SFPE Member Webinar Series
May 24, 2021

Understanding and Reducing the Fire Risk of Residential Upholstered Furniture Fires

www.nist.gov/el/fire-research-division-73300/flammability-reduction-73304/low-heat-release-upholstered-furniture

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Some of the data in this presentation hasn't been through the NIST review process and should be considered experimental / draft results.

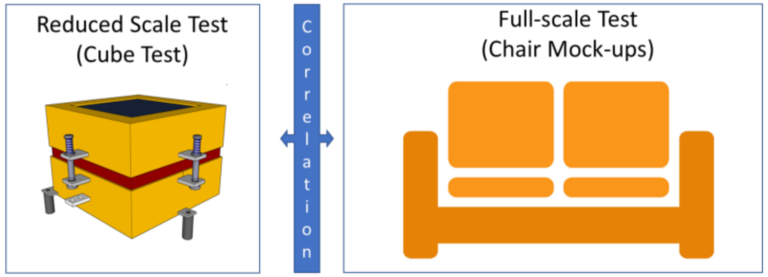
“Low Heat Release Upholstered Furniture” Project

Project Goal: to conduct research aimed at helping U.S. industries’ efforts to reduce the fire losses associated with residential upholstered furniture fires.

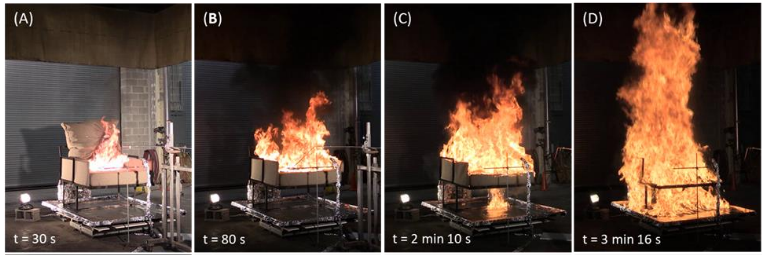
What do we do?

- Maintain and develop standard reference cigarettes required for smoldering ignition resistance classification

- Develop bench-scale tests to predict full-scale performance in smoldering and flaming scenarios



- Provide a methodology and guidance on non-fire-retardant mitigation strategies



Outline

- Introduction: Background Information and Objectives
- PART 1
  Smoldering Hazard → Cigarette Ignition Tests; SRM Cigarettes
- PART 2
  Flaming Hazard → Barrier Fabrics → Why BF? Action mechanism? Failure mechanism? Full scale-performance? Performance Prediction?
- Conclusions

Residential Upholstered Furniture (RUF): Fire Losses

- 74 % of U.S. fire deaths and injuries occur in home fires [1]
- RUF persists as the **leading cause of residential fire deaths*** in U.S [1,2]

  - 570 civilian deaths (about 22 % of civilian deaths in home fires)
  - 900 civilian injuries
  - $357 million in direct property damage

  yearly averages 2013-2017

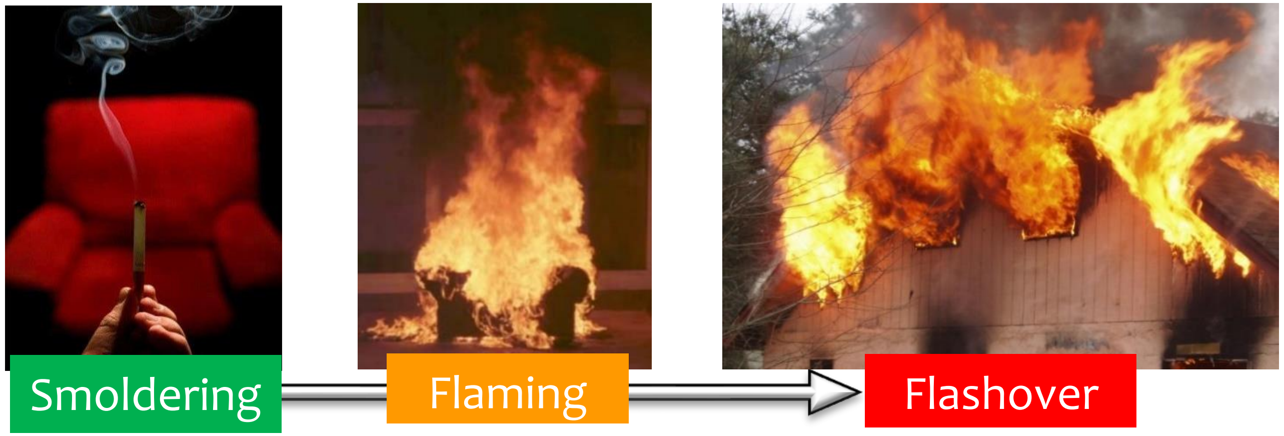
  *followed by cooking (21 % fire deaths), heating (19%) electrical (19%) and mattress/bedding (14%)
- RUF fires are about fourteen times (14 x) more likely to result in fire deaths than other home fires [2]
- Deadly RUF fires are more likely to start with a smoldering source (about 55 %) rather than a flaming source [3]
- Independent of ignition source, most RUF fire deaths occur as a result of flaming, often after transition from smoldering to flaming [4]
- About 70% of RUF fire deaths occurs in fires that reach flashover [5]

[1] Home Structure Fires, National Fire Protection Association, 2019
[2] Ahrens, M. "Soft furnishing fires: They're still a problem" Fire and Materials 2021;45:8–16
[3] Hall JR. Estimating Fires When a Product is the Primary Fuel But Not the First Fuel, With an Application to Upholstered Furniture. Fire Technology. 2015;51(2):381-391
[4] Pitts W., NIST TN1757r1 - Summary and Conclusions of a Workshop on “Quantifying the Contribution of Flaming Residential Upholstered Furniture to Fire Losses in the U.S.” NIST; August 2013, https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1757r1.pdf
[5] M Ahrens, Home Fires That Began With Upholstered Furniture February, 2017, www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/US-Fire-Problem/Fire-causes/osupholstered.pdf

How can we reduce RUF fire losses?

1. Fire Prevention

increasing resistance to flaming and smoldering ignition sources
(safest approach, not always feasible especially without FRs)



2. Fire Mitigation

decreasing heat release rate
(less effective than fire prevention, feasible without FRs)

PART 1: SMOLDERING RISK REDUCTION

- Fire Testing for Upholstered Furniture
  - **Fire Prevention**: Increase in Ignition Resistance
    - **Smoldering Ignition Resistance Test**
    - Flaming Ignition Resistance Test
  - **Fire Mitigation**: Burning Rate Reduction
    - Heat-Release-Rate Test

Fire Testing Classification for Upholstered Furniture

PART 1: SMOLDERING RISK

1. Maintain/develop SRMs (cigarettes)

- **SRM 1196a**

(high ignition propensity cigarette - certified on 2/18/2020)

required for 16 CFR Part 1632, NFPA 260/261 and ASTM 1353/1352

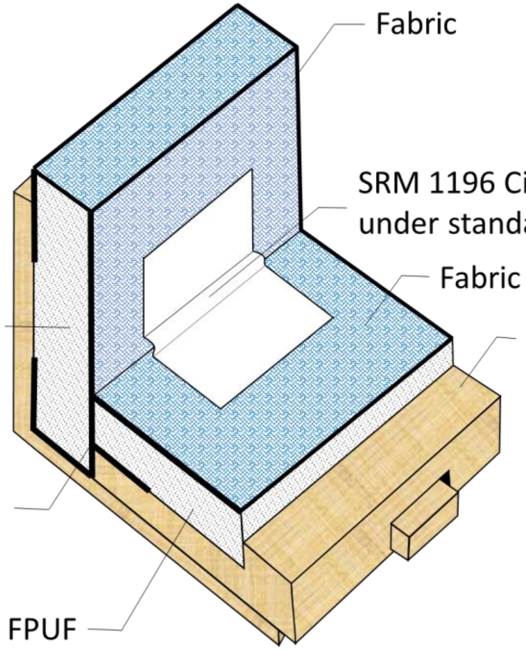
- **SRM 1082**

(reduced ignition propensity, RIP, cigarette, required to verify compliance of commercial cigarettes with RIP criteria)

2. Develop bench-scale tests:

- Cigarette ignition strength (ASTM E2187-20a)
- Bench-scale tests for the classification of upholstery materials smoldering propensity

Cal TB117-2013 to be adopted as Federal Standard



Based on NIST research [1]

TB117 underestimates smoldering propensity of RUF: not able to predict smoldering ignitions observed at full-scale (Cal TB116) in (37 to 40)% of the cases [2].

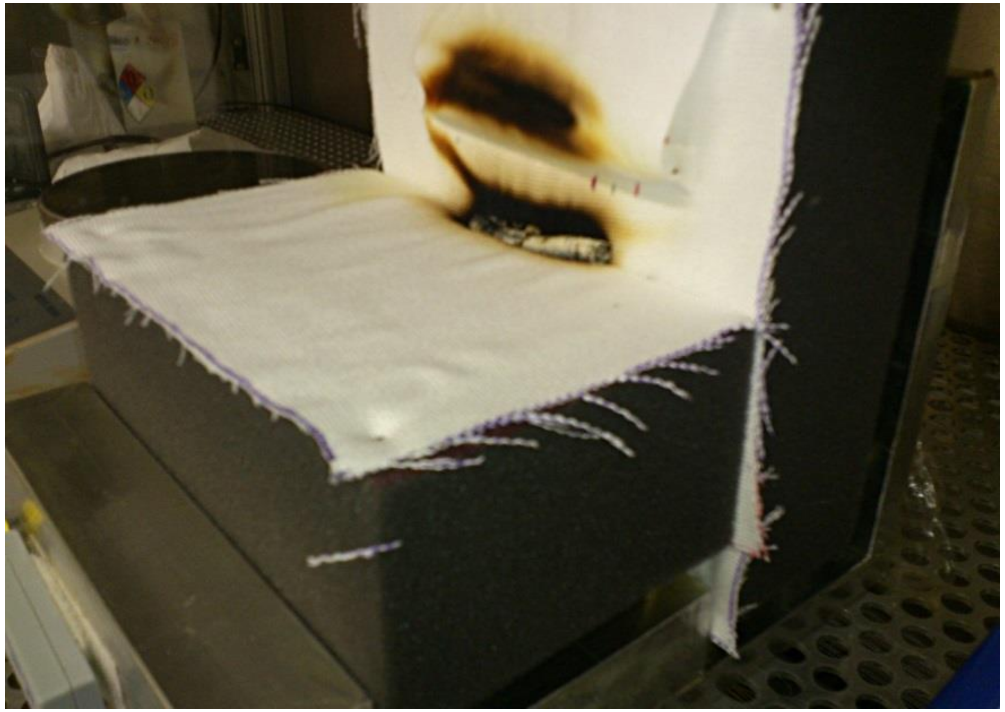
NIST research aims to improve the correlation between smoldering bench-scale tests (TB117-2013, UFAC, ASTM E1353, NFPA 260) and full-scale performance.

Two major proposals based on NIST research were submitted to NFPA Committee on Fire Tests:

- "Concealed smoldering" (accepted and moved to the next stage)
- Modification of testing apparatus (deferred)

[1] J.J. Loftus, Test Method for Classifying Cigarette Ignition Characteristics of Upholstered Furniture, NBS report to CPSC, March 6, 1975
[2] Jiuling Yang, Guillermo Rein, Haixiang Chen, Mauro Zammarano, J. Applied Thermal Engineering, 181 (2020) 115873

"Concealed" Smoldering in Bench-Scale testing

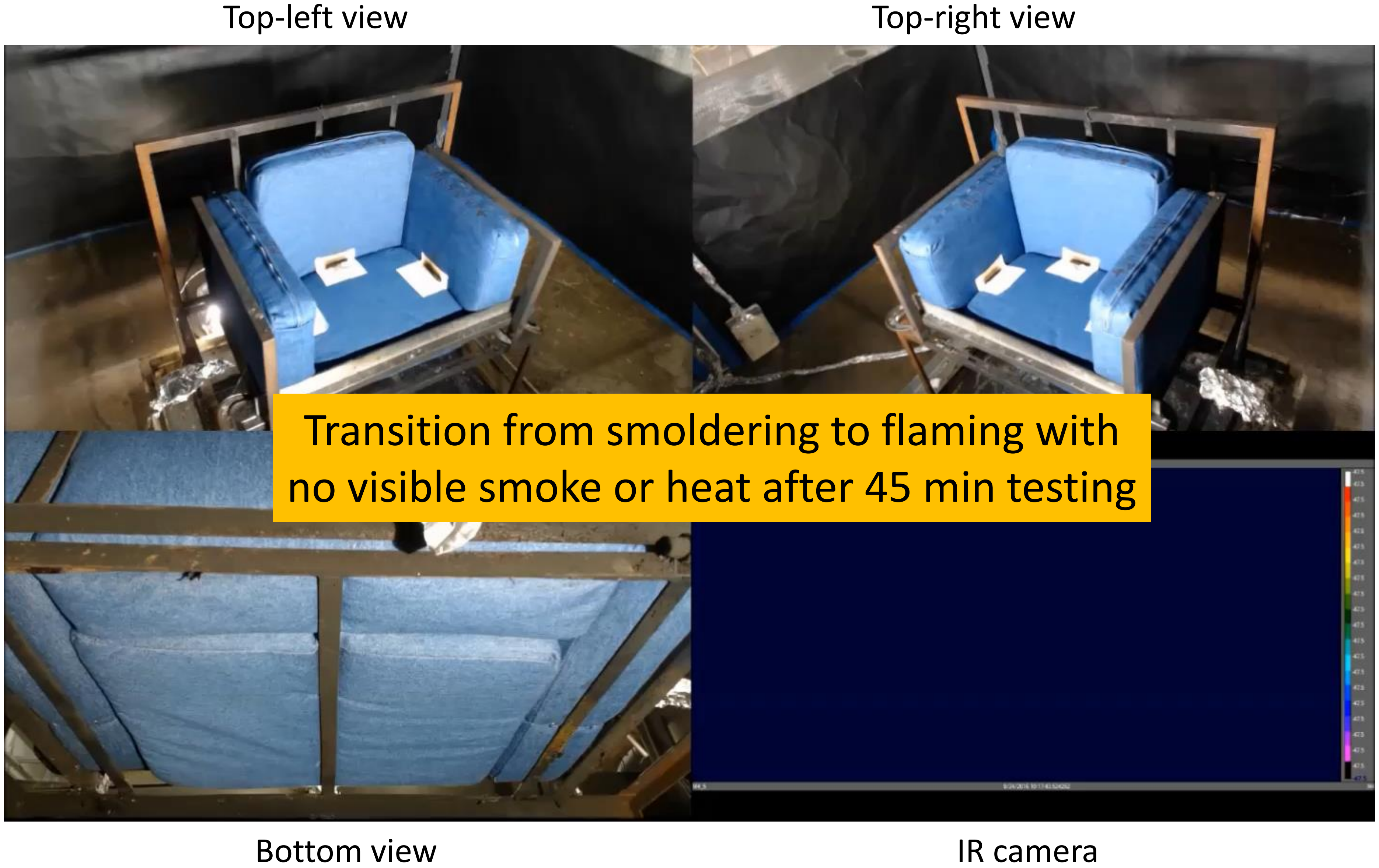


No obvious ignition (smoke or glowing generation) at the end of the 45 min test duration

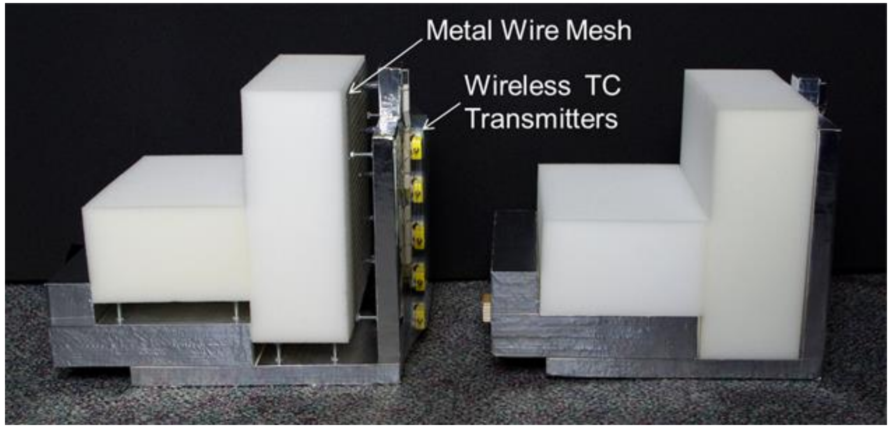
Obvious glowing and smoke generation inside the crevice when the two panels are separated at the end of the test.

The two foams panels shall be separated at the end of the test to exclude the presence of concealed smoldering

Effect of “Concealed” Smoldering in Full-Scale Tests



Modification of testing apparatus

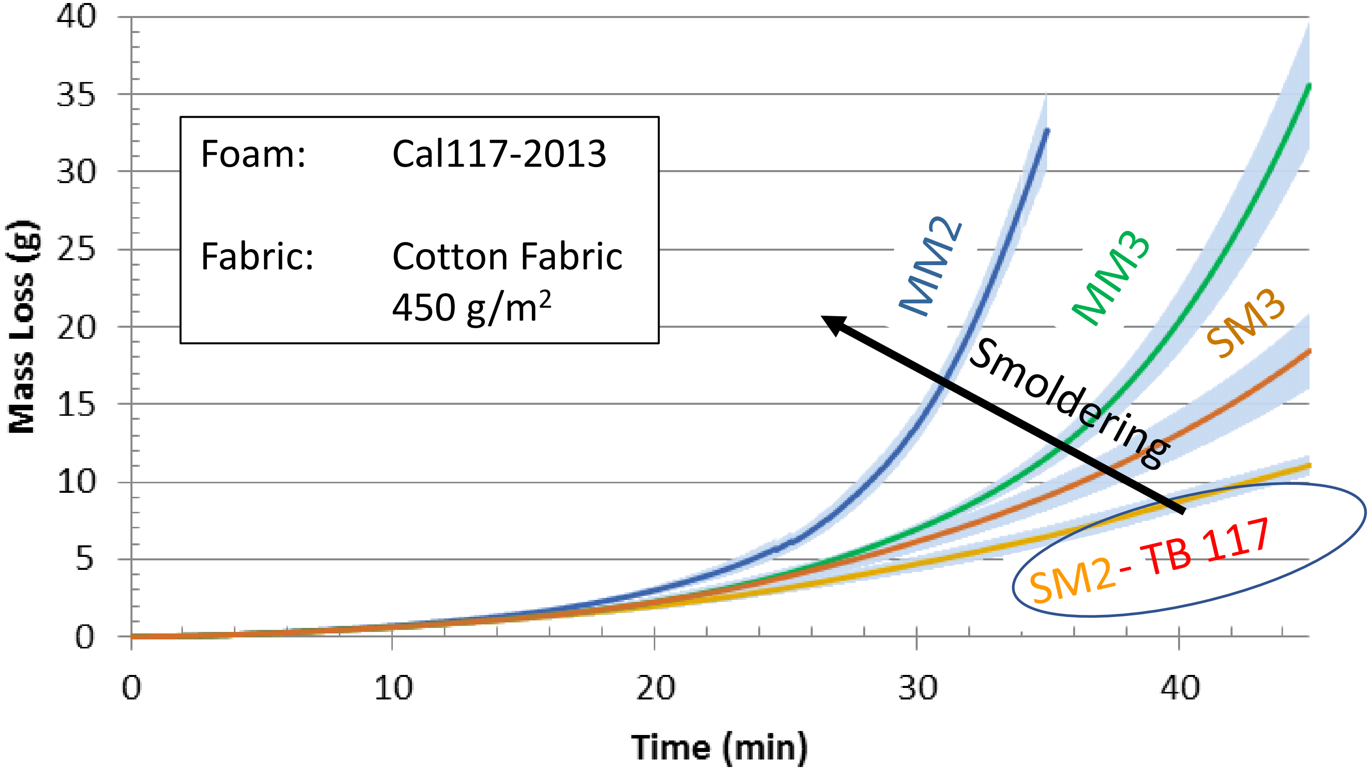


MODIFIED MOCKUP (MM)

STANDARD MOCKUP (SM)

FOAM THICKNESS: either 51 mm or 76 mm

SM2: standard mock-up, 51 mm thick foam
SM3: standard mock-up, 76 mm thick foam
MM2: modified mock-up, 51 mm thick foam
MM3: modified mock-up, 76 mm thick foam

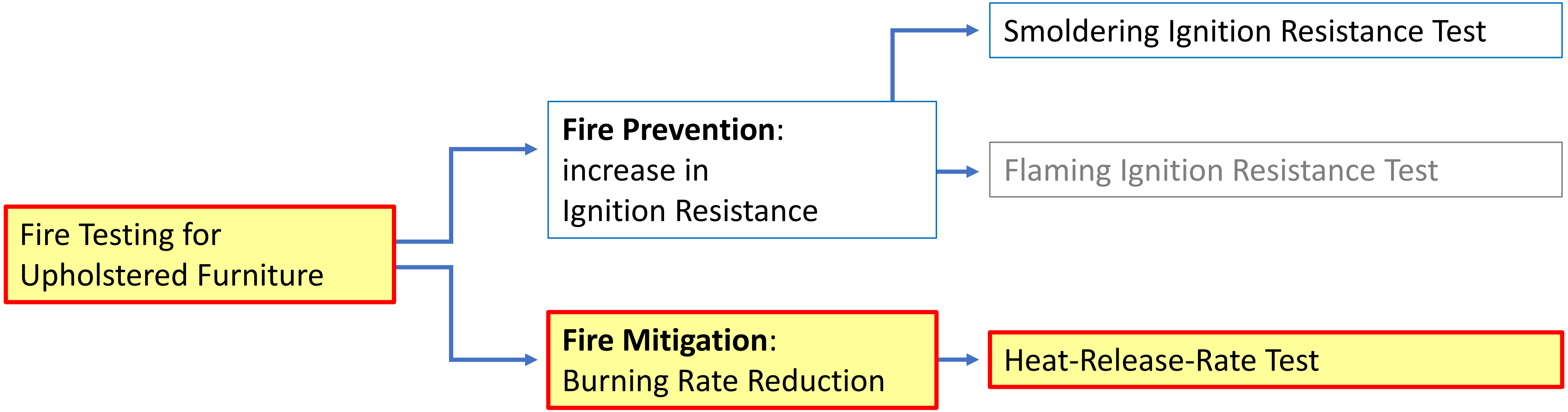


Dynamic mass loss (average and 1 standard Deviation) (3 tests)

$\Rightarrow$ **5-fold increase in Mass Loss at 35 min** [1]

[1] Jiuling Yang, Guillermo Rein, Haixiang Chen, Mauro Zammarano, J. Applied Thermal Engineering, 181 (2020) 115873

PART 2: FLAMING RISK REDUCTION



Fire Testing Classification in Upholstered Furniture

Fire Mitigation: A Success Story

From www.flammabilitytestingequipment.com/

16 CFR Part 1633, CPSC:

- flaming regulation for mattresses, introduced in 2007,

  Heat Release Rate (HRR) < 200 kW
- based on NIST test method and analysis showing the HRR range that would lead to measurable and significant life savings
- allowed a **reduction of ≈ 70 % in fire deaths** from bed fires with about 50 % to 80 % of the mattresses replaced so far [1]
- unquestionably demonstrated the effectiveness of fire mitigation strategies

→ **Comparable reduction in fire deaths expected in RUF with the implementation of Fire Mitigation Technologies**

[1] SW Gilbert, DT Butry RD Davis RG Gann, April 2020, Estimating the impact of the mattress fire safety Standard 16 CFR Part 1633 on bed fire outcomes, Fire and Materials. 2021;45:17–27, https://doi.org/10.1002/fam.2932

Severe Restrictions on FRs in USA

FEDERAL LEVEL

[CPSC Docket No. CPSC–2015–0022, ’17 https://s3.amazonaws.com/public-inspection.federalregister.gov/2017-20733.pdf]

CPSC recommends refraining from intentionally adding nonpolymeric, organo-halogen FRs in:

- children’s products
- upholstered furniture (UF) sold for use in residences
- mattresses (and mattress pads)
- plastic casings surrounding electronics.

STATE LEVEL:

- **California State** [Assembly Bill 2998, 2018 https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB2998]

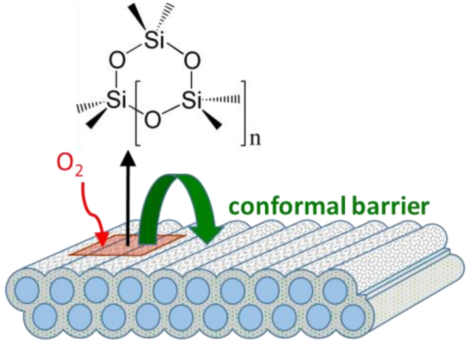
bans the use of FR based on halogenated, organo-phosphorous, organo-nitrogen, nanoscale chemical, chemicals of high concern in children’s products, mattresses, or upholstered furniture

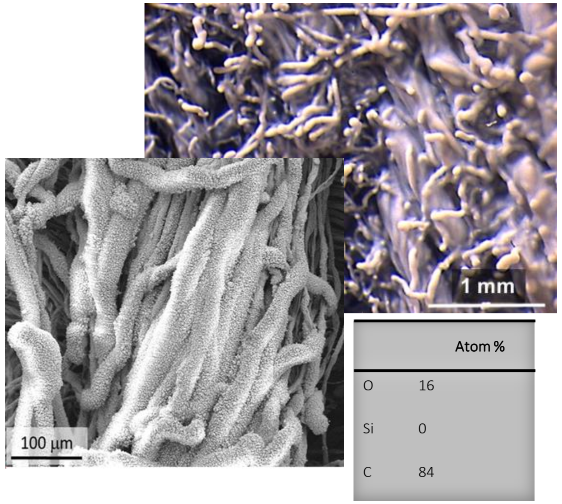
- **State of Maine** [HP013801 https://www.mainelegislature.org/legis/bills/bills_128th/billtexts/HP013801.asp]

first State to ban all flame retardants in RUF

Backcoating for Cover Fabrics

Silicone Backcoating





Backcoating Formulation: aluminum hydroxide and silicone - compliant with CA AB2998

[1] Zammarano et al., Adv. Mater. Interfaces 2016, 1600617 [2] www.nap.edu/catalog/9841/toxicological-risks-of-selected-flame-retardant-chemicals

Flaming (18 kw square burner)

Pristine fabric

Backcoated fabric

Smoldering

Pristine fabric

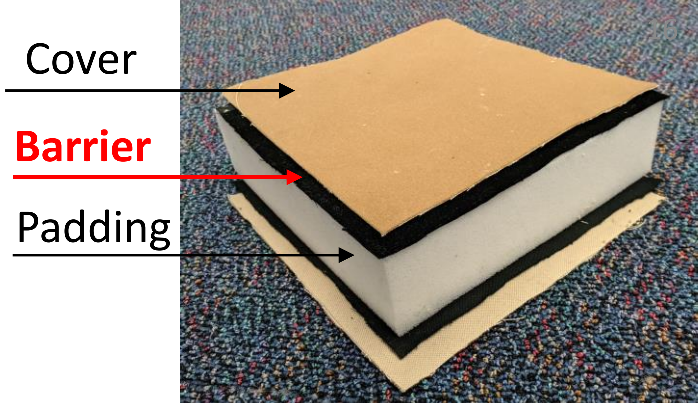
Backcoated fabric

All-in-one solution for Smoldering and Flaming Hazard Reduction

[2] www.nist.gov/el/fire-research-division-73300/flammability-reduction-73304/upholstered-furniture-fire-videos

Barrier Fabrics:

protective layers designed to decrease the HRR generated by the padding material (main contributor to fire growth in upholstered furniture).



Flame Reduction Mechanisms in Fire Barriers

- Chemical Mechanisms
  - Radical Trapping
  - Charring
- Physical Mechanisms
  - Heat Transfer Reduction
  - Mass Transfer Reduction
  - Endothermic Effects
  - Dilution Effects

BARRIERS

ACTIVE

- exploit chemical and physical mechanisms of flame retardancy
- rely on the use of Fire-Retardant Chemicals

PASSIVE

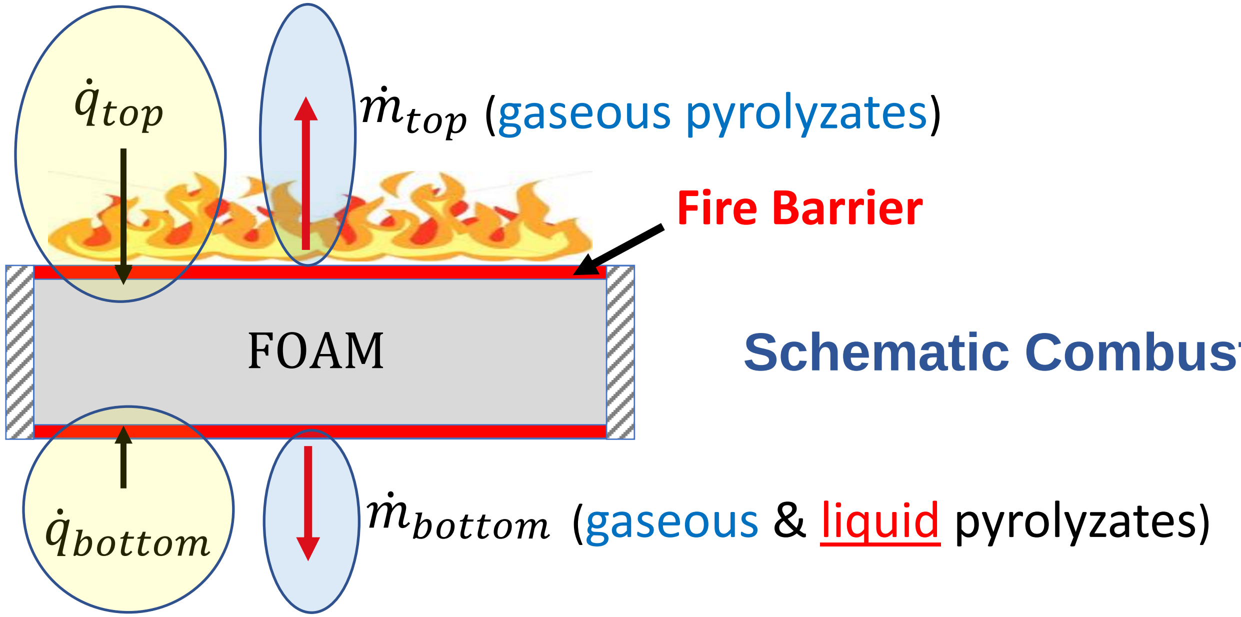
- exploit physical mechanisms of flame retardancy
- rely on intrinsically Fire-Resistant Fibers
- no Fire-Retardant Chemical required

Heat / Mass Transfer Reduction (Physical Mechanisms)

POLYMER PYROLYSIS

$$\textit{POLYMER} \xrightarrow{\text{Heat}} \textit{Gaseous products} + \textit{Liquid products}$$

Idealized cross-section of a RUF Cushion [1]



Schematic Combustion Process

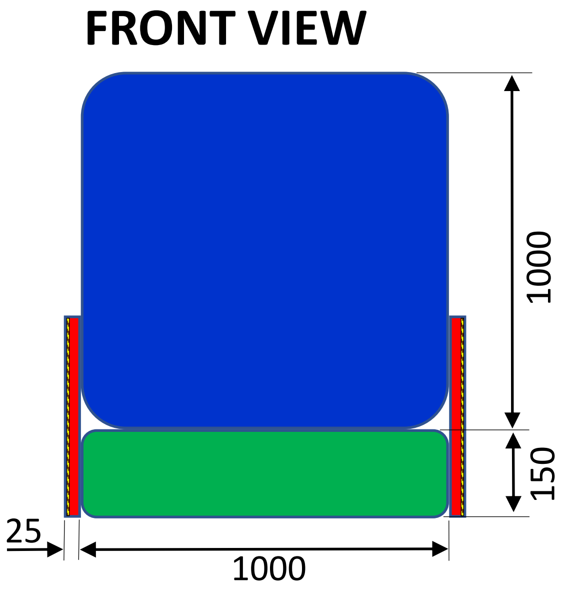
Two-fold mechanism of action:

(1) Limiting generation rate of flammable pyrolyzate (**Heat Transfer**)

(2) Limiting or controlling the rate and location at which pyrolyzates are released and able to burn (**Mass Transfer**)

[1] M. Zammarano, JR Shields, I Leventon, I Kim, S Nazare, AL Thompson, RD Davis, A Chernovsky, M Bundy, Reduced-scale test to assess the effect of fire barriers on the flaming combustion of cored composites: An upholstery-material case study doi.org/10.1002/fam.2910

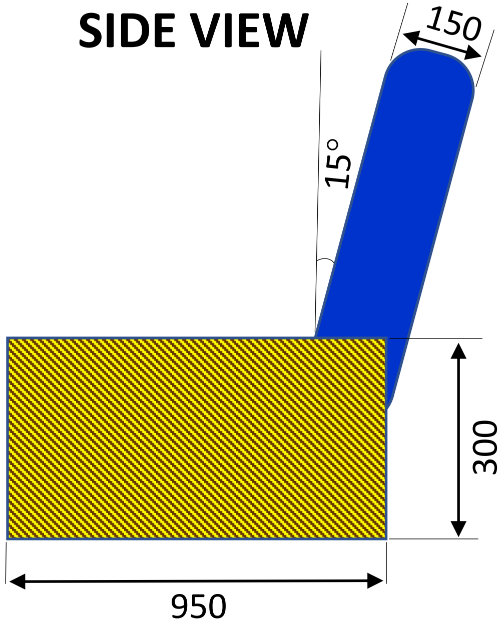
Case Study: Chair Mock-ups



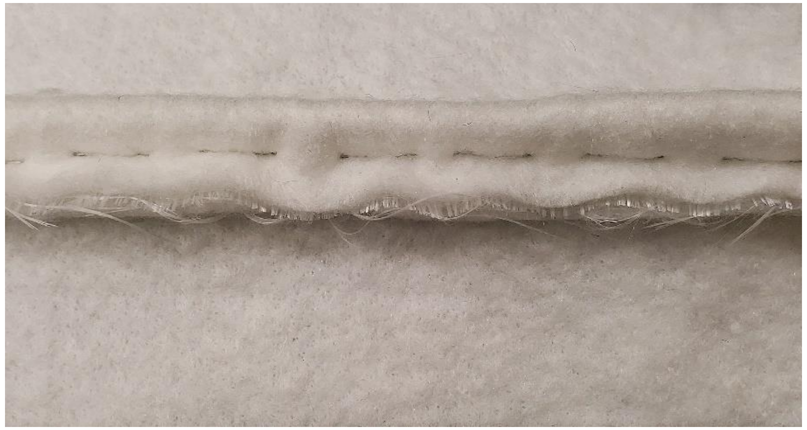
Back cushion (polyester fibers)
Seat cushion (TB117-2013 foam)
Armrest padding (TB117-2013 foam)
Armrest support (5 mm plywood)

Dimensions in mm

All chair components protected by FB



Seams (Metal Staples)



7 chair types:
Chair C0: cover fabric (C0) only
Chair B1 to B6: cover (C0) +1 barrier (B1 to B6)

7 chair types in triplicate tests: tot. of 21 chairs

B1 to B6 are expected to be compliant with California Bill AB 2998

Barrier and Cover Fabric Composition

(A) (B) (C) (D) (E) (F) (G)

- **C0**: PP cover fabric (Figure A)
- **B1**: bi-layer nonwoven fabric using polyester fibers as binder where the outer layer was made of regenerated cellulose/polysilicic acid fibers, and the inner layer was made of cotton fibers (Figure B)
- **B2**: woven (plain weave) fabric made of E-glass fibers without sizing, developed for fiber-reinforced composites (Figure C)
- **B3**: nonwoven fabric made of oxidized polyacrylonitrile fibers and using regenerated cellulose (5 % by mass) as binder (Figure D)
- **B4**: identical to B2 but with a lower density (Figure E)
- **B5**: woven fabric with a core spun yarn where para-aramid fibers were twisted around a fiberglass core (Figure F)
- **B6**: bilayer fabric with outer layer made of needle-punched hybrid yarn (regener. cellulose/polysilicic acid), inner layer made of woven glass (Figure G)

Screening for Fire Retardants in Barriers

Elemental concentrations by XRF, IC, Kjeldahl, ICP-AES and ICP-OES, and targeted FRs content by GC-MS. XRF data are semi – quantitative.

	XRF (ppm)				IC (ppm)	Kjeldahl (ppm)	ICP-AES (ppm)						ICP-OES (ppm)	GC-MS (ppm)
	P	Sb	Br	Cl	Cl	N	B	Br	P	S	Sb	Si	B	FRs
C0	ND	< 22	< 10	733 ± 87	71	1620	< 5	< 80	316	1110	15	14500	NT	ND
B1	NA	NA	NA	NA	488	< 971	3690	< 80	207	926	73	50500	NA	ND
B1OL	19600 ± 1500	< 40	< 22	1620 ± 301	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B1IL	35900 ± 1700	< 76	< 33	14000 ± 600	NA	NA	NA	NA	NA	NA	NA	NA	< 1	NA
B2	ND	< 28	< 18	< 152	< 81	< 977	20700	< 80	265	3370	11	233000	NT	ND
B3	ND	< 37	< 13	3005 ± 203	< 95	184000	51	< 80	16	656	15	899	NT	ND
B4	ND	< 36	< 28	< 150	NT	NT	NT	NT	NT	NT	NT	NT	NT	ND
B5	ND	24 ± 14	< 10	2170 ± 90	120	72700	7660	< 80	259	3890	68	84900	NT	ND
B6	NA	NA	NA	NA	91	< 978	5430	< 80	69	1180	16	146000	NT	ND
B6OL	10600 ± 800	< 40	< 18	< 119	NA	NA	NA	NA	NA	NA	NA	NA	NT	NA
B6IL	ND	< 35	< 13	728 ± 161	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Abbreviations: NT, not tested; NA, not applicable as entire sample was digested; ND, none detected; OL, outer layer of fabric; IL, inner layer of fabric; < δ, measurement below the detection limit δ. Ion chromatography (IC); inductively coupled plasma atomic emission spectroscopy (ICP-AES); X-ray fluorescence (XRF) spectroscopy

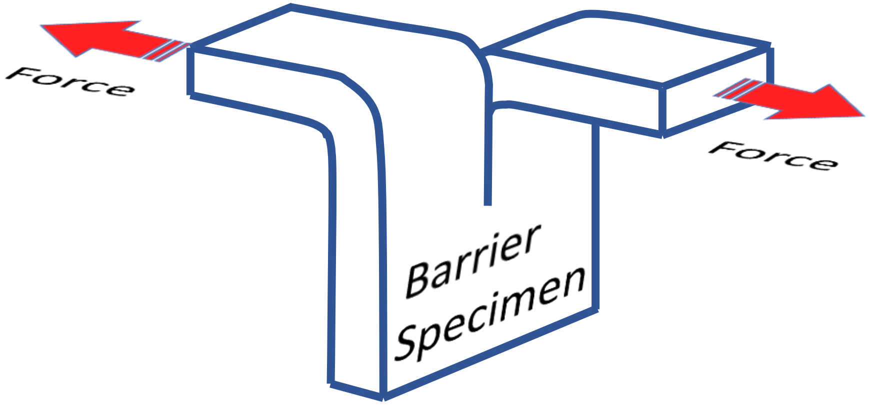
GC-MS excluded the presence of tributyl phosphate (TBP), tri(2-chloroethyl) phosphate (TCEP), tris(2-chloroisopropyl) phosphate (TCPP), tris(1,3-dichloroisopropyl) phosphate (TDCPP), triphenyl phosphate (TPP), and 1,2,5,6,9,10-hexabromocyclododecane (HBCD)

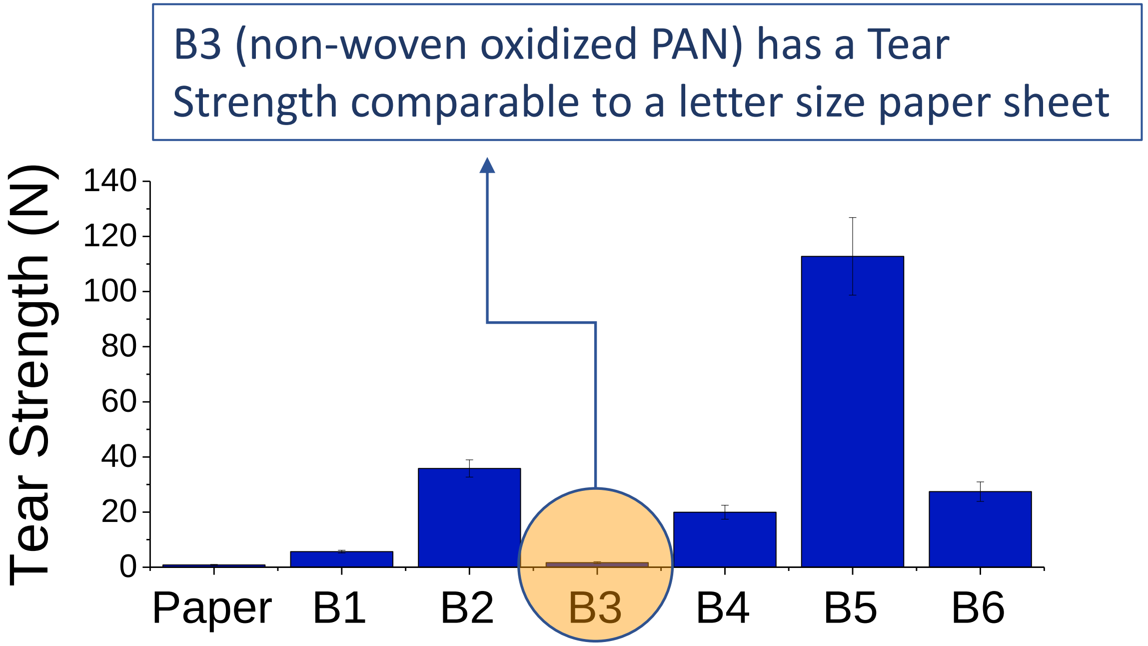
→ Insufficient presence of common fire retardants to significantly affect the performance of the barriers

[1] AL Thompson, I Kim, A Hamins, M Bundy, and M Zammarano, Performance and Failure Mechanism of Fire Barriers in Full-Scale Chair Mock-ups, submitted to FAM

Tear strength of barriers

ASTM D2261-13 (2017)



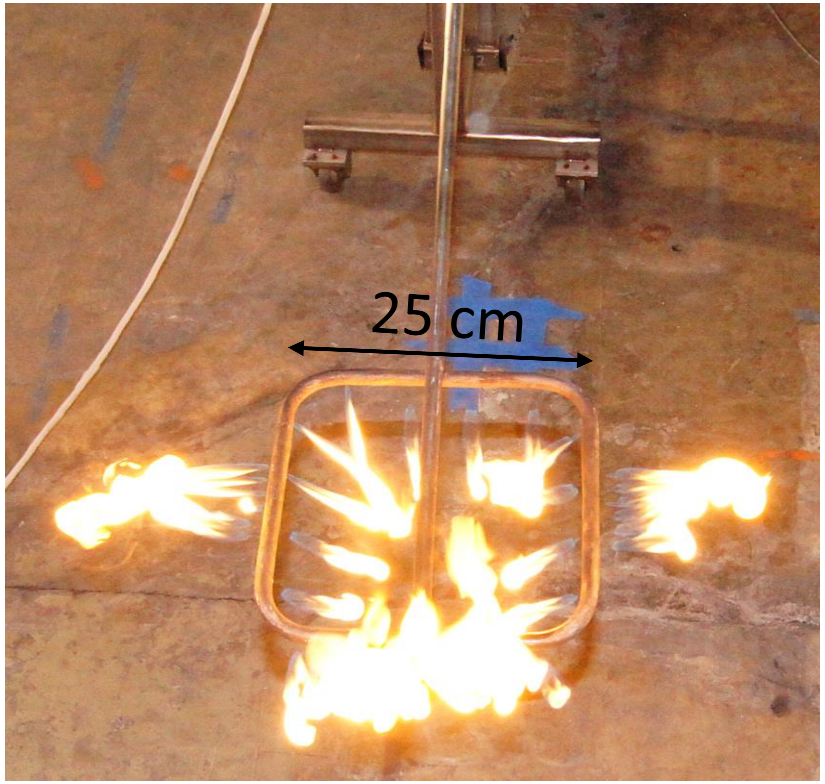


The padding material encased within the barrier was slid inside the cover-fabric cushions through the open zipper. **Shear between the barrier and the cover fabric caused tearing of B3**. Torn areas were patched by removing the cover fabric and applying an extra layer of barrier, which was stapled over the original barrier layer. The padding material encased within the patched barrier was then slid again inside the cover-fabric cushions with extra care, but the formation of additional tears could not be excluded.

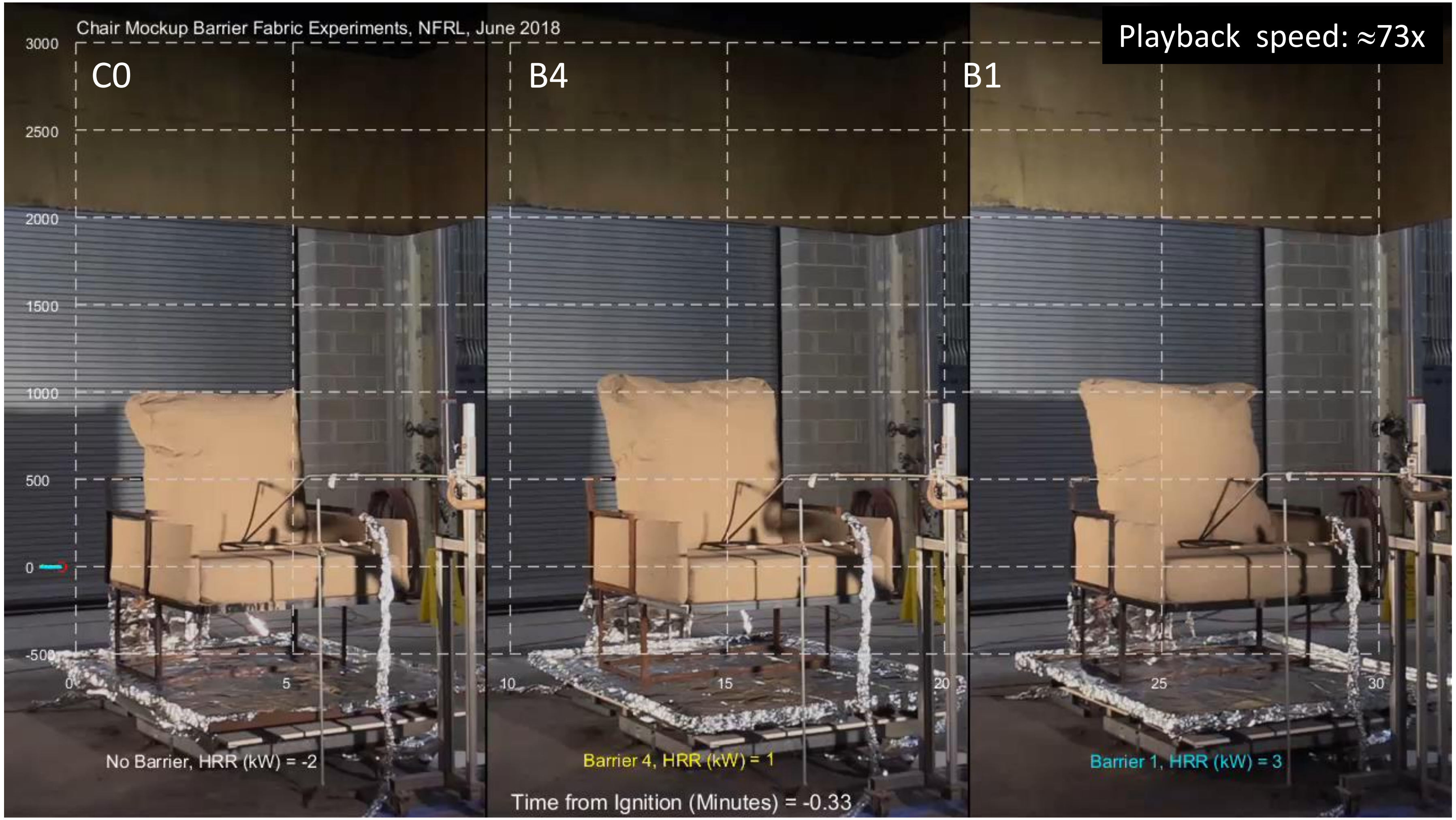
→ Performance of B3 in full–scale chair mock-ups could be significantly affected by tearing

Ignition Source

- Square Burner (18 kW for 80s)



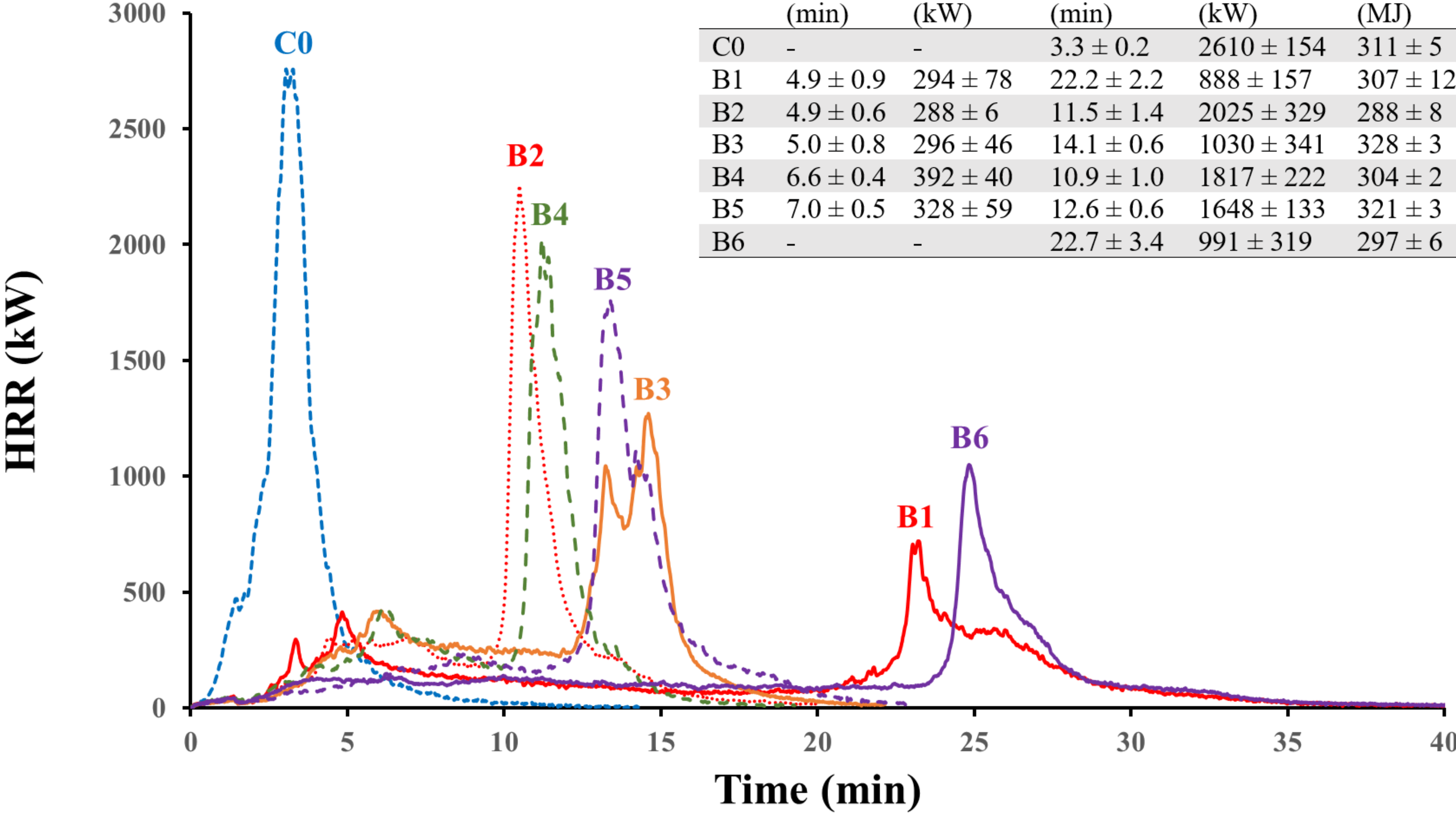
Effect of Barriers



Credit to:
Matt Bundy for composite video and data overlay

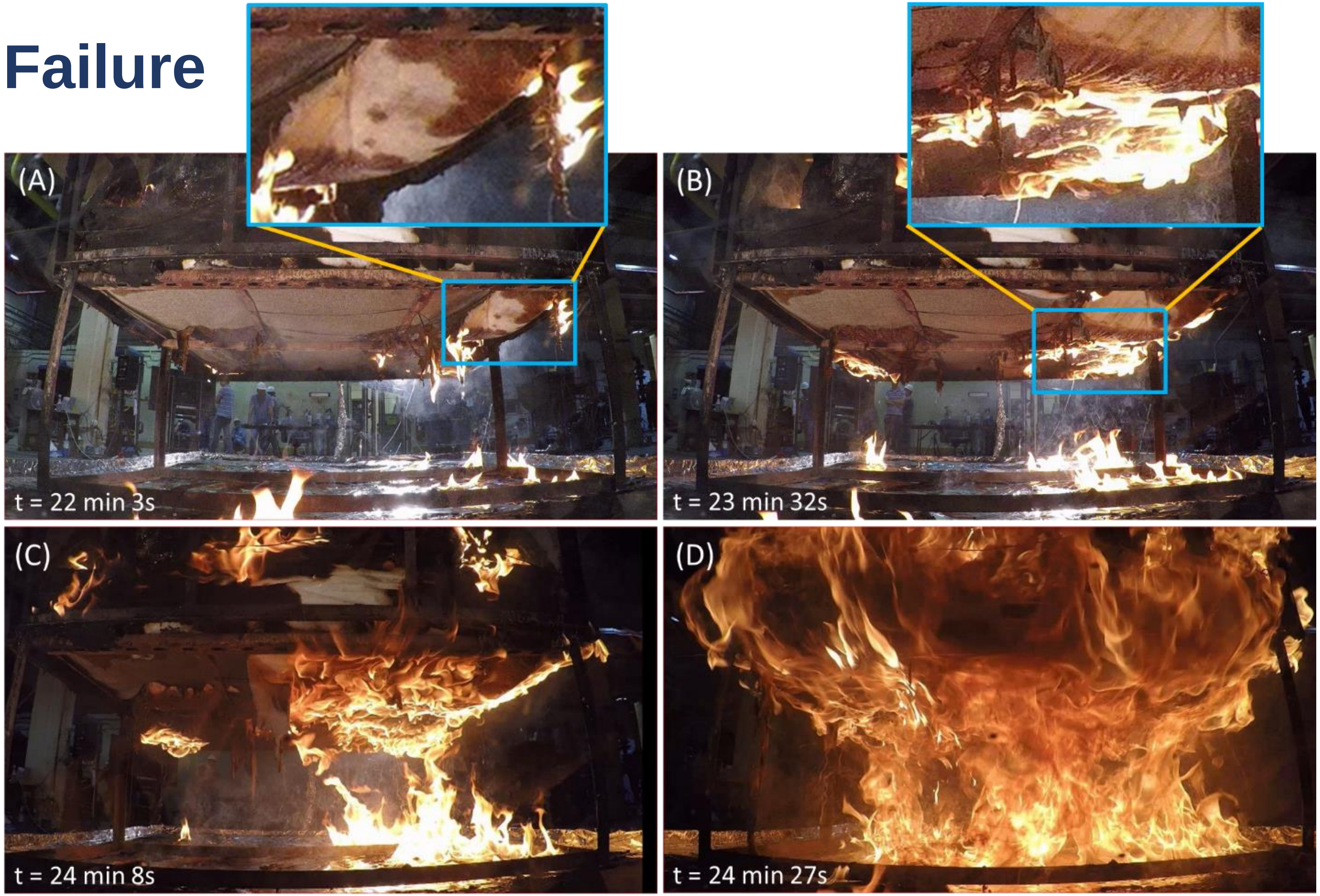
- increase time to peak HRR from 3 min (C0) to 22 min (B1 and B6)
- decrease peak HRR from about 3 MW (C0) to about 1 MW (B1 and B6)

Barrier Performance



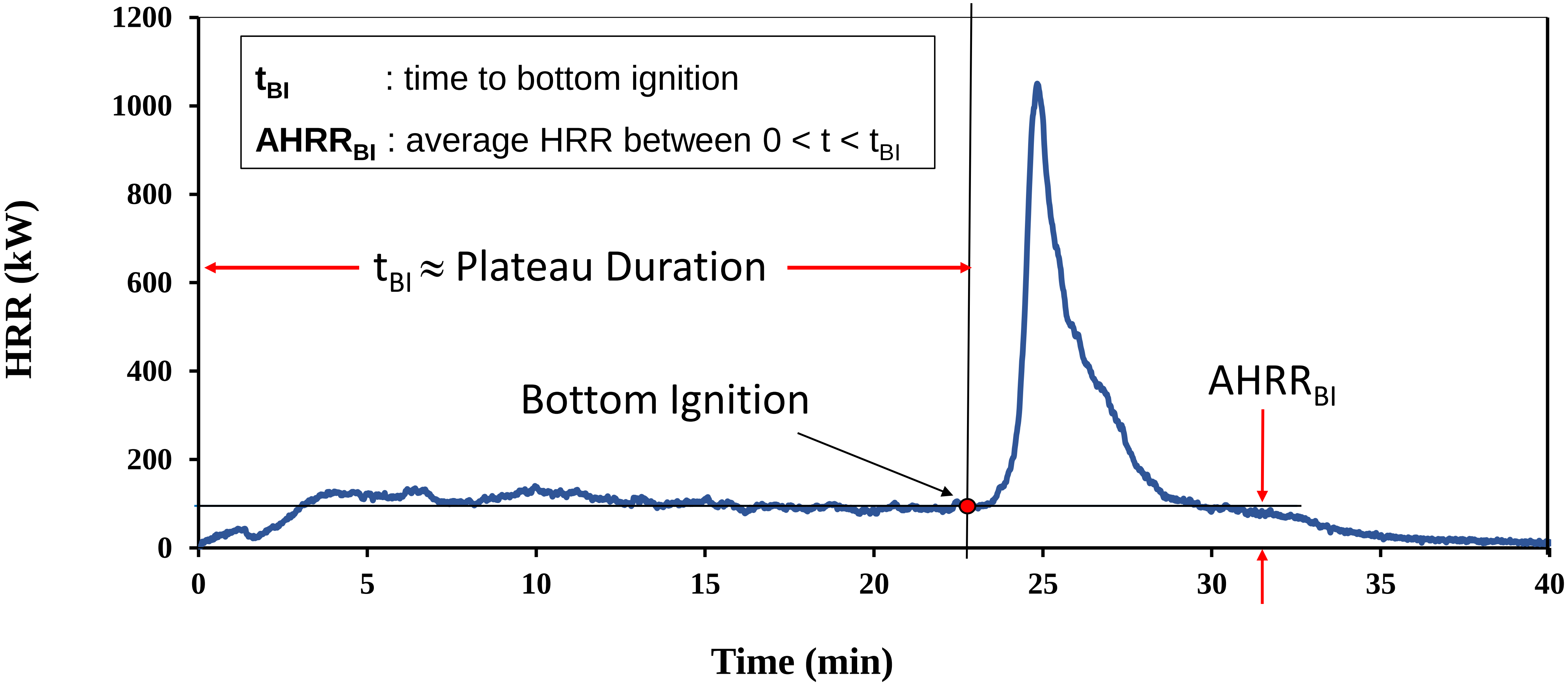
	t_{P1} (min)	$PHRR_1$ (kW)	t_{P2} (min)	$PHRR_2$ (kW)	THR (MJ)	EHC (MJ/kg)	ML (%)
C0	-	-	3.3 ± 0.2	2610 ± 154	311 ± 5	24.3 ± 0.4	93 ± 3
B1	4.9 ± 0.9	294 ± 78	22.2 ± 2.2	888 ± 157	307 ± 12	22.4 ± 0.3	87 ± 1
B2	4.9 ± 0.6	288 ± 6	11.5 ± 1.4	2025 ± 329	288 ± 8	23.9 ± 0.1	82 ± 2
B3	5.0 ± 0.8	296 ± 46	14.1 ± 0.6	1030 ± 341	328 ± 3	23.7 ± 0.2	87 ± 2
B4	6.6 ± 0.4	392 ± 40	10.9 ± 1.0	1817 ± 222	304 ± 2	24.0 ± 0.2	89 ± 1
B5	7.0 ± 0.5	328 ± 59	12.6 ± 0.6	1648 ± 133	321 ± 3	23.8 ± 0.2	83 ± 1
B6	-	-	22.7 ± 3.4	991 ± 319	297 ± 6	22.2 ± 0.3	83 ± 1

Barrier Failure



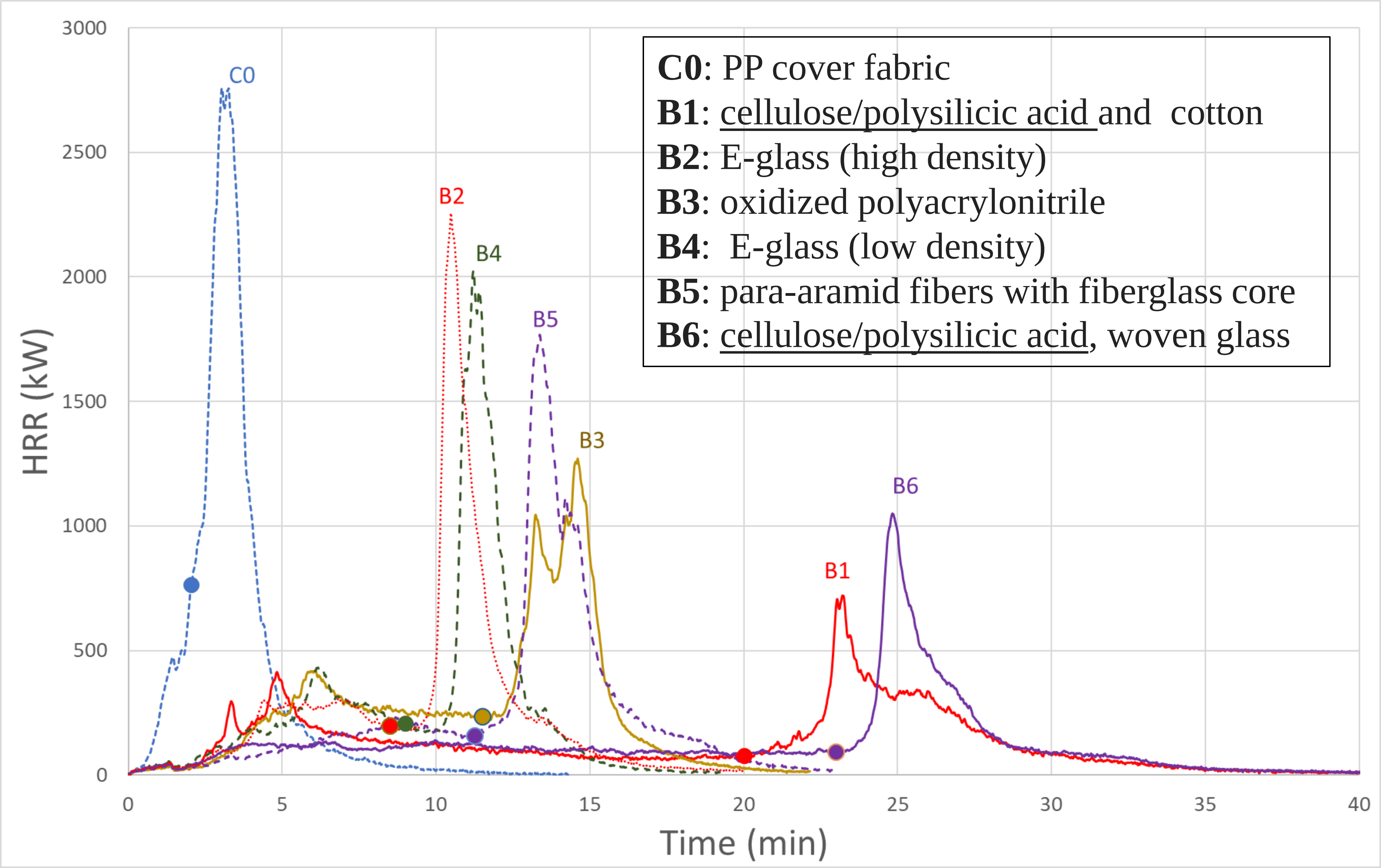
A, **"wetting"** of the barrier due to the percolation of liquid products; B, ignition of liquid products (**"bottom ignition"**); C, pool fire formation, and; D, feed-back between the flame on the pool fire and the remaining fuel in the chair mock-up at the time of $PHRR_2$. (Snapshots from Chair B6)

Burning of Upholstered Furniture



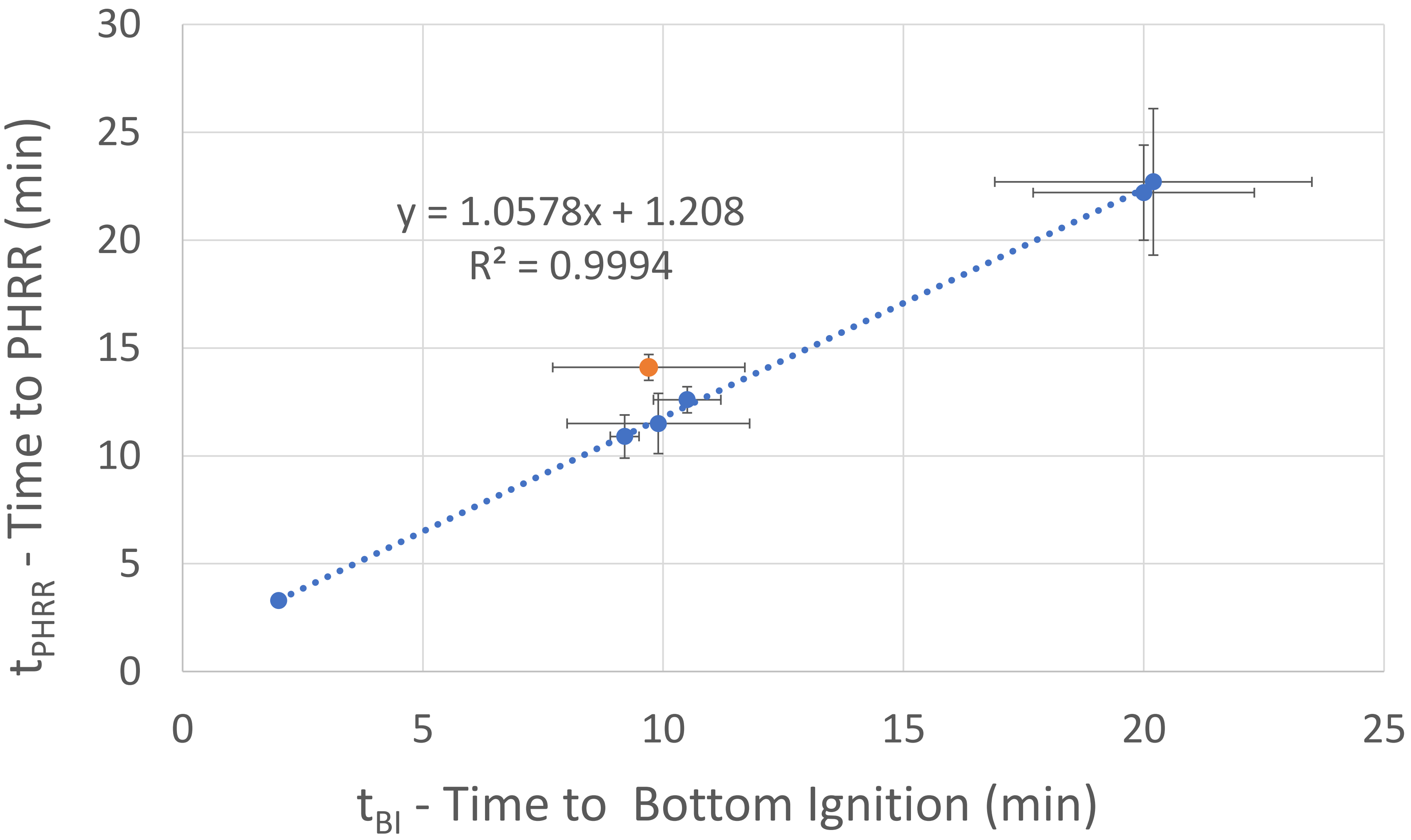
t_{BI} and $AHRR_{BI}$ are used to characterize "Plateau Phase" burning stage

Bottom Ignition (BI)



Bottom Ignition (BI) and PHRR

Bottom Ignition leads to PHRR within (2 ± 1) min

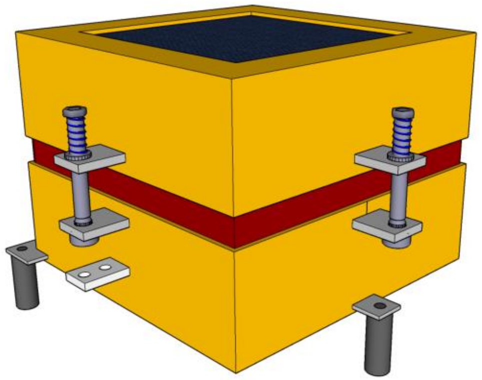


Bench-scale to Full-scale Correlation

Materials

- 1 Polyurethane Foam (TB117-2013)
- 1 Cover Fabric (Polypropylene)
- 6 Fire Barriers compliant with California Assembly Bill No 2998

Reduced Scale Test
(Cube Test)



Correlation

Full-scale Test
(Chair Mock-ups)

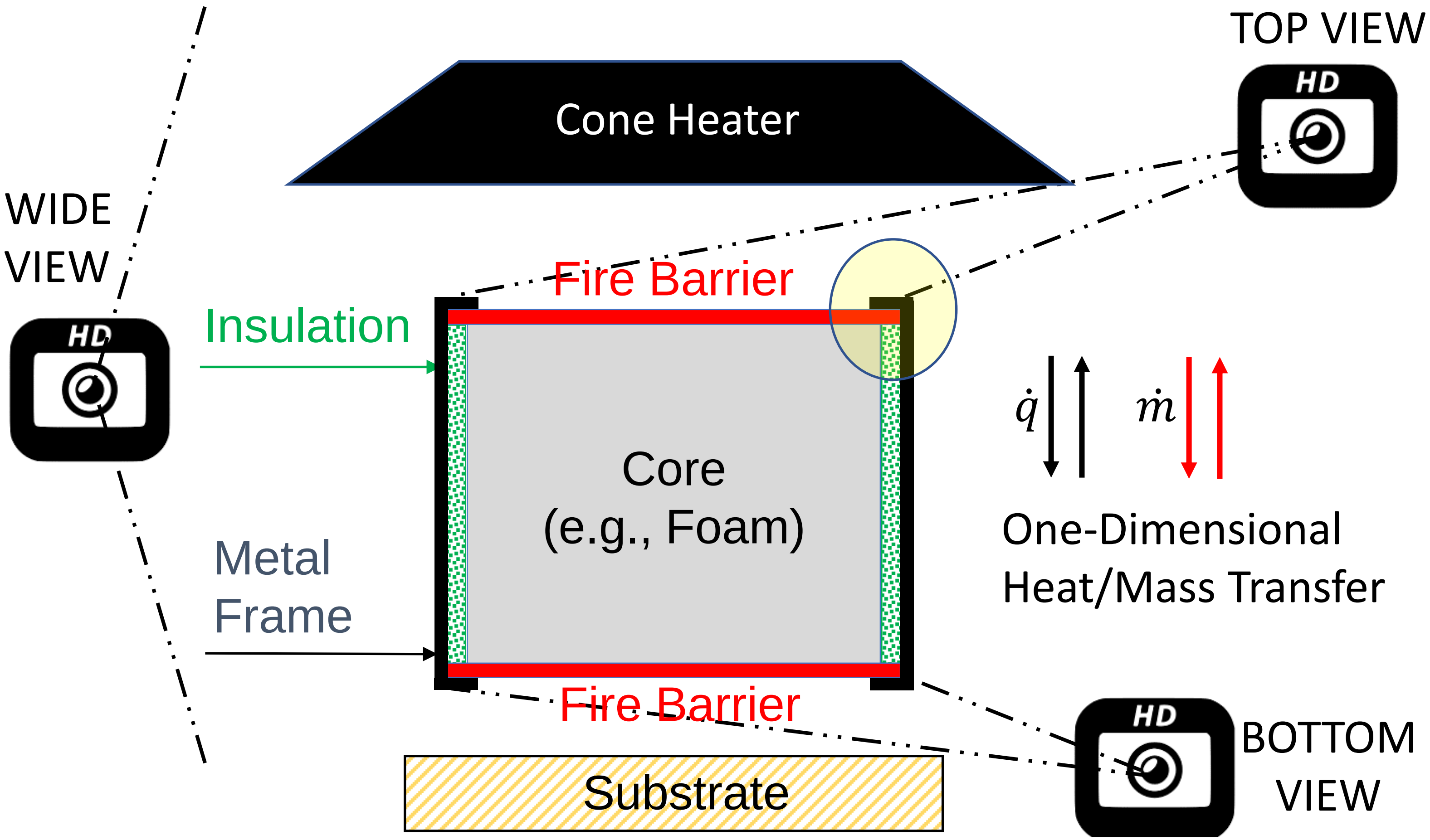
NIST Cube Test

- New bench-scale test, developed at NIST based on the Cone Calorimeter
- It allows to characterize mass and heat transfer phenomena in multi-component products containing a flammable core and superficial layers that may act as fire barriers

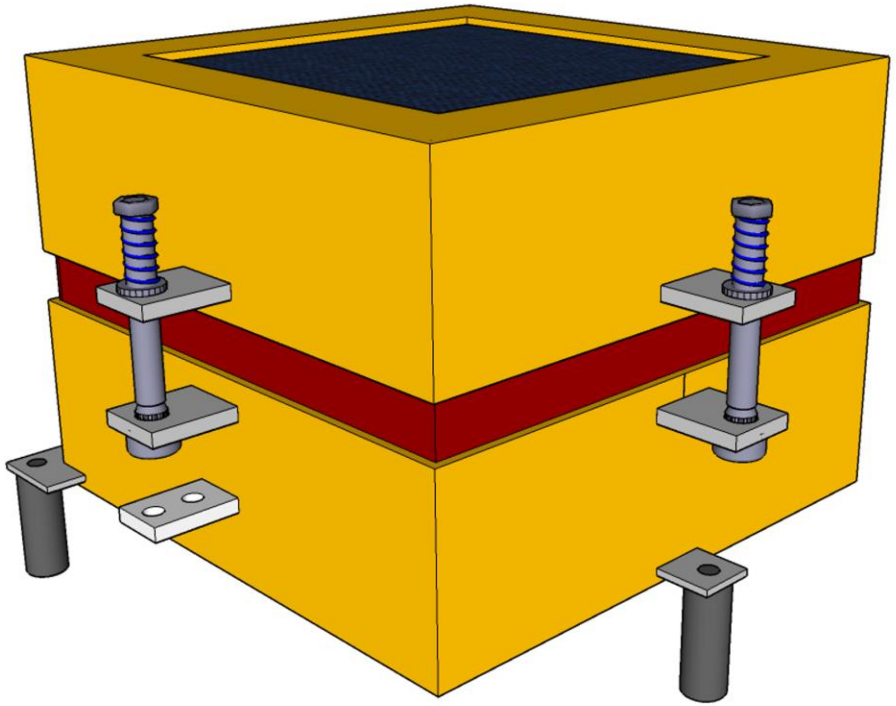
The sample is intended to be a representative cross-section of an item (e.g., seat cushion)

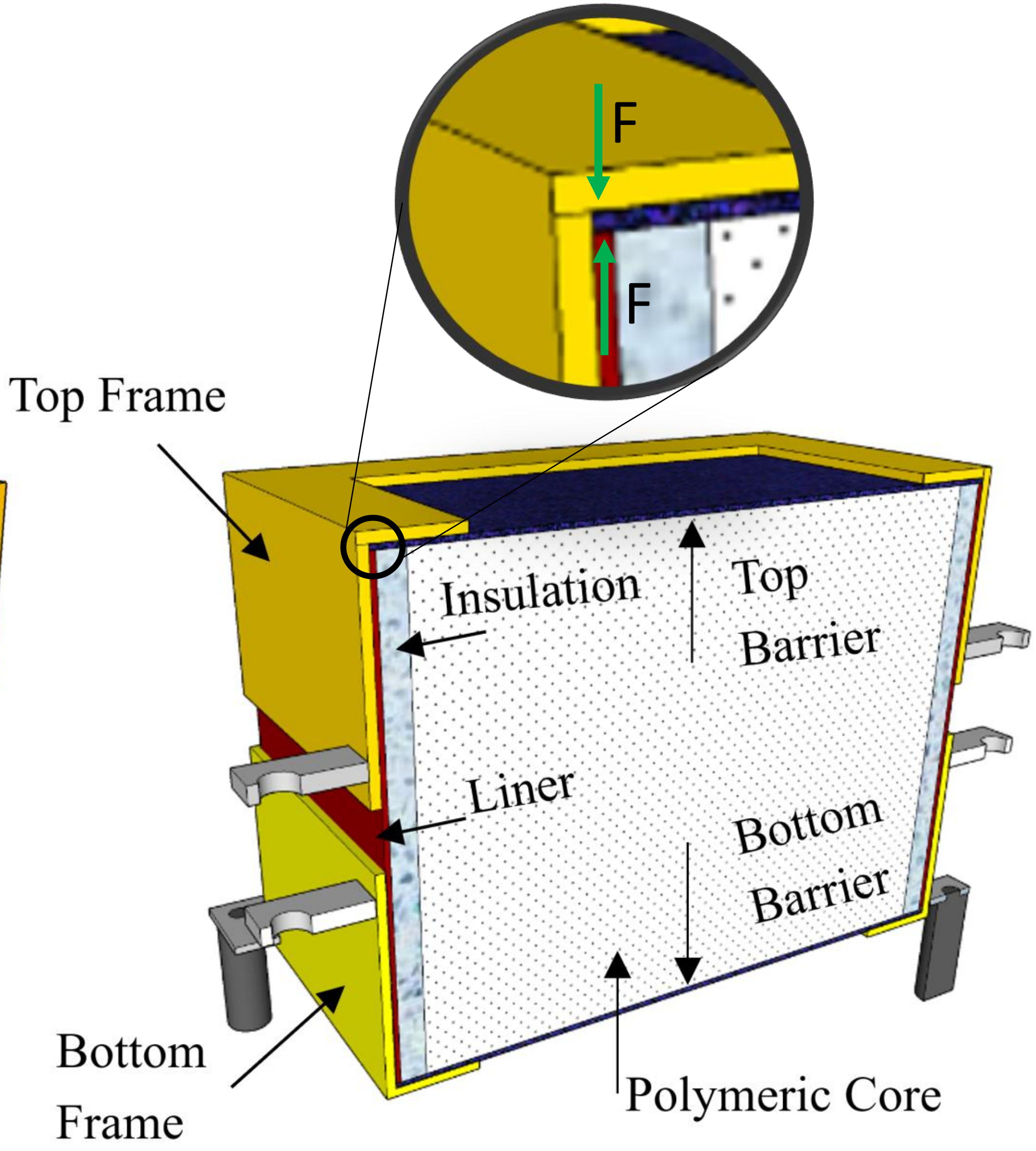
Foam dimensions (uncompressed) : (108 × 108 × 108) mm^3

(ASTM WK65005)



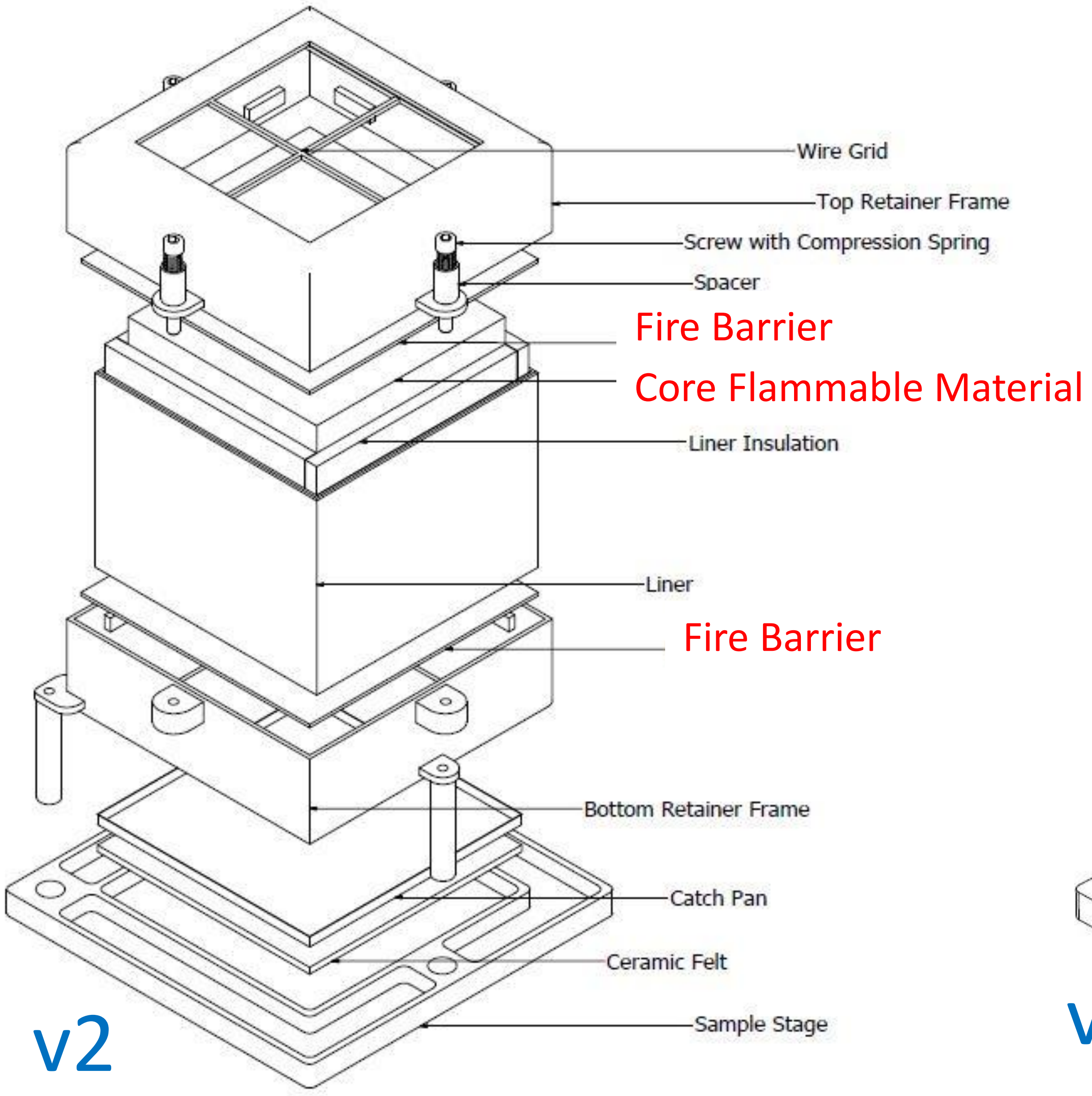
Schematic Drawing

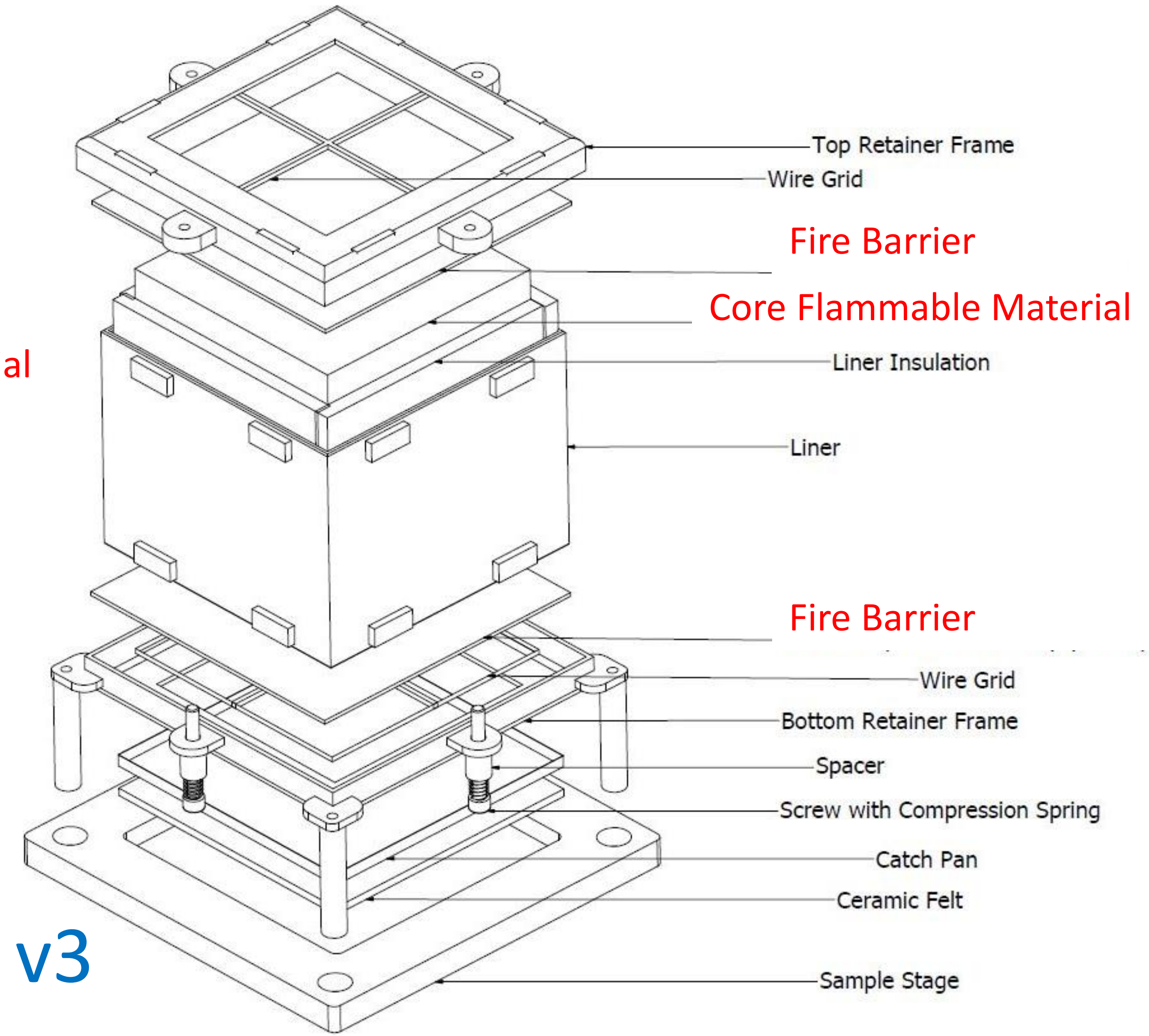




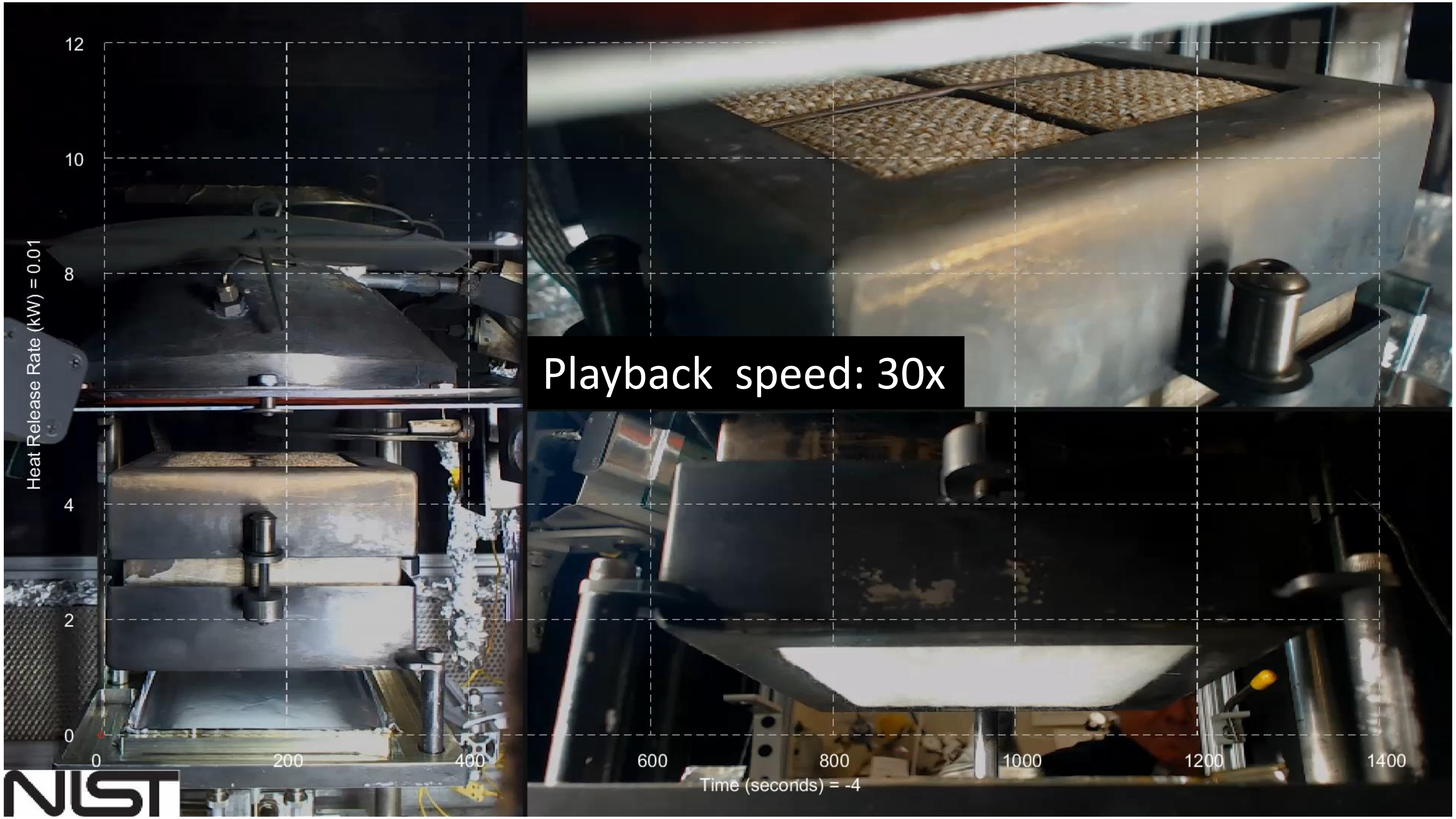
Sample Holder Design

ASTM E05-21 WK65005





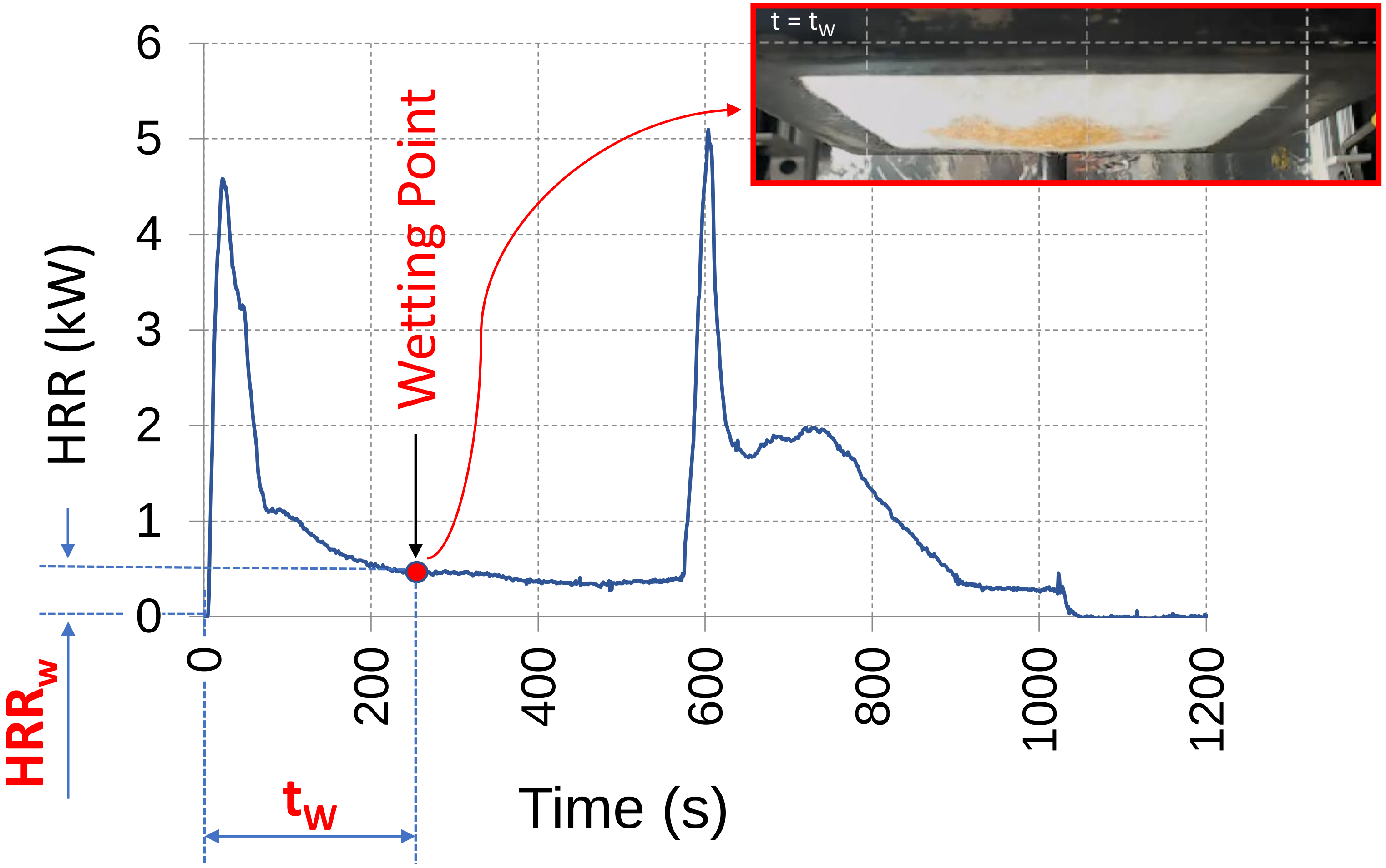
Cube Test (Barrier B6)



Credit to:
Matt Bundy for composite video and data overlay

"**Wetting**": appearance of visible liquid pyrolyzates on the bottom barrier

Example of HRR Curve in the Cube Test



t_W= time to foam liquefaction + time for liquid percolation

[1] M. Zammarano et al., Reduced-scale test to assess the effect of fire barriers on the flaming combustion of cored composites: An upholstery-material case study doi.org/10.1002/fam.2910

Cube to Full-Scale Correlation?

Fire Safety Evaluation of Barrier Fabric in a Furnished Room

NIST conducted 3 full-scale tests on furnished living rooms, where the sofa was the main fuel load [1,2]

All tests used the same room configuration and furniture, except for a different combination of cover fabrics/barrier in the sofa:

- Test 1: Sofa with cellulosic cover fabric
- Test 2: Sofa with cellulosic cover fabric and passive barrier fabric (B6)
- Test 3: Sofa with thermoplastic cover fabric

Purpose and Scope:

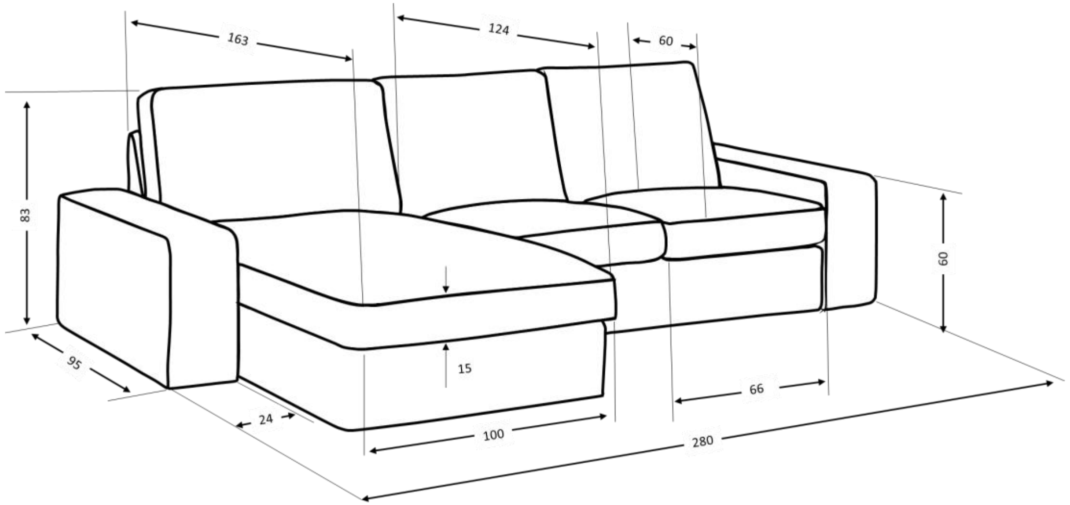
Measure the effect of passive fire barriers on the fire hazard of RUF in a realistic living-room-like scenario

[1] Mauro Zammarano, Matthew S. Hoehler, John Randy Shields, Andre L. Thompson, Ickchan Kim, Isaac Leventon, Matthew F. Bundy. NIST TN2129 - Full-Scale Experiments to Demonstrate Flammability Risk of Residential Upholstered Furniture and Mitigation Using Barrier Fabric, December 11, 2020, https://doi.org/10.6028/NIST.TN.2129

[2] www.nist.gov/el/fire-research-division-73300/flammability-reduction-73304/low-heat-release-upholstered-furniture

Sofa

sectional RUF with a chaise section (on the left) and a loveseat section (on the right)



Schematic drawing of the couch (dimensions are in cm)

Mass of the main components used for the construction of the Sofas

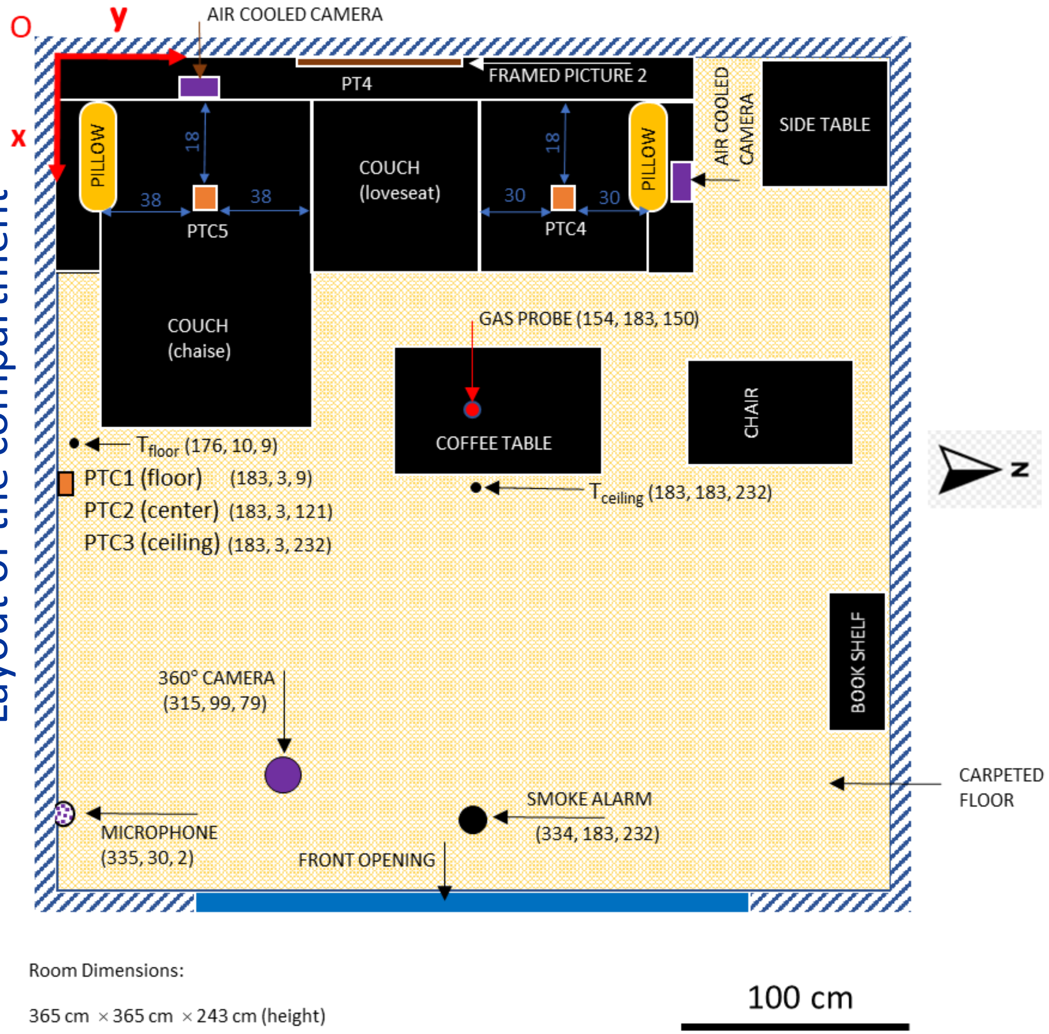
	Test 1	Test 2	Test 3
FPUF* (kg)	16.4	15.9	16.3
Fiber fill (kg)	7.1	7.1	7.2
Cover fabric (kg)	6.7	6.3	6.3
Barrier fabric (kg)	0	4.1	0
Frame (kg)	74.4	74.4	74.4
Total (kg)	121.0	123.6	120.5

In Test 2, all padding components in the cushions and the frame were wrapped by a Barrier; metal staples were used to build the seams and fasten the barrier to the frame.

Room Layout

Picture of the furnished compartment

Layout of the compartment



Room Dimensions:

365 cm × 365 cm × 243 cm (height)

All dimensions in cm

Expanded uncertainty ± 2.5 cm

Water Cooled Camera (470, 142, 69)

Air cooled cameras

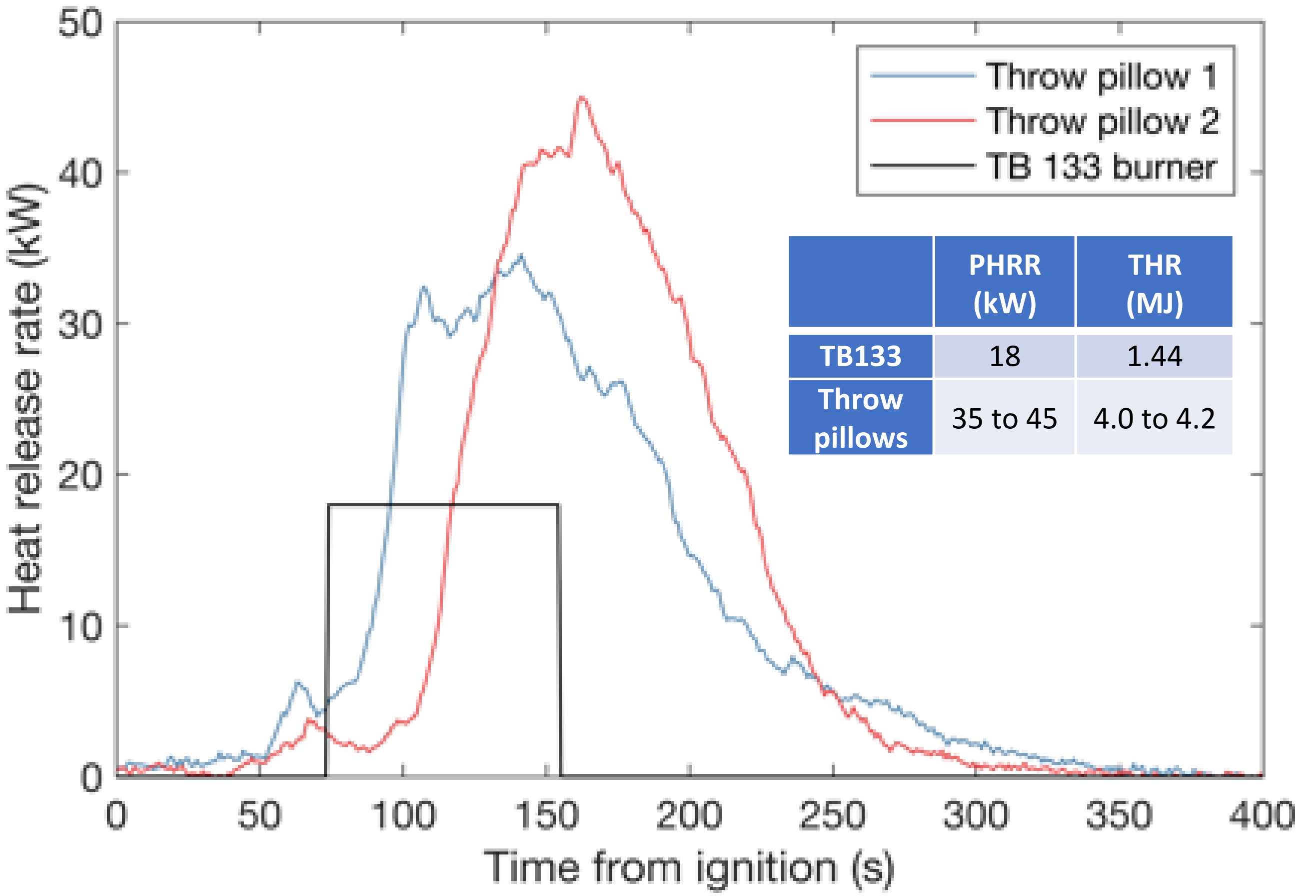
Water cooled 360° camera (BOB)

Ignition

- the throw pillow on the right arm of the couch was ignited by a ≈ 3 cm long propane diffusion flame applied under the pillow for about 25 s to 30 s (see Fig. 1)
- the HRR generated by a single throw pillow was measured (Fig.2)

Figure 1

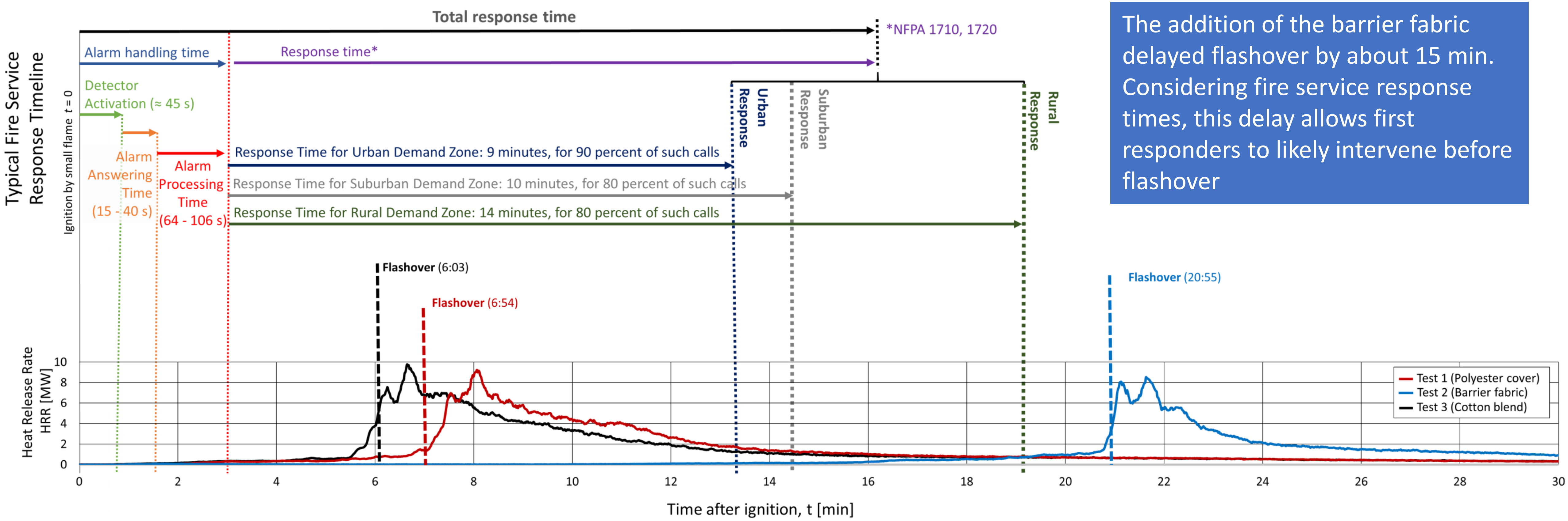
Figure 2



	PHRR (kW)	THR (MJ)
TB133	18	1.44
Throw pillows	35 to 45	4.0 to 4.2

Figure 3: HRR generated by: (1) TB 133 burner and (2) throw pillows

Flashover time *vs.* first responder's response time



The addition of the barrier fabric delayed flashover by about 15 min. Considering fire service response times, this delay allows first responders to likely intervene before flashover

	Time to smoke alarm triggering (s)	Time to flashover (min)	Time to peak heat release rate (min)	Peak heat release rate, PHRR (kW)	Total heat release rate, THR (MJ)	$t_{ceiling\ 200\ °C}$ (min)	Available safe egress time, ASET* (min)
Test 1	42 ± 2	7.0 ± 0.2	8.1 ± 0.2	9180 ± 550	2550 ± 160	3.92	2.63
Test 2	47 ± 2	21.0 ± 0.2	21.7 ± 0.2	8420 ± 500	2250 ± 140	16.03	15.25
Test 3	45 ± 2	6.0 ± 0.2	6.7 ± 0.2	9640 ± 580	2640 ± 160	3.05	2.30

Fire Safety Evaluation of Barrier Fabrics

Low Heat Release Upholstered Furniture

Video/audio editing: Matt Hoehler

NIST

Conclusions

- Fire mitigation strategies have been proved to drastically decrease fire losses
- As demonstrated by backcoatings/passive barriers, technologies promoting fire safety and health/environment safety in residential upholstered furniture not only exist but are commercially available
- Passive barriers mitigate the flaming hazard of RUF by slowing down the fire growth and generating an initial low HRR plateau
- At the end of the HRR plateau, percolation and ignition of liquid pyrolizates underneath the RUF item can lead to a rapid increase in HRR (i.e., barrier failure)
- The Cube test has been developed to predict this barrier failure mechanism; this is accomplished by measuring the time required for liquid polyols percolation in a specimen mimicking a cross-section of the seat cushion
- The full-scale performance of the barrier (HRR at plateau, plateau duration, PHRR, time to PHRR) shows a strong correlation with the time to wetting in the Cube test (within the limited data set available)
- In a realistic living room scenario, barrier fabrics delay fire growth to most likely allow first responders to intervene before flashover

THANK YOU!

This presentation is dedicated to the memory of our friend and colleague John Randy Shields, whose contributions to the project were essential

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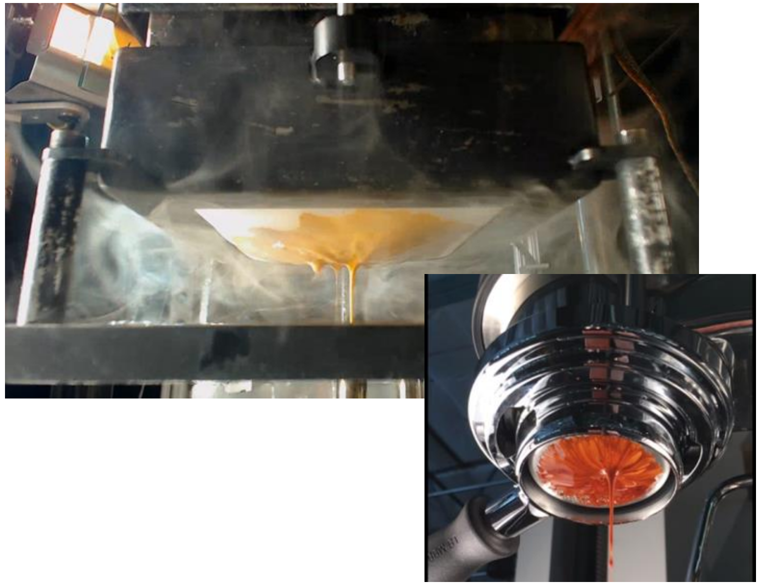

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"Low Heat Release Upholstered Furniture" Project page:
www.nist.gov/el/fire-research-division-73300/flammability-reduction-73304/low-heat-release-upholstered-furniture