. Var.	8%	<10%

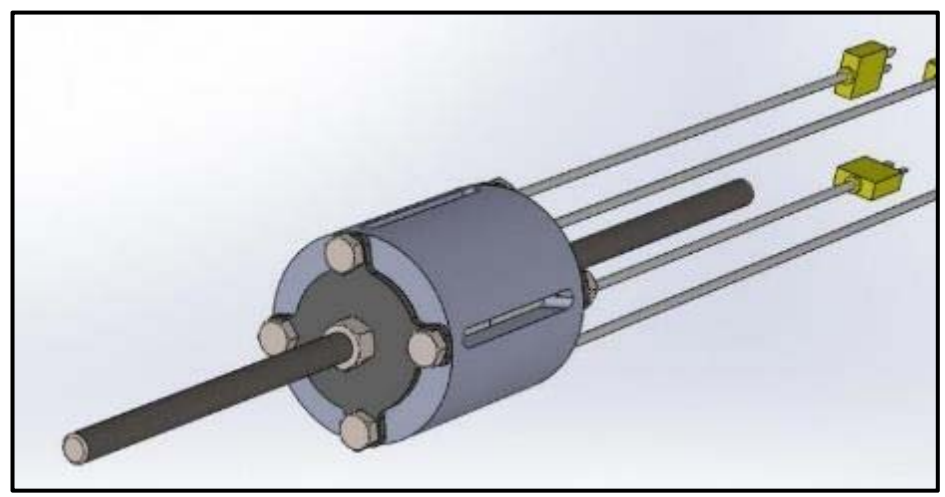




Heat Flux Instrumentation

- Directional Slug Calorimeter
  - Total heat flux measurement on top, bottom, left and right of cylinder
  - Measures total absorbed heat flux in kW/m^2



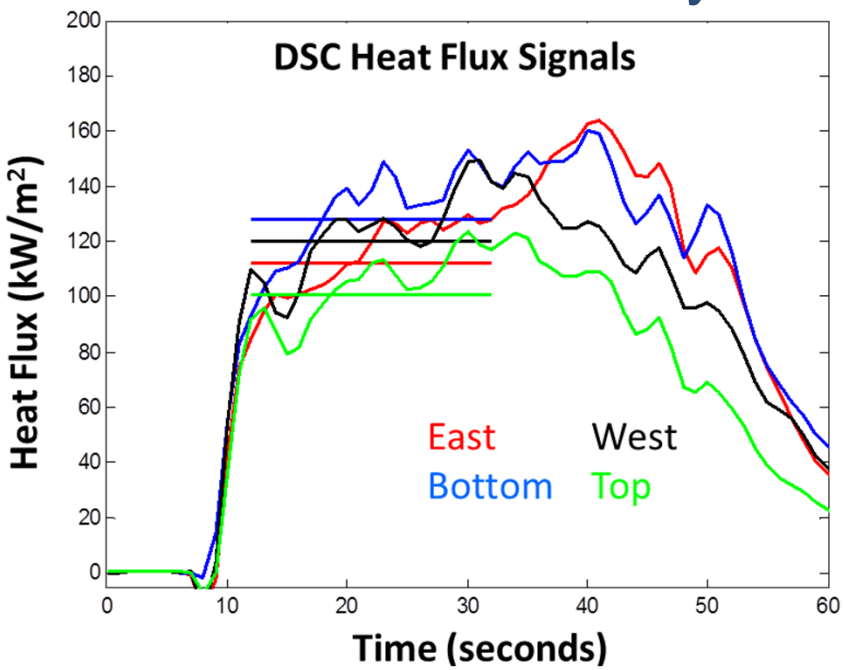


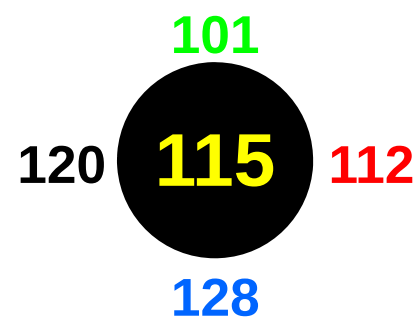
rad + conv q_{stored} q_{out}

$$q_{in} = mC\frac{\partial T}{\partial t} + \varepsilon\sigma T^4$$

How Heat Flux Data is Displayed

- DSC provides heat flux signals in four directions
  - Each heat flux signal is averaged for 20 seconds after 800°C requirement is met
  - Overall average from four averages – 115 kW/m^2
  - Directional uniformity – 90%





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

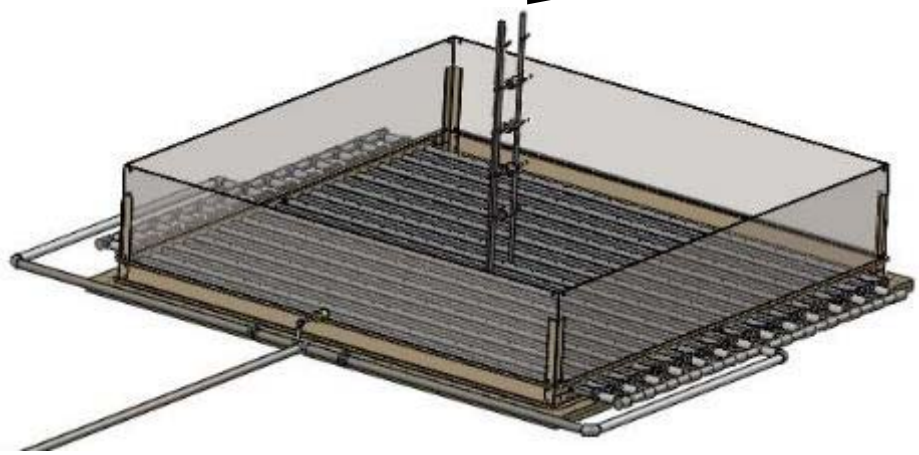
= 90%

≥75% considered good

Coefficient of variation: standard deviation normalized by the mean

Testing Overview – Heat Flux

Stand supports four DSCs within burner



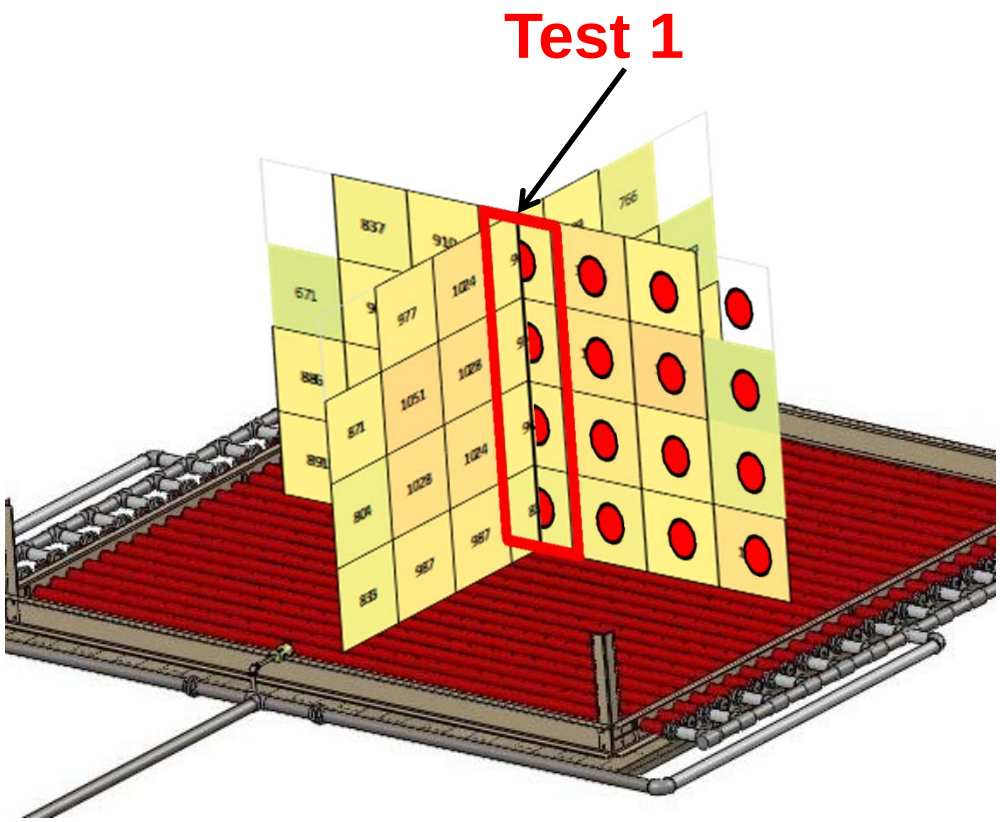
Determine the region within burner that meets 80 kW/m^2 requirement

Allows simultaneous testing with **<u>four</u>** directional slug calorimeters placed at different heights

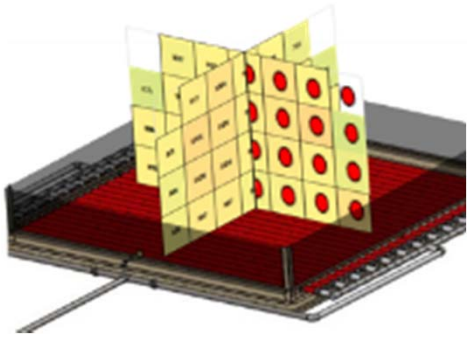
- 1.5, 3.0, 4.5 and 6 feet above burner

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

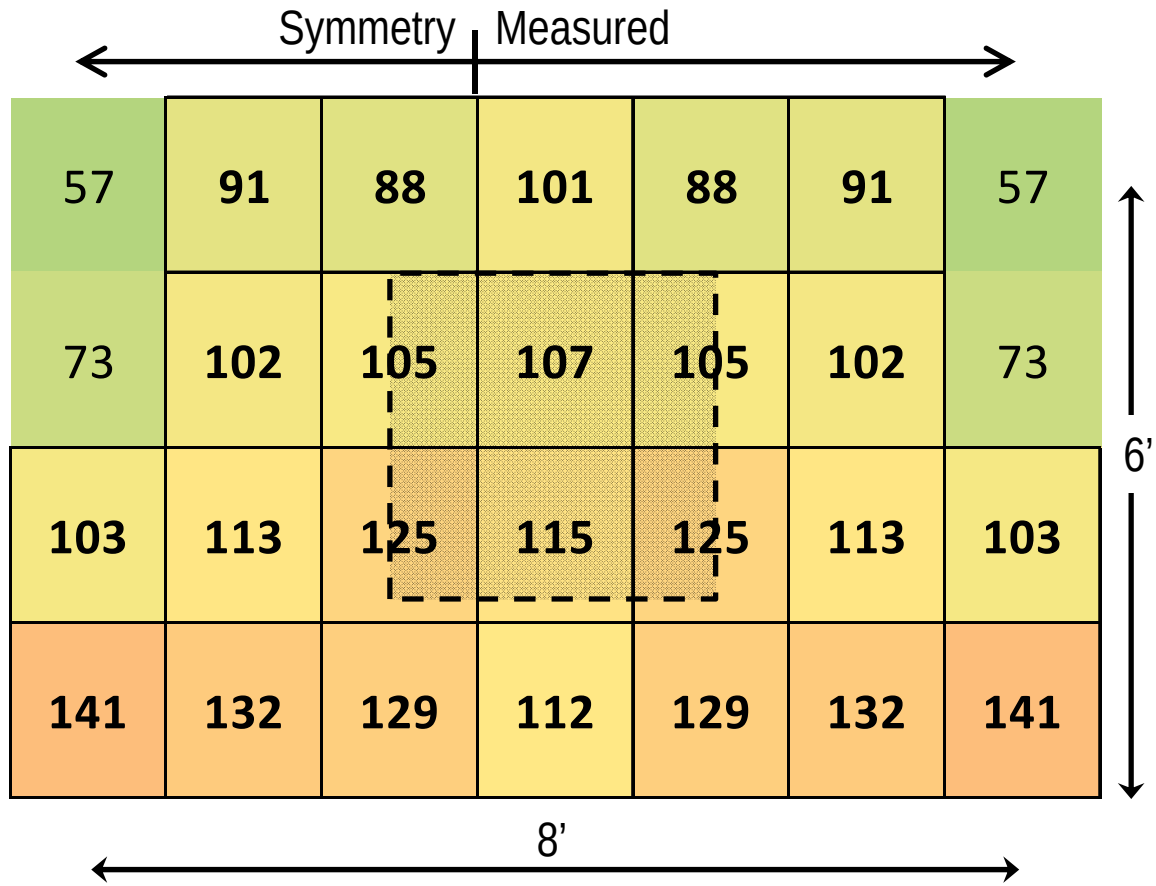


Heat Flux Measurements (kW/m^2)



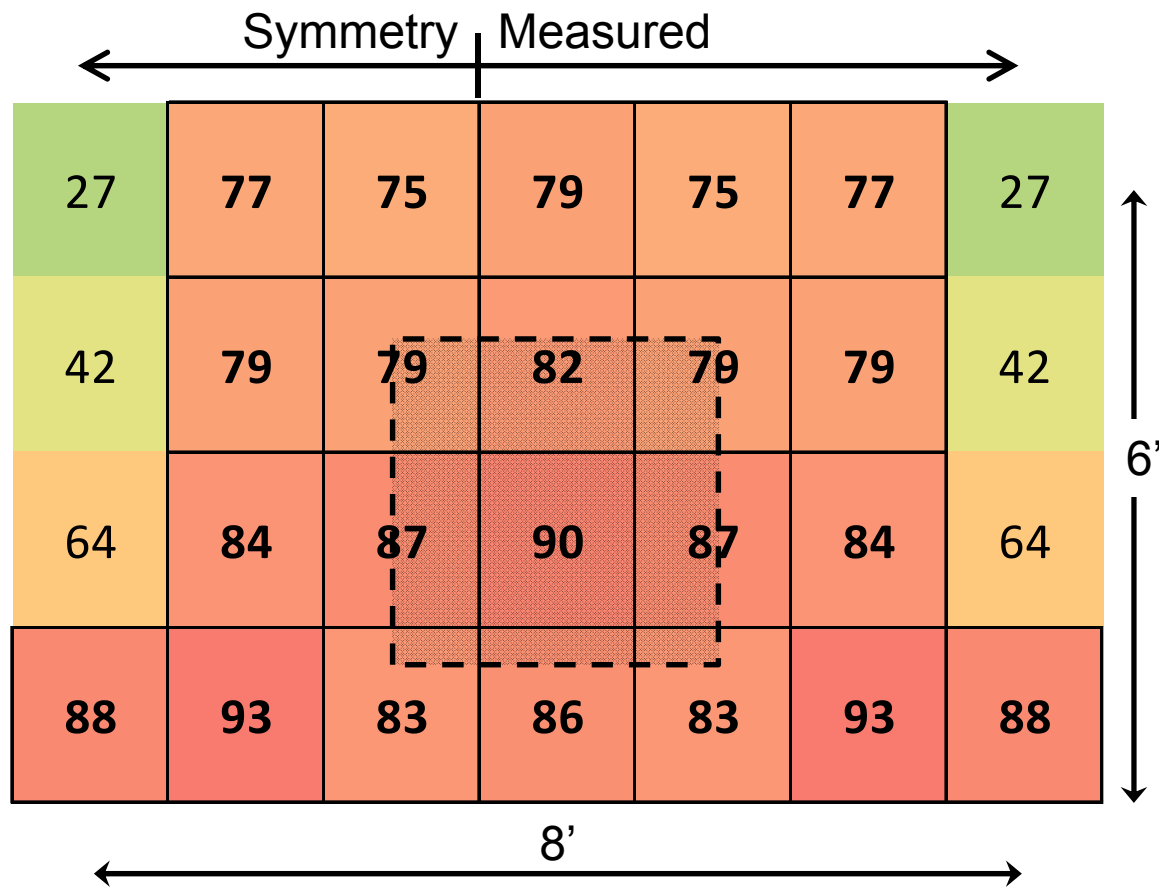
Average heat flux exceeds 80 kW/m^2 over large percentage of volume

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



Directional Uniformity

- ≥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 Thermal Testing

- The propane burner has met the design requirements and contains a volume where
  - The flame temperature is greater than 800°C
  - The heat flux is greater than 80 kW/m^2
  - The heating is uniform
  - The majority of the heating is radiative

Q&A Session 1

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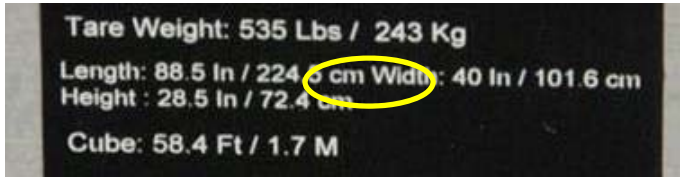
Energetic and Inert Items Test Results

- The effect of inert items in propane burner was tested
- The propane burner was used to test the reaction of ordnance items in a fast cookoff situation
  - Reduction of fuel usage
  - Equal scoring of ordnance item tested
  - Ease of test setup and burner repair

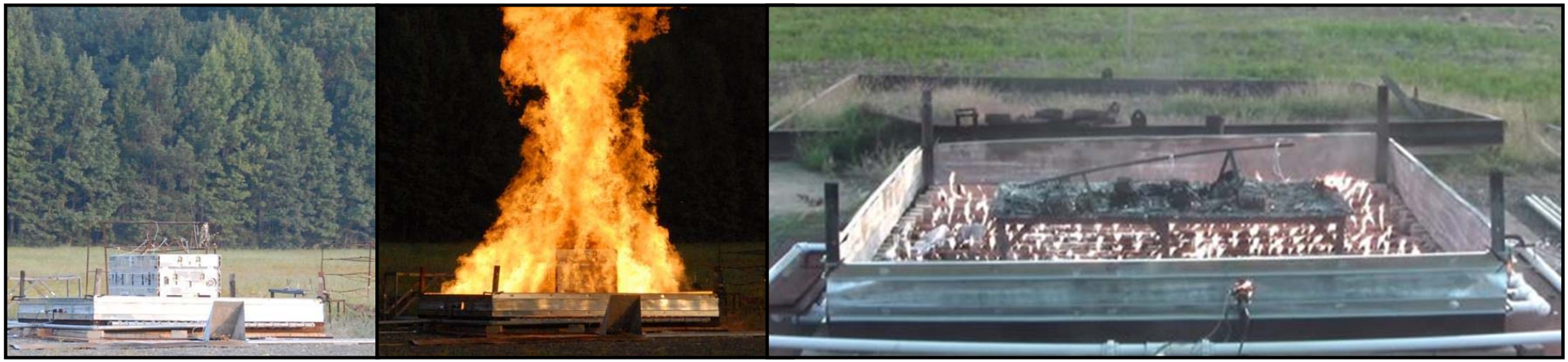
Aluminum Container Test

- Large aluminum container tested
  - Specifically requested by the Air Force
  - Concern that melting aluminum would effect burner performance
  - Munitions container – largest item ever tested in our burner



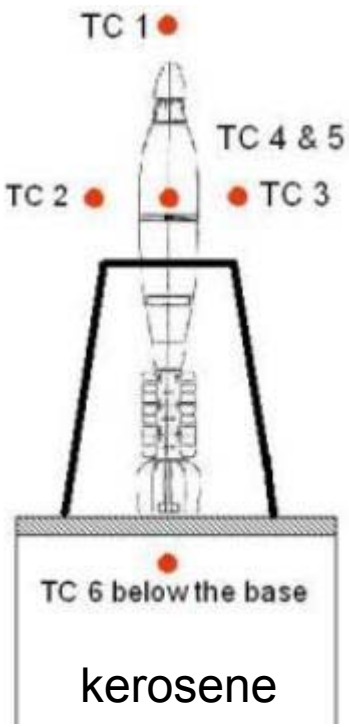
Aluminum Container Test

- Container completely engulfed by flames
- 863°C (1585°F) average temperature on 12 thermocouples surrounding container
- Total melt (500 lbs) occurred within 3½ minutes
- Burner appeared unaffected by melting aluminum, flames penetrated molten aluminum



81 mm Fast Cookoff Testing

- IMX-104 explosive fill
- Kerosene fuel fast cookoff previously performed by ARDEC at Picatinny Arsenal, New Jersey, USA
- Fast cookoff with propane burner to replicate kerosene fuel cookoff

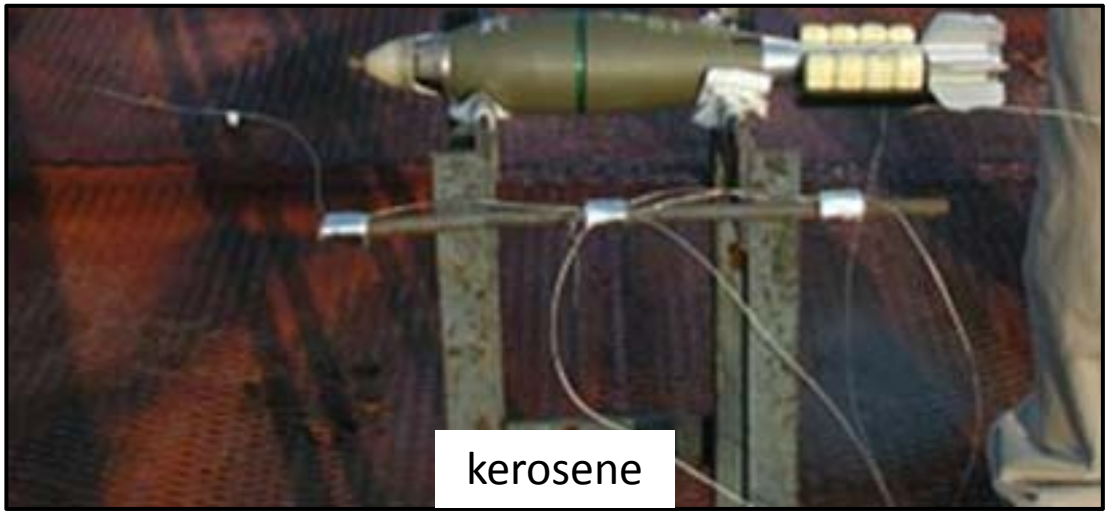


81 mm Fast Cookoff Testing

- IMX-104 explosive fill
- Reduction of fuel usage – 3,785 liters kerosene fuel to 568 liters propane
- Equal scoring of ordnance item tested – Officially scored V with kerosene fuel to engineering assessment of [V]
- Ease of test setup and burner repair – No damage to propane burner

81 mm Fast Cookoff Testing

- Composition B explosive fill (violent reaction expected)
- Kerosene fuel fast cookoff previously performed by NSWCDD at Dahlgren, VA, USA
- Fast cookoff with propane burner used same test stand as 81 mm IMX-104 explosive fill mortar (orientation vertical instead of horizontal)



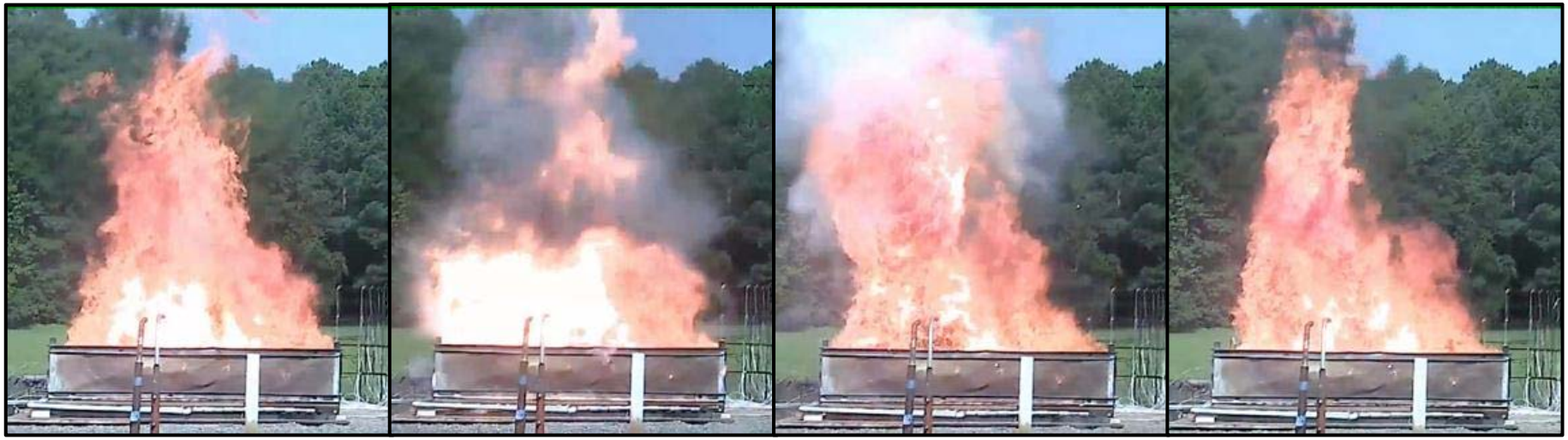
81 mm Fast Cookoff Testing

- Composition B explosive fill
- Reduction of fuel usage – 3,180 liters kerosene fuel to 208 liters propane
- Equal scoring of ordnance item tested – Officially scored II with kerosene, engineering assessment of [II]/[III]
- Ease of test setup and burner repair – Damage to three pipes, did not affect test, less than an hour to repair

M821 81 mm Mortar with Comp B Fill

M821 81 mm Mortar with Comp B Fill

- Photographs of propane fire showing sequence of violent event with 81 mm mortar with Comp B explosive fill
- Sequence is 3 seconds
- Even with 3 damaged pipes, consistent engulfing flame after violent event



Additional Benefits to Propane Burner

- Photographs after ignition: 2 seconds, 10 seconds, 20 seconds and 40 seconds
- Consistent and quick ignition process will make more repeatable tests

(**a**)
Pool Fire

(**b**)
Propane Fire

105 mm M1 Cartridge Test

- Inert warhead, live propulsion system
- Packed in a PA190 vented shipping container
- Tested in both liquid pool fire and propane burner

105mm M1 Cartridge Test

Fire Type	Liquid-Pool Test			Propane Test
Flame Temperature (°F)	1327	1835	1785	1795
Reaction Time	12:05	11:37	9:34	9:51
Fuel Used (Gallons)	2000	2000	2000	220
Reaction Assessment	(V)	(V)	(IV)*	(IV)

* *There can be inherent variability in FCO testing. Sponsor said that in multiple tests, cartridge was ejected about half the time*

2.75” CLAW (PBXN-112 Fill)

- Live warhead, mass simulant APKWS and rocket motor
- Packed in a simulated CNU-711E container
- Tested in both liquid pool fire and propane burner

2.75” CLAW (PBXN-112 Fill)

Fire Type	Liquid-Pool Test	Propane Test
Flame Temperature (°F)	1652	2138
Reaction Time	2:02	1:03 and 6:40
Fuel Used (Gallons)	2,000	220
Reaction Assessment	(V)	(V)

M72 LAW

(HE Warhead)

(Inert Warhead)

Fire Type	Liquid-Pool Test	Propane Test
Flame Temperature (°F)	1653	1603
Reaction Time	0:53	0:44
Fuel Used (Gallons)	500	200
Reaction Assessment	(I), includes warhead	(V), same initial reaction

Energetic Testing Summary

Item	Fuel Type	Fuel Quantity	Time to Reaction	Average Flame Temp	IM Score
81mm IMX-104	Kerosene	1000 gal	43 sec	1742°F	V
	Propane	150 gal	44 sec	1526°F	(V)
81mm Comp B	JP-5	850 gal	29/61 sec	1824°F	II
	Propane	55 gal	43/52 sec	1868°F	(I) or (II)
105mm M1	JP-5	2000 gal	725 sec	1327°F	(V)
	JP-5	2000 gal	697 sec	1835°F	(V)
	JP-5	2000 gal	574 sec	1785°F	(IV)
	Propane	220 gal	591 sec	1795°F	(IV)
2.75" CLAW	JP-5	2000 gal	122 sec	1652°F	(V)
	Propane	220 gal	63/400 sec	2138°F	(V)
M72 LAW (HE)	Jet-A	500 gal	53 sec	1653°F	(I)
M72 LAW (INERT)	Propane	200 gal	44 sec	1603°F	(V)

Transition of Burner to New Site

- Built and installed 10’ by 20’ burner
  - Permanent firing system
  - Ability to run either propane or jet fuel FCO tests
  - Currently characterizing burner

Transition of Burner to New Site

- Design is easily adapted to new locations
- 8’ by 8’, 12’ by 12’ and 10’ by 20’ burners have all been built and successfully calibrated
- We can help you build a propane burner at your site

Standardization

- The US Joint Services Insensitive Munitions Technical Panel (JSIMTP) unanimously endorses the overall effort. They anticipate supporting through OUSD(AT&L)/JROC approval process (Fiscal Year 2017)
- AOP 4240 rewritten to allow propane burners
  - Going through approval process
- Patent submitted

Conclusions

- The propane fast cookoff burner has the correct temperatures and heat fluxes
- The reaction of ordnance items in the propane burner is the same as the jet pool fire
- The propane burner can be used for environmentally friendly fast cookoff testing
- The burner can transition to other sites

For additional information, please visit

https://serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Fuels-and-Greenhouse-Gases/WP-201320

Speaker Contact Information

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Q&A Session 2

SERDP DOD • EPA • DOE | ESTCP

The next webinar is on September 8, 2016

"Assessment of Redox-Based Groundwater Remediation Technologies"

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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