AN INVESTIGATION OF THE UL-94V PLASTICS FLAMMABILITY TEST

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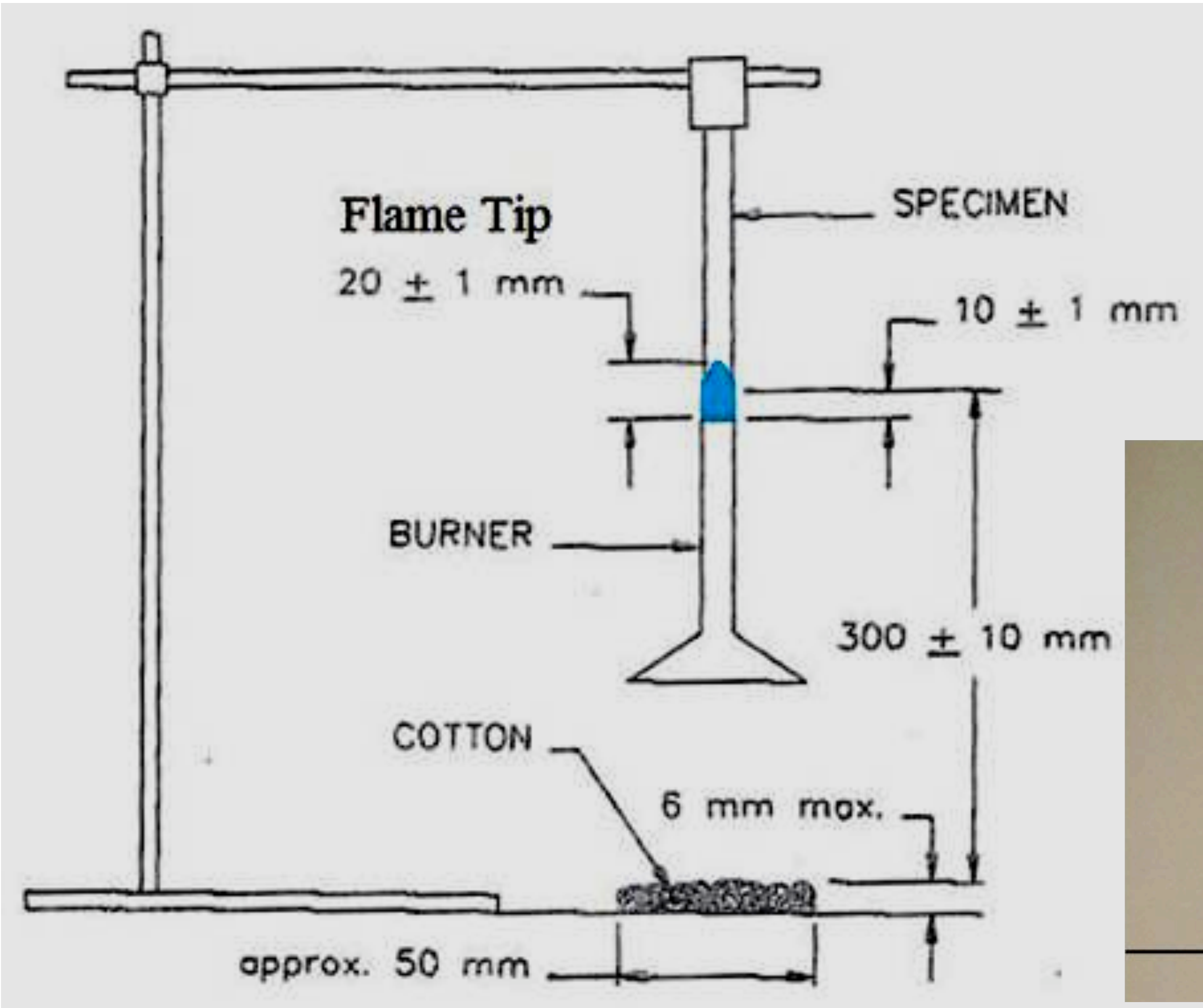
Presentation Outline

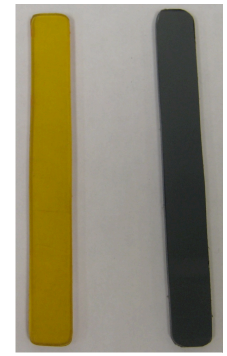
- What is UL94V?
- How can it be modeled?
- Experimental results for modeling
- Relationship between rating and model
- Summary and Conclusions

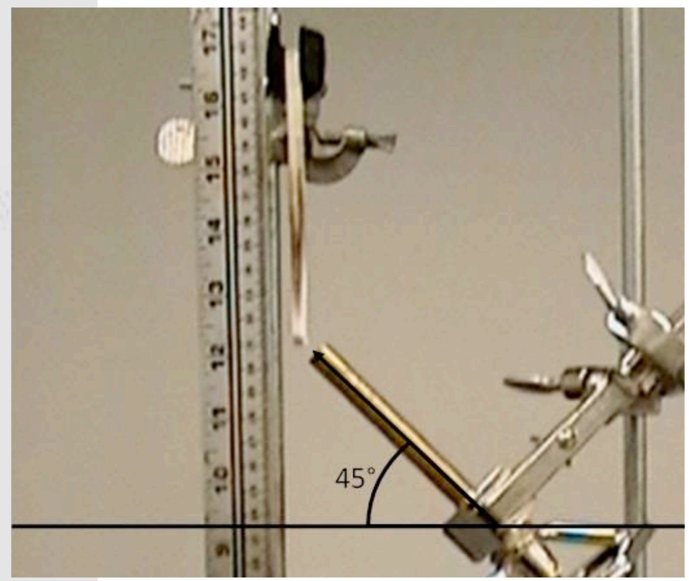
Motivation

- Research support from the Federal Aviation Administration (FAA)
- This study will focus on UL-94V: Vertical Burning Test
- A Bunsen burner test that dominates use of plastics
- Limited studies have examined UL-94V without sufficient resolution regarding its basis
- Cannot continue to have tests without meaning or without phenomenological explanation

UL-94V: Vertical Burning Test

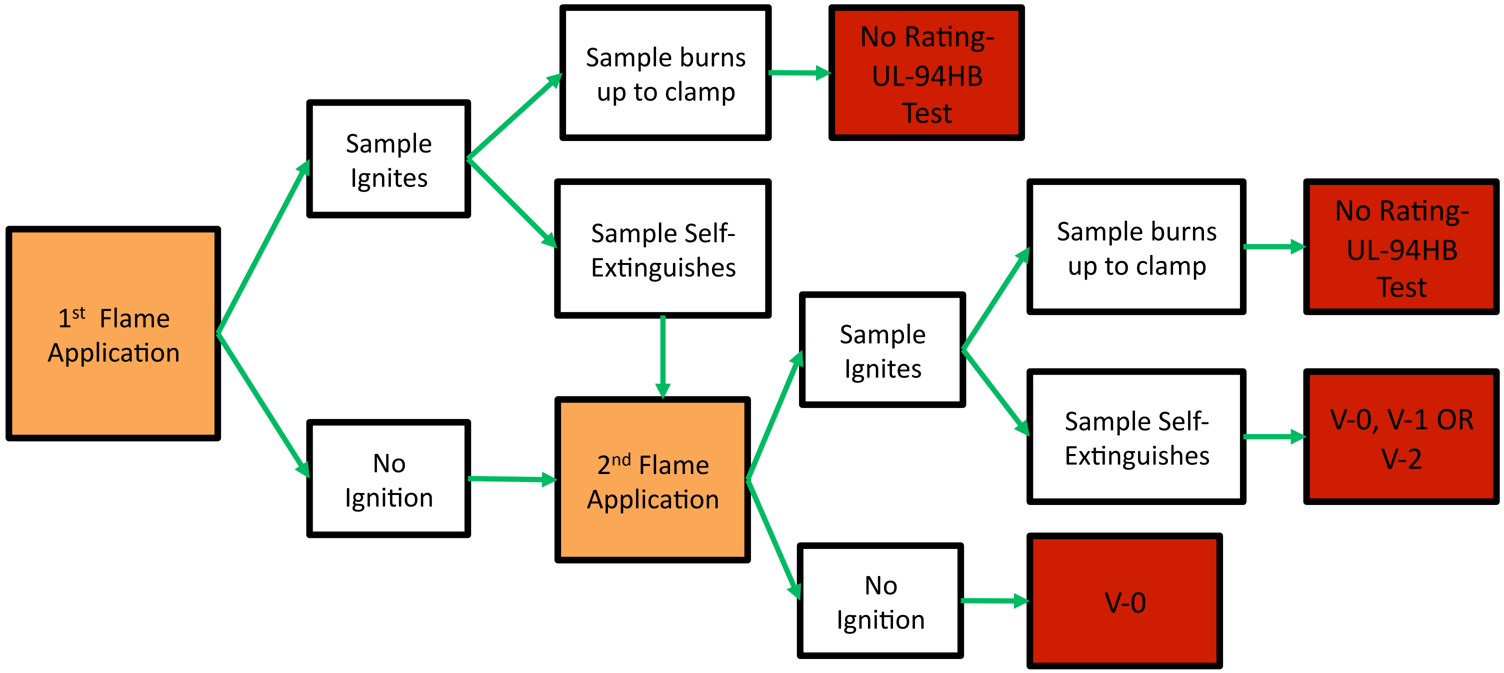






UL-94V Test Setup

UL-94V: Rating Process



Criteria Conditions	V-0	V-1	V-2
t_1 or t_2 for each individual specimen	≤ 10 s	≤ 30 s	≤ 30 s
$\Sigma(t_1+t_2)$ for the five (5) specimens	≤ 50 s	≤ 250 s	≤ 250 s
t_2+t_3 for each individual specimen	≤ 30 s	≤ 60 s	≤ 60 s
Afterflame or Afterglow up to Holding Clamp	No	No	No
Cotton Indicator Ignited	No	No	Yes

UL-94V Rating & Fire Phenomena

t_{flame}	Rating	Fire Phenomena
≤ 10 s	V-0	Material does not (or barely) ignites
10 s ≤ t_{flame} ≤ 30 s	V-1, V-2 (V-2： Flaming Drips)	Burning is not sustained
> 30 s	HB	Burning is sustained and flame spread to holding clamp

Need to know heat flux, and material properties to predict.

Modeling Process

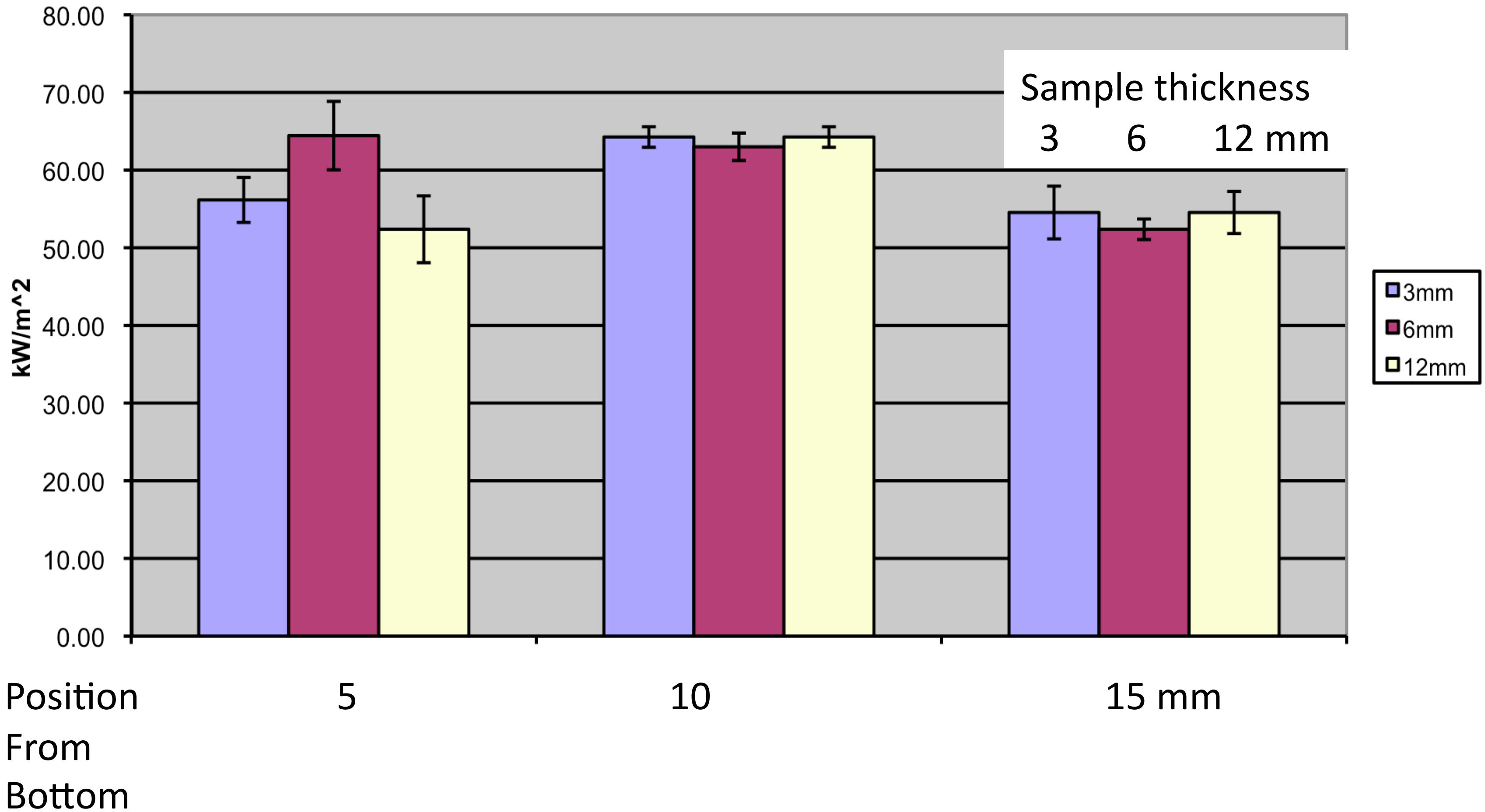
- Measure heat flux during burner ignition
- Determine heat flux by flame in burning and in spread
- Determine relationship for the laminar flame height
- Identify body of data on properties and UL94V rating
- Determine conditions for sustained ignition, burning and flame spread

Measure Heat Flux by Burner

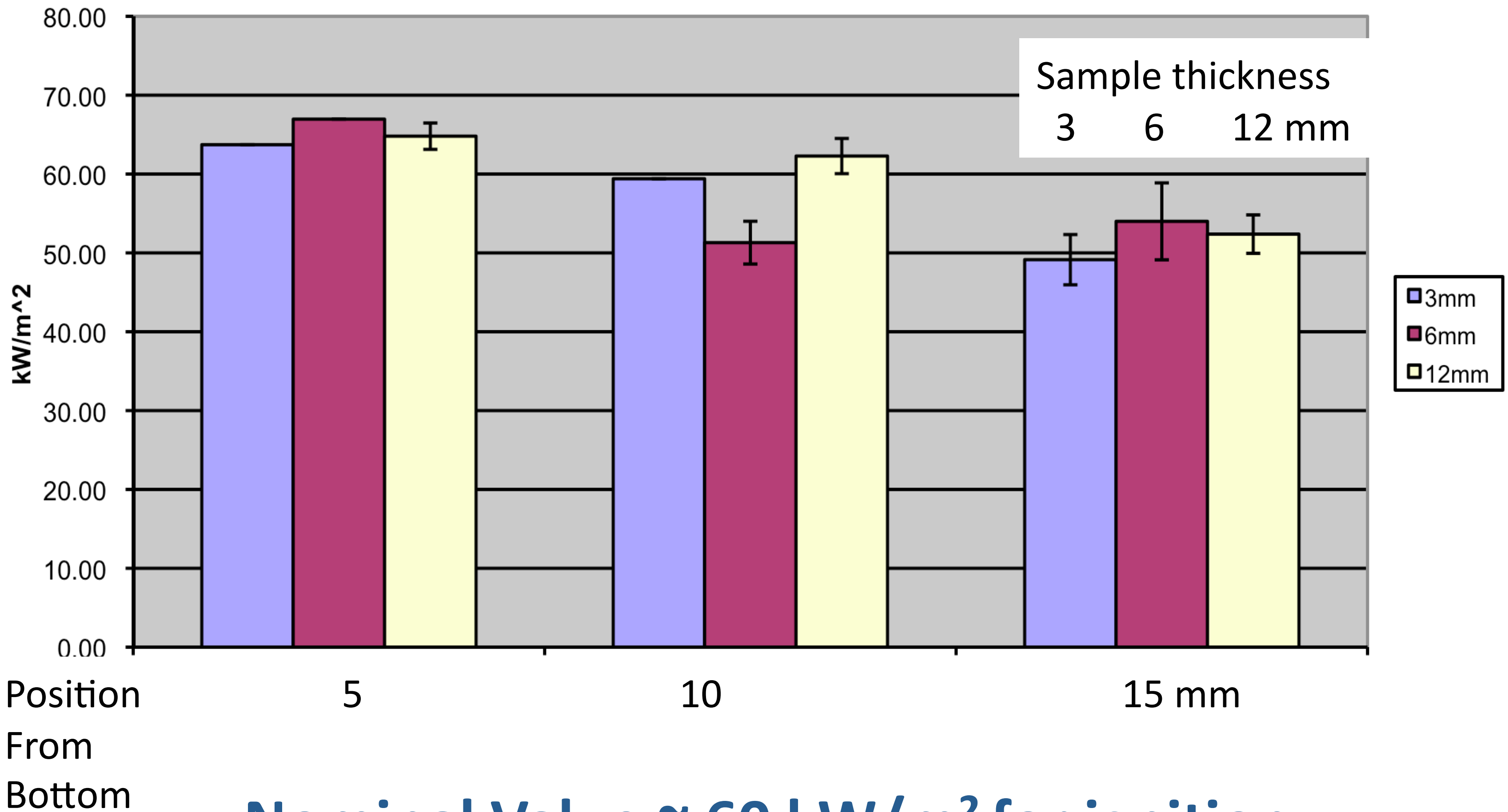
- Heat Flux Gauge
  - Diameter of 1/8th in.
  - Water-cooled
  - HF (kW/m^2)=10.8 * ΔV (mV)

- Tirrill Burner
  - Premixed Flame Burner ASTM D-5025
  - 20 mm flame, 10 mm below

Burner Results (vertical)



Burner Results (45 degrees)



Nominal Value ~ 60 kW/m^2 for ignition

Burning & Flame Spread

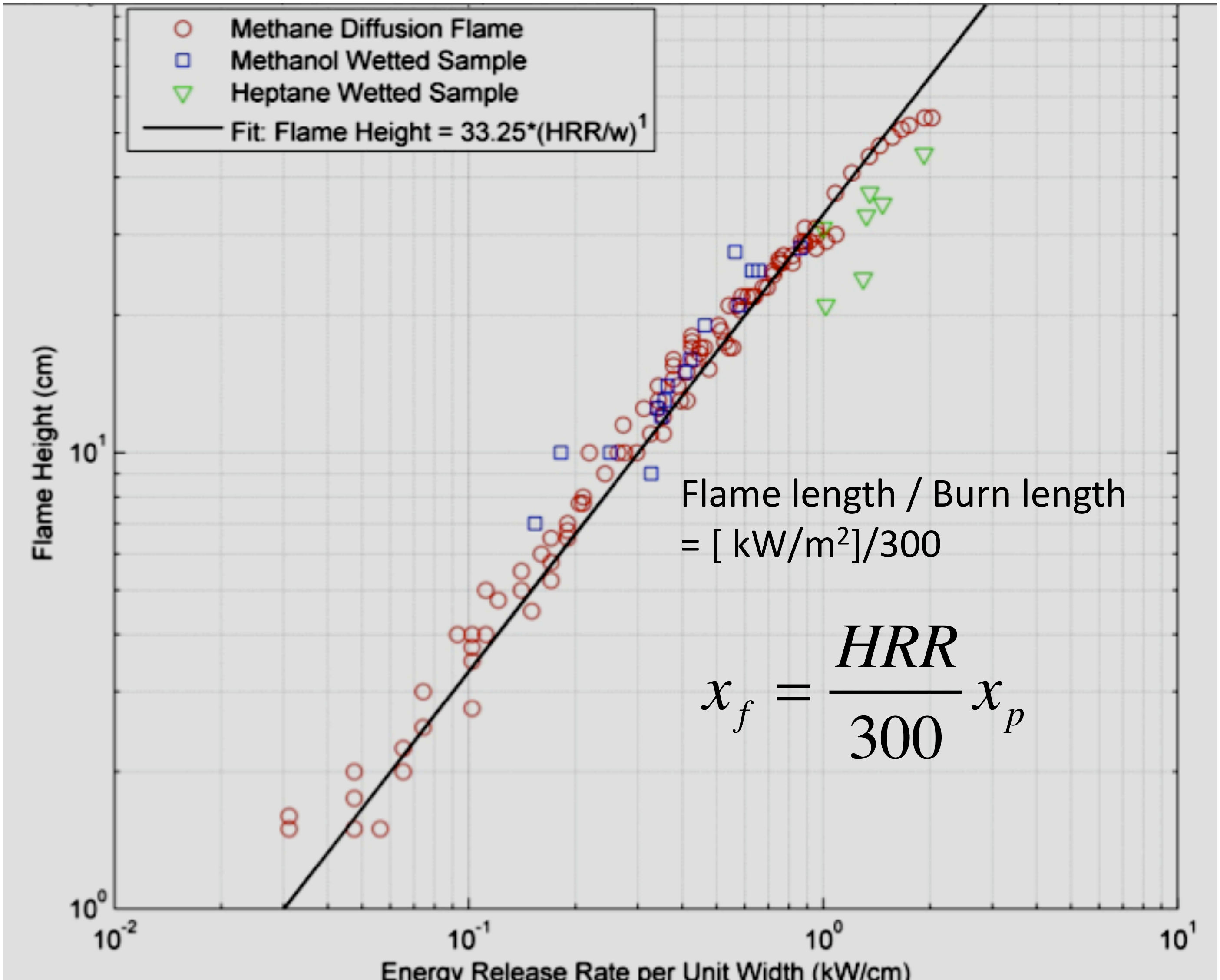
Flame Height &Flame Heat Flux

- Measure Flame Height vs Heat Release Rate
  - Methane Line Burner
  - Wetted Samples
- Plot $X_f \;\; vs. \;\; \left(\dot{Q}'\right)$

$$C_f = 33.25\, cm^2/kW \; and \; n = 1$$

$$X_f = 33.25\left(\dot{Q}'\right)^1$$

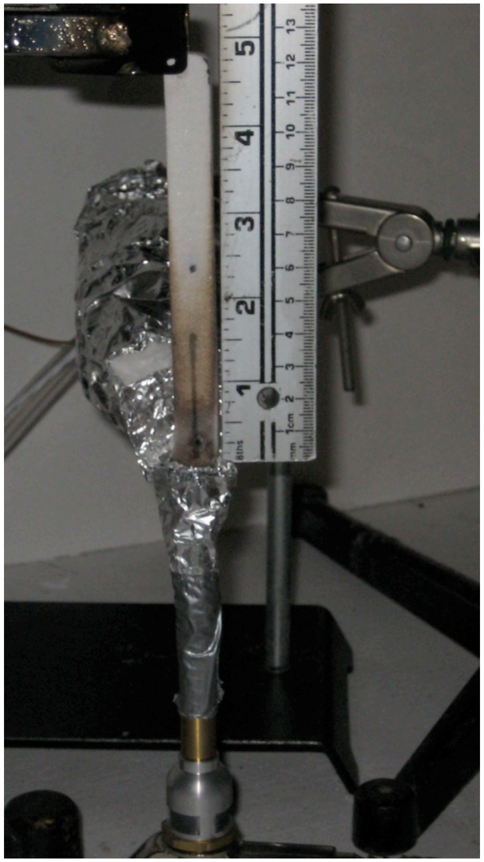
Flame Height

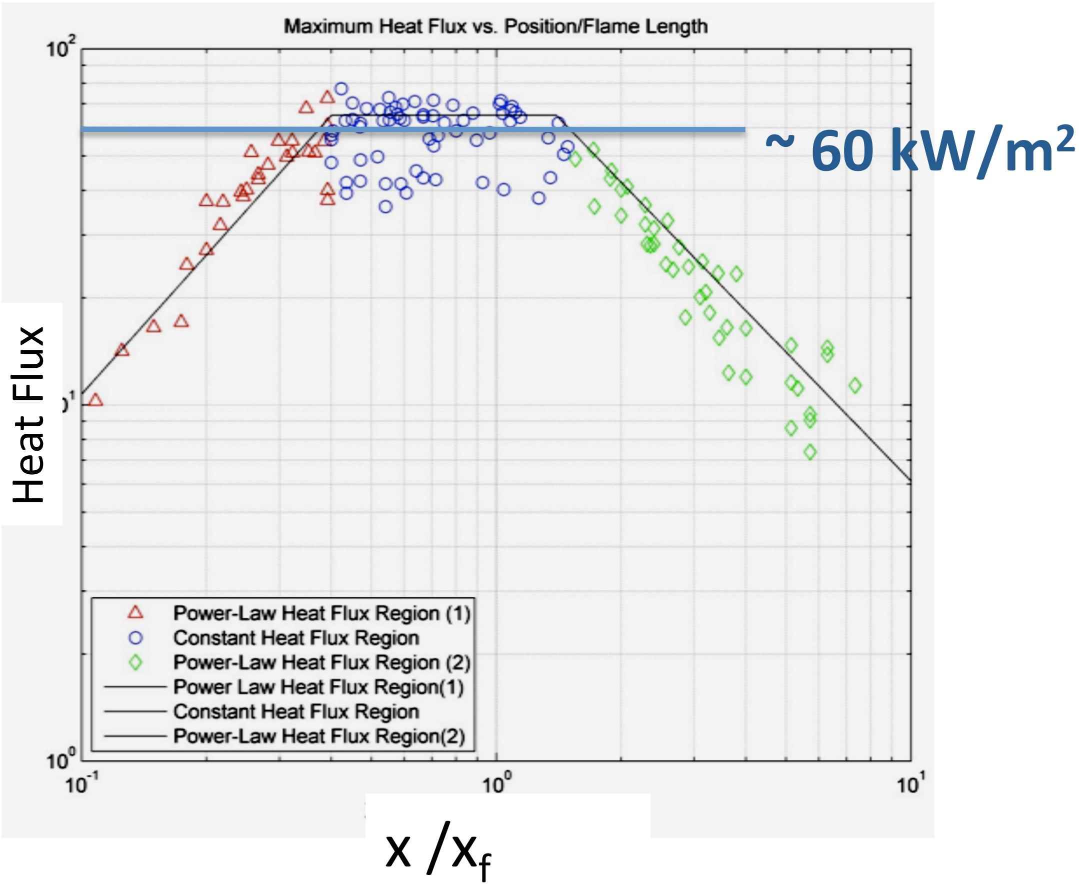


Flame length / Burn length
= [kW/m²]/300

$$x_f = \frac{HRR}{300} x_p$$

Flame Heat Flux





Theory: Ignition

$$t_{ig,o} = \left(\frac{TRP}{\dot{q}''} \right)^2 .$$

$$\dot{q}'' = \underbrace{\dot{q}''_{flame}}_{60} - CHF_f$$

Critical HHR for Ignition

$$HRR_{ig} = 1.28 h_c \text{ in kW/m}^2$$

For a height of 10 mm corresponding to ignition and initial burning, the convective coefficient is found as 63 W/m^2-K.

$$HRR_{ig} = 80 \text{ kW/m}^2$$

Burning Rate

$$HRR = (\dot{q}''_{flame} - CHF_f)/HRP$$

60

Critical Value:

$$HRR_b = \dot{m}''_{crit}\Delta h_c \approx \frac{\left(\frac{h_c}{c_p}\right) Y_{ox,\infty}\Delta h_{ox}}{\left[1 - \frac{c_p (T_{f,crit} - T_\infty)}{Y_{ox,\infty}\Delta h_{ox}}\right]} = 5.24\, h_c (\mathrm{W/m^2 - K}) \text{ in } \mathrm{kW/m^2}$$

250 +/- 75 kW/m^2

Flame Spread

to top at the clamp 12.5 cm

$$t_{top} = \left[\frac{\ln(12.5/k_f)}{k_f - 1} \right] t_{ig}, \; k_f = HRR(\mathrm{kW/m^2})/300$$

$k_f = 1 \longrightarrow$ **$HRR_f = 300$ kW/m²**

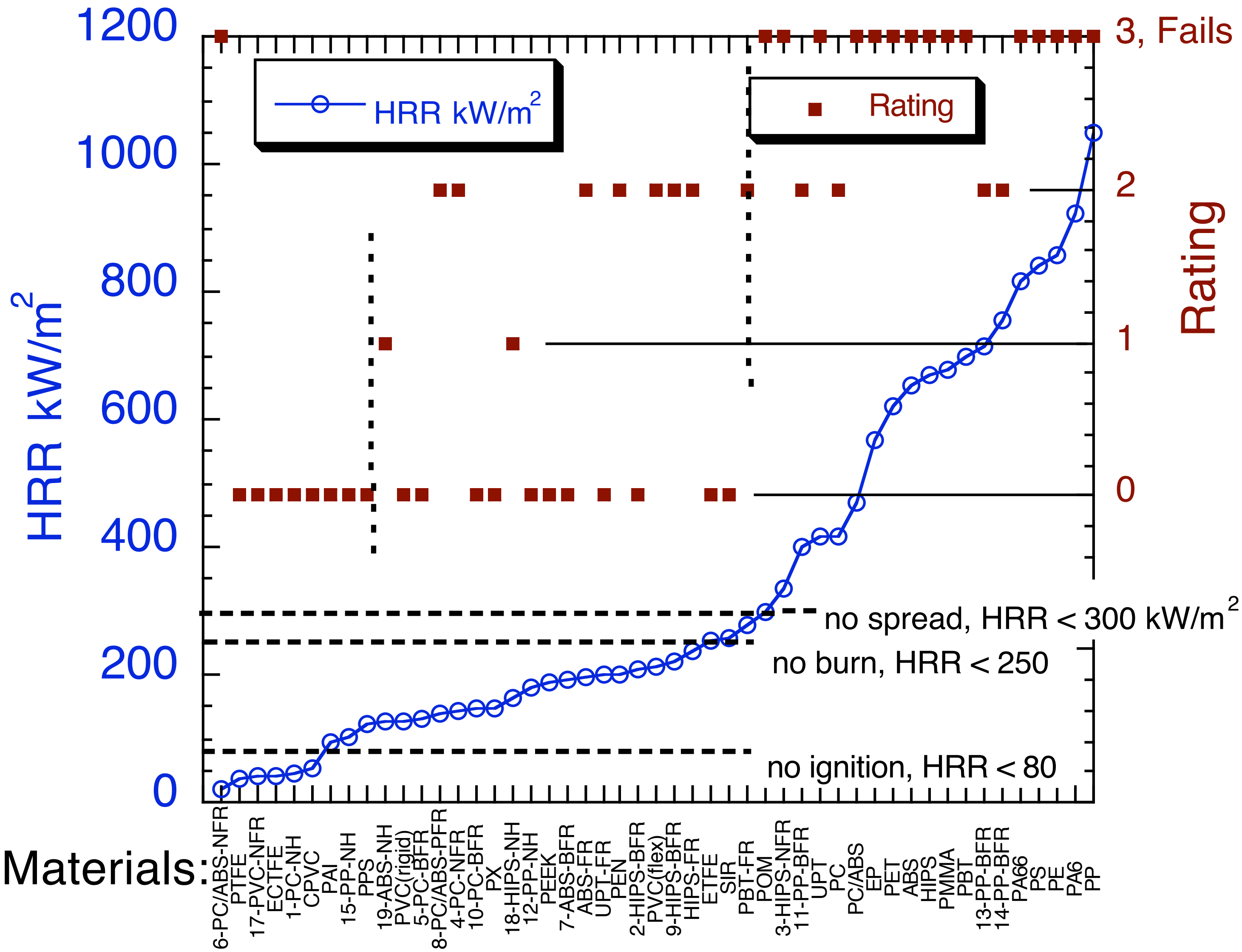
Data from Bundy et al & Lyon

Material	Rating	HRP	CHF_f kW/m^2	TRP $kW\text{-}s^{1/2}/m^2$
1-PC-NH	0	0.8	5.9	349
2-HIPS-BFR	0	3.6	2	265
3-HIPS-NFR	3	5.6	0.31	358
4-PC-NFR	2	2.6	4.8	535
5-PC-BFR	0	2.3	3	425
6-PC/ABS-NFR	3	0.34	0	455
7-ABS-BFR	0	3.2	0	392
8-PC/ABS-PFR	2	2.3	0	450
9-HIPS-BFR	2	3.7	0	389
10-PC-BFR	0	3.3	15.8	296
11-PP-BFR	2	7	2.6	387
12-PP-NH	0	3	0	343
13-PP-BFR	2	12.8	4.3	299

50 materials

General Results

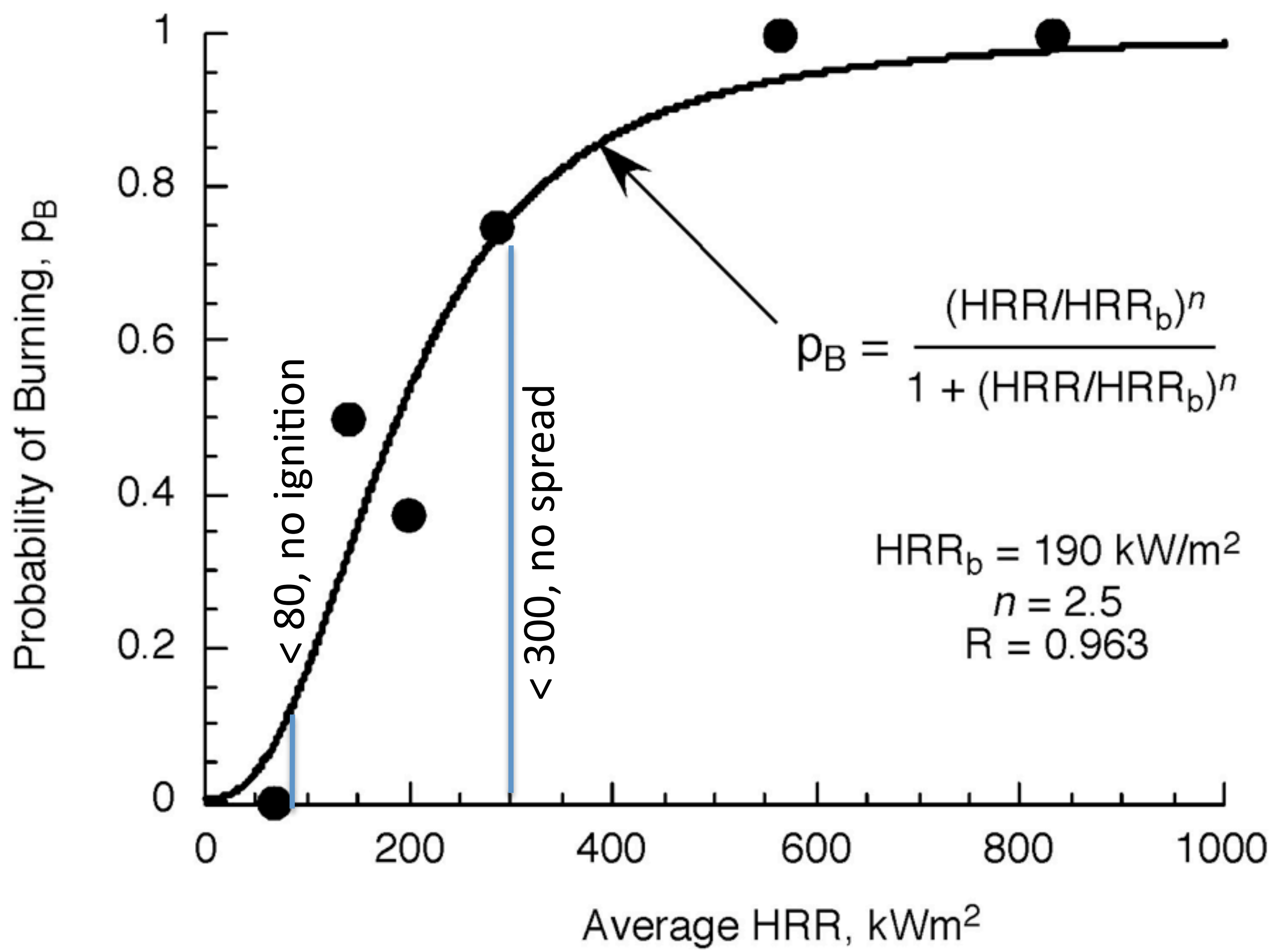
HRR < 200 kW/m^2	contain mostly V0
HRR_{ig} < 80 KW/m^2	no ignition
HRR_b < ~ 250 KW/m^2	no sustained burning
200 < HRR < 300 kW/m^2	mixture of V0, V1, and V2
HRR_f > 300 KW/m^2	continuous spread
HRR > 300 kW/m^2	mostly materials that fail.



1200
1000
800
600
400
200
0
HRR kW/m2
HRR kW/m2
Rating
3, Fails
2
1
0
Rating
no spread, HRR < 300 kW/m2
no burn, HRR < 250
no ignition, HRR < 80
Materials:
6-PC/ABS-NFR
PTFE
17-PVC-NFR
ECTFE
1-PC-NH
CPVC
PAI
15-PP-NH
PPS
19-ABS-NH
PVC(rigid)
5-PC-BFR
8-PC/ABS-PFR
4-PC-NFR
10-PC-BFR
PX
18-HIPS-NH
12-PP-NH
PEEK
7-ABS-BFR
ABS-FR
UPT-FR
PEN
2-HIPS-BFR
PVC(flex)
9-HIPS-BFR
HIPS-FR
ETFE
SIR
PBT-FR
POM
3-HIPS-NFR
11-PP-BFR
UPT
PC
PC/ABS
EP
PET
ABS
HIPS
PMMA
PBT
13-PP-BFR
14-PP-BFR
PA66
PS
PE
PA6
PP

Probability of Failing UL94V

8 bins and [Ratings except V0/All Ratings]



Conclusions

- UL94V rating can be explained in terms of fire theory and properties
- Variables in test are poorly controlled
  - Hand held igniter
  - Human observations subjective
  - Dripping materials problematic
- Why not use properties: TRP, HRP, CHF?

The End