Heat Flux Study and Flame Propagation Evaluation of Composite Materials

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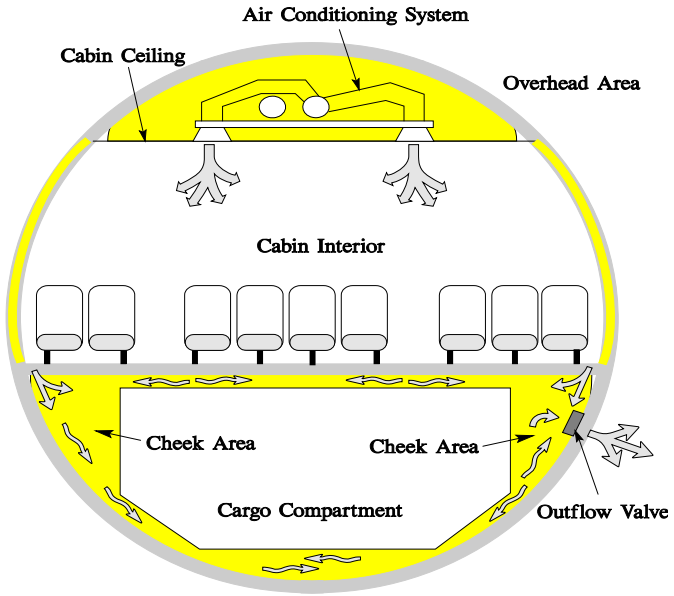
Test Method Development Overview



The FAA is developing new proposed requirements for non-accessible areas. FAATC task groups are developing new test methods for evaluating flame propagation.

This presentation describes research evaluating the behavior of common materials used in the inaccessible areas under three different test methods:

- Foam Block
- Radiant Panel
- Meeker Burner

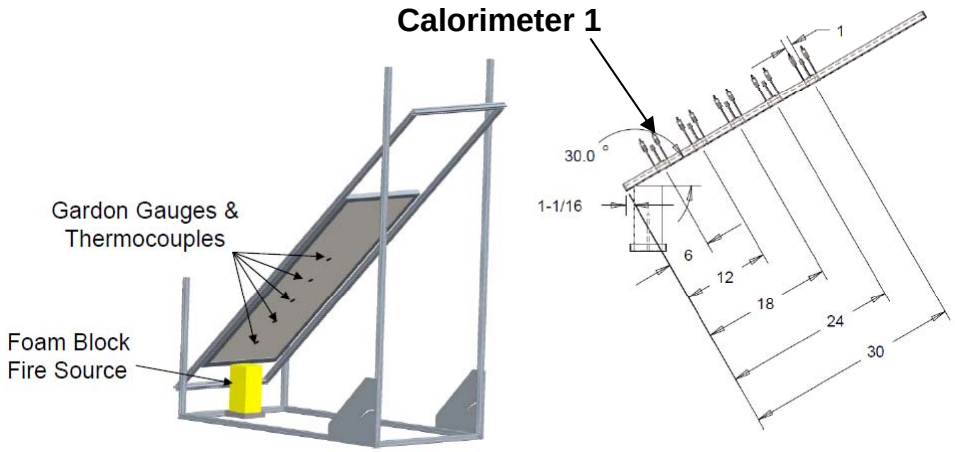
The goal of this evaluation was compare test methods and determine if there is correlation.

Summary of test results and recommendations are presented.

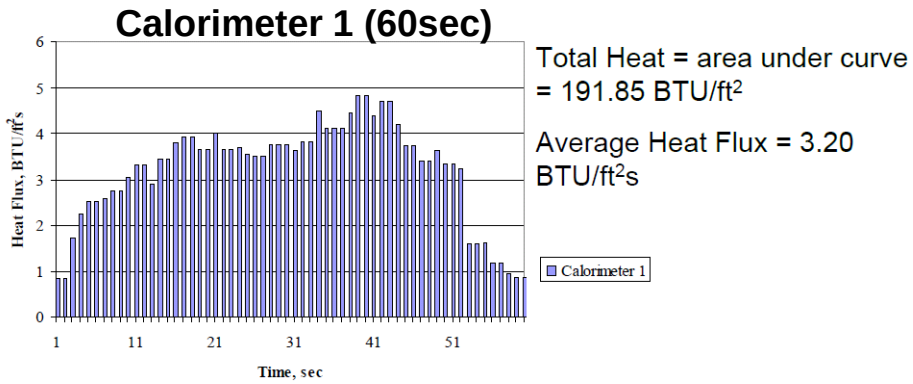
Agenda

- **Heat Flux Study**
- **Material Test Matrix**
- **Foam Block Testing**
    1. Foam Block Rig
    2. Test Results
    3. Photos
    4. Conclusions/Observations
- **Radiant Panel Testing**
    1. Insulation Test Method (25.856(a))
    2. Ducting Test Method (low heat flux)
    3. 30 degree orientation
    4. Conclusions/Observations
- **Meeker Burner Study**
- **Final Remarks**

Heat Flux from Foam Block



Reference: FAA Presentation: Development of a Flame Propagation Test Method for Structural Composite Materials in Inaccessible Areas, 10/19/11.



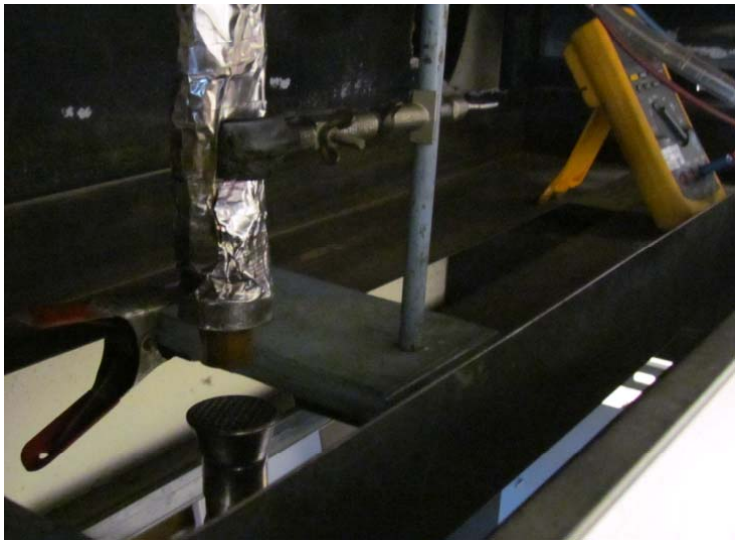
Total Heat = area under curve = 191.85 BTU/ft^2

Average Heat Flux = 3.20 BTU/ft^{2}s

Peak Heat Flux=	55 Kw/m^2
1 Minute Total Heat Flux=	36 Kw-min/min^2

Heat Flux from Meeker and Bunsen Burner

- **Calorimeter range: 0-12 w/cm^2**
- **Conversion Factor: .605 Mv/w/cm^2 ± 6%**
- **Calorimeter location: 1” from base**



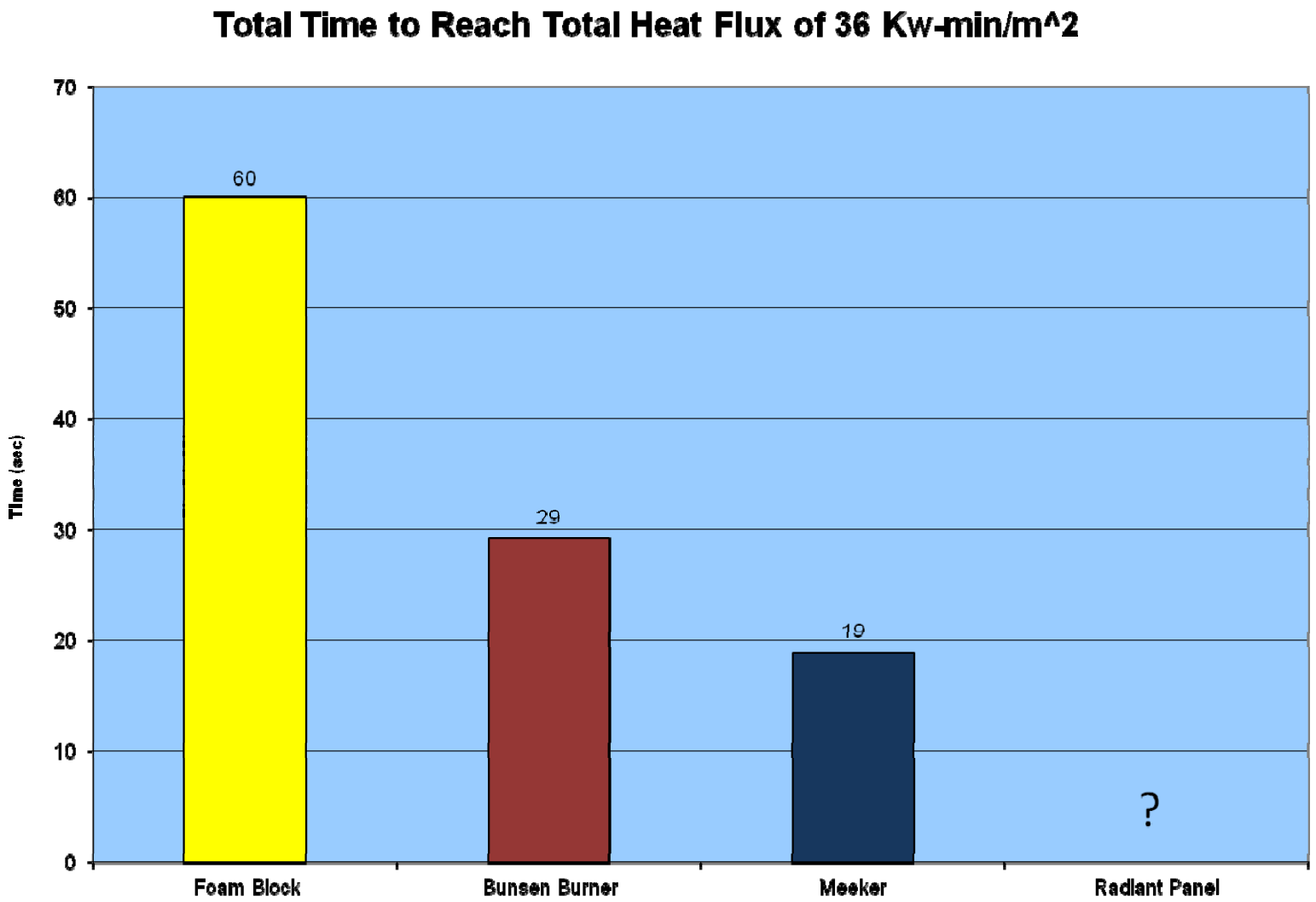
Meeker:

Temp 1" above burner=	**2265F ± 50**
Heat Flux=	**113 kw/m^2**

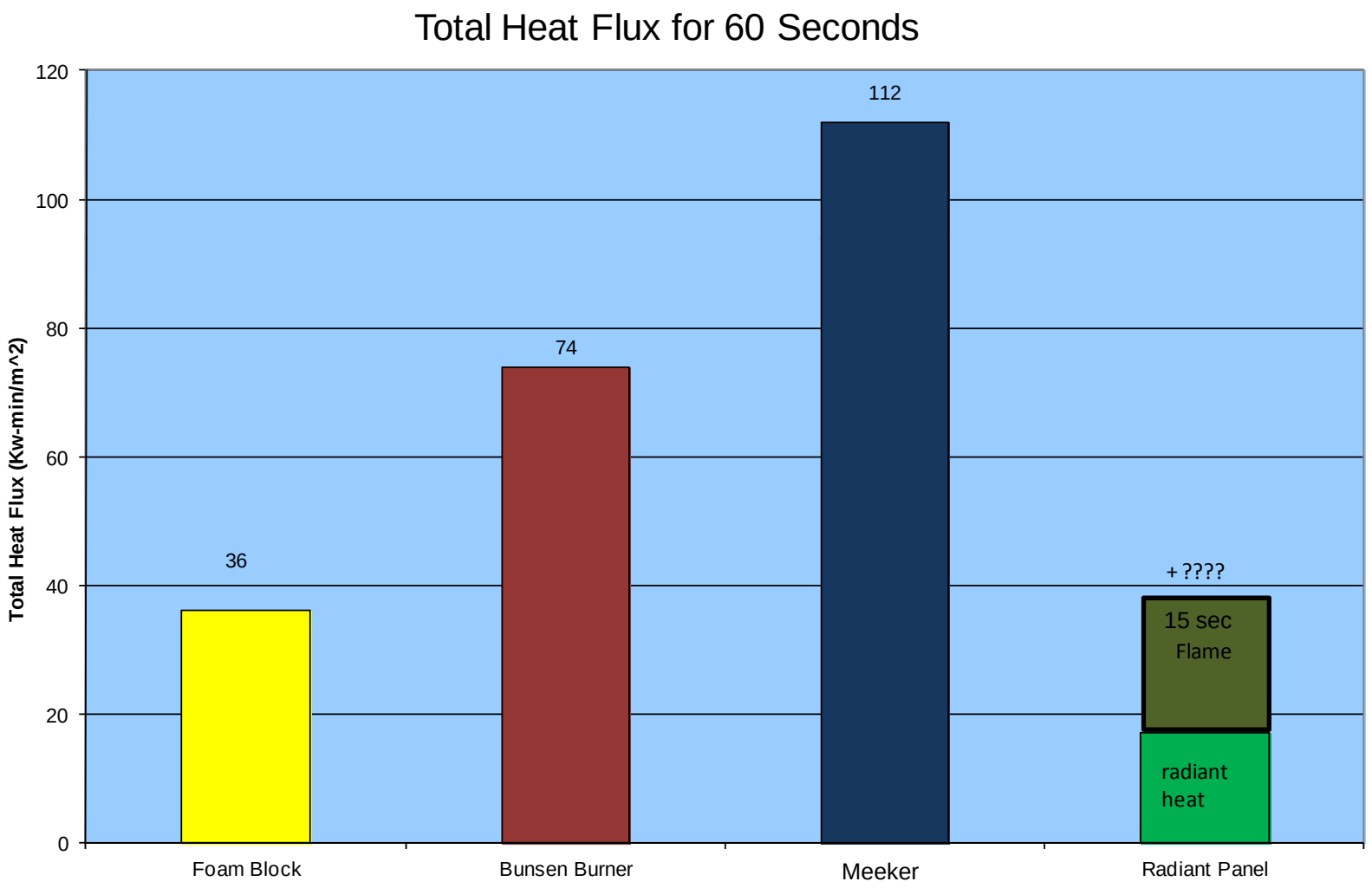
Bunsen Burner:

Temp 1" above burner=	**1800F**
Heat Flux=	**74 kw/m^2**

Time to Reach Foam Block Heat Flux



Heat Flux Comparison for 60 Seconds:



Heat Flux Summary

- Bunsen and Meeker burner can reach the same heat flux as the foam block in less time.
- Bunsen and Meeker burner tests can generate higher heat flux at a localized area compared to FB.
- Using a Meeker burner shows potential as a more stringent test method and better represents the intermediate scale foam block orientation.
  - Simpler test for airplane certification
  - Enhances safety due to higher heat flux

Test Method Comparison

ARAC Goals	Current Bunsen Burner	Foam Block	New Bunsen Burner	New Meeker Burner	Horiz. Radiant Panel
Enhance Safety: * Greater Application * Larger Ignition/Fuel Source	☑	☑	☑	☑	☑
Simple Test Method	☑ 3	☑ 1	☑ 3	☑ 3	☑ 2
Fire Threat Correlation * Method & requirements define correlation potential	☑	☑	?	?	?

1 Large samples, configuration specific, many part configurations, variation in foam

2 Variation from calibration, complex heat flux/pilot flame contribution, non-representative test samples,

3 Easy to setup and repeat, accommodates unique sample constructions

	highly
	somewhat
	no

Material Test Matrix

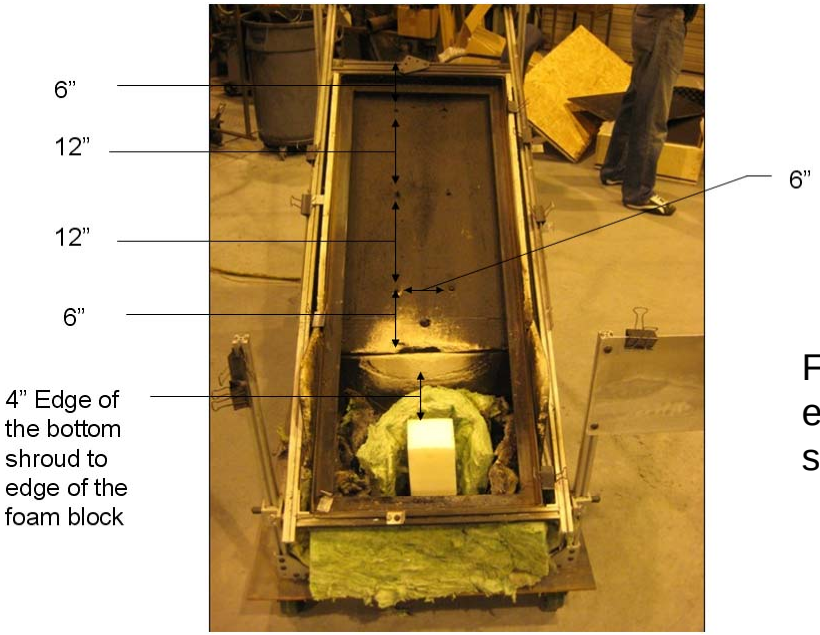
Category	Description
Controls	.063 Aluminum Sheet
	.036 Aluminum Sheet
	.5" Marinite Board
	.036"-.072" Structural Bondend Al
Floor Panels	5lb Nomex core, Low density
	12lb Nomex core, High density
	7lb Kevlar core, High density
	5lb Kevlar core, Low density
	9lb Kevlar core, High density
	6lb Alum core, Low density
	8.5lb Alum core, High density
	5lb Nomex core, Low density
Cargo Liner	.013 Rigid, FR Plastic Sheeting
	.045 Rigid, FR Plastic Sheeting
	.070 Rigid, FR Plastic Sheeting
	.070 Rigid, FR Plastic Sheeting
	.013 Rigid Woven FG
	.050 Rigid Woven FG
	.070 Rigid Woven FG
	.027 Rigid Woven FG
	14.0 ± 1.0 oz.yd^2, Flexible
	32.0 ± 3.0 oz/yd^2, Flexible

Material Test Matrix (continued)

Composite Laminates	250F Polyester fiberglass fabric
	a. 4 ply (.036")
	b. 8 ply (.072")
	c. 12 ply (.120")
	250F cure epoxy fiberglass
	a. 4 ply (.044")
	b. 8 ply (.095")
	c, 12 ply (.135")
	250F cure epoxy fiberglass, FR
	a. 4 ply (.030")
	b. 14 ply (.105")
	c, 24 ply (.180")
	250F cure epoxy carbon fabric
	a. 4 ply (.036")
	b. 10 ply (.090")
	c, 16 ply (.145")
	350F cure epoxy fiberglass
	a. 4 ply (.018")
	b. 14 ply (.065")
	c, 24 ply (.106)
Sidewall - Crushed Core	a. Fiberglass/Crushed Core
	b. Carbon Fiber/Crushed Core
Stowbins/closets	Phenolic HC/foil dec 0.35
	Phenolic FR HC 0.35
	Phenolic HC 0.35
	Phenolic HC 0.375
	Phenolic HC 0.47
	Phenolic HC/foil dec 0.5

Foam Block Testing

- Built according to FAA Specs
- 30 degrees from horizontal.
- Polyurethane Foam with 10cc of heptane
- 8 Thermocouples at different locations.



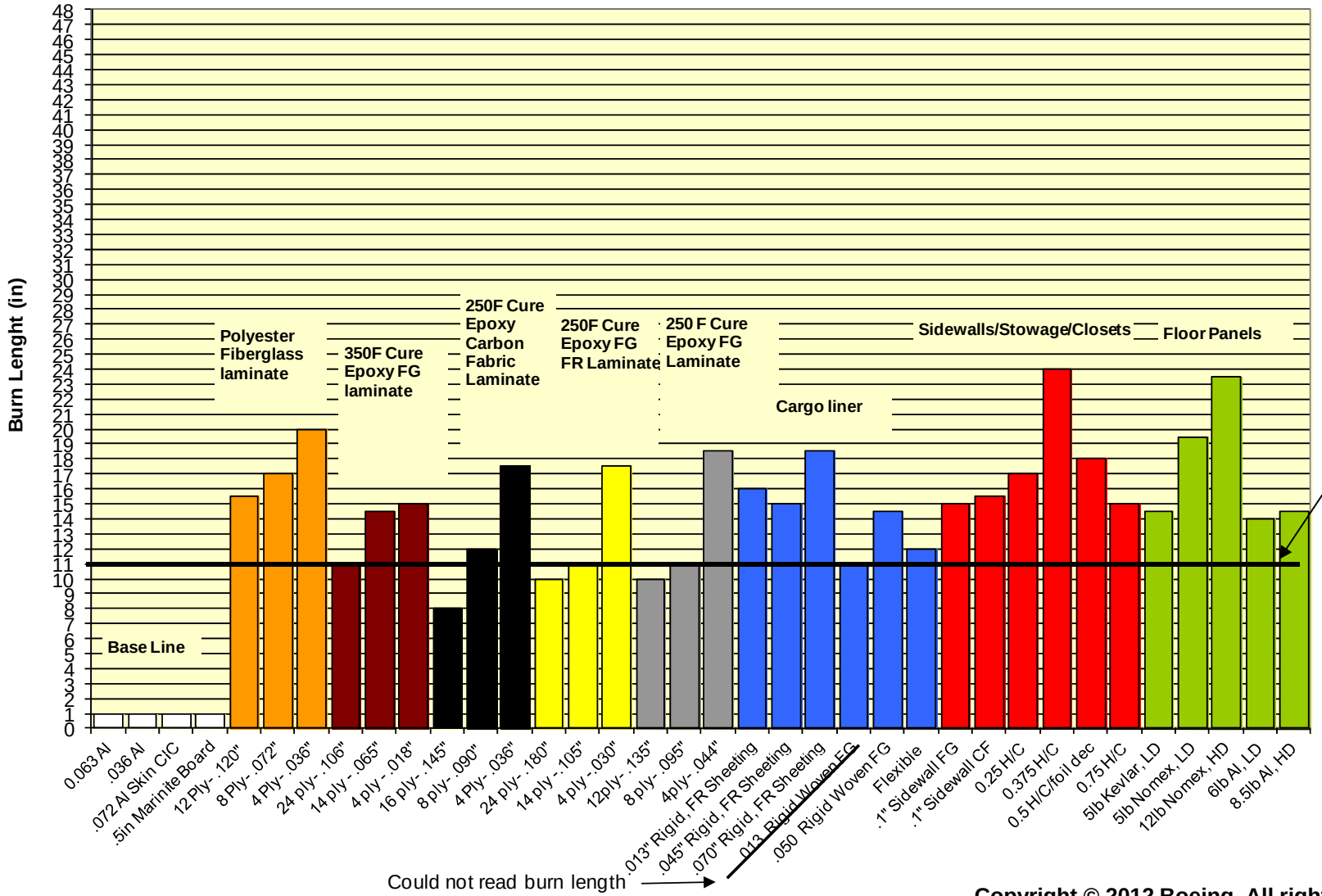
FAA Rig

Test Data Recorded:

- Burn length
- Maximum Temperature
- “Smoke Time”

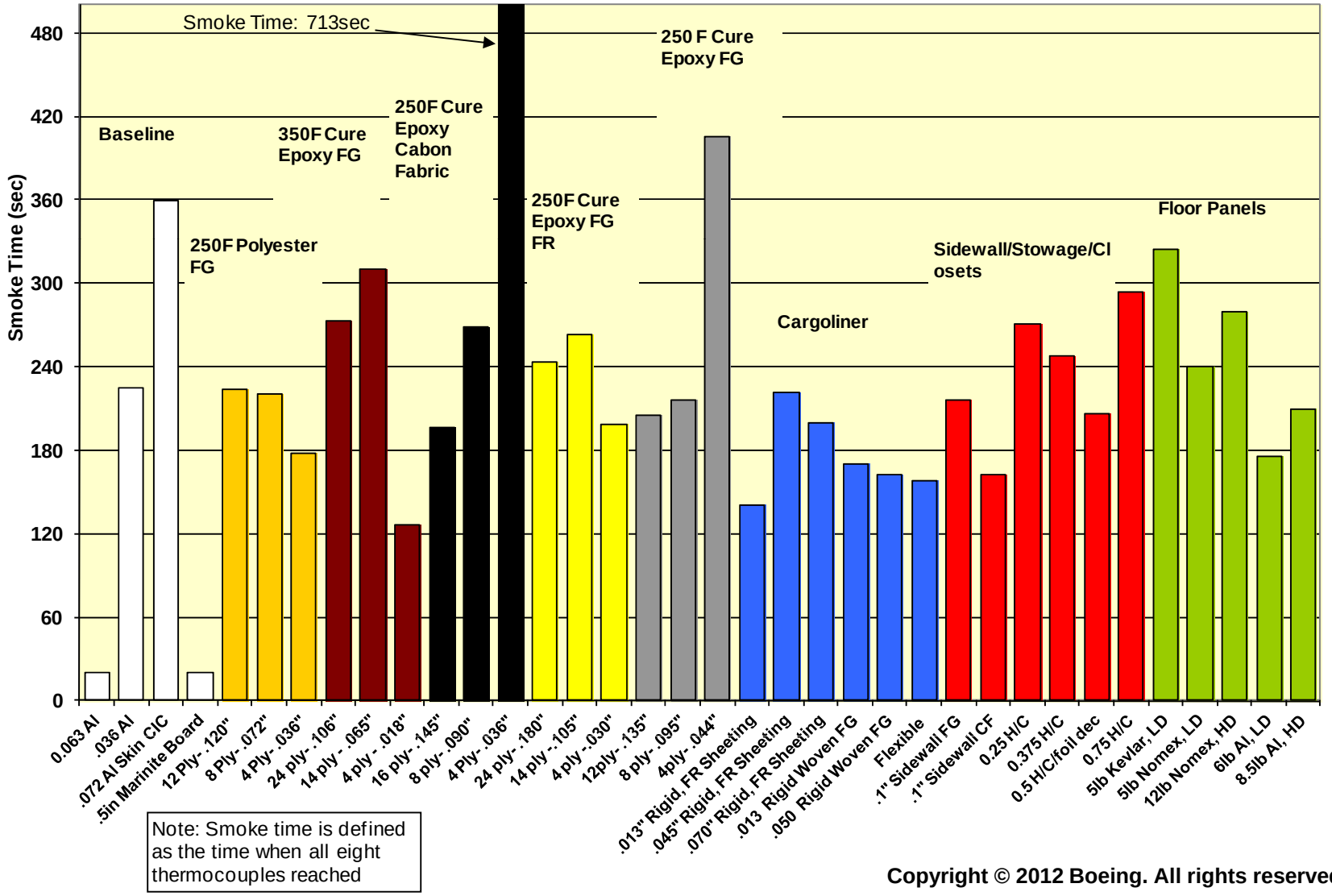
Boeing Rig

Foam Block Results: Burn Length



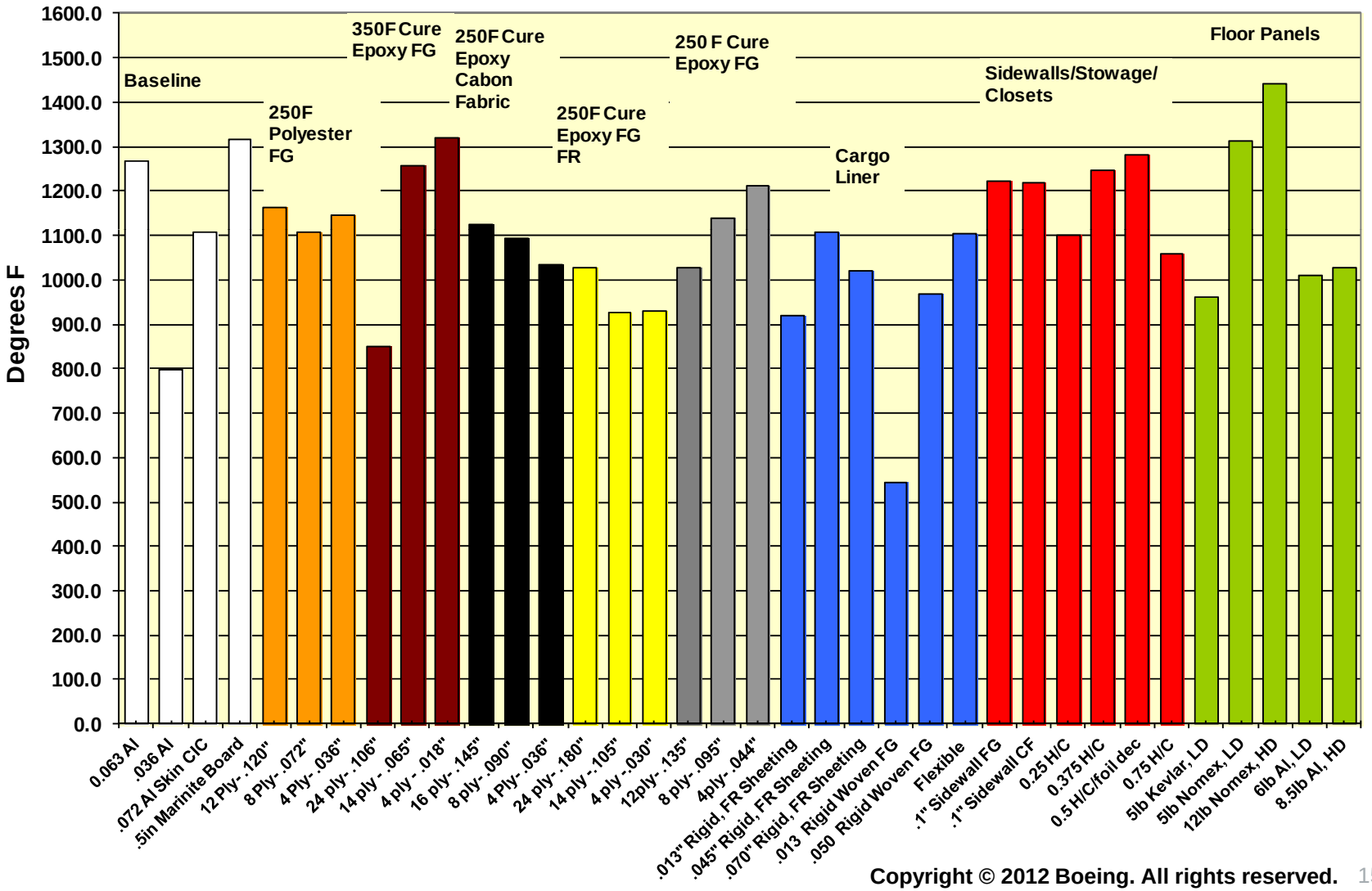
These results represent the burn length results of one sample per configuration.

Foam Block Results: Smoke Time

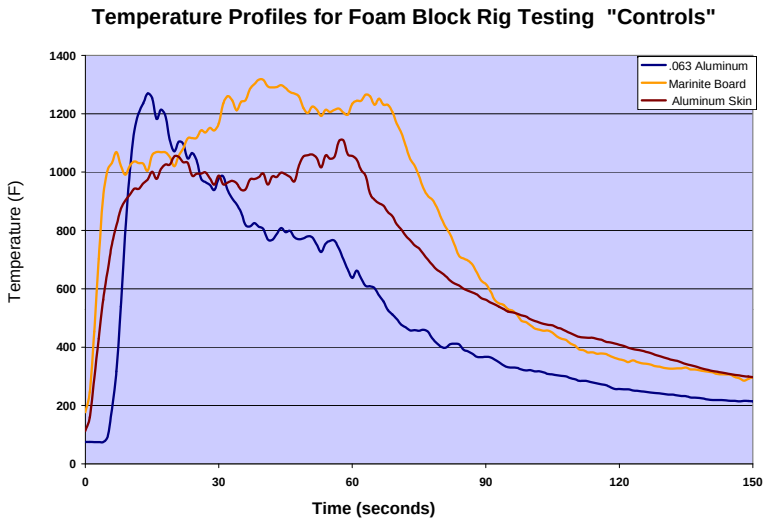


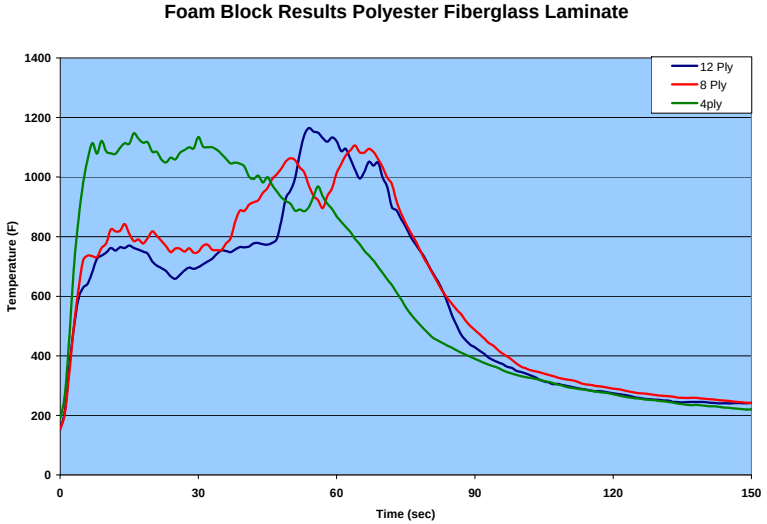
Note: Smoke time is defined as the time when all eight thermocouples reached

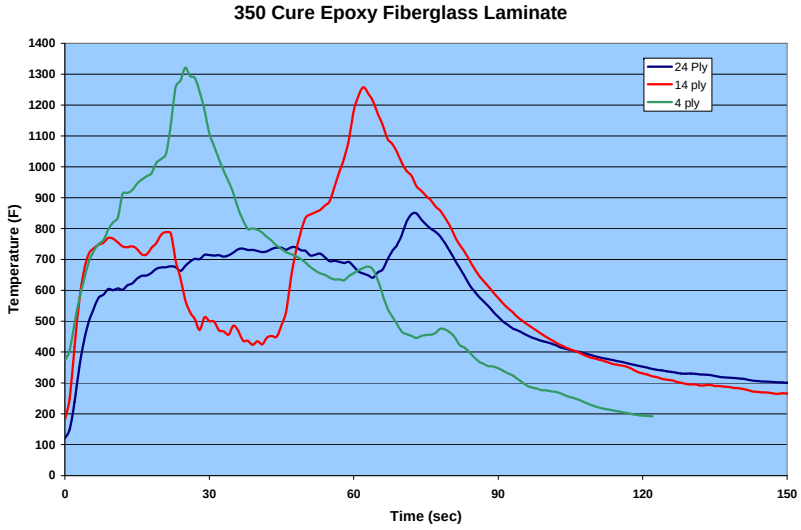
Foam Block Results:Max Temperature

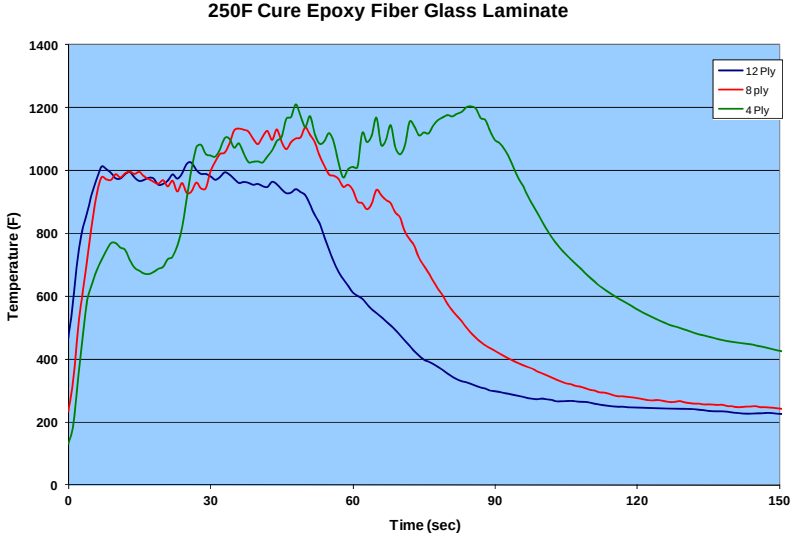


Foam Block Temperature Profiles









Foam Block Test Results: Observations

- **General Testing**
  - Smoke time and max temperature results had significant variation –unable to draw any conclusions
- **Laminates:**
  - Burn length beyond flame impingement varied from 0”- 9”
  - Thickness pattern : Thickest laminates generate the lowest burn length and thinnest laminates record the highest burn length.
  - Polyester Fiberglass laminates record the highest burn lengths.
- **Cargo Liners:**
  - Burn length beyond flame impingement varied from 0” to 7”
  - Maximum Temperatures ranged from 550F to 1100F
- **Sidewalls/Storage/Closets:**
  - Burn length beyond flame impingement varied from 4” to 13”
  - All panels recorded similar maximum temperatures from 1080F to 1290F
  - Honeycomb core did not present any signs of char.
- **Floor Panels:**
  - Burn length beyond flame impingement varied from 3” to 13.5”
  - Maximum temperatures recorded ranged from 950F to 1450F

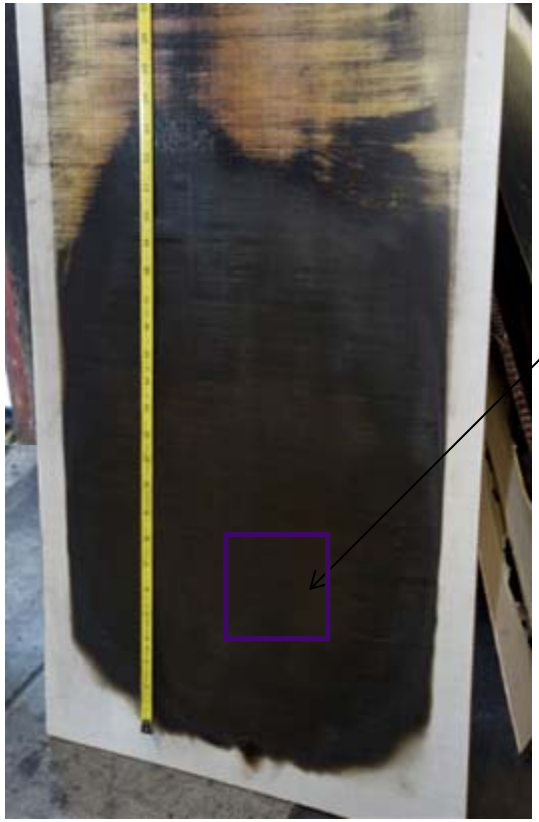
Foam Block Post-test Photos

250F cure epoxy carbon fabric 4 ply

250F Cure Epoxy Fiberglass 14 ply

350 Epoxy Fiber Glass 4 ply

Foam Block Post-test Photos



cut off area

Floor Panel 12lb nomex core, 4plies of uniglass tape.

Foam Block Post-test Photos

0.25” Honeycomb/ phenolic prepreg

0.25” Honeycomb/ phenolic prepreg

0.10” Side Wall Crushed Core - Test Face

0.10” Side Wall Crushed Core - back

Foam Block Post-test Photos

Rigid Cargo Liner, t = 0.013”
- Test side

Rigid Cargo Liner (front side). Specimen still in test fixture. Tedlar pealed off during the test.

Rigid Cargo Liner, t = 0.013”
- Test side

Radiant Panel Testing Summary

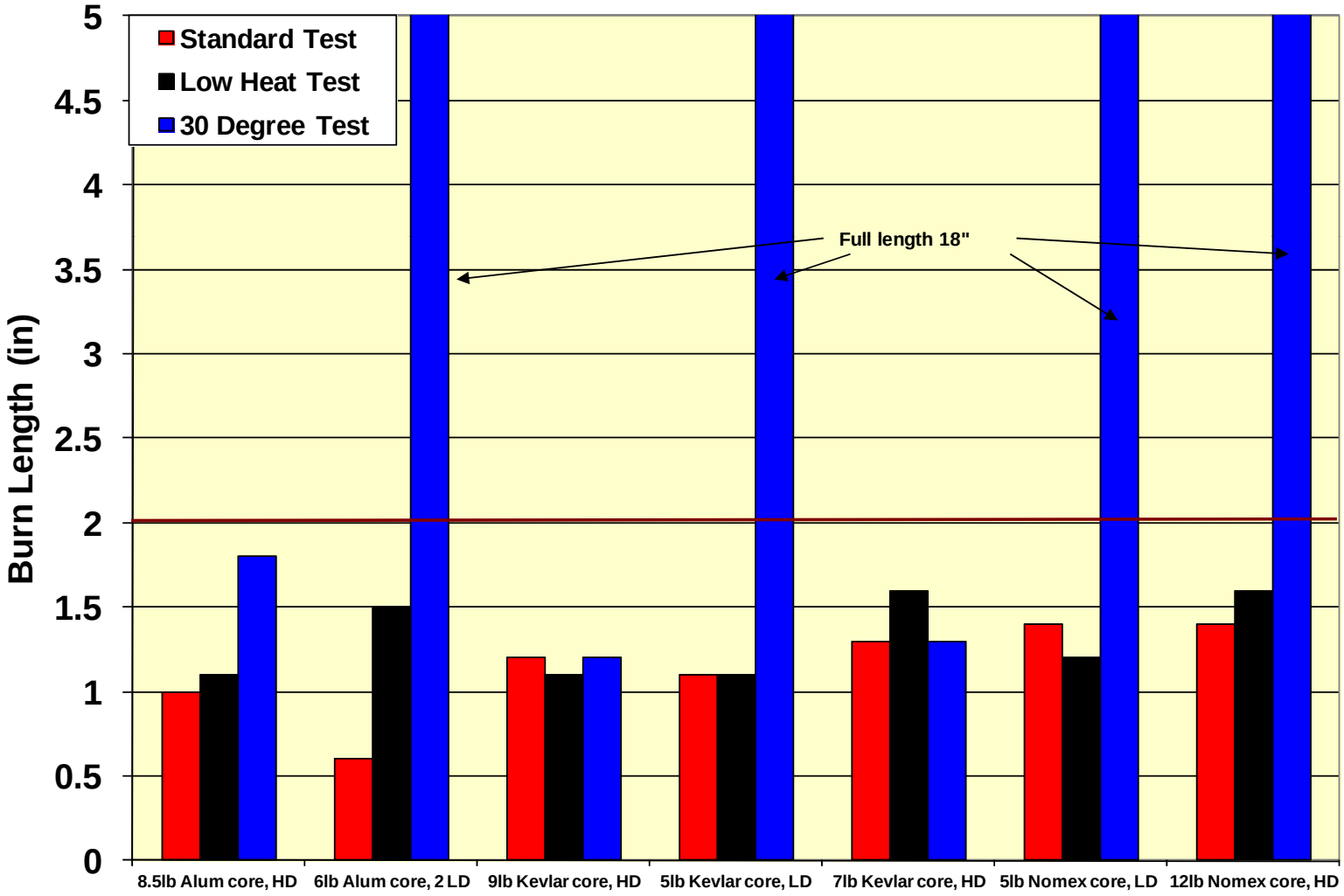
- Insulation RP Method - 25.856 (a)
- Ducting Test Method
- 30 degree orientation
- Conclusions/Observations

Radiant Panel Test Specs

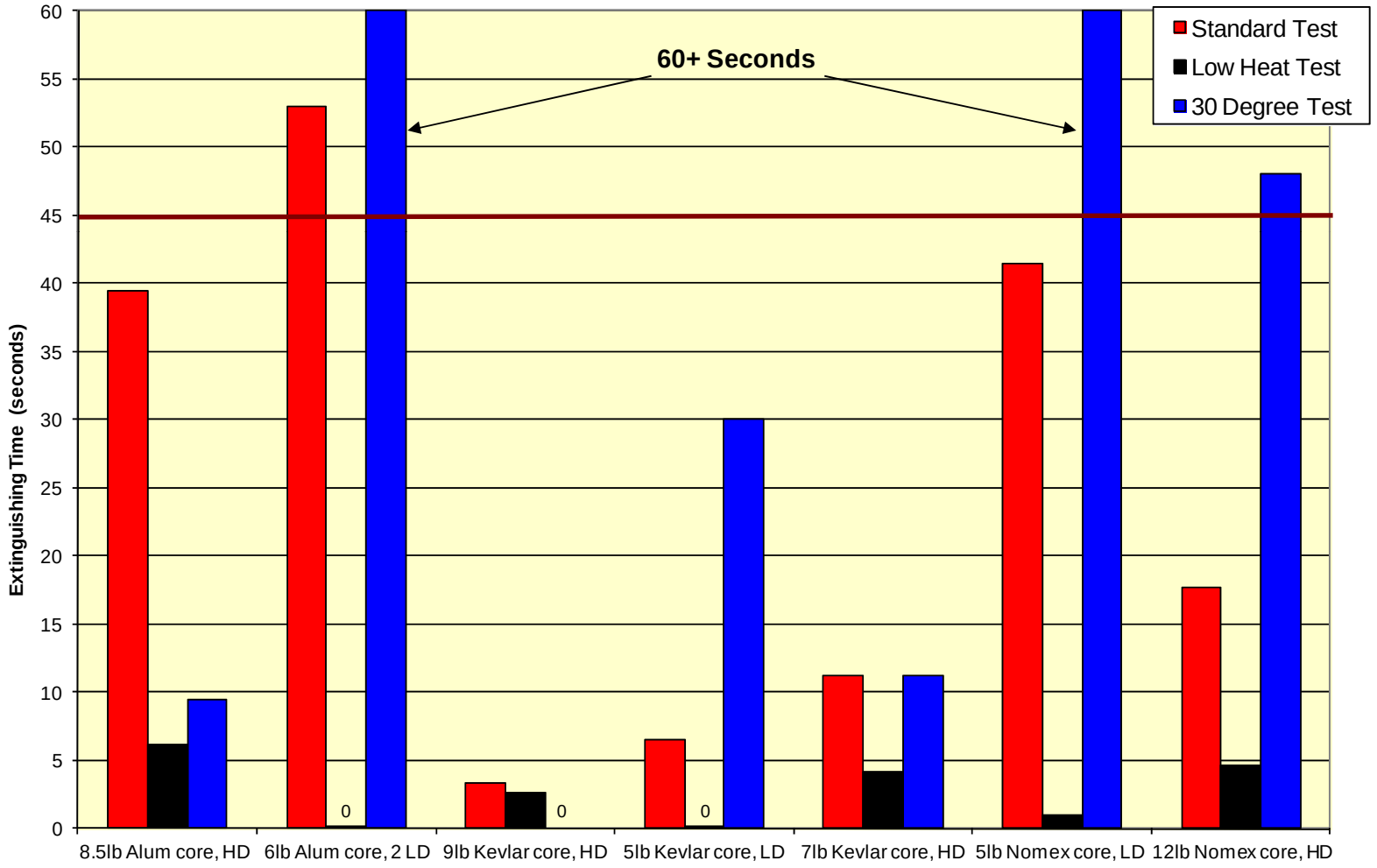
					Requirements	
Radiant Panel Test	Specimen Orientation	Radiant Heat Source (W/cm^2)	Heat Soaked Time (sec)	Pilot Flame Time (sec)	Burn Length (in)	After Flame Time (sec)
Test Per 25.856 (a)	Horizontal	1.7	0	15	2	3
Ducting Method	Horizontal	1.3	60	15	2	45
30 Degree Method	30degrees	1.7	60	15	N/A	N/A

Radiant Panel Test Results

Floor Panels - Burn Length



Radiant Panel Test Results
Floor Panels – Extinguishing Time



Floor Panel Test Result Observations:

30 Degree Orientation Test Method:

- Nomex core panels recorded a full burn length for the 30 degree test. All other panels recorded burn length less than 2". Unclear how skin layup is involved with the results.
- Nomex core panels had extinguishing times above 45secs for the 30 degree tests. Unclear how skin layup is involved with the results.
- During the 30 degree test we witnessed skin delamination during preheat. This test configuration is very stringent in terms of heat flux evenly across the entire panel surface

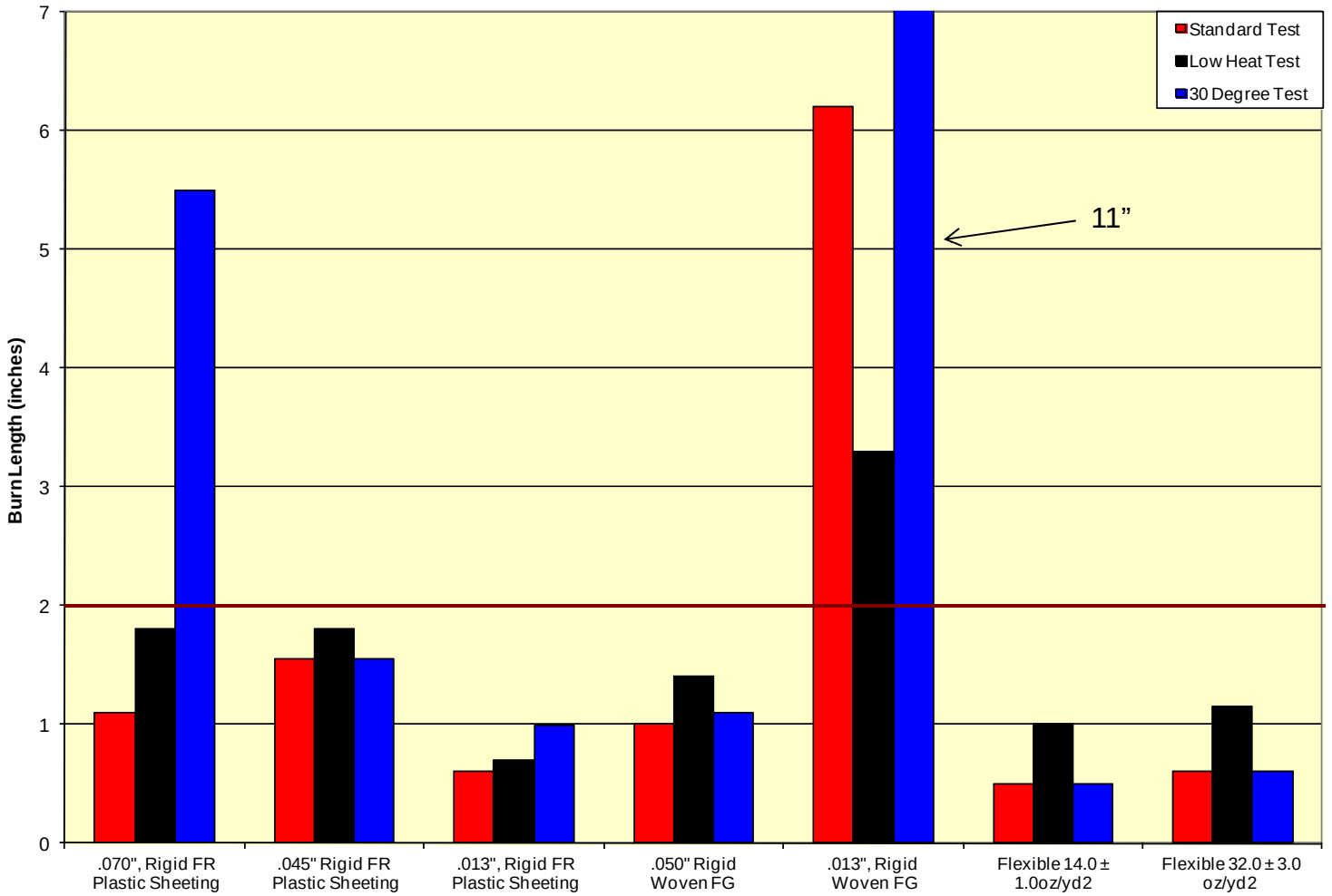
Ducting Test Method:

- After flames for ducting method were generally the shortest

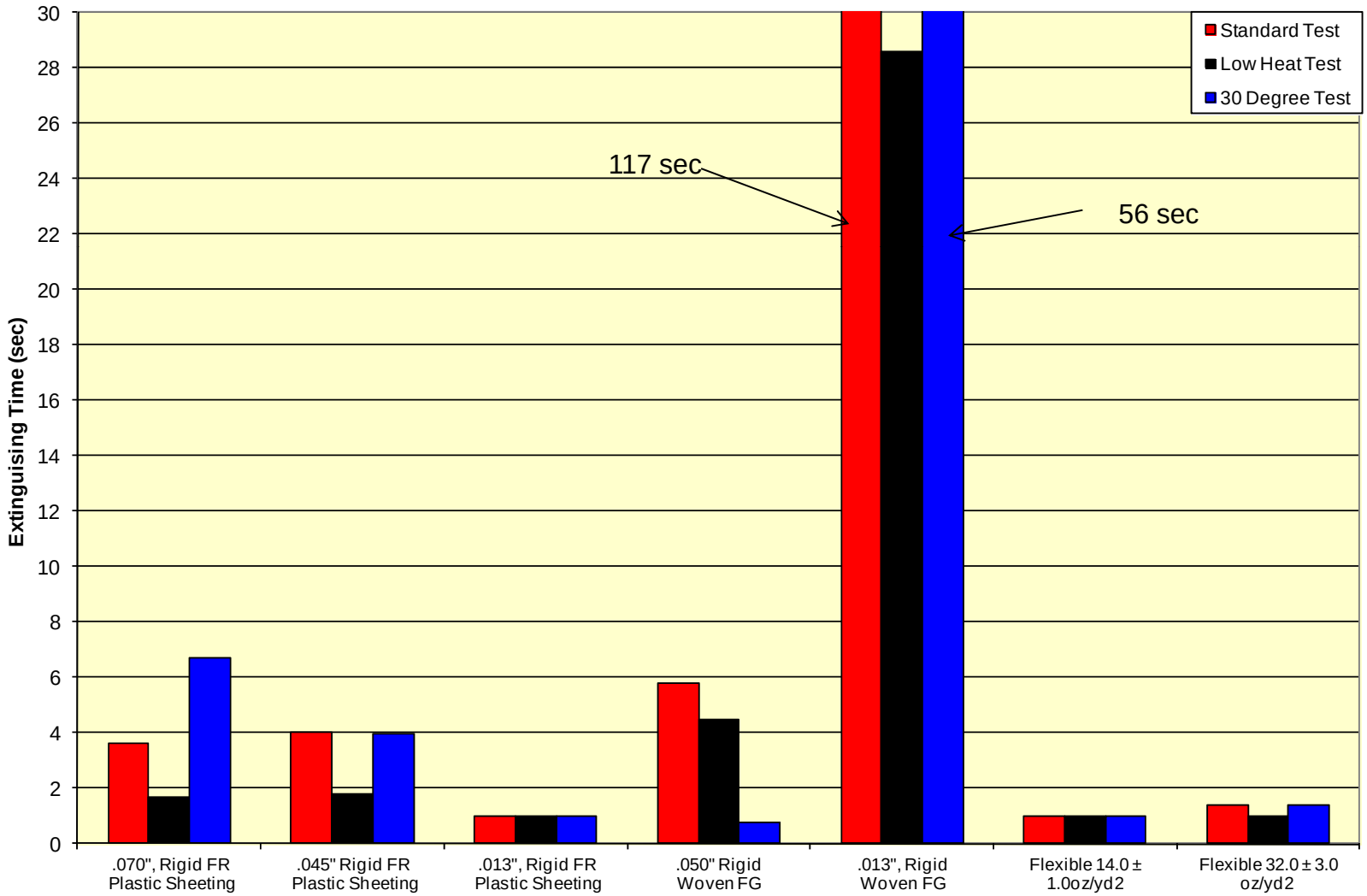
25.856(a) Test Method:

- 25.856 (a) test obtained longer after flame time for aluminum core panels.

Radiant Panel Test Results
Cargo Liners - Burn Length



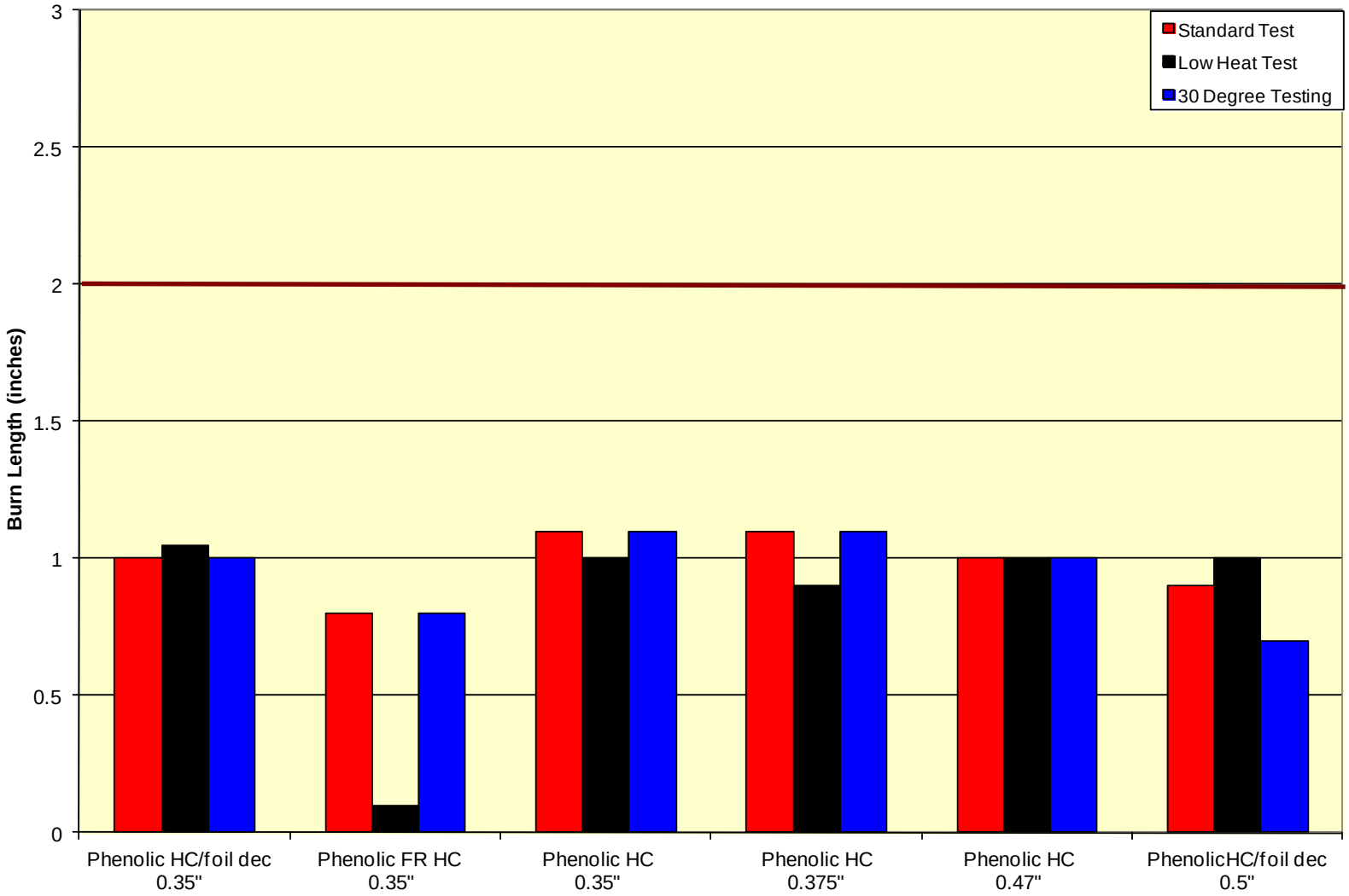
Radiant Panel Test Results
Cargo Liners – Extinguishing Time



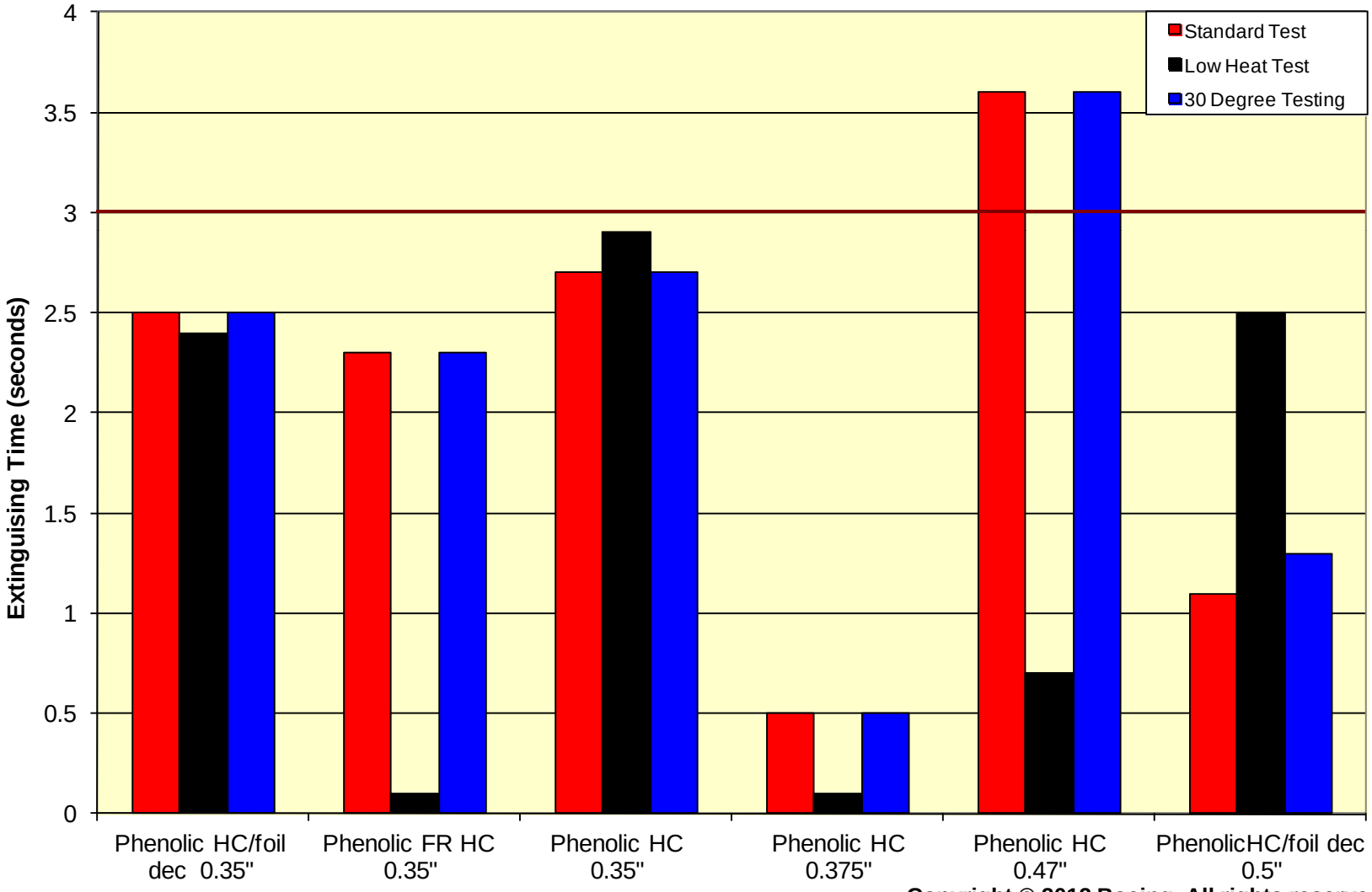
Cargo Liners Test Result Observations

- Generally good flame propagation resistance for cargo liner materials.
- Burn length for rigid fine weave recorded the highest burn lengths and after flame time (this was observed at the thinnest thickness of .013” but not thicker configuration at .050”).
- Due to unique products (resin and reinforcement differences) it is difficult to draw firm conclusions comparing the three different test methods.

Radiant Panel Test Results
Honeycomb Panels – Burn Length



Radiant Panel Test Results
Honeycomb Panels – Extinguishing Time

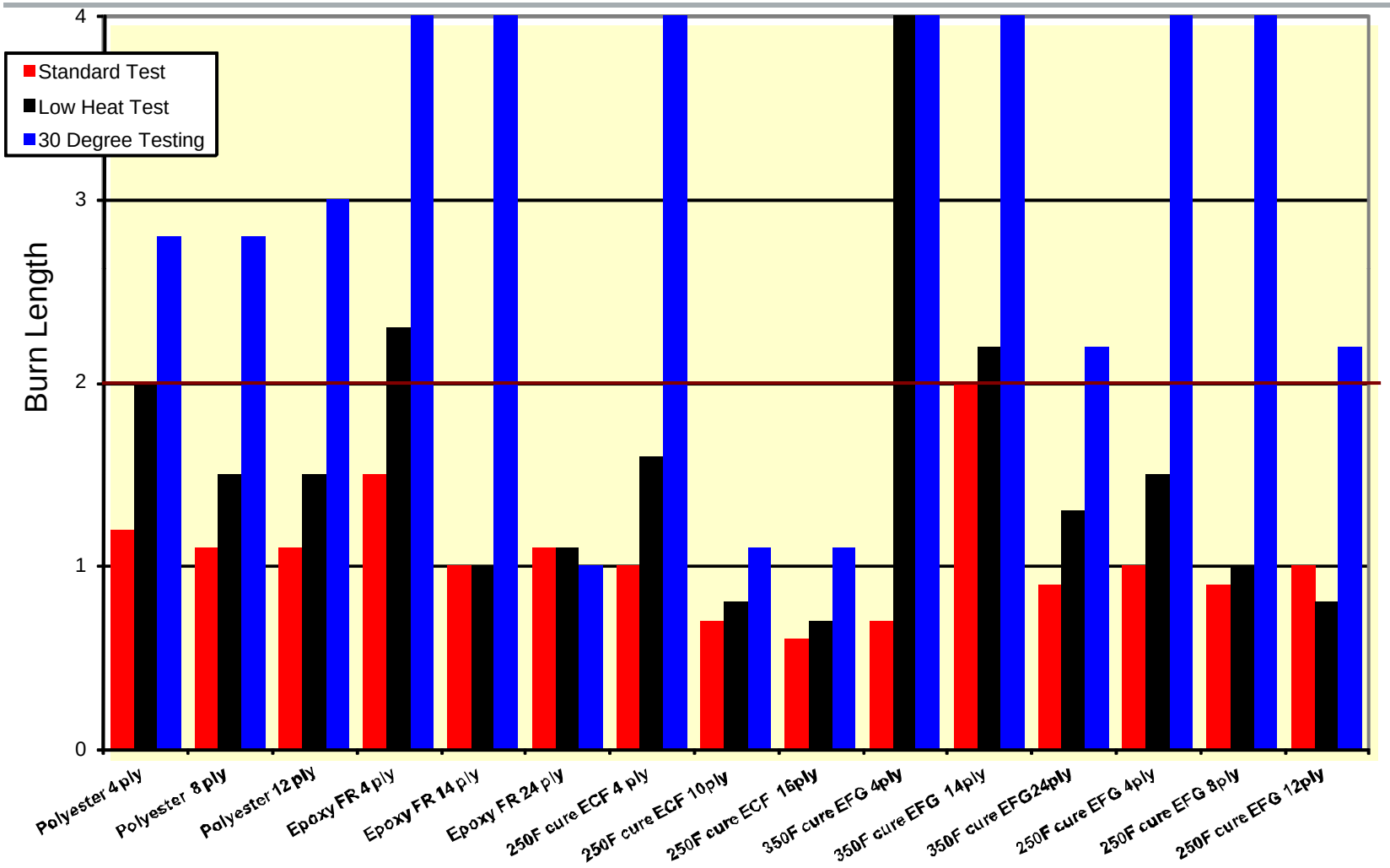


Honeycomb Panel Test Result Observations

- Burn length results were all below 2’’ for all panels and test methods
- After flame time was below 4 seconds for all panels and test methods

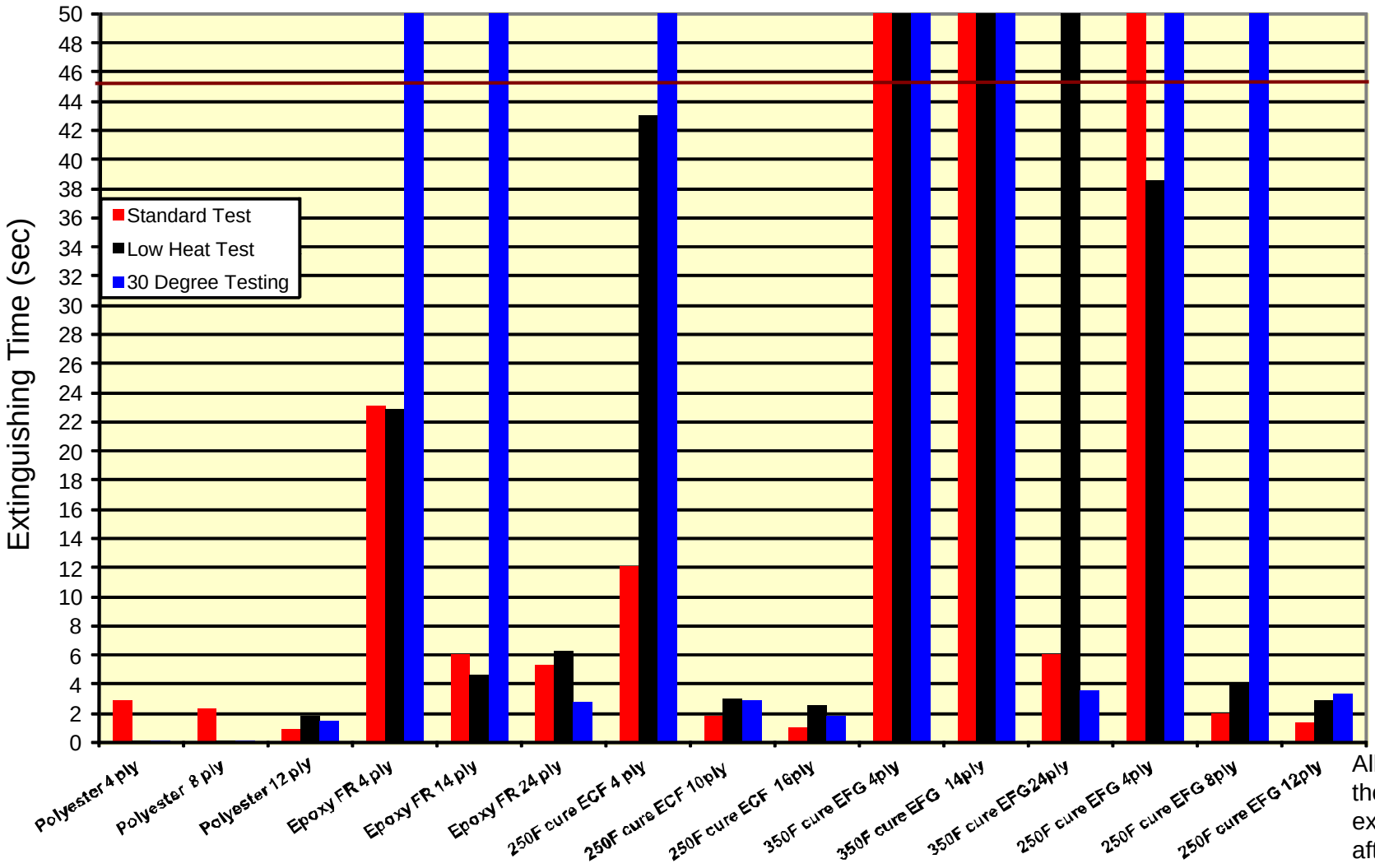
  Note: Only tested one ply skins with different core thicknesses. All phenolic prepregs.

Radiant Panel Test Results
Composite Laminates - Burn Length



Note: bars off the chart represent a burn lengths of above 10" to full burn

Radiant Panel Test Results
Composite Laminates – Extinguishing Time

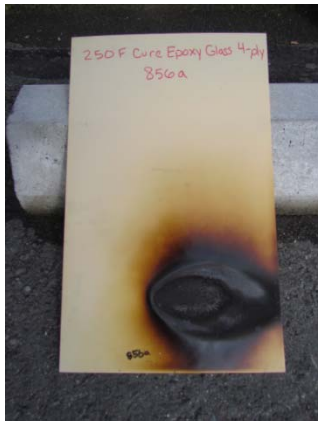


All values off the chart extinguished after 60 +sec

Composite Laminate Test Result Observations

- Burn length using 25.856(a) tests was very similar ranging from .5” to 2”.
- Burn length using the ducting method gave burn lengths below 2” for all but one 4 ply sample.
- 30 degree test method gave the highest burn lengths and after flame times
- 4 out 5 “4ply” laminates tested by the 30 degree method recorded values from 11” to full length.
- Polyester FR laminates had very low extinguishing times for all three test methods and all three thicknesses.
- In general, the thinner the laminate the higher the burn length and extinguishing time.
- Specific resin system will influence how thickness influences test results.

Radiant Panel Test Photos:



4ply 250F Epoxy Fiberglass

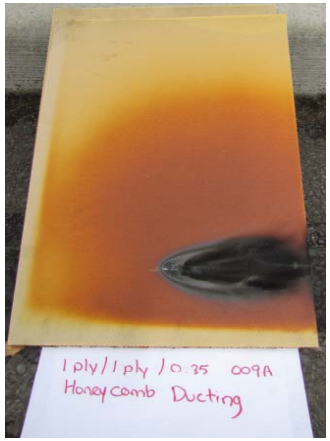
4ply Polyester FR Fiberglass

4ply Epoxy Carbon

25.856 (a)

12 ply 250F Epoxy Fiberglass

Rigid Cargo Liner



Phenolic Honeycomb, t = 0.35”

Ducting Method

Radiant Panel Photos

4ply 250F Epoxy Fiberglass

8ply 250F Epoxy Fiberglass

8ply Polyester FR Fiberglass

4ply 250F Epoxy Carbon

30 degree Test Method

Foam Block & Radiant Panel Test
General Conclusions/ Observations

- **Different flame dynamics**

  Foam Block: Unstable flame and heat loss (no radiant heat source)

  Radiant Panel: Constant flame & radiant heat source.

- **Different flame orientations**

  Foam block: Applies heat directly underneath.

  Radiant Panel: Tests applies the flame to the top of the test coupon at an angle.

- **Visibility/Witnessing**

  Foam Block: Test configuration does not allow to visually witness the test. Therefore, there is no way to identify after flame time. Temperature profiles provides some qualitative indication of continued combustion of the test sample.

  Radiant Panel: Can witness the entire testing without any visual constrains.

- **Test results:**

  Foam block: Difficult to read burn lengths for floor panels and stowage bins/closet panels.

  Radiant Panel: Easy to observe flame propagation.

  Both tests can only be compared by using burn length results not extinguishing times.

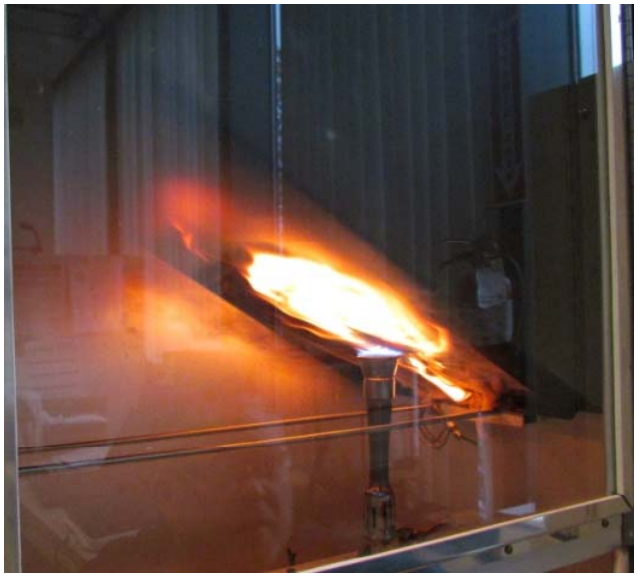
- **Conclusion:**

  No clear correlation of testing results between RP tests and Foam Block test.

  For laminates, a correlation does not exist. Due to the low number of samples tested, repeatability in the test methods have not been determined.

Meeker Burner Test Study

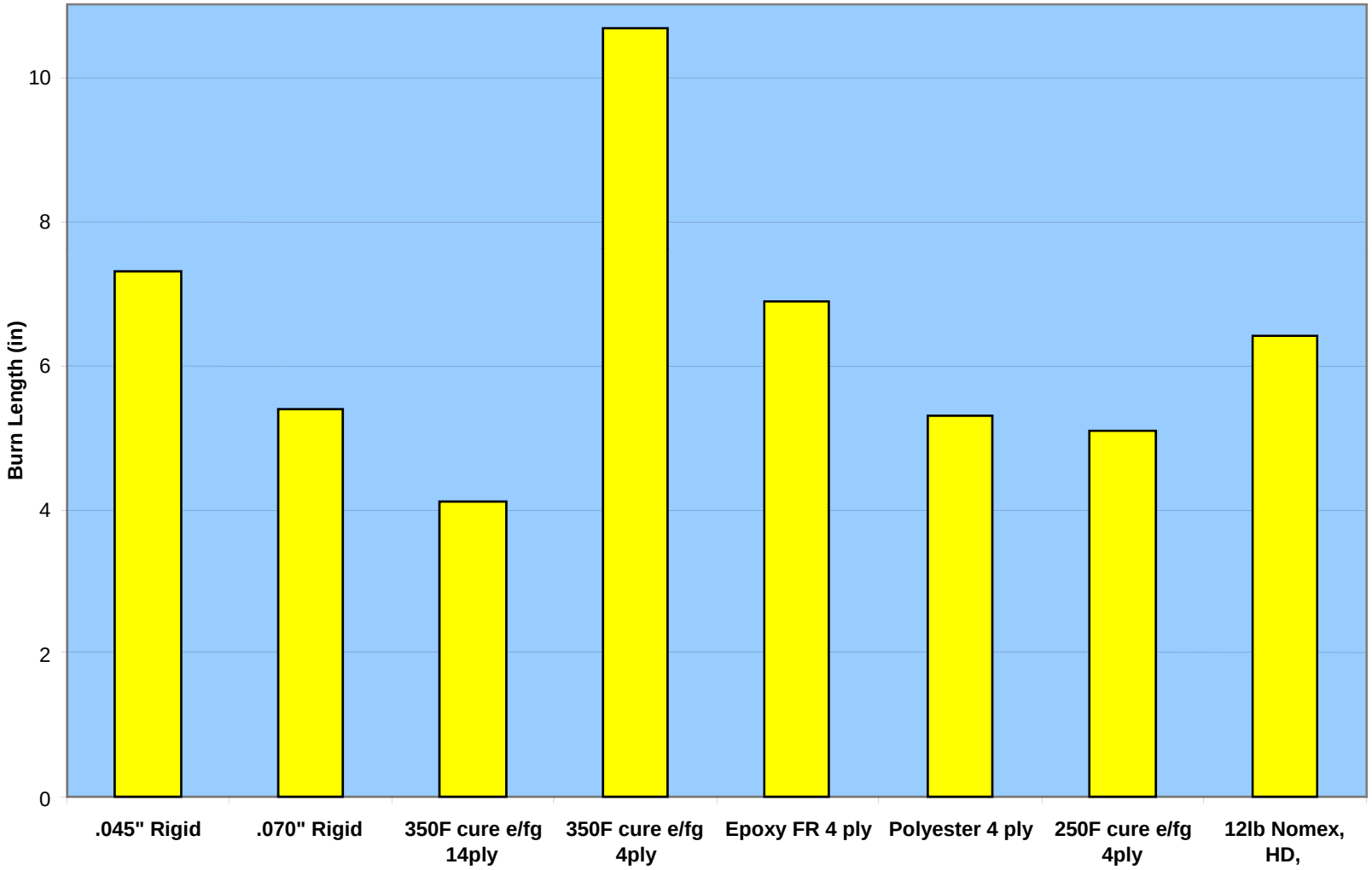
- Meeker Burner has a wider opening and hotter flame than the Bunsen burner.
- It can generate a heat output of 3.5kWh and flame temperatures of 2250°F ± 50
- Sample located at 30degrees from horizontal.
- Flame applied to test specimen for 30 seconds.



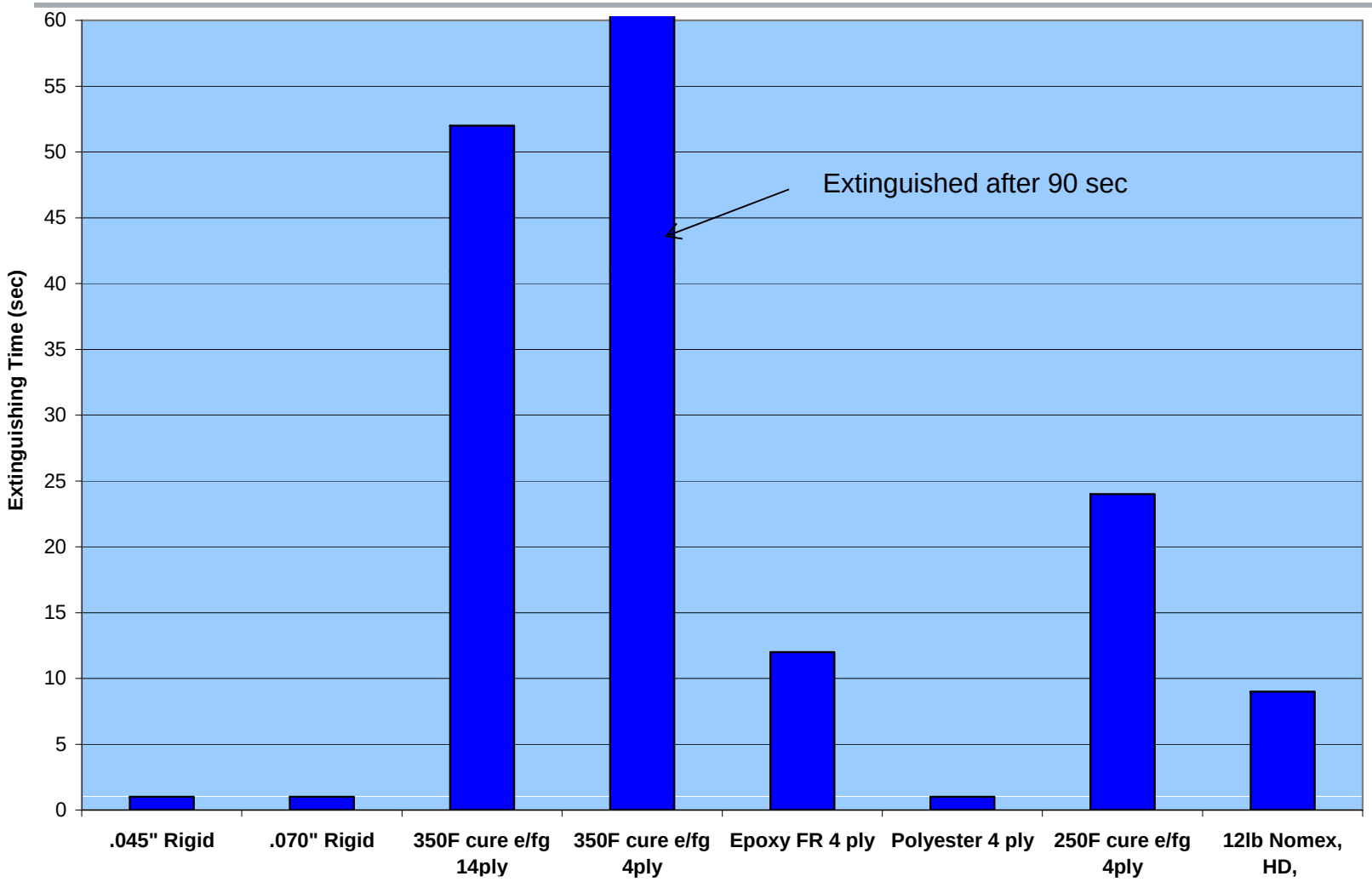
Initial Meeker Test Study

.045"	Rigid Cargo Liner A
.070"	Rigid Cargo Liner B
.065”	14 ply 350F cure Epoxy Fiberglass
.018”	4 ply 350F cure Epoxy Fiberglass
.030”	4 ply Epoxy FR Fiberglass
.036”	4 ply Polyester FR Fiberglass
.044”	4ply 250F cure Epoxy Fiberglass
.50”	Fiberglass Epoxy Floor Panel, 12lb Nomex

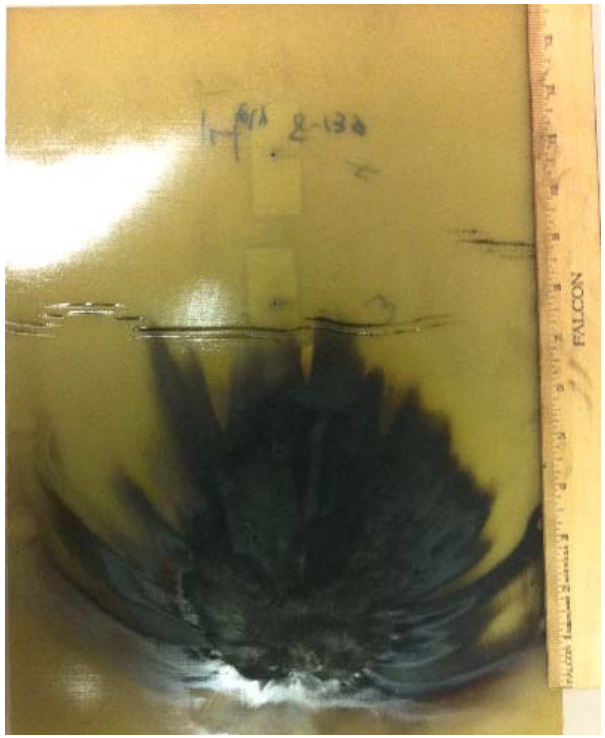
Meeker Test Results: Burn Length



Meeker Test Results: After Flame Time



Observations/Photos

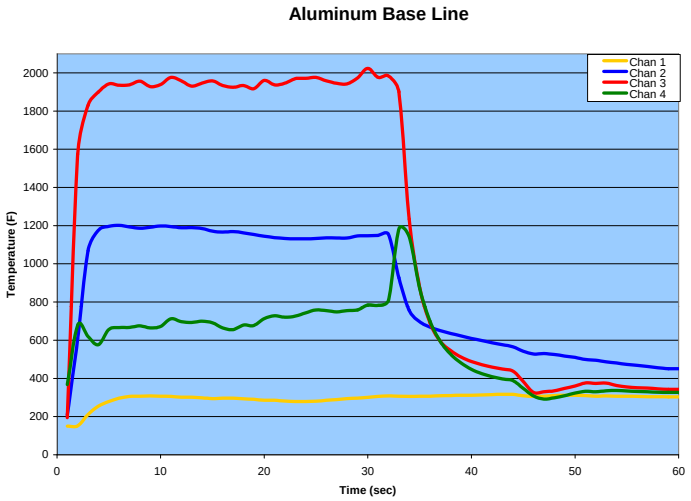


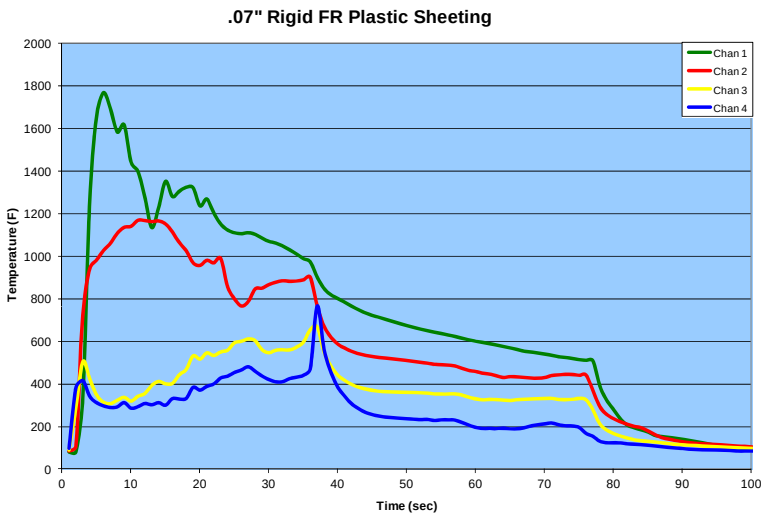
350 F Epoxy Fiber Glass 14 ply

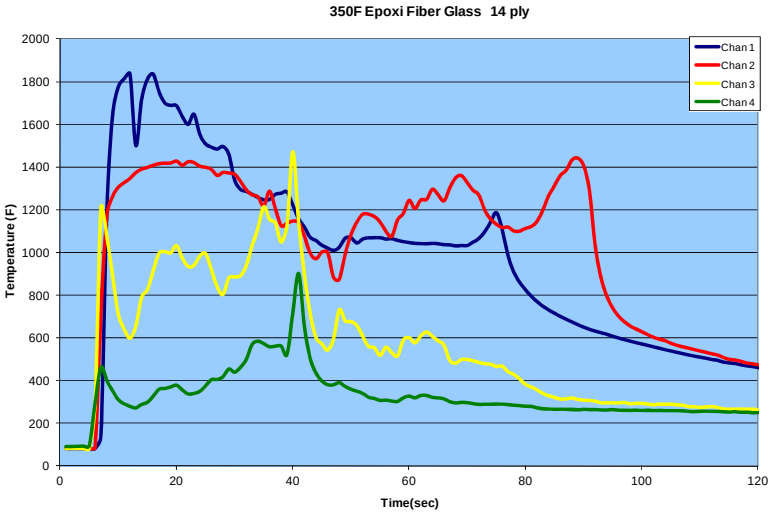
250 Epoxy FR Fiber Glass 4 ply

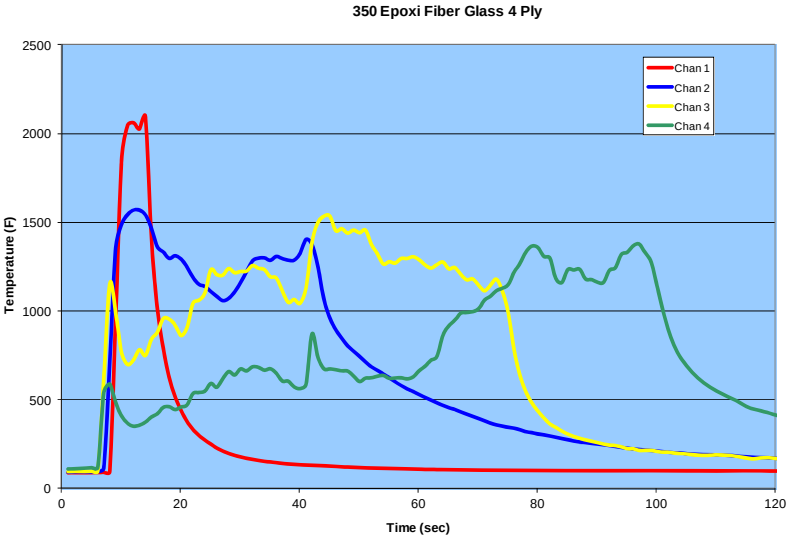
.070 Rigid , FR Plastic Sheeting

Meeker Temperature Profiles









Meeker Burner Observations

- Additional Testing needs to be done to draw any conclusions about similarity to foam block or radiant panel results.
- Limited testing indicates closer correlation to Foam Block test method than radiant panel.
- Holding fixtures and test enclosures need more development. Need to develop a way to control air/gas mixture.
- Meeker burner allows for easy observation of ignition, propagation and after flame time.
- Recommended Next steps:
    1. Further Meeker burner evaluations to standardize burner test setup.
    2. Evaluate additional laminates (different thicknesses and quantities) to understand repeatability.
    3. Evaluate and compare samples in other flame propagation test methods (e.g. Vertical RP)

Final Remarks

- Using the radiant panel at a 30 degree orientation is not representative of the intermediate scale foam block.
- 25.856(a) & ducting test methods need further work to understand the viability and correlation to intermediate scale foam block. The combination of heat flux from the radiant panel and pilot flame needs to be better understood in any RP test configuration.
- Challenges of Radiant Panel Test Methods
  - Calibration
  - Test complexity
  - Test configuration limits ability to test complicated part designs (more adaptability to parts using meeker).
  - Multiple configurations and test setups/requirements (Not material universal)
- Using a Meeker burner shows potential as a more stringent test method and better represents the intermediate scale foam block orientation.
  - Simpler Test for airplane certification
  - Enhances safety due to higher heat flux (comparative to FB)
  - Supports ARAC goals

Thank You!