Assessing the Effect of Backcoatings and Fire Barrier Technologies on Upholstered Furniture Flammability

May 20-23, 2018
Stamford, CT

Mauro Zammarano

Project Leader,
Reduced Flammability of Residential Upholstered Furniture,
Flammability Reduction Group, Engineering Laboratory,
National Institute of Standards and Technology, USA.

Recent Advances in Flame Retardancy of Polymeric Materials
BCC Meeting on Flame Retardancy

Disclaimer
Some of the data in this presentation hasn't been through NIST review process and should be considered experimental / draft results. However, the data has been analyzed by subject matter experts within the research team and is believed to be scientifically sound and consistent with the integrity expected of NIST research

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Outline

- Residential-Upholstered-Furniture (RUF):

  moving away from Flame Retardants (FRs)

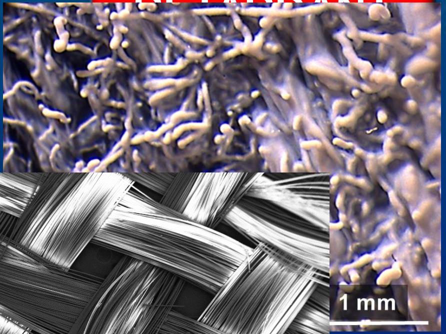
- Fire safe RUF without Flame Retardants

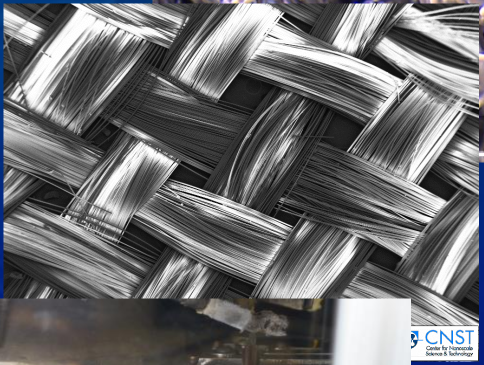
- NIST Silicone Backcoating

- Fire Barriers

- Testing (CUBE TEST)

  composite cone-based-test for assessing Fire Barriers and Backcoatings





Residential Upholstered Furniture (RUF)

RUF fires are the largest cause of civilian deaths in US home fires*

How can we reduce RUF fire deaths?

1. Fire Prevention (ignition suppression)

⇒ Reduce smoldering ignitions (most frequent ignition source - 1st item)

2. Fire Mitigation (heat release rate reduction)

⇒ >90 % of casualties from fires spreading beyond the initial burning object

⇒ >70 % from fires spreading outside the initial fire room**

*J.R. Hall Jr, Estimating Fires When a Product is the Primary Fuel But Not the First Fuel, With an Application to Uphol.Furn., NFPA, 2014.
**Ahrens, Home Fires that Began with Upholstered Furniture, NFPA, 2017

NFPA 277:
Sudden Death of a Draft Standard Flaming test for RUF

- 2014: started development of NFPA 277
- April 2018: NFPA Standard Council voted to cease NFPA 277

- NFPA stated that [1]:

 - The concerns about the toxicity of flame retardant chemicals raised by participants, including first responders, need to be answered.

[1] https://www.nfpa.org/News-and-Research/News-and-media/Press-Room/News-releases/2018/NFPA-Standards-Council-votes-to-cease-standards-development-of-NFPA-277

Other Positions

- Fire Fighters: It would appear that any proposed new fire test designed to resists ignition from a second item and/or designed to limit growth of Heat Release Rate will require much higher levels of FR than those required to pass TB117. Probably at similar levels or exceeding TB133 (15-30%)"

  Why Do Fire Fighters Support the Banning of Flame Retardants?

  Joseph Fleming PFFM (Professional Fire Fighters of Massachusetts)

  http://greensciencepolicy.org/wp-content/uploads/2018/02/6-Fleming_FRDPresentation_2518.pdf

- CPSC recommends to refrain from intentionally adding nonpolymeric, organohalogen FRs

  [CPSC Docket No. CPSC–2015–0022, Sept'17]

- State of Maine first State banning all flame retardants in RUF

  Effective on Jan 1 2018 - https://www.mainelegislature.org/legis/bills/bills_128th/billtexts/HP013801.asp

Other Positions

- Fire Fighters: It would appear that any proposed new fire test designed to resists ignition from a second item and/or designed to limi… levels
c…
l…
v…
J…
r… .pdf

FLAME RETARDANT

moving away from Flame Retardants in RUF

- CPS… eric, orga…

[CPSC Docket No. CPSC–2015–0022, Sept'17]

- State of Maine first State banning all flame retardants in RUF

Effective on Jan 1 2018 - https://www.mainelegislature.org/legis/bills/bills_128th/billtexts/HP013801.asp

What is NIST doing?

- NIST SP1220 Workshop Report: Research Roadmap for Reducing the Fire Hazard of Materials in the Future (2018):

https://www.nist.gov/publications/workshop-report-research-roadmap-reducing-fire-hazard-materials-future

identified RUF as the top priority application for fire safety research in terms of overall impact on the fire problem

- **NIST project - Low Heat Release Upholstered Furniture**

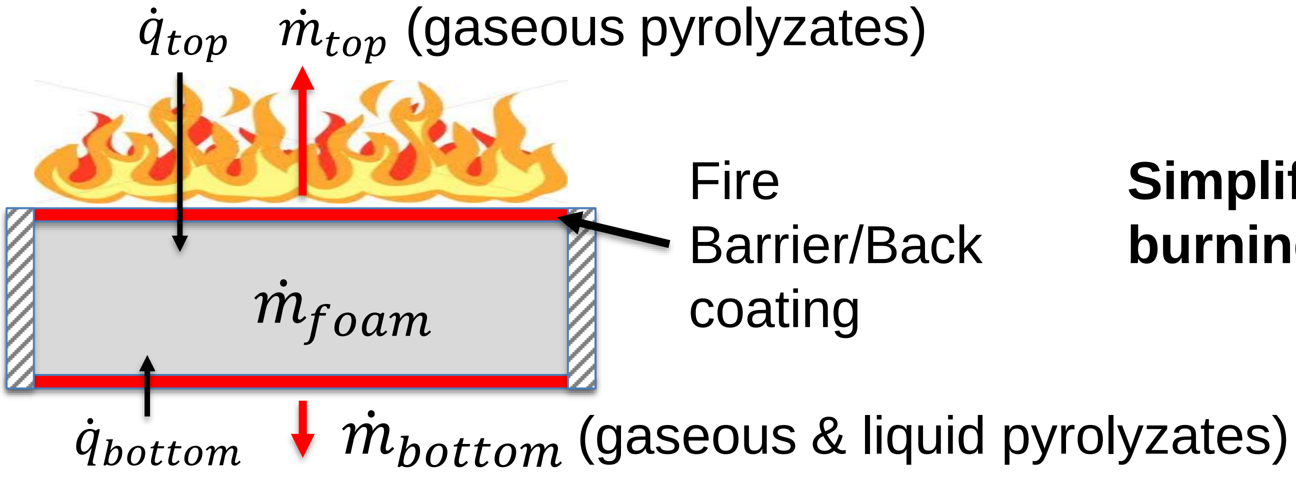
Project Objectives:

- low heat release rate RUF without the need for fire FR.
- bench-scale methodology for predicting the RUF flaming hazard.
- robust standard reference cigarettes for smoldering ignition testing
- bench-scale methodology for predicting the RUF smoldering hazard.

Fire Barriers

Reduce flammability without the use of chemical FRs by reducing

(1) Heat Transfer and (2) Mass Transfer (of pyrolyzates produced by foam decomposition)



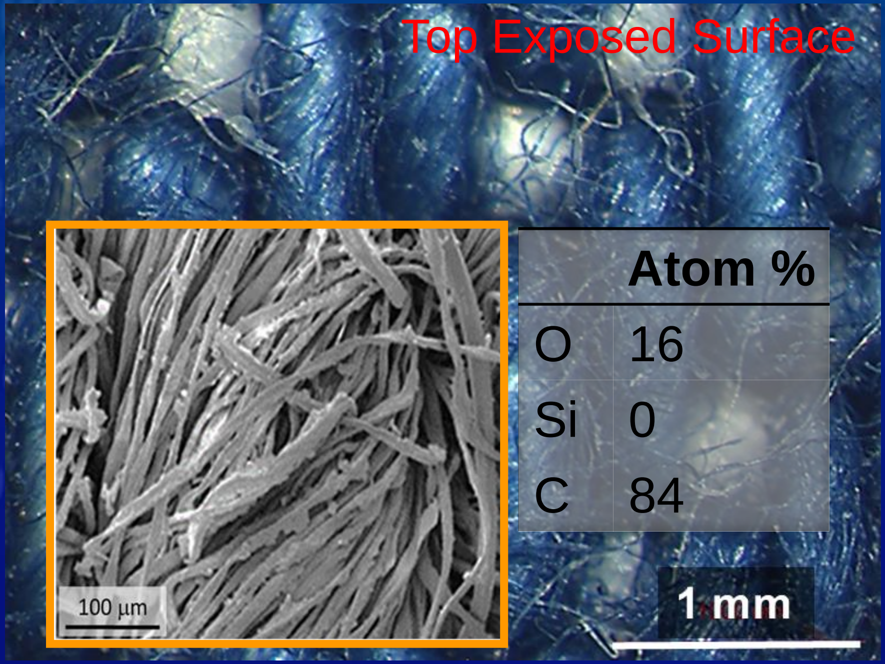
Simplified Model of a burning cushion

NIST Silicone Backcoating

Zammarano et al., Smoldering and Flame Resistant Textiles via Conformal Barrier Formation, Adv. Mat. Interf., Nov 2016

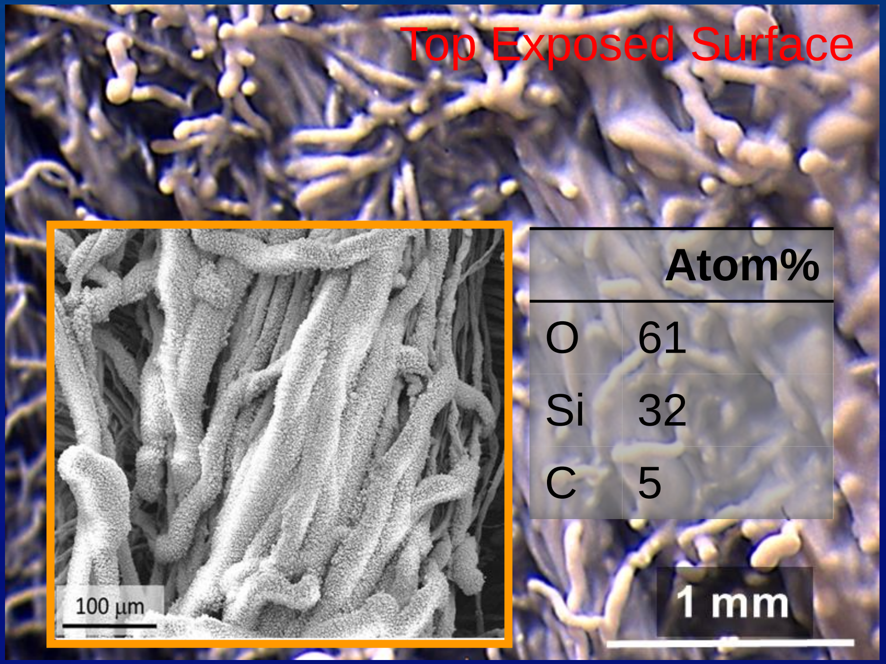
FORMULATION (Flexible Pre-ceramic):

- Vinyl terminated PDMS crosslinked by Pt-catalyzed hydrosilation.
- Vinyl-modified aluminum-hydroxide (65 % by mass)
- vinyl-modified nanosilica (13 % by mass)
- Ethyl acetate (solvent)



	Atom %
O	16
Si	0
C	84

Before Cone Test



	Atom%
O	61
Si	32
C	5

After Cone Test

Silicone Backcoating – Large Scale

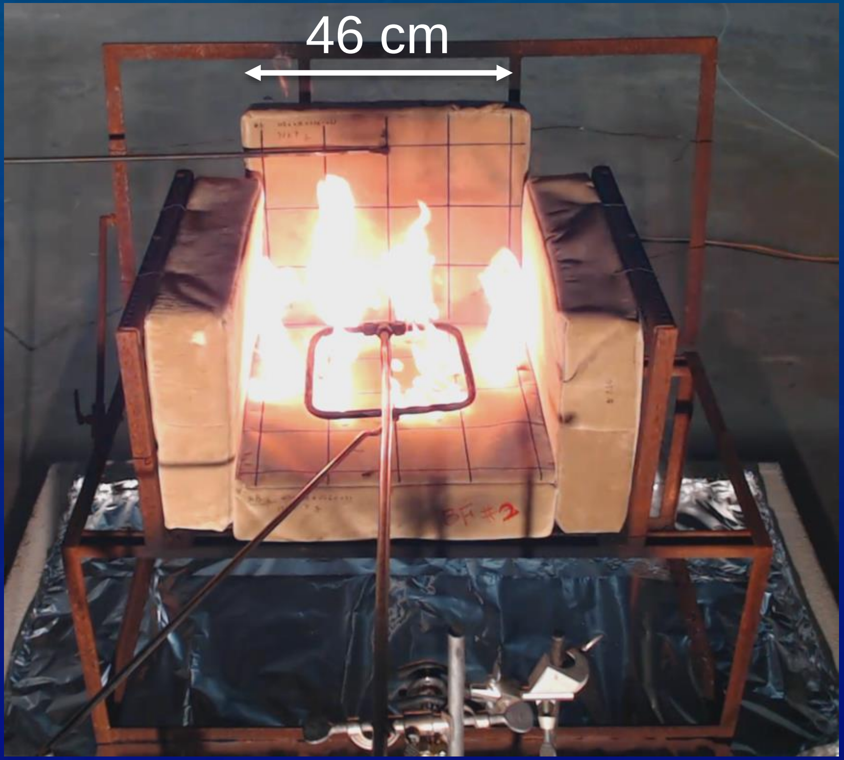
- Four cushion **mock-ups**:
- California TB 133 **burner**

(18 kW square burner) – 80 s

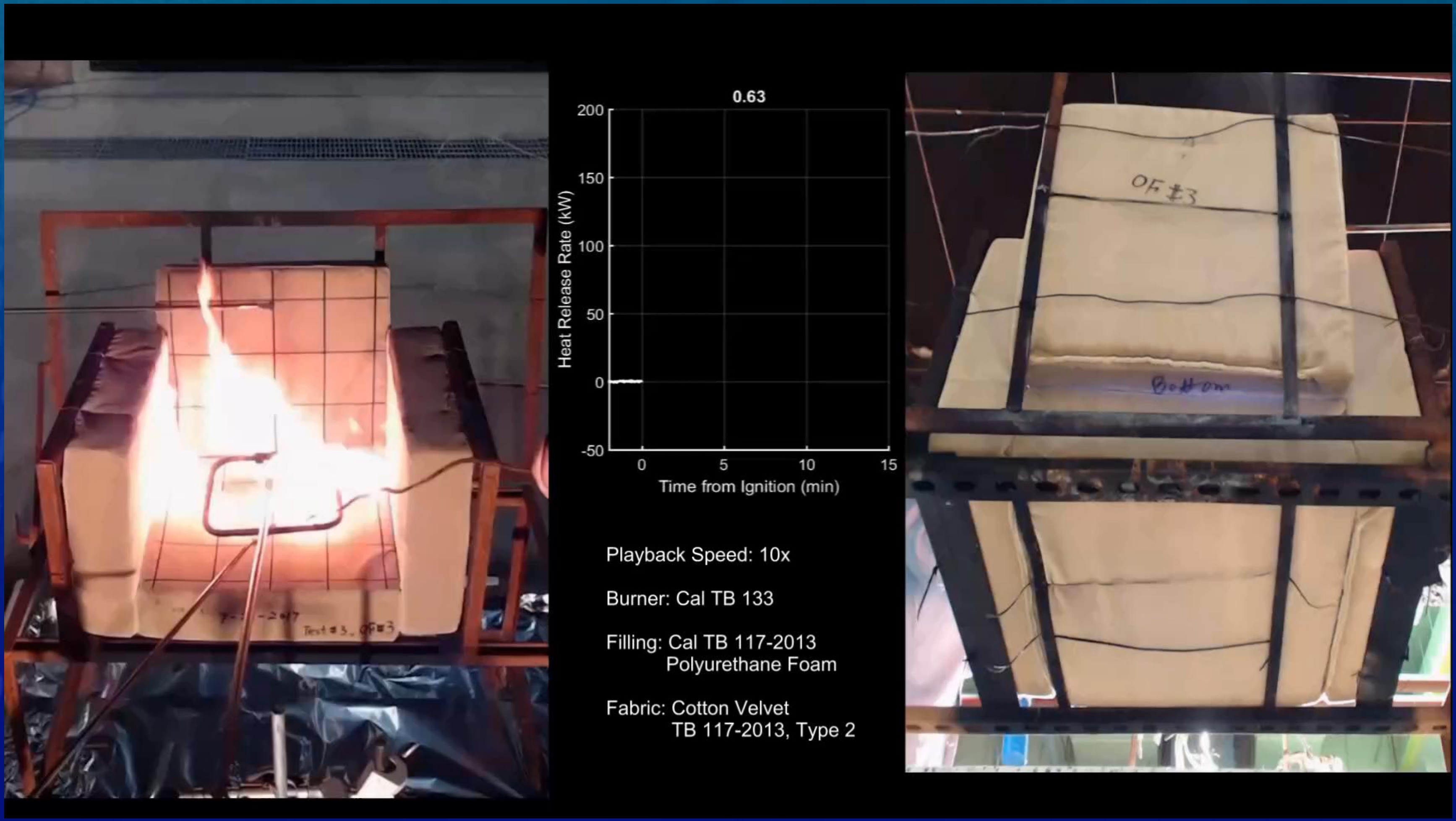
- Cover **Fabric** (Cotton velvet):

Uncoated (UC) vs. Backcoated (BC)

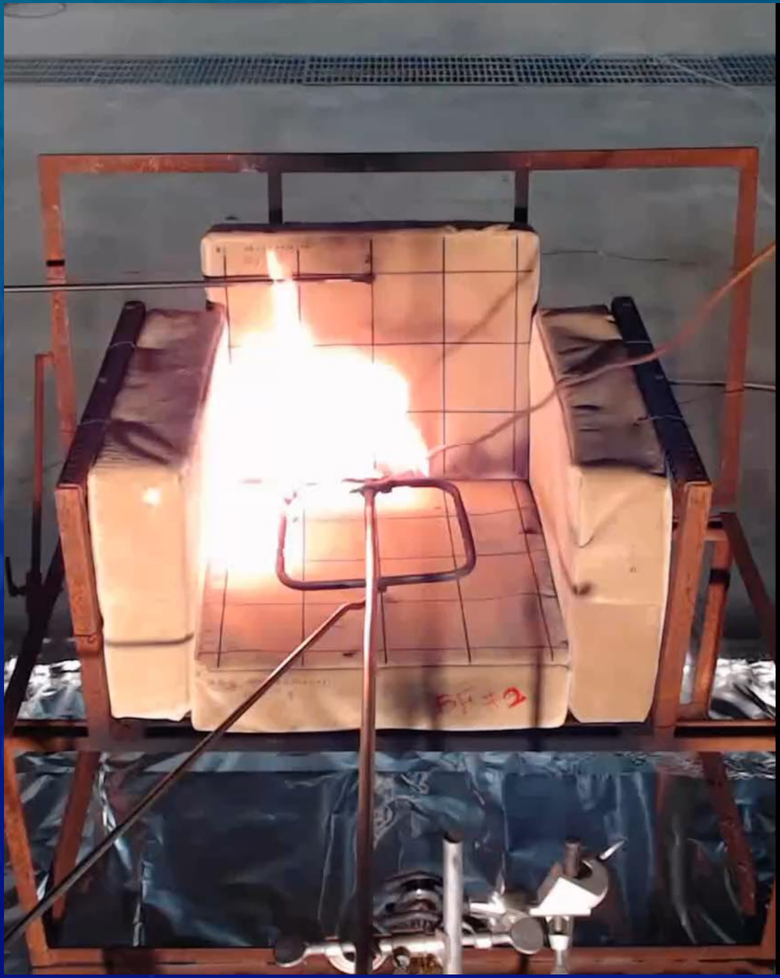
Sample	Area density [g m^{-2}]	Thickness [mm]
Uncoated	447±3	1.3 ±0.2
Backcoated	813±16	1.5 ±0.3



Uncoated Mock-up



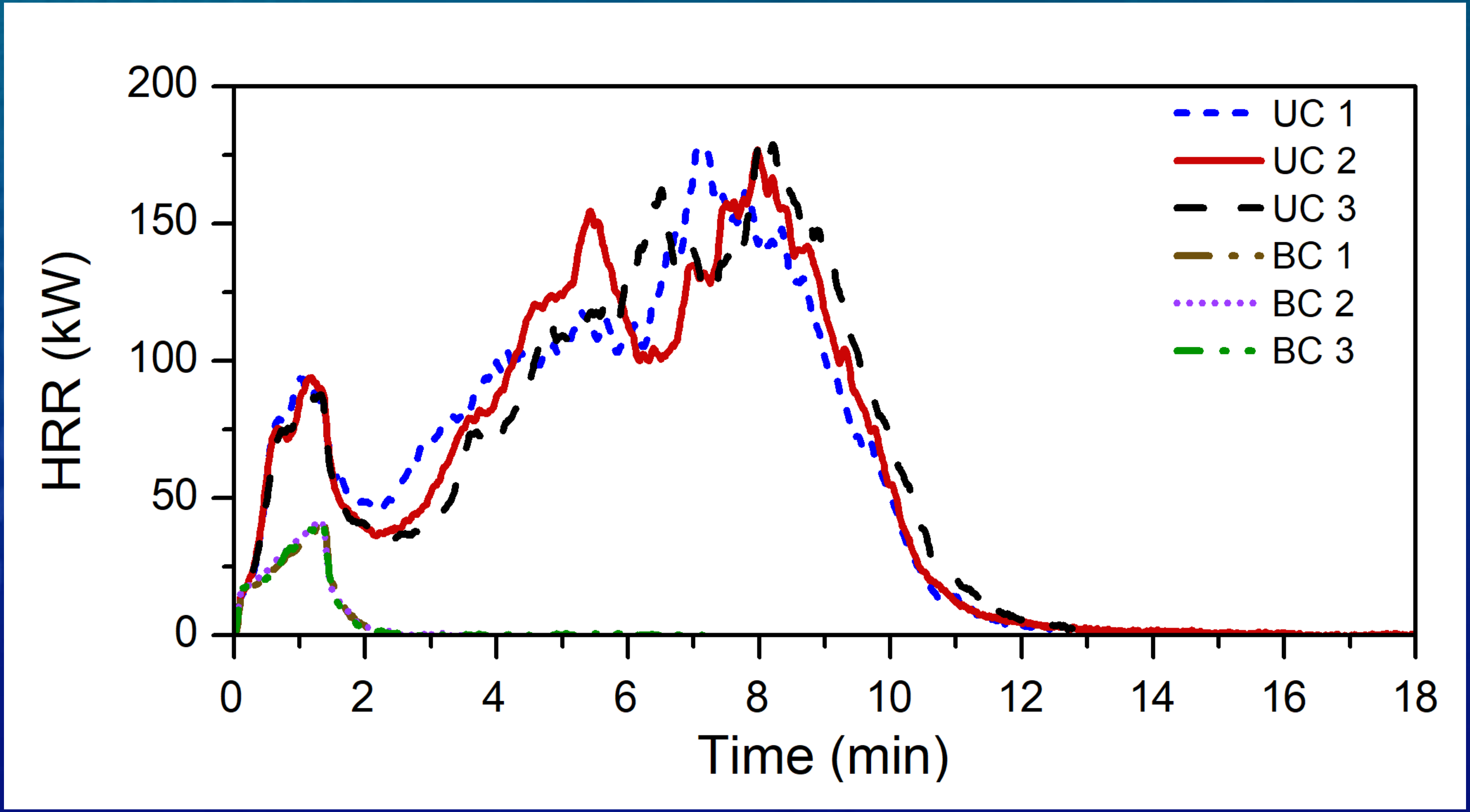
Backcoated Mock-up



Seams are Critical

- Backcoated fabric: no sign of failure
- Kevlar thread failure

HRR



Triplicate tests with high repeatability

Data Summary

	Peak HRR	Total Heat Release	Mass Loss	EHC
	[kW]	[MJ]	[%]	[kJ/g]
Uncoated	179±2	59.2 ±0.7	95.5 ±0.8	22.6 ±0.1
Backcoated	24±1	1.3 ±0.1	3.8 ±0.1	8.3 ±0.5

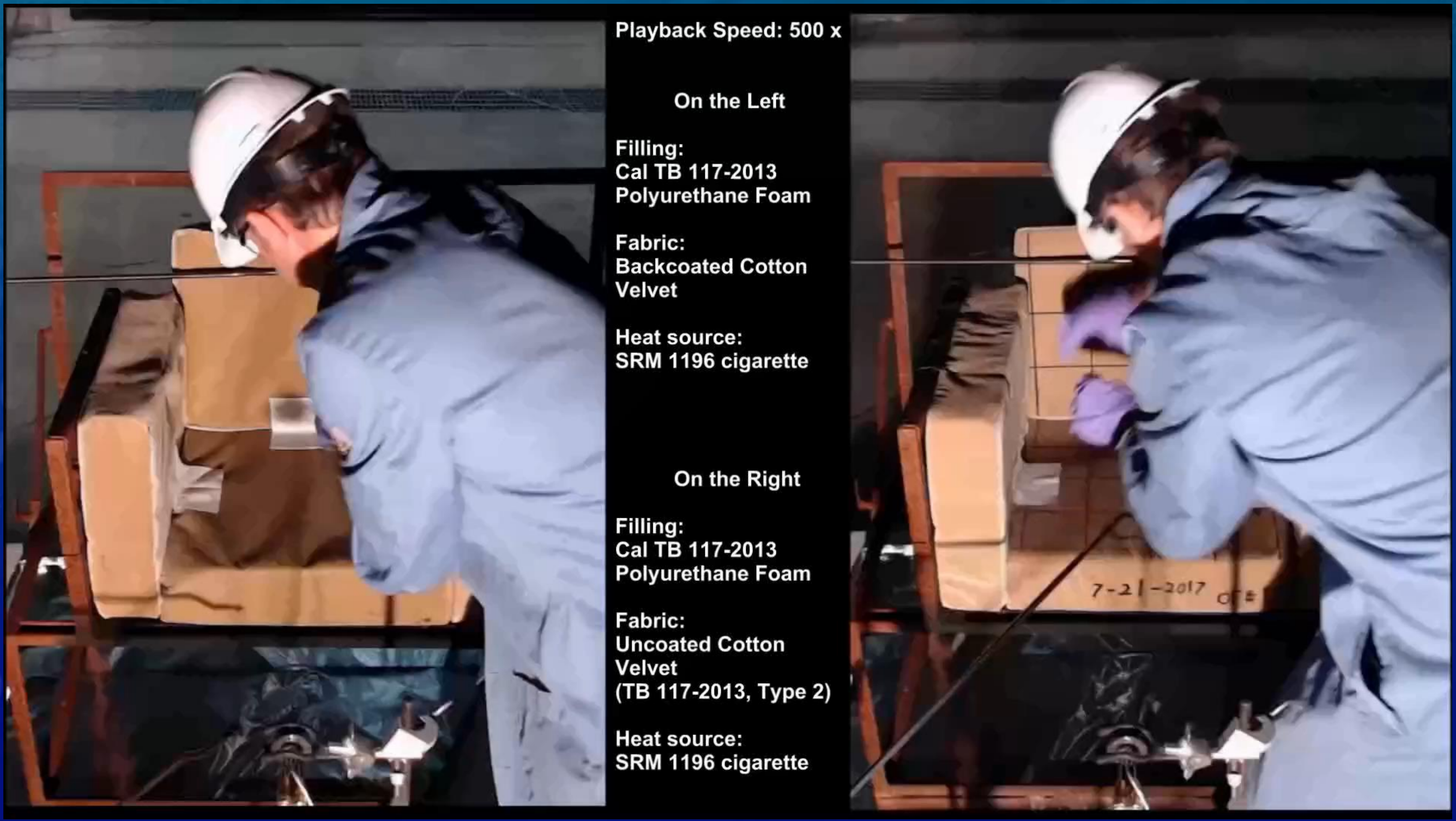
Backcoated sample after test

Backcoated sample without cover fabric

Uncoated sample after test

Smoldering Ignition Resistance

NIST Docket number:
15-026US1
U.S. PATENT
filed on April 21, 2016



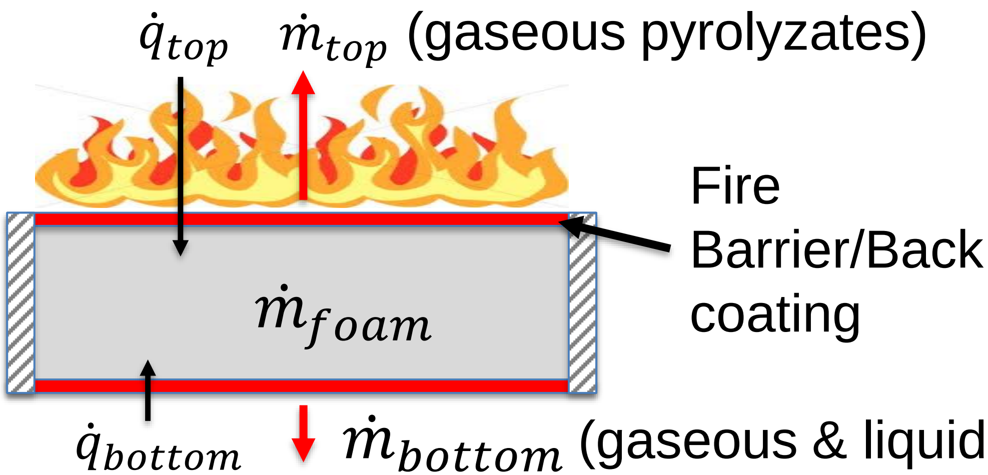
Backcoated

Uncoated

Fire Barriers

Reduce flammability without the use of chemical FRs by reducing

(1) Heat Transfer and (2) Mass Transfer (of pyrolyzates produced by foam decomposition)



Simplified Model of a burning cushion

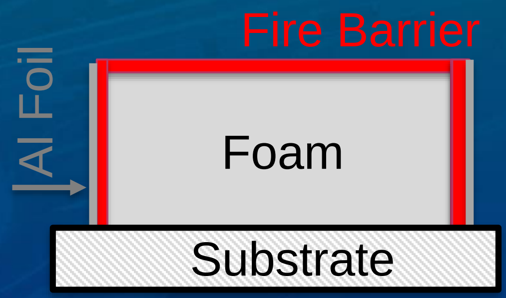
Challenge - Design a bench-scale test capable of capturing the effect of Heat Transfer and Mass Transfer on HRR of RUF after ignition

Cone Calorimetry for RUF

- CBUF Test (*de-facto* standard)

  Foam Size: ≈ 4″ × 4″ × 2″

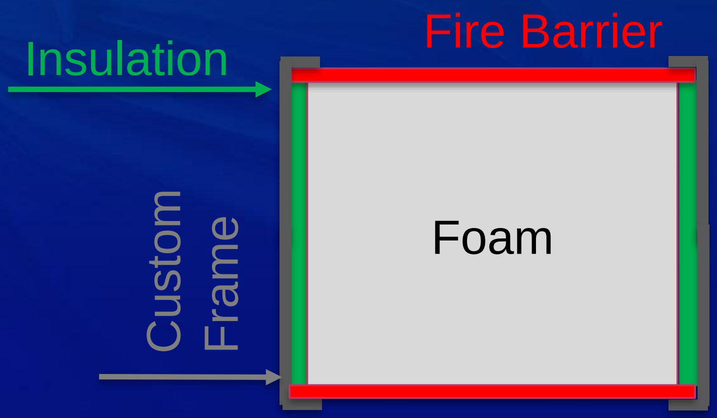
  ≈ (102 × 102 × 51) mm^3



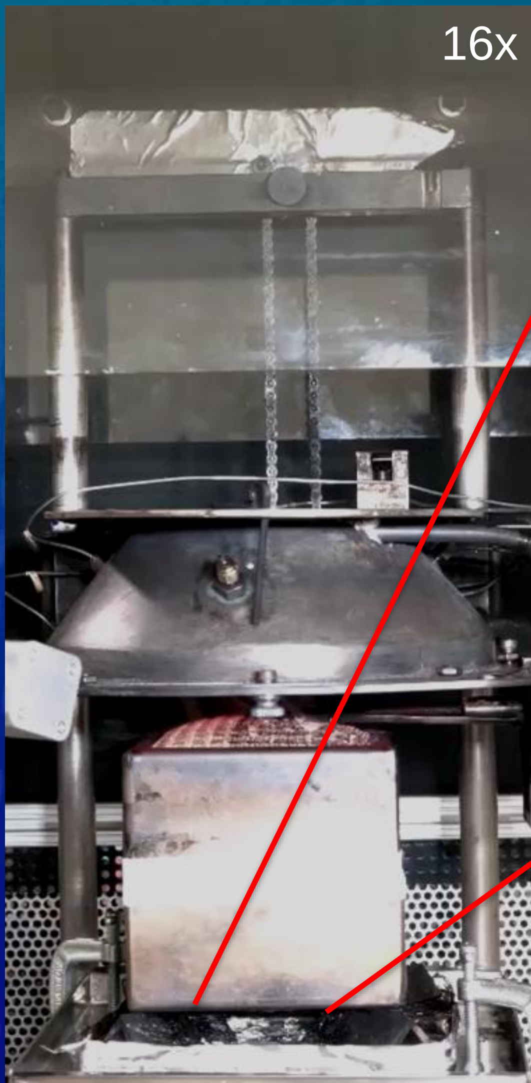
- NIST Cube Test

Foam Size: ≈ 4$_{1/4}$″ × 4$_{1/4}$″ × 4$_{1/4}$″

≈ (108 × 108 × 108) mm^3



Cube test: capturing mass transfer effects



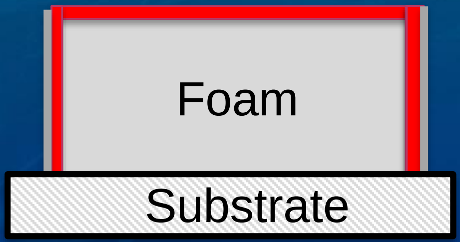
POOL FIRE!

Combustion Efficiency ↓

Fabric to Foam ratios

	Area$_{fabric}$/Volume$_{foam}$ (m^{-1})
RUF Cushion*	19.1
Cube	19.0
CBUF	58.8

CBUF Test

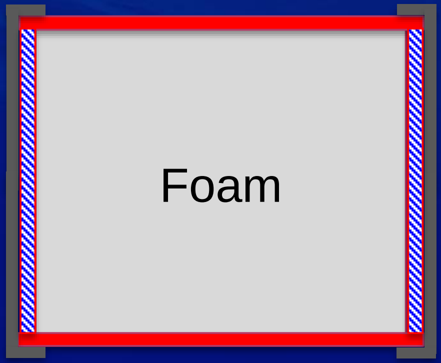


*(610×737×152)cm^3≈ (24×29×6)in.^{3}

For ρ_{foam}=29 kg/m^3 and ρ_{fabric}= 0.4 kg/m^2

	Mass$_{foam}$/Mass$_{fabric}$
RUF Cushion*	3.8
Cube	3.8
CBUF	1.2

CUBE Test

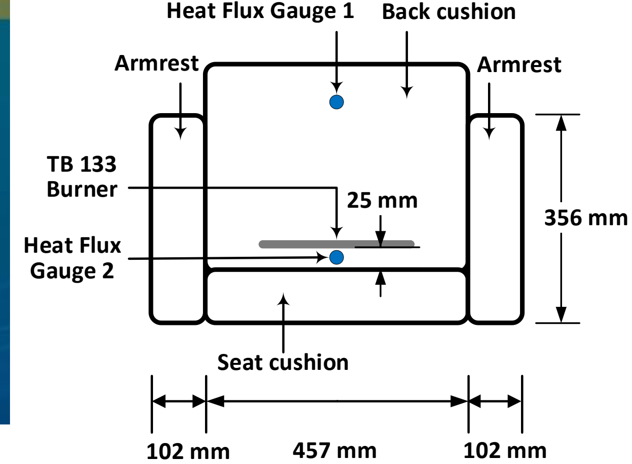


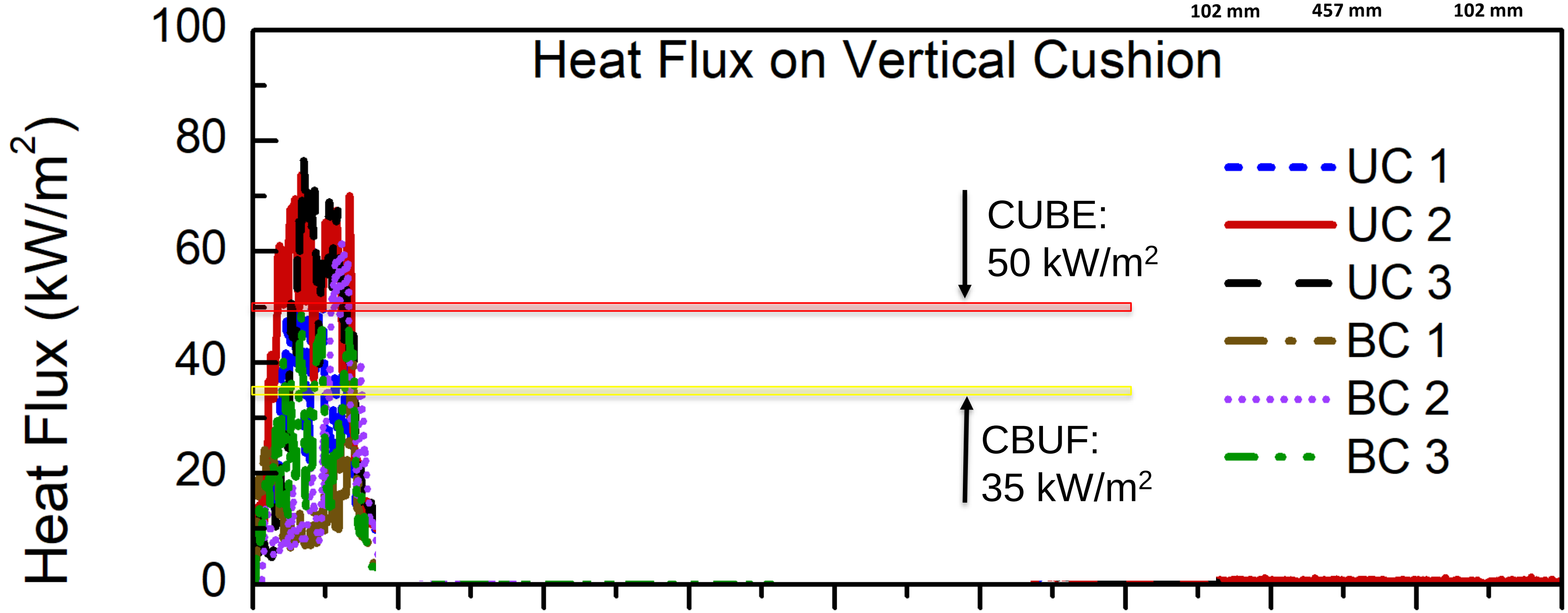
CBUF Test: Sample Preparation (≈30 min+24h)

Cube Test: Sample Preparation

Which Heat Flux?

Heat Flux measured in full-scale mock-ups





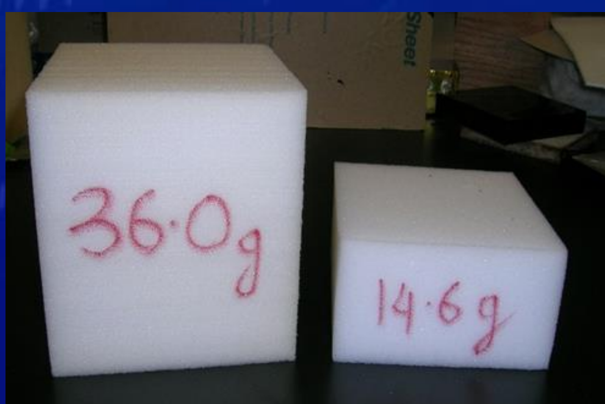
Incident Heat Flux can reach values up to 70 kW/m^2
⇒ 50 kW/m^2 adopted in the Cube test

Correlation between CUBE and CBUF tests

- 11 Commercial Barriers were tested in triplicate tests in the CUBE and CBUF test
  - Type barrier: woven, non-woven, knitted, backcoated
  - Thickness range: 0.5 mm to 10 mm
  - FRs: X, Sb, P, N, Si

- 1 Foam:

  - No-FR, TB117-2013 foam

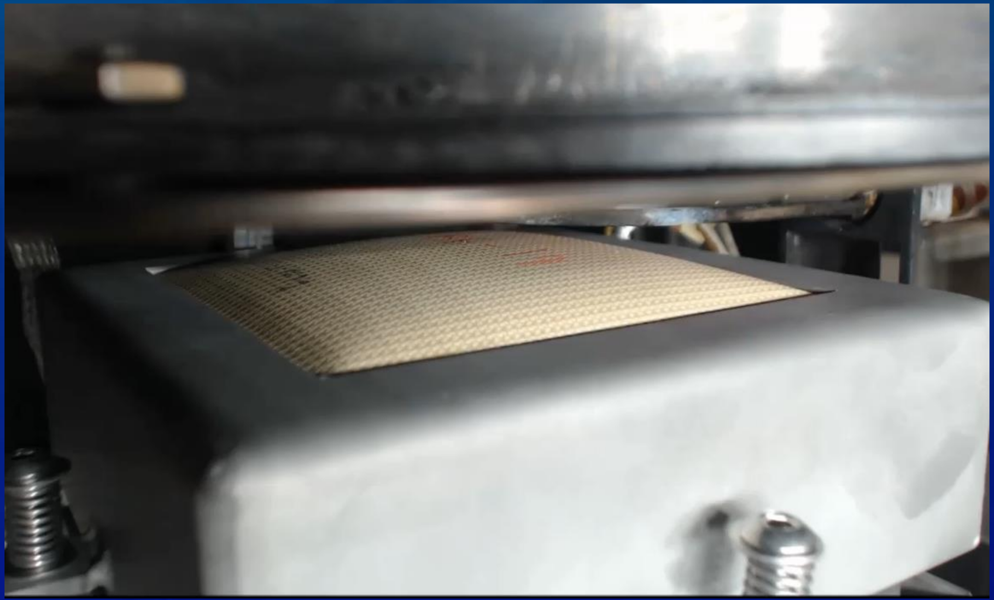


Edge Effects

BF19 - External Heat Flux: 50 kW/m2

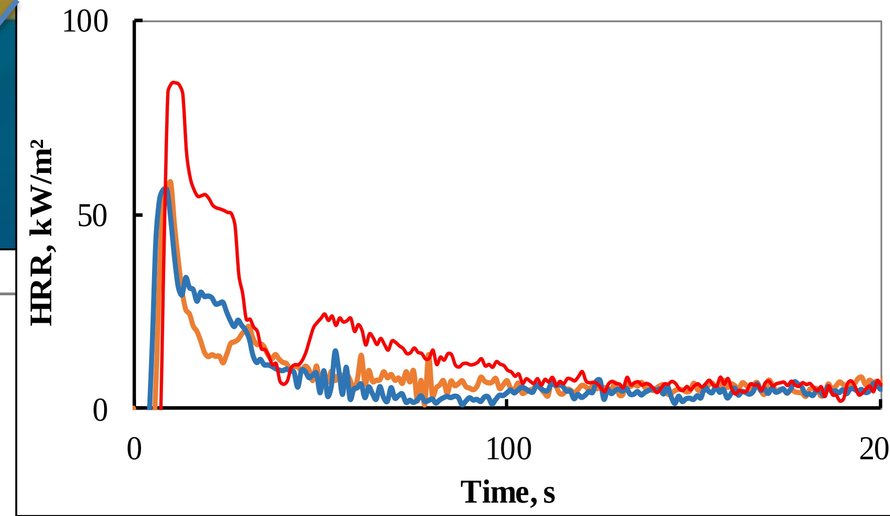
Playback Speed: 32x

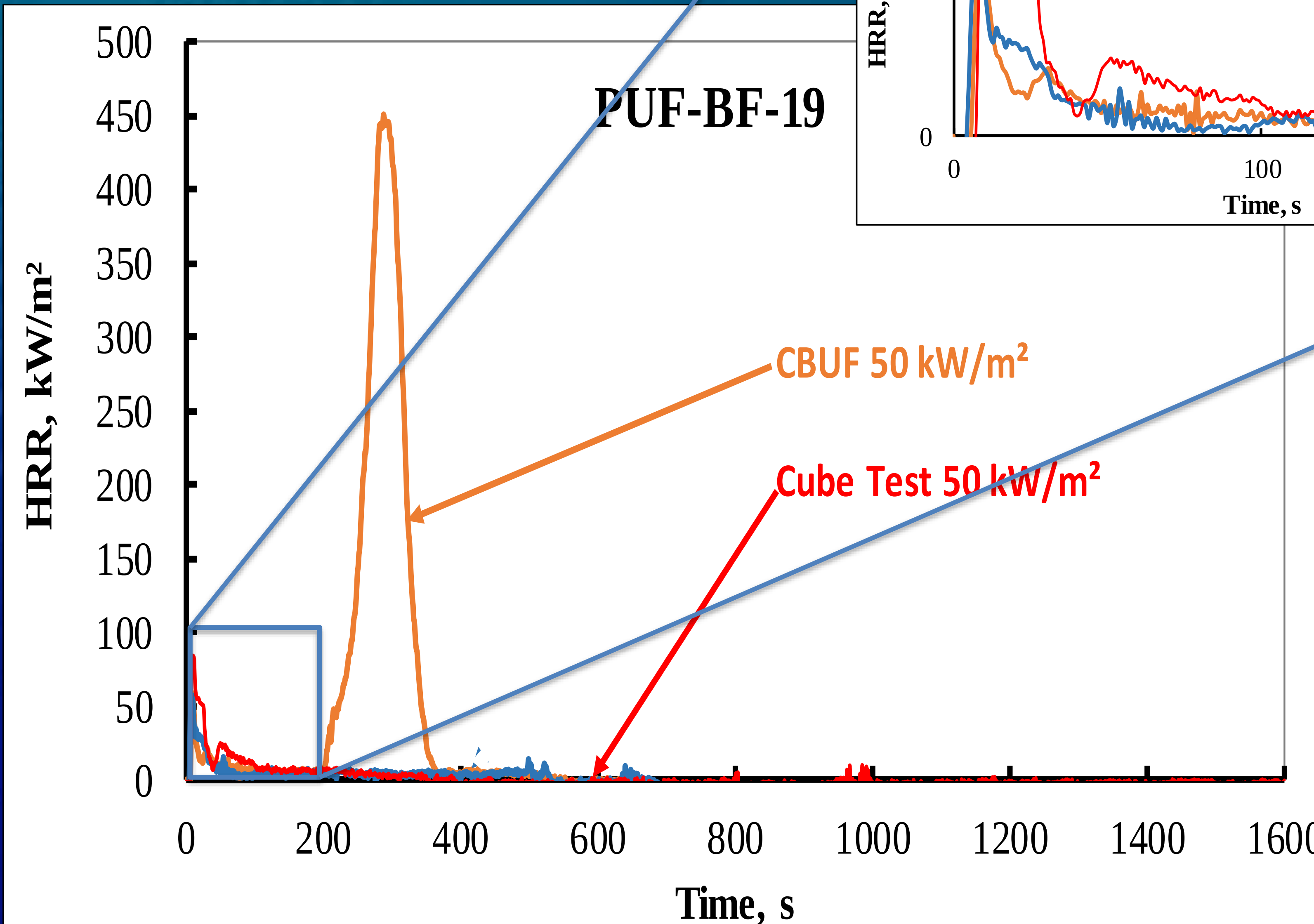
CBUF



Cube Test

Edge effects





Failure Induced by Barrier Shrinkage

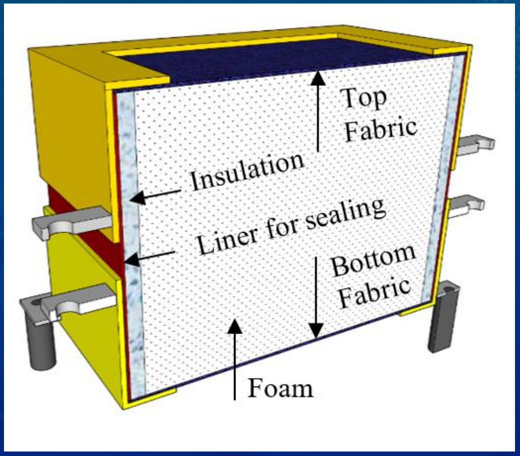
Certain fire barriers tend to shrink (e.g., cellulosics)

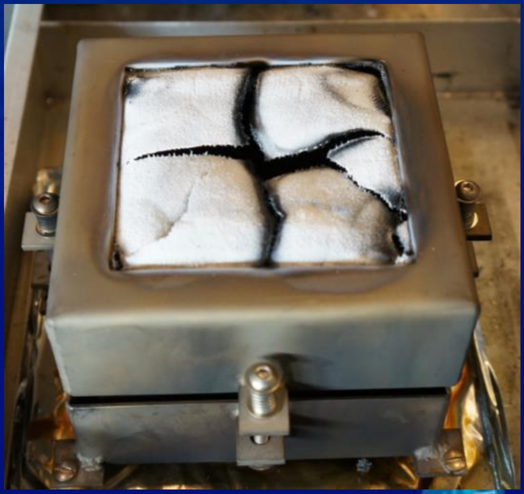
CBUF:
Barrier is not constrained

No stress induced failure

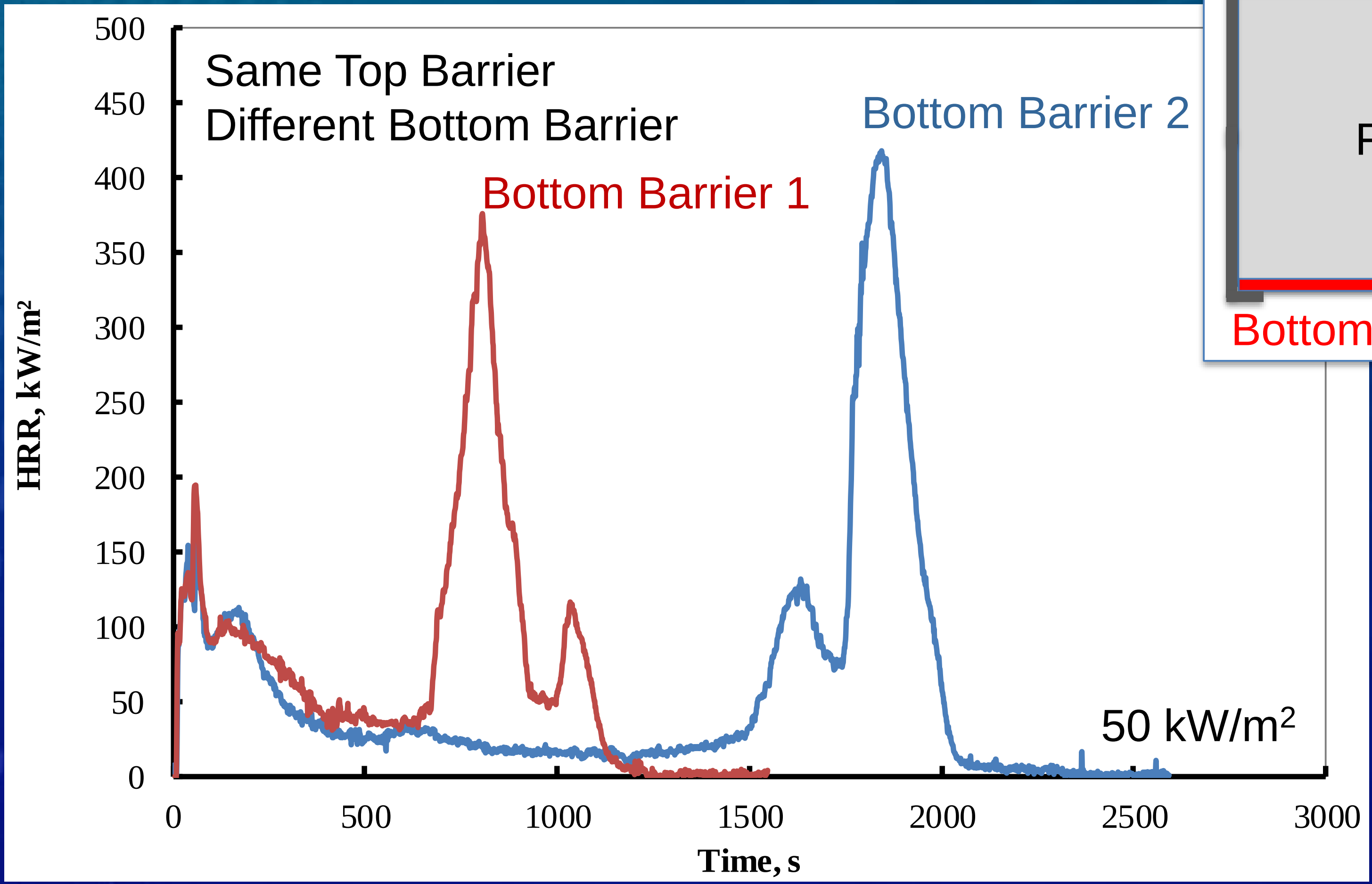
Cube Test:
Barrier is constrained by edge seal

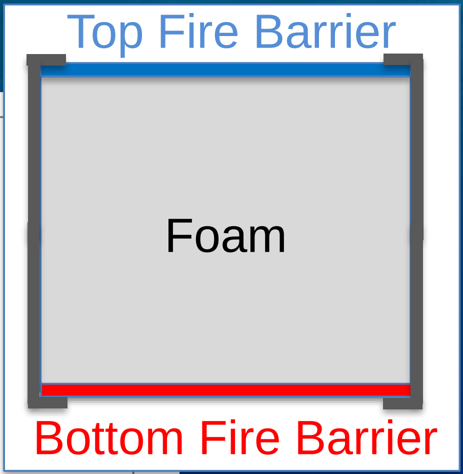
Shrinkage induces stress and possible failure





Cube Test: Effect of Bottom Upholstery Fabrics



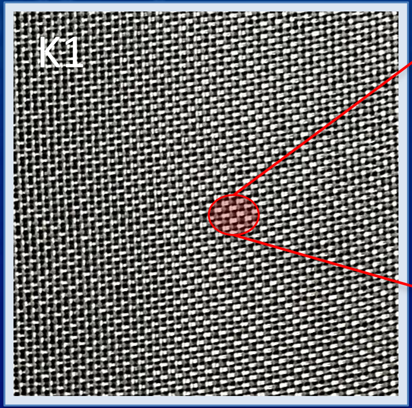


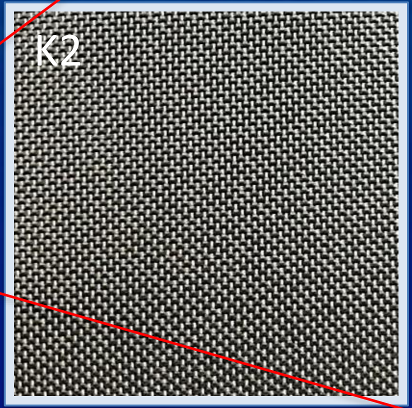
The cube test captures the effect of bottom fire barrier

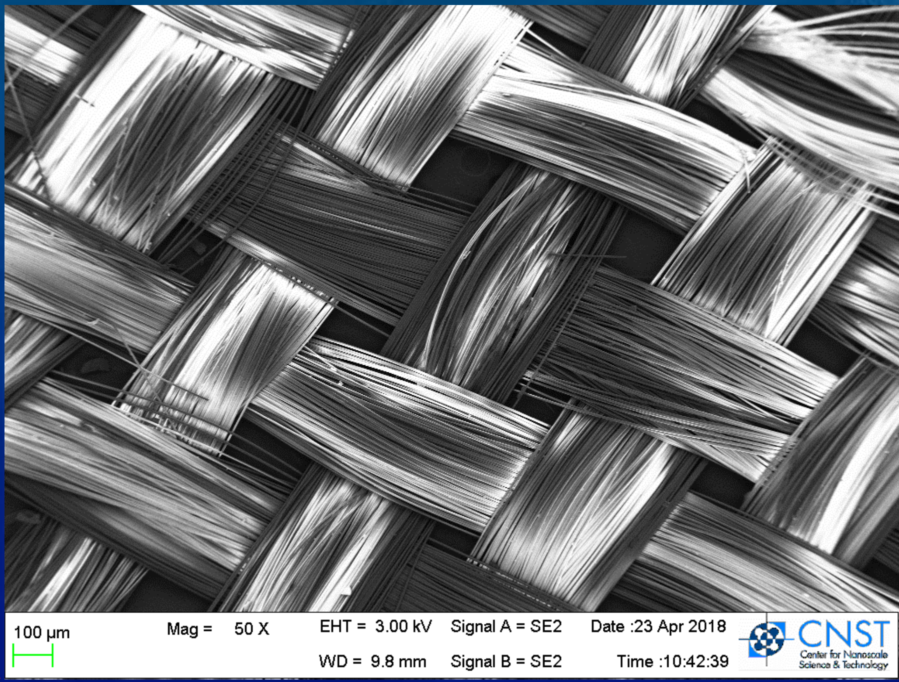
FR-free barriers: Glass Fabrics

3 fabrics (K1, K2, K3), 100% Glass, no sizing

	Density (g/m^2)	Glass (%)	Permeability (L/s)
K1	46 ±2	100	158 ±35
K2	102 ±1	100	53 ±11
K3	102 ±2	100	81 ±26



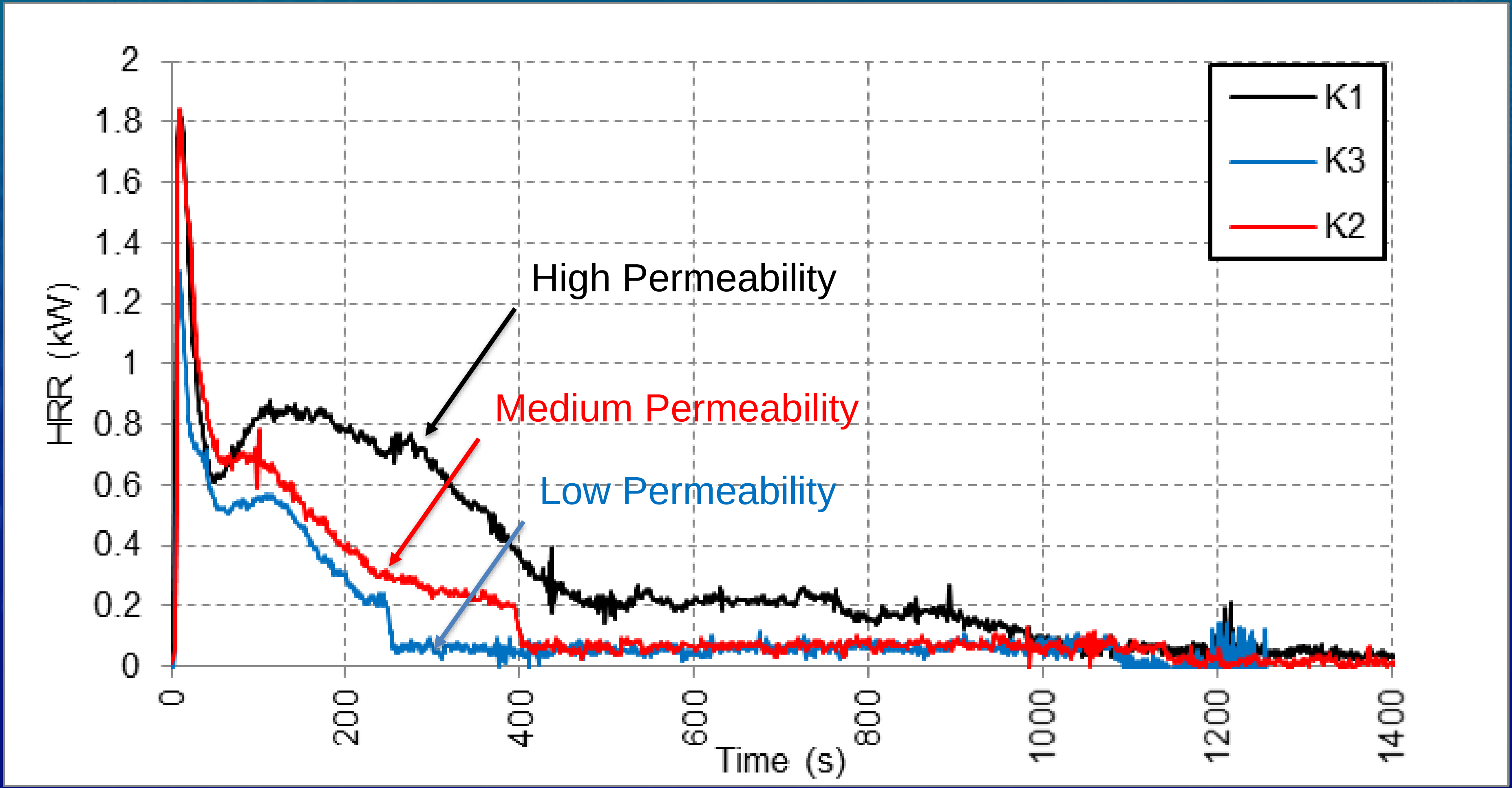




Pictures of the 3 glass fabrics (25 mm by 25 mm)

K1: Plain weave, nominally 48.5 g/m^2 (1.43 oz/yd^2)
K2: Plain weave, nominally 107.1 g/m^2 (3.16 oz/yd^2)
K3: Satin weave, nominally 107.1 g/m^2 (3.16 oz/yd^2)

Glass Fabrics as Fire Barriers – Cube Performance



Glass fabrics appear to be very effective even at a very low areal densities of 46 g/m^2

In a typical cushion the glass would account for less than 3 % of the mass of the cushion

Glass Fabrics as Fire Barriers – Summary

	ti (s)	PHRR (kW)	AHR (kW)	THR (KJ)	EHC (MJ/kg)	Foam ML (%)
Foam	2 ±1	10.2 ±0.3	4.6 ±0.2	938 ±15	27.0 ±0.3	97 ±2
K1+Foam	3 ±1	1.8 ±0.1	0.35 ±0.14	461 ±24	21.2 ±0.2	58 ±4
K2+Foam	5 ±1	1.4 ±0.1	0.17 ±0.03	238 ±71	13.9 ±0.7	47 ±11
K3+Foam	5 ±1	1.7 ±0.1	0.16 ±0.02	237 ±17	16.8 ±0.9	39 ±2

The use of glass fabrics as fire barriers induces:

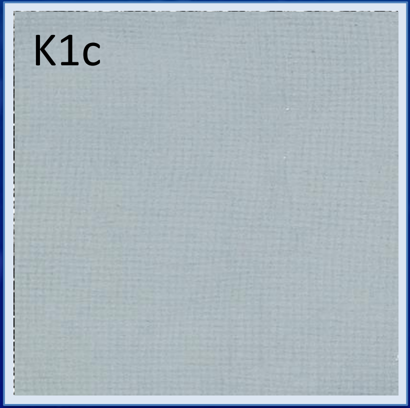
- 6- to 7-fold reduction in PHRR
- 1.3- to 2-fold reduction in EHC

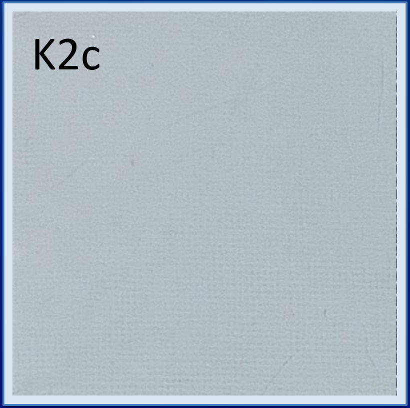
Combustion Efficiency ↓

Glass Fabrics + Silicone Coating

SILICONE COATING FORMULATION:

- Vinyl terminated PDMS crosslinked by Pt-catalyzed hydrosilation.
- Vinyl-modified aluminum-hydroxide (65 % by mass)
- vinyl-modified nanosilica (13 % by mass)
- Ethyl acetate (solvent)



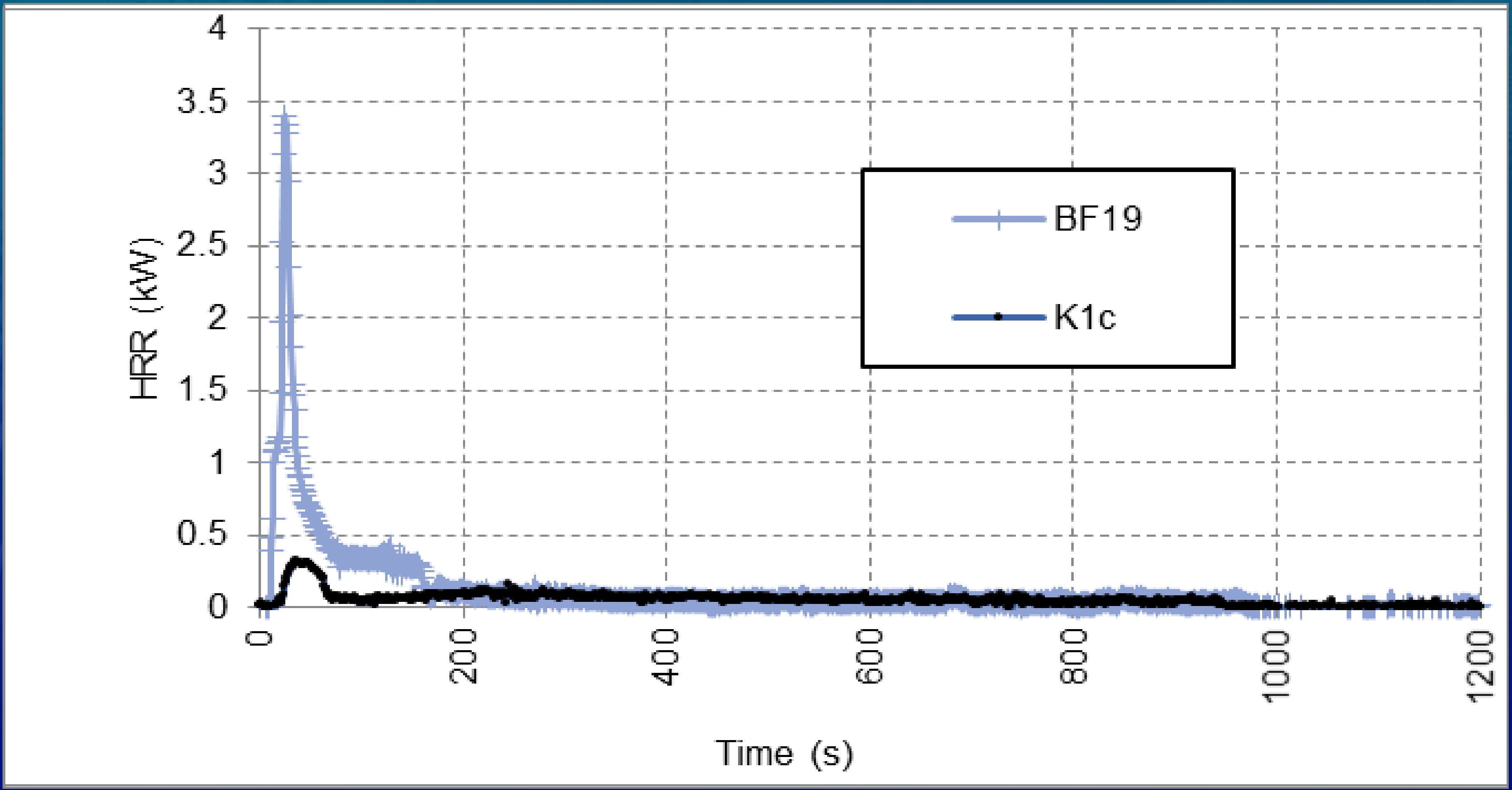


	Density (g/m²)	Glass (%)
K1c	244 ±18	30 ±2
K2c	390 ±37	41 ±4
K3c	429 ±34	36 ±5

Sample size shown (25 mm by 25 mm)

Case Western Reserve University:
Kimberly DeGracia, PhD Candidate,
Prof. David A Schiraldi

Glass Fabrics + Silicone Coating – Cube



Glass Fabrics + Silicone Coating – Cube

	Ignition time (s)	Peak HRR (kW)	AHR (kW)	THR (KJ)	EHC (MJ/kg)	Mass Loss (%)
Foam	2 ±1	10.2 ±0.3	4.6 ±0.2	938 ±15	27.0 ±0.3	97 ±2
K1+Foam	3 ±1	1.8 ±0.1	0.35 ±0.14	461 ±24	21.2 ±0.2	55.4 ±3.7
K2+Foam	5 ±1	1.4 ±0.1	0.17 ±0.03	238 ±71	13.9 ±0.7	42.6 ±10.3
K3+Foam	5 ±1	1.7 ±0.1	0.16 ±0.02	237 ±17	16.8 ±0.9	35.1 ±1.5
K1c+Foam	25 ±4	0.3 ±0.02	0.051 ±0.003	55 ±7	-	5.9 ±0.25
K2c+Foam	35	0.58	0.05	54	-	2.33
K3c+Foam	31	0.62	0.04	51	-	2.9

The addition of the coating to the glass fabrics induces:

- 7-fold increase in ignition time
- 2- to 8-fold reduction in Peak HRR
- 9- to 18-fold reduction in Mass Loss of the foam

Conclusions

- NIST developed silicone backcoatings have proven to be an effective all-in-one solution for fire-safe RUF
- A bench-scale test for fire barriers has been developed at NIST
- Glass Fabrics appear to be effective Fire Barriers

Ongoing NIST research (Real-scale tests):

- Feasibility of Low Heat Release Furniture without FRs
- Full-scale performance prediction by Cube test

THANK YOU!

Acknowledgements:

Flammability Reduction Group, NIST:
Shonali Nazaré, Randy Shields, Ickchan Kim, Andre Thompson, William M. Pitts, Sung Chan Kim, Isaac Leventon, Anthony Hamins, Dick Gann, Rick Davis

Case Western Reserve University:
Kimberly DeGracia, PhD Candidate,
Prof. David A Schiraldi

Contact Information:
Mauro Zammarano
Phone: 301-975-5244
e-mail: mauro.zammarano@nist.gov