Development and Validation of a Bench-Scale Flash Fire Materials Tester

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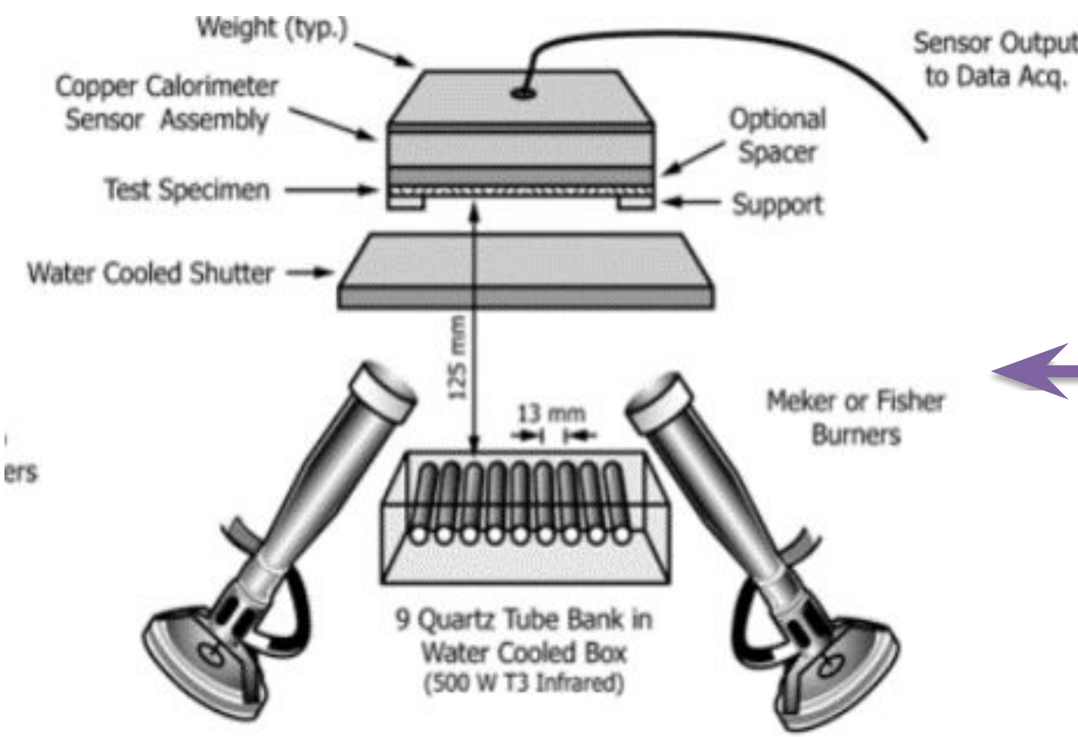
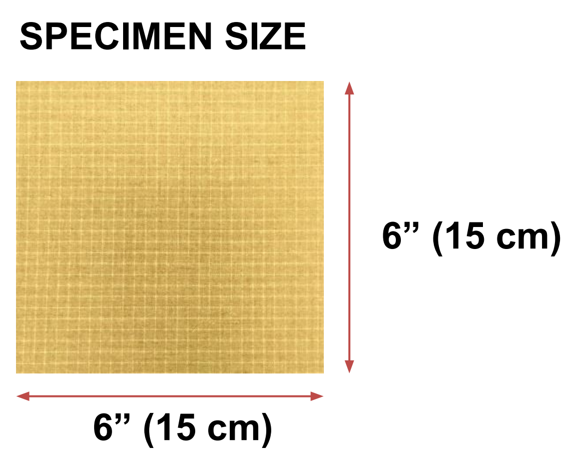
Overview

- Do we really need another test device?
- Development Overview
- Device Usage
- System Validation
- Use and Standardization

Material Tests – Flat Samples

ISO 17492 (HTI), ASTM F2700 (HTP/TPP), EN 469





Flash Fire Manikin – Full Garments

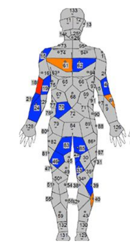
ISO 13506-1, ASTM F1930

Missing dimension in flame exposure testing

1-D

TPP

3-D



MANIKIN

N° of sensors	1
Specimen Size	6”x6” (15 x 15 cm)
Geometry	Flat Samples
Variables	Material, air gap
Exposure	84 kW/m^2

Gap

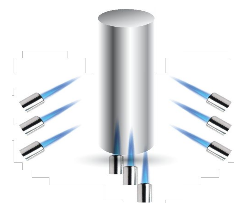
>120
Full garment
Per garment pattern
Material, garment fit, garment construction
84 kW/m^2

Flash Fire Cylinder Fills the Gap

1-D

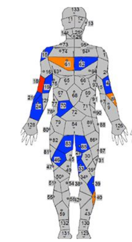
TPP

2-D



FLASH FIRE CYLINDER

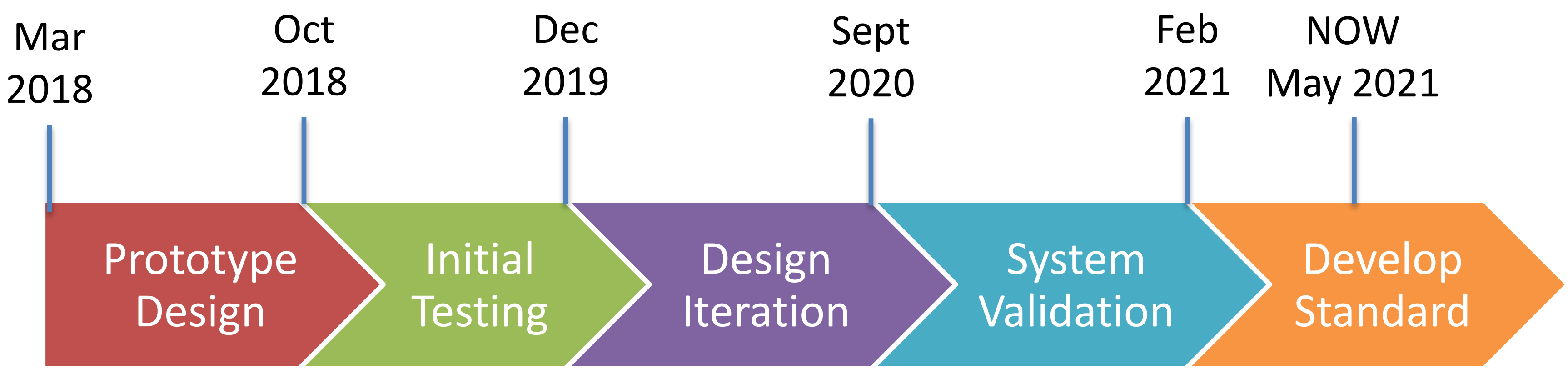
3-D



MANIKIN

N° of sensors	1	15	>120
Specimen Size	6”x6” (15 x 15 cm)	13.25” x 11.25” (33.6 cm x 28 cm)	Full garment
Geometry	Flat Samples	Cylindrical Samples	Per garment pattern
Variables	Material, air gap	Material, air gap, compression	Material, garment fit, garment construction
Exposure	84 kW/m^2	84 kW/m^2	84 kW/m^2

Development Overview



Prototype Development – Key Constraints

- Compact for use in lab environment
- Familiar technology elements (transfer from FF manikin)
- Increased flame uniformity (vs FF manikin)
- Integrated and robust safety precautions
- Easy sample prep and install
- Cylinder size in-between arm and leg circumference

Original FFC Prototype

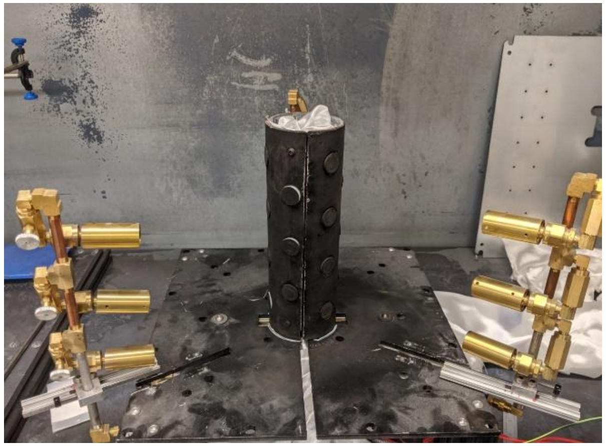
- Integrated System
- 9 Burners in 3x3 configuration
- 15x Copper disc calorimeters
- Data collection and analysis software
- Computations of sensor heat flux, energy, predicted burn

Feedback Received

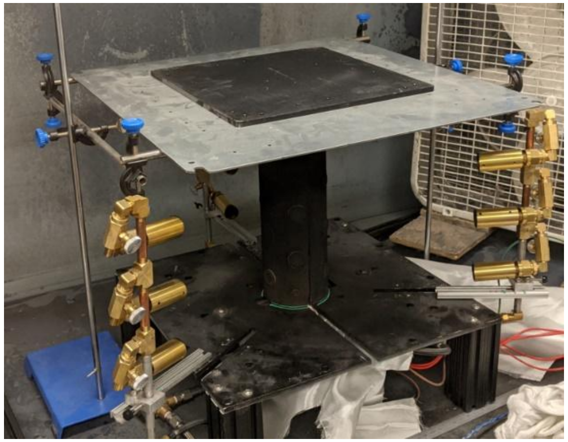
- Compact size is a plus – desire to fit in lab hood
- Prioritize operator and facility safety
- Flame profile consistency and uniformity is important
- Consider method to monitor gas flowrate during use for interlab tuning
- Ensure repeatable air gap and sample positioning
- What are appropriate device data outputs for material testing
- Can this system be used for a hand or head?

System Redesign – Burners

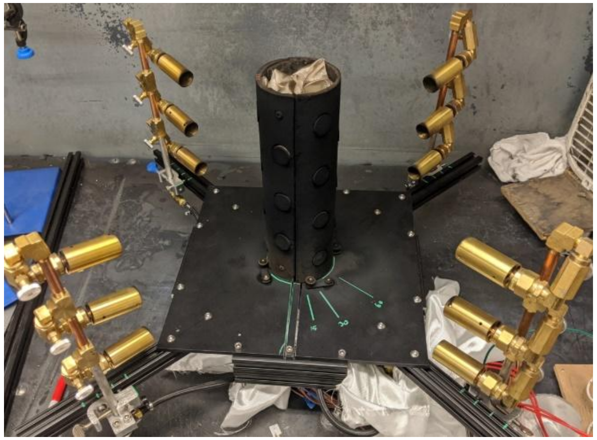
- Key Variables:
  - Number and position of burner heads
  - Flame profile adjustability
  - Fuel Supply (pressure/torch orifice)
- Measures (n=306 tests)
  - Mean device Incident Heat Flux (nominal 84 kW/m2)
  - Spatial variation of sensors
  - Temporal variation (within test)
  - Test repeatability



3x3 Torches



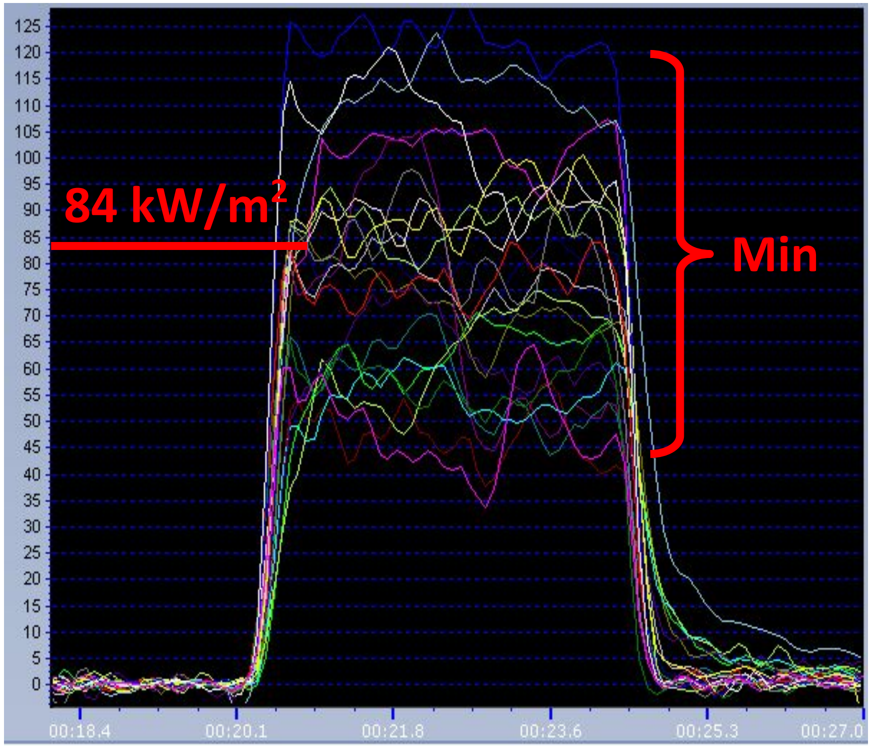
3x3 with “Hat”



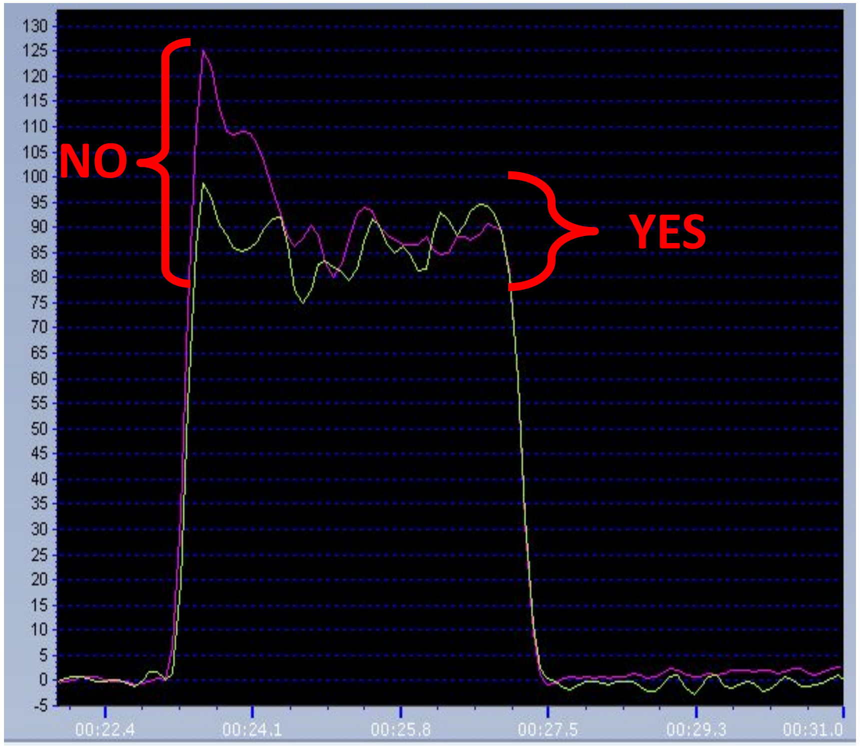
4x3 & 4x2 Torches

Refining the Flame Profile

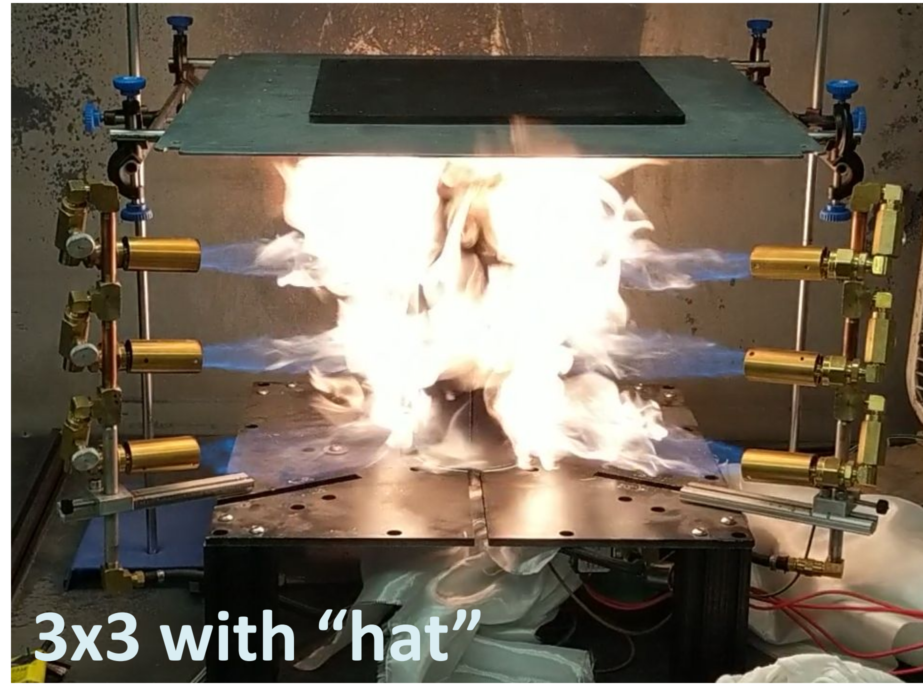
Full Device

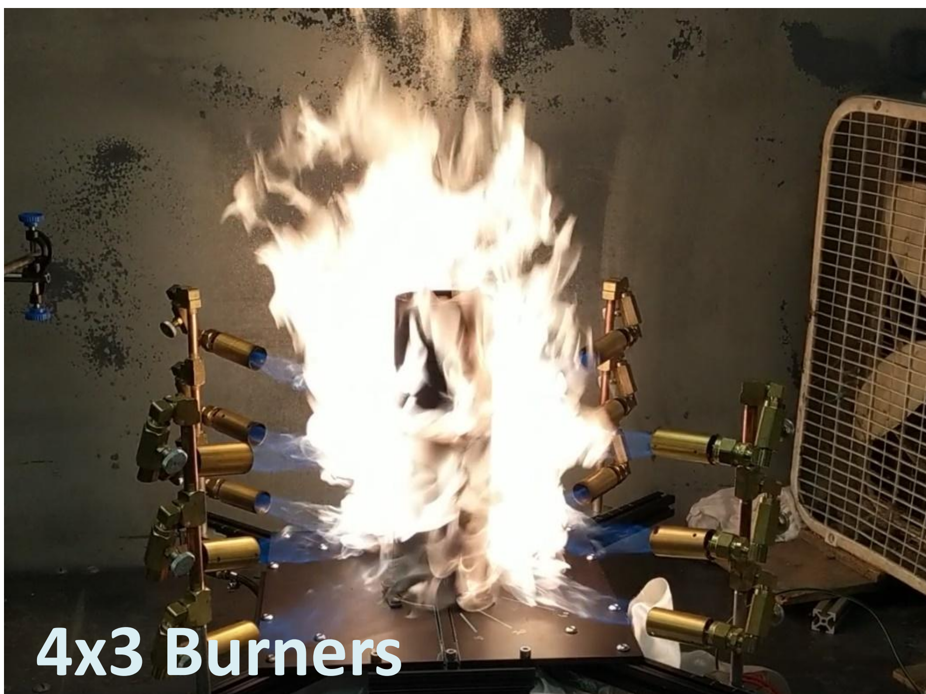


Individual Sensors




3x3 Burners


3x3 with “hat”


4x3 Burners


4x2 Burners

Key Conclusions

1. We could reliably achieve 84 kW/m^2 for all configurations
2. Sensor spatial bias was very consistent on multiple tests. Hot and cold spots could be “moved” by tuning and they would remain on replicate tests
3. Adding the “hat” increased average heat flux by 3 kW/m^2 and increased SD by 2 kW/m^2
4. 4x burner risers was easier to tune and better spatial uniformity than 3x torch risers
5. 4x2 configuration resulted in lower overall flame height vs 4x3

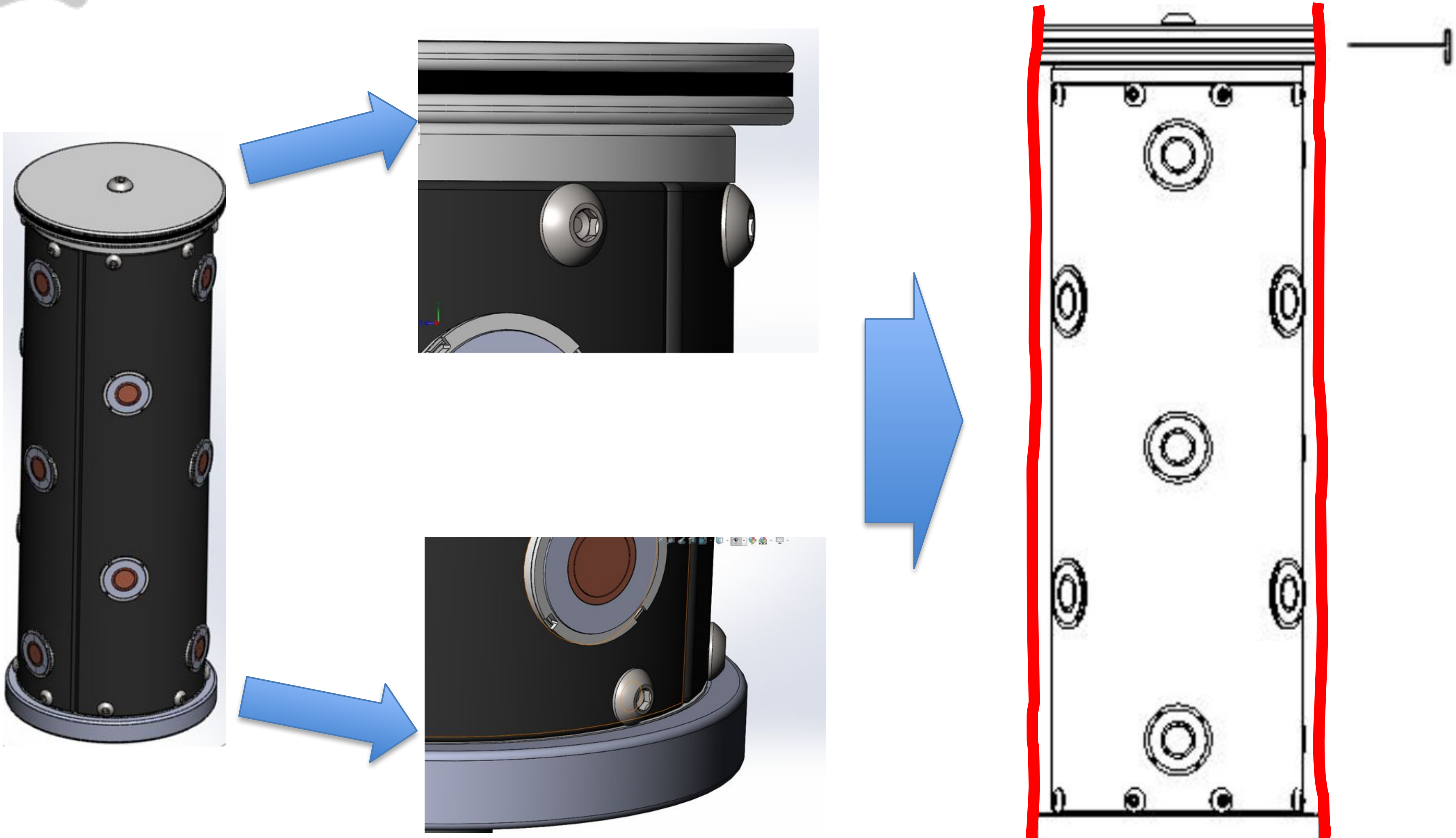
Ultimately, 4x2 configuration with no hat was selected for comparable or better performance at lower complexity

Burner Detail

- Adjustable torch risers
- Individually aim-able torch nozzles
- Single adjustable main gas regulator
- Flow control valve on each nozzle

Typical system tuning takes ~ 1 day during initial setup

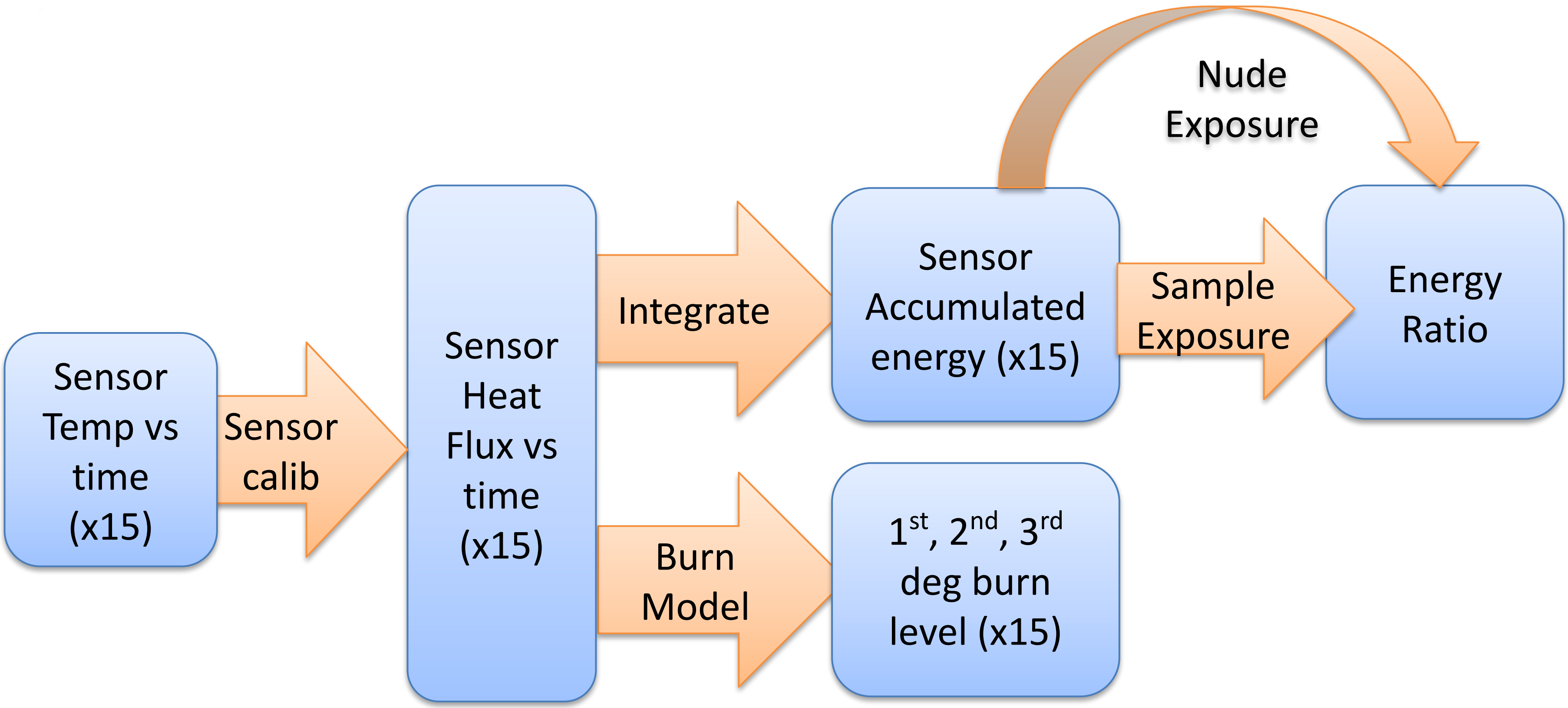
Sample Holder with Air Gap



System Design – User and Device Safety

- Extensive fault and safety analysis as part of design iteration
- Safety Features
  - Remote electronics/fuel system
  - Rated component selection
  - Dedicated process/safety control PLC
  - Pilot flame detection
  - Overtemperature monitoring
  - External e-stop interface

FFC Data Outputs



What is Energy Ratio?

- Burn injury prediction not a great fit for FFC
  - Not a permissible result for ISO standardization
  - 15 sensors: resolution of % area computation is 6.67%
  - If the heat flux is uniform and the sample is uniform, all sensors would achieve the same burn level simultaneously
- Energy Ratio
  - Similar to Energy Transmission Factor from ISO 13506-1
  - To the question: How much of the incident energy gets through the test specimen?
- Computation
  - Energy Ratio = Transferred Energy/Incident Energy * Exposure duration factor
  - Exposure duration factor = scale to adjust for difference in nude/sample exposure time

Flash Fire Cylinder/Hand System

Controls, Safety Systems and Data Logging

Cylinder, Sensors, and Fuel Control

Device Usage

Prepare & Condition Samples

Nude Flame Exposure

Install Sample

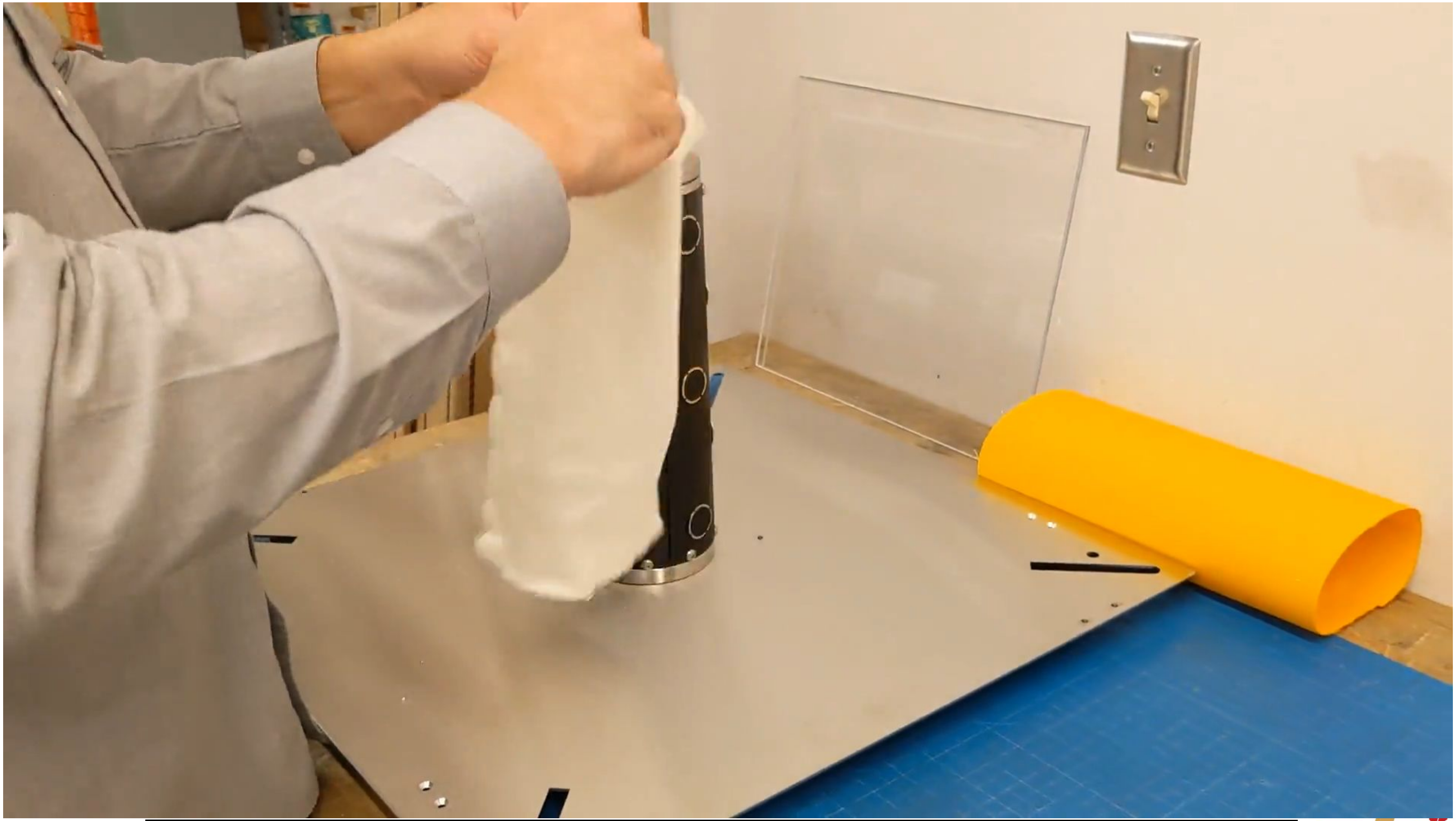
Repeat (xN)

Sample Flame Exposure

Nude Flame Exposure

Making a Sample

Fitting Samples



System Validation

Nude Exposure	Single Layer Samples	Composite Samples
• Average Heat Flux • Spatial SD	• Comparison of Energy Ration and % Burn Area • Sample Differentiation • Repeatability SD/CV	• Comparison of Energy Ration and % Burn Area • Repeatability SD/CV

Test Validation- Calibration Consistency

- 193 nude exposures
  - 170: 4 second exposures
  - 23: 3 second exposures
- Average Heat flux: 83.82 kW/m2
  - Only 4 second exposures: 83.81 kW/m2
  - Only 3 second exposures: 83.88 kW/m2
  - ASTM F1930 Requirement: 84 kW/m2 ± 5% (4.2 kW/m2)
- Average Standard Deviation: 8.29 kW/m2
  - Only 4 second exposures: 8.54 kW/m2
  - Only 3 second exposures: 6.45 kW/m2
  - ASTM F1930 Requirement: 21 kW/m2

Test Validation- Single Layer Fabrics

- Each material laundered 1x prior to testing
- 3 second exposures
- n = 30

		% 2^{nd} and 3^{rd} degree body burn	Transferred Energy (kJ)	Energy Ratio
Material A	Average	54.00%	11.762	0.461
	Standard Deviation	13.70	0.474	0.022
	CV %	25%	4%	4.8%
Material B	Average	1.56	7.358	0.284
	Standard Deviation	3.30	0.416	0.018
	CV	212%	5.7%	6.3%

Test Validation- 3 Layer Turnout Composite

- Laundered 1x prior to testing
- 10 second exposures
- n = 30

	% 2nd and 3rd degree body burn	Transferred Energy (kJ)	Energy Ratio
Average	15.56%	15.636	0.182
Standard Deviation	9.64	0.643	0.007
CV	62%	4.1%	4.1%

Test Validation- Findings

- The test produces repeatable, uniform flame exposures
  - Minimal difference between exposure times
- Test results are consistent for multiple materials and multiple layers
  - Energy Ratio is the preferred metric
- The test differentiates between different materials

Use and Standardization

- 5 Client Systems delivered
  - Round robin being planned
- ASTM work item WK70964
  - Under second ballot
- NFPA 2112
  - Accepted in 1st draft of next edition
- To be introduced to more standards as they enter revision cycles

Thank You for your attention

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