The Effect of Dimensional and Morphological Changes in Cellular Plastics during Combustion.

The Sixth Triennial International Aircraft Fire and Cabin Safety Research Conference, October 25-28, 2010, Atlantic City

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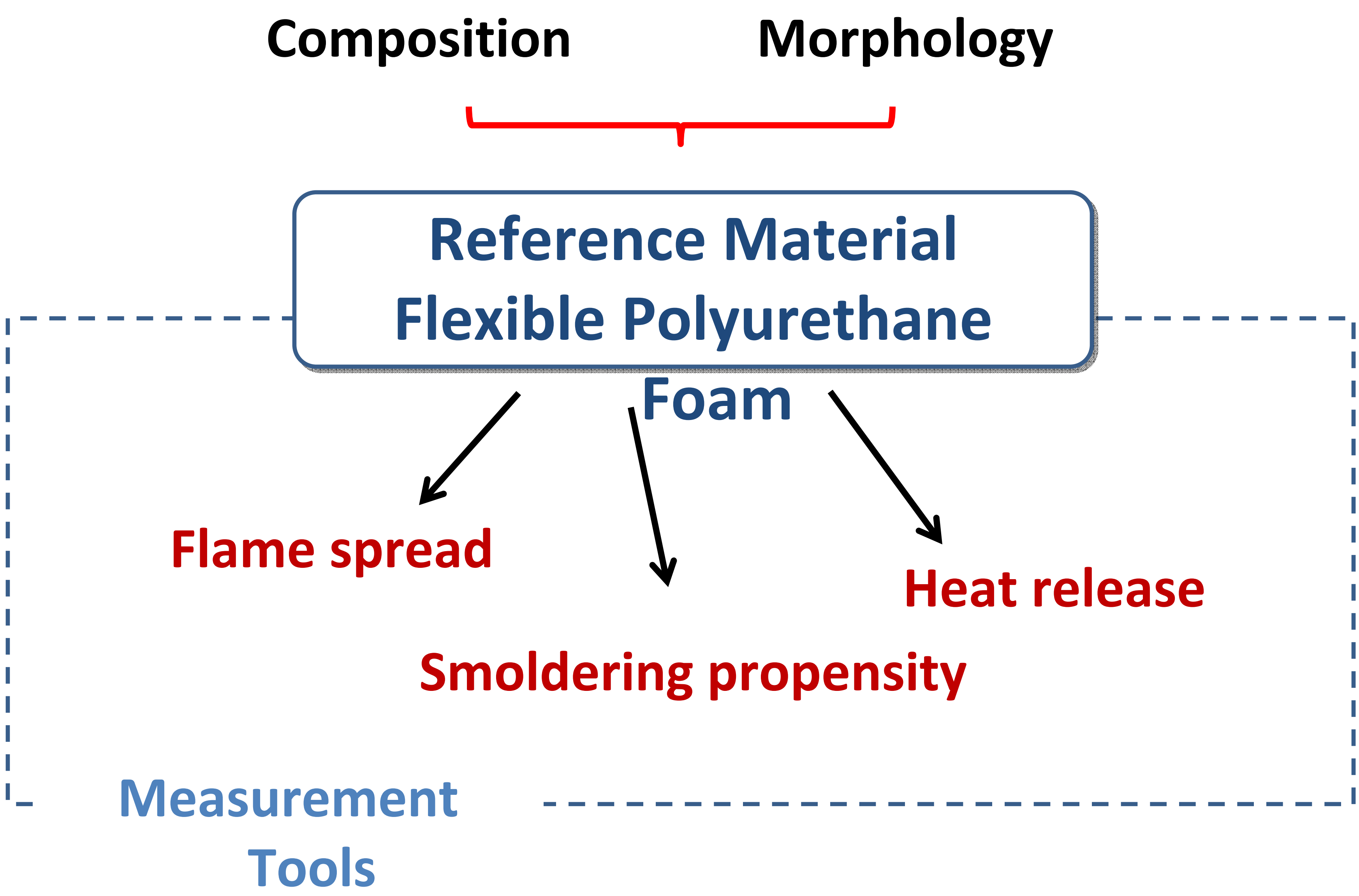
BACKGROUND: Feasibility study



Potential areas of application:

- Testing of smoldering propensity of furniture fabrics.
- Verification of foam flammability tests on multiple scales.
- Soot production under controlled conditions.
- Verification of numerical models of foam combustion.

Problem: Variations in commercial foam properties

Burned residues in NIST Smolder Box.

Foam I

Foam II

Foam III

10 cm

Specifications:

no flame retardant
density 1.8 lb ft^{-3}
IFD 25 - 30
air flow > 4 ft^3 min^{-1}

Challenges: Complexity of foam formulations

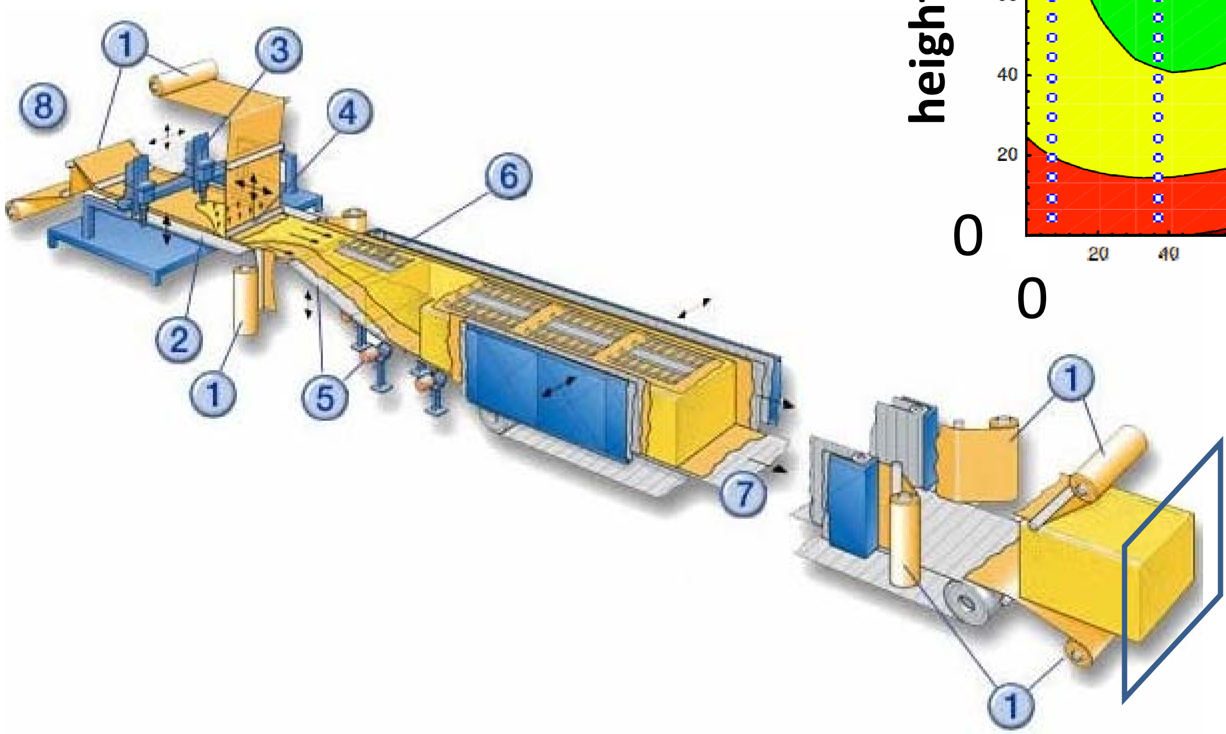
Component	Parts	mass.%
Polyether polyol (M_w~3000, trifunctional)	100	58.8
Deionized Water	3.8	2.2
Auxiliary Blowing Agent	2.6	1.5
Amine Catalyst (blowing catalyst)	0.2	0.12
Tin Catalyst (curing and blowing)	0.23	0.14
Silicon Surfactant	1	0.59
Toluene Diisocyanate (TDI)	51.52	30.3
(Flame Retardant, optional)	10.6	6.4

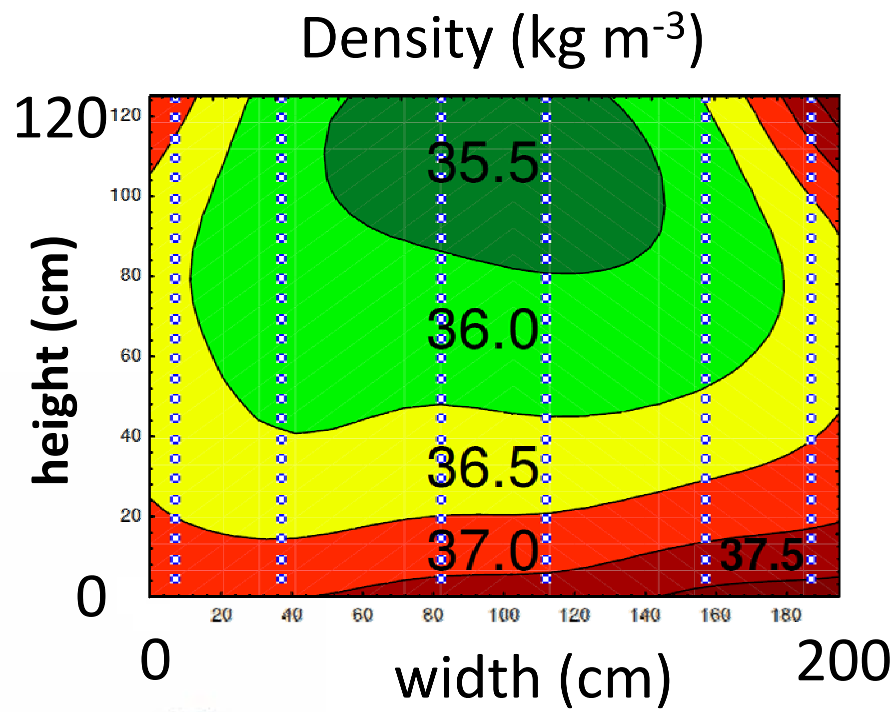
+ graft polymers

+ additives (stabilizers, cell-openers…)

Challenges: Variability in foam quality in production

Foam production line:





Source: Huntsman Polyurethanes, *www.huntsman.com/pu/Media/2008_Utech_presentation.pdf*

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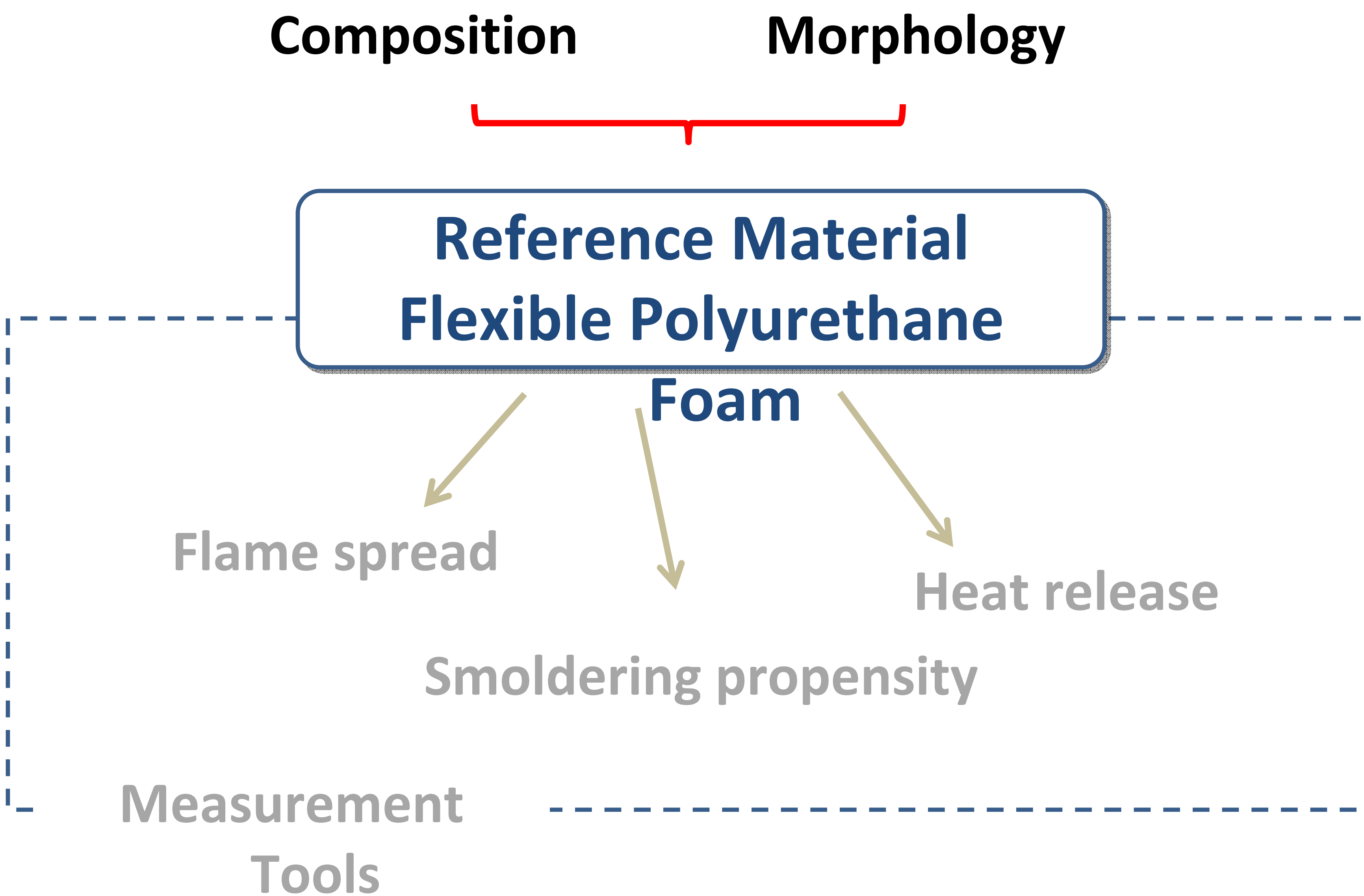
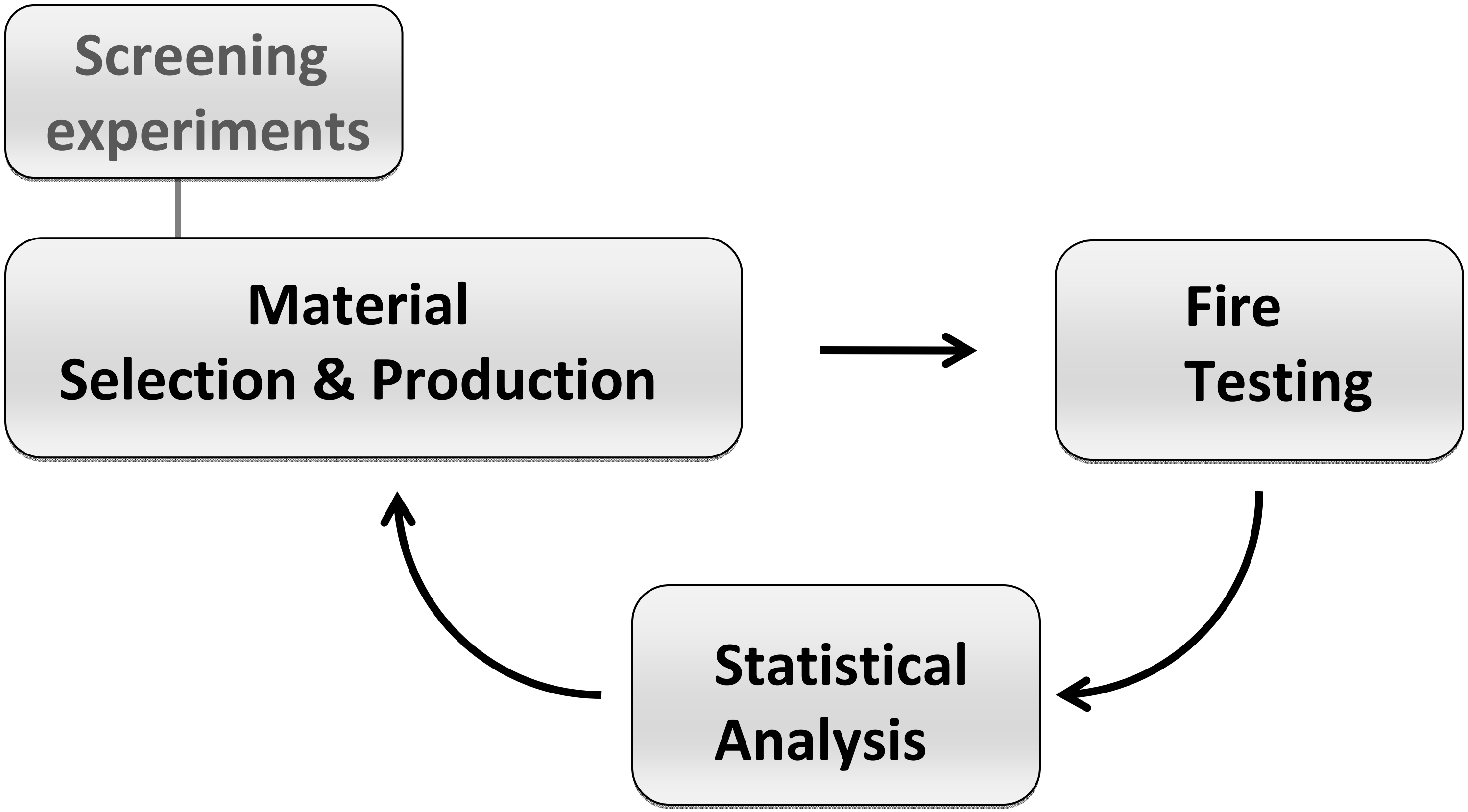
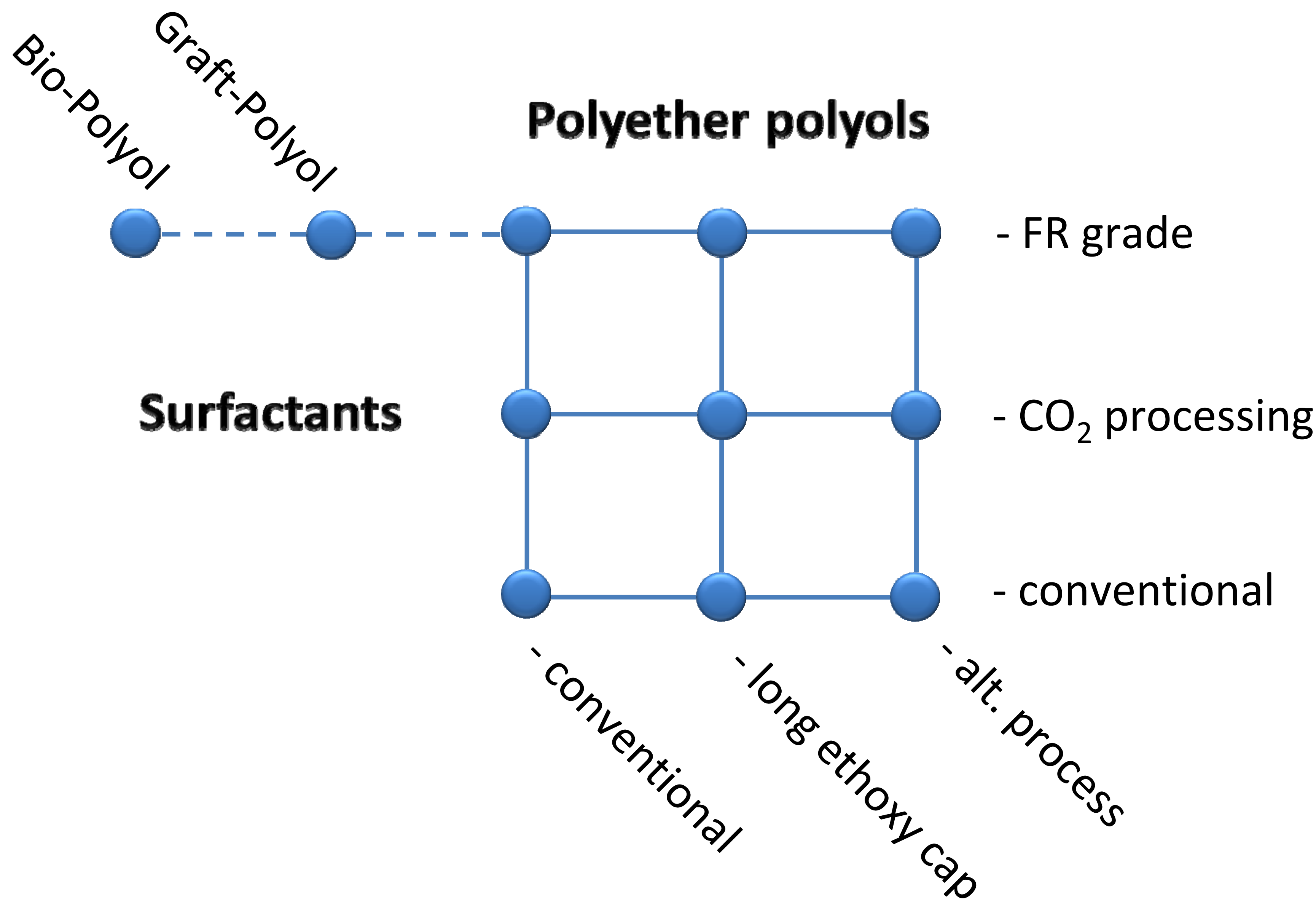


Experimental design with 3 iterations

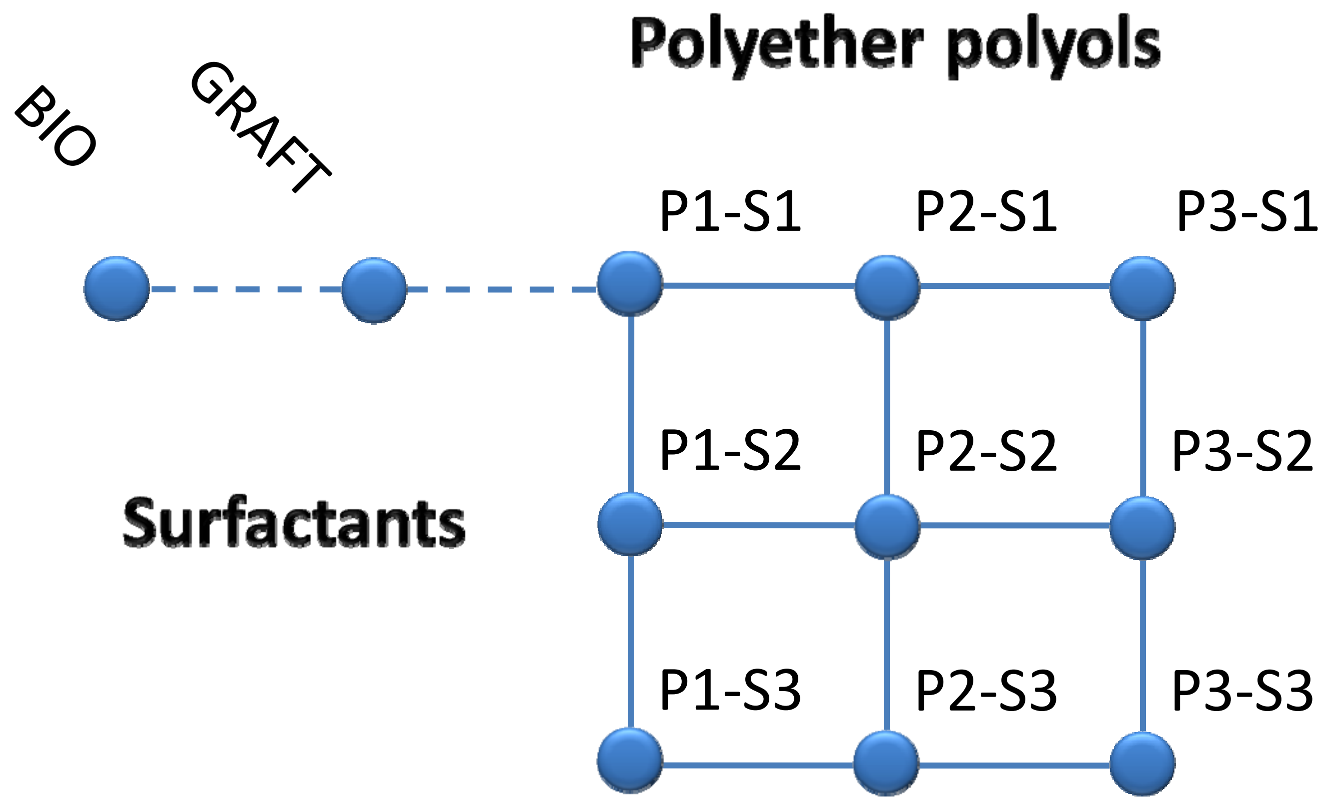


I	**Chemical composition**	raw materials, impurities
II	**Morphology**	air flow, density, …
III	**Scale-Up & Correlation**	(selection)

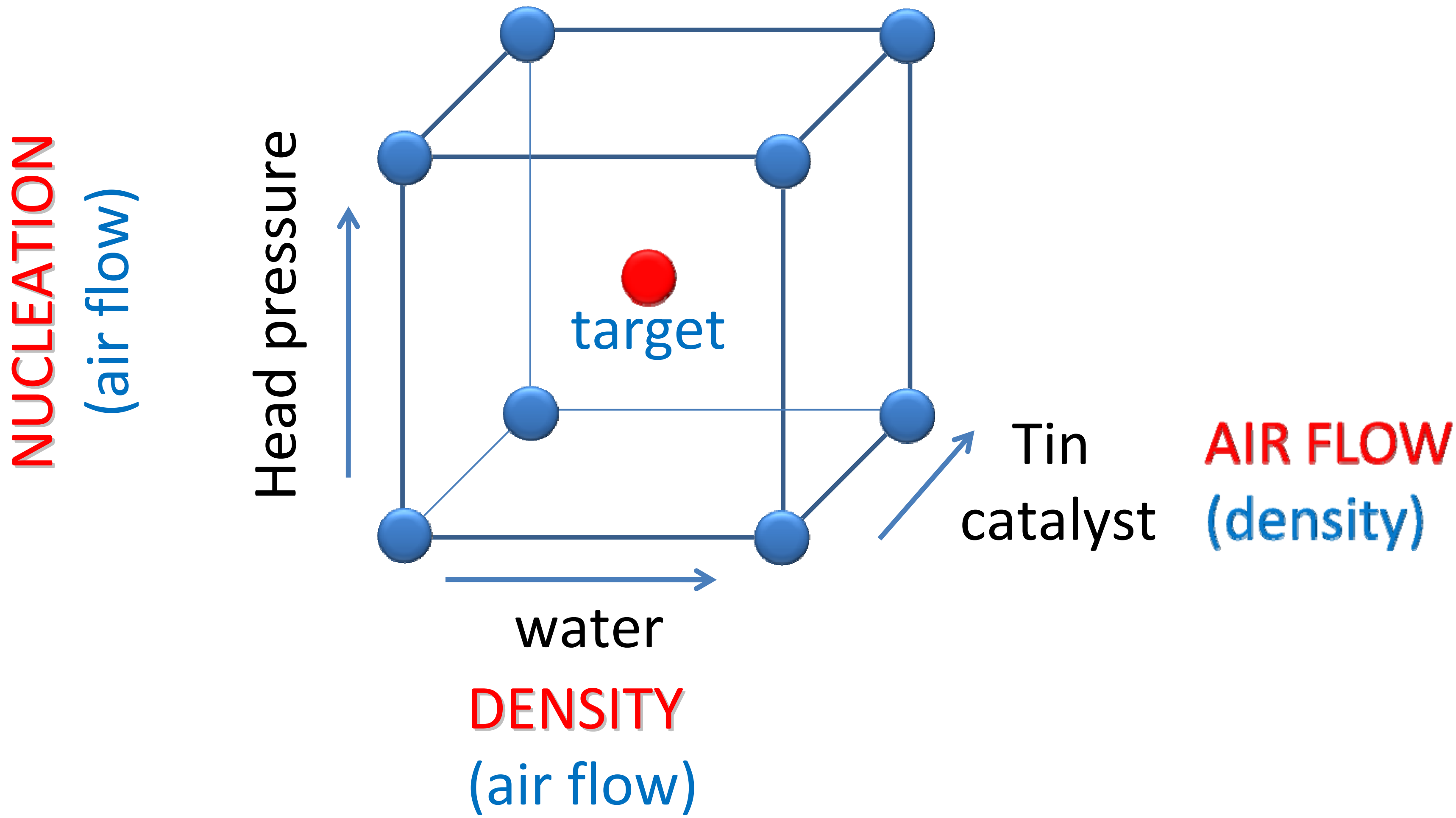
1^{st} Iteration: Chemical Composition



1st Iteration: Chemical Composition



2nd Iteration: Morphology



BACKGROUND: Feasibility study

Composition Morphology

Reference Material Flexible Polyurethane Foam

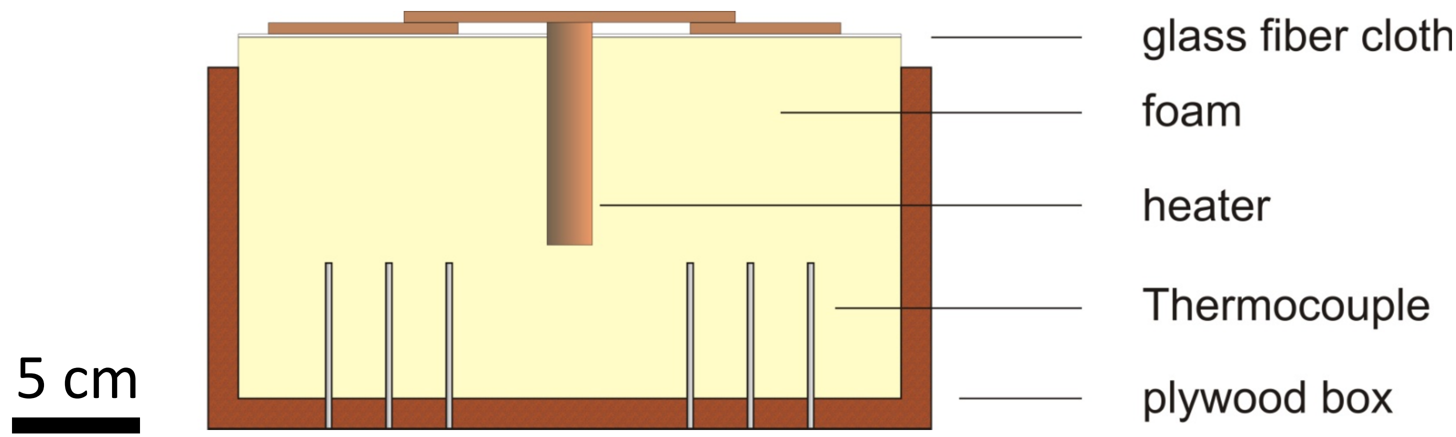
Flame spread

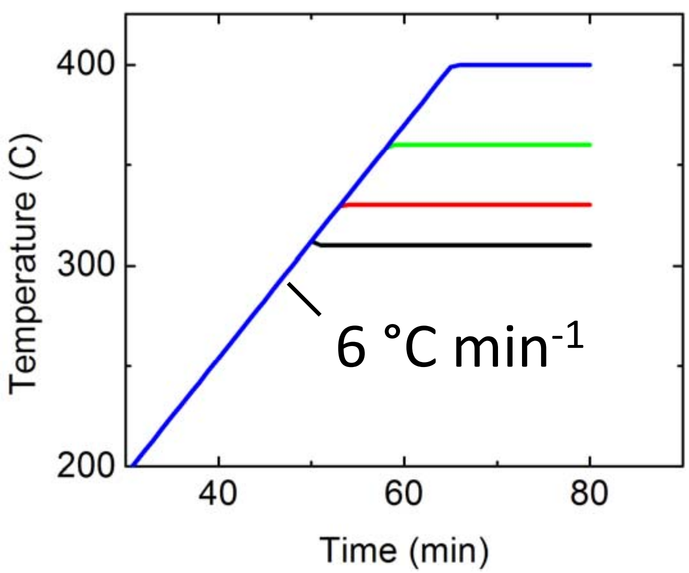
Heat release

Smoldering propensity

Measurement Tools

NIST Smolder Box



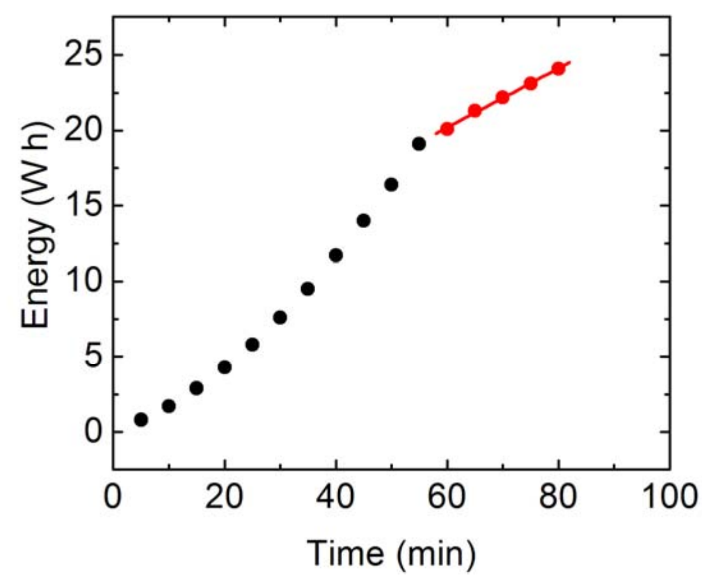


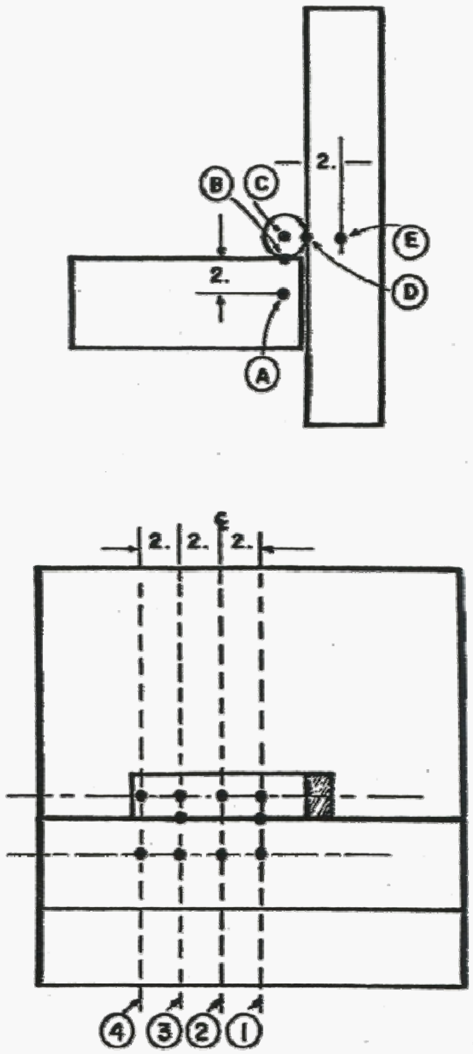
T = 360 °C

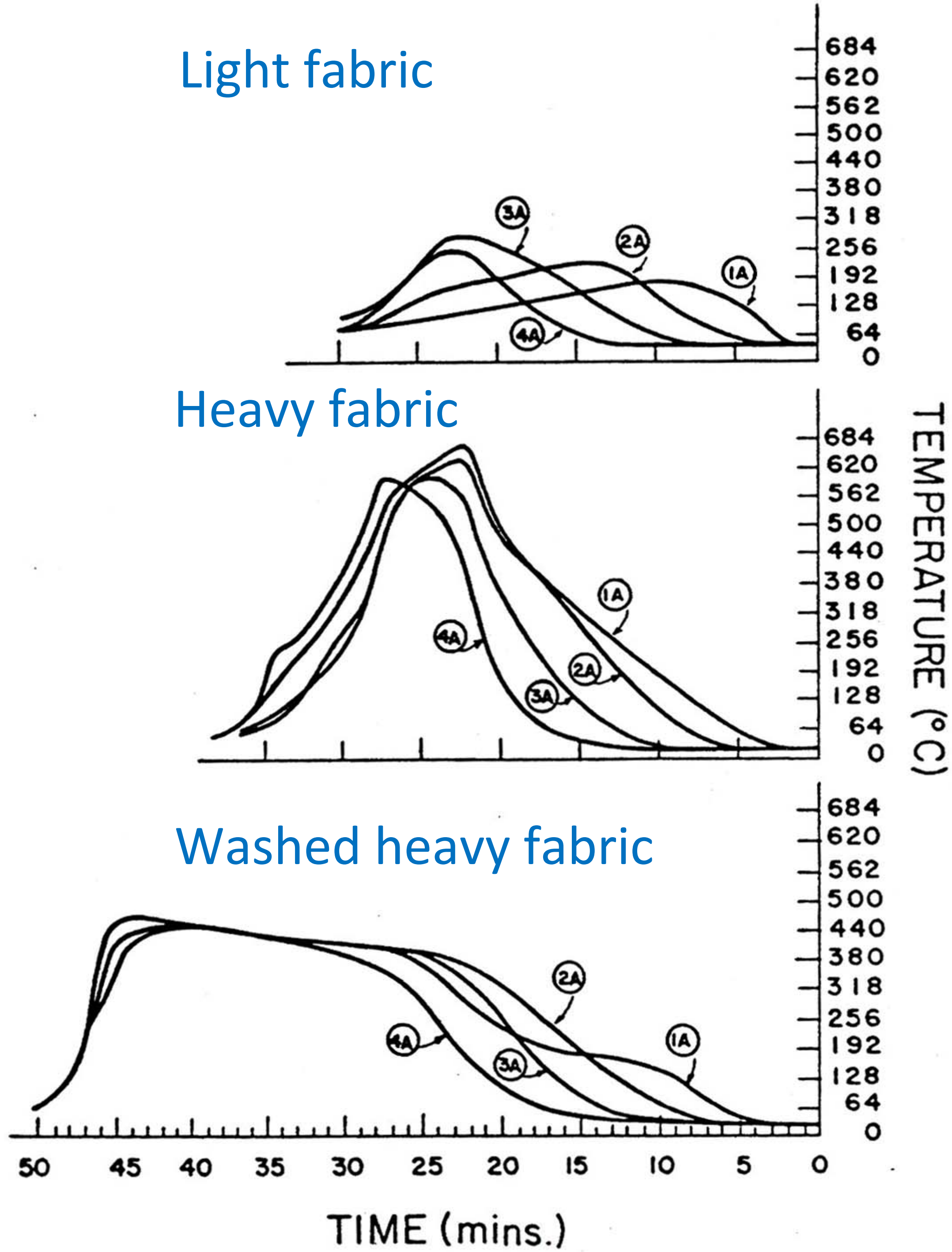
T = 340 °C

T = 330 °C

T = 320 °C







Tesoro et al., BCC Conf., 1991

NIST Smolder Box

Test output:

- Temperature profile
- Mass loss and size of smolder zone
- Power supplied to the heater

Foam I 360 °C

— 5 cm

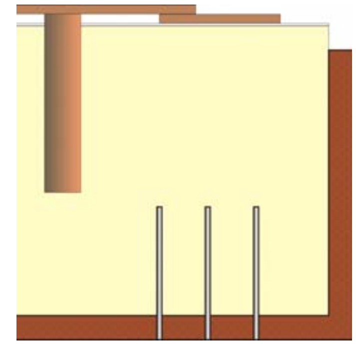
Foam II 360 °C

— 5 cm

NIST Smolder Box

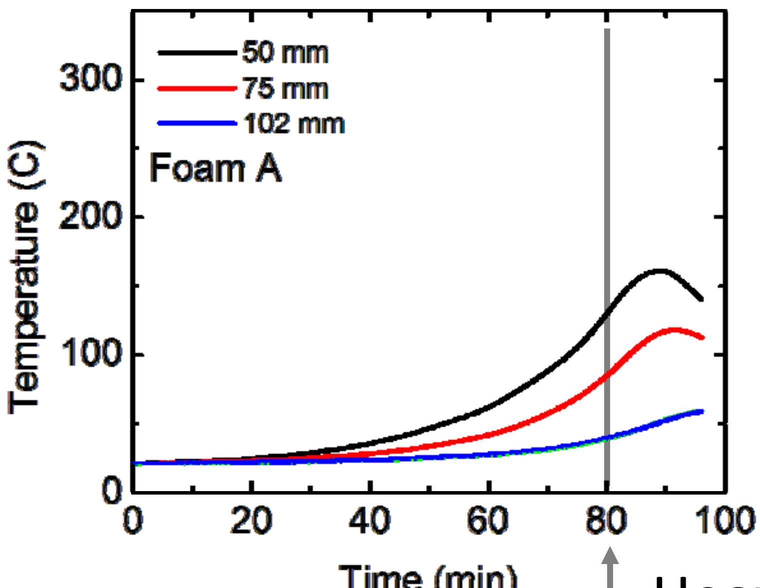
Test output:

- Temperature profile
- Mass loss
- Size of the smolder zone



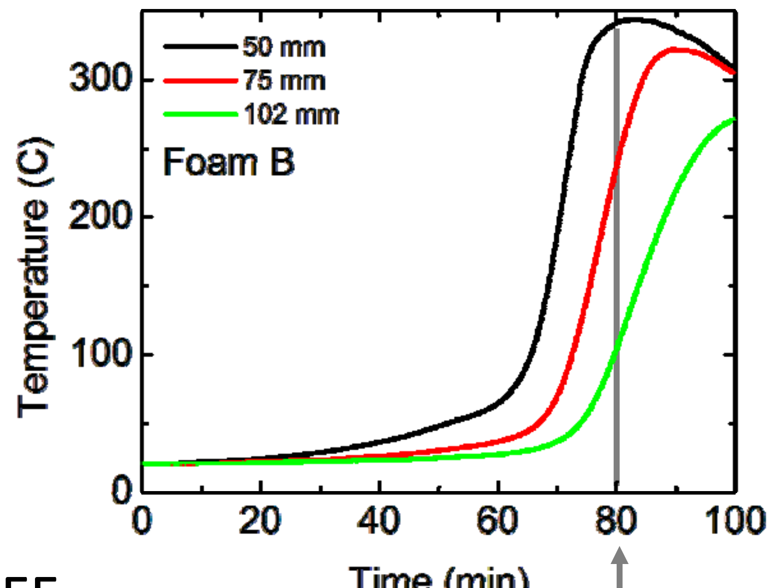
50 mm -102 mm

Foam I 360 °C



Heater OFF

Foam II 360 °C



Heater OFF

NIST Smolder Box – Sample residue

T_{heater} = 340 °C

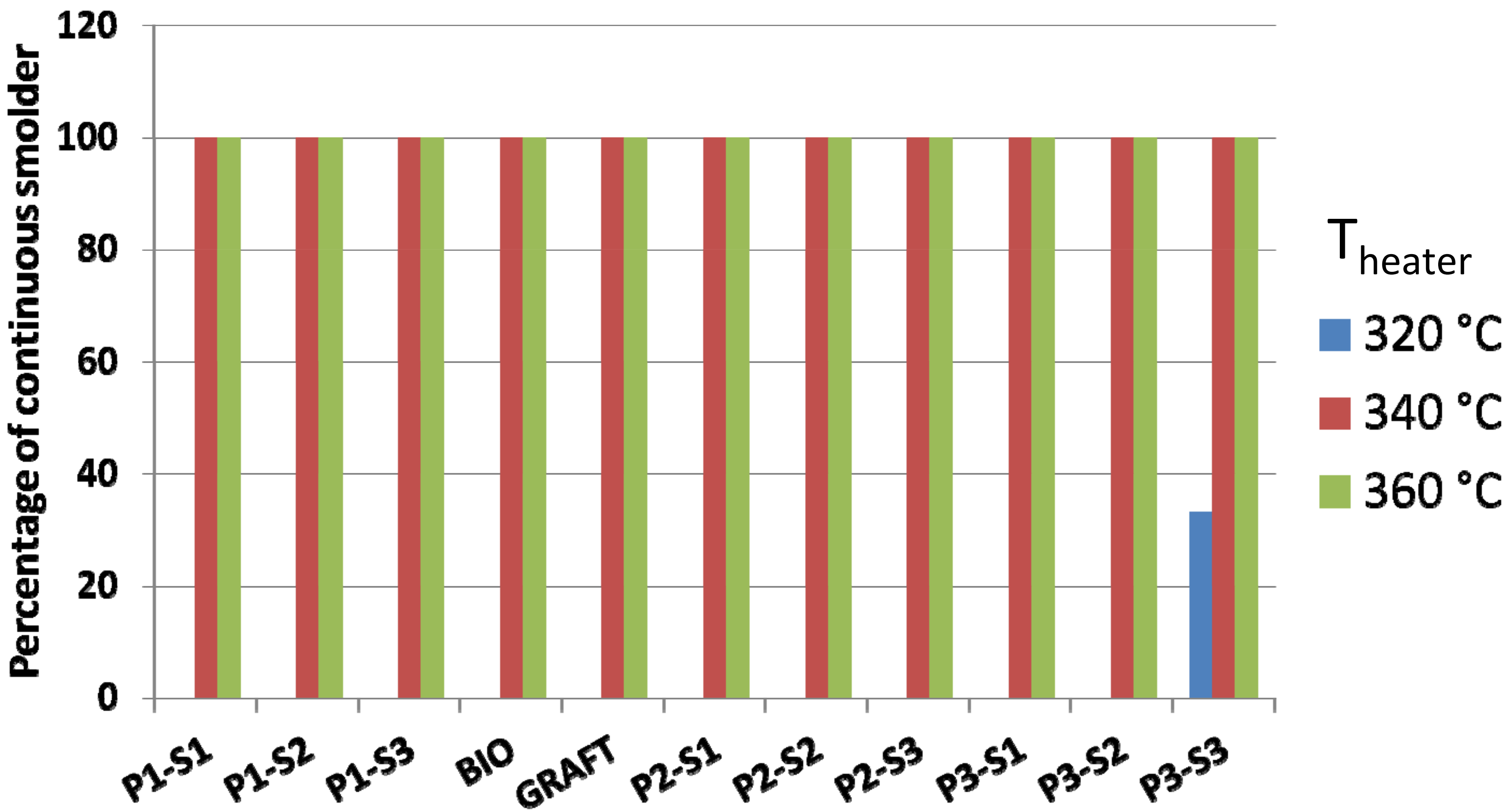
5 cm

Variation of parameters and test results T_{heater} = 340 °C

Sample size: 20 runs

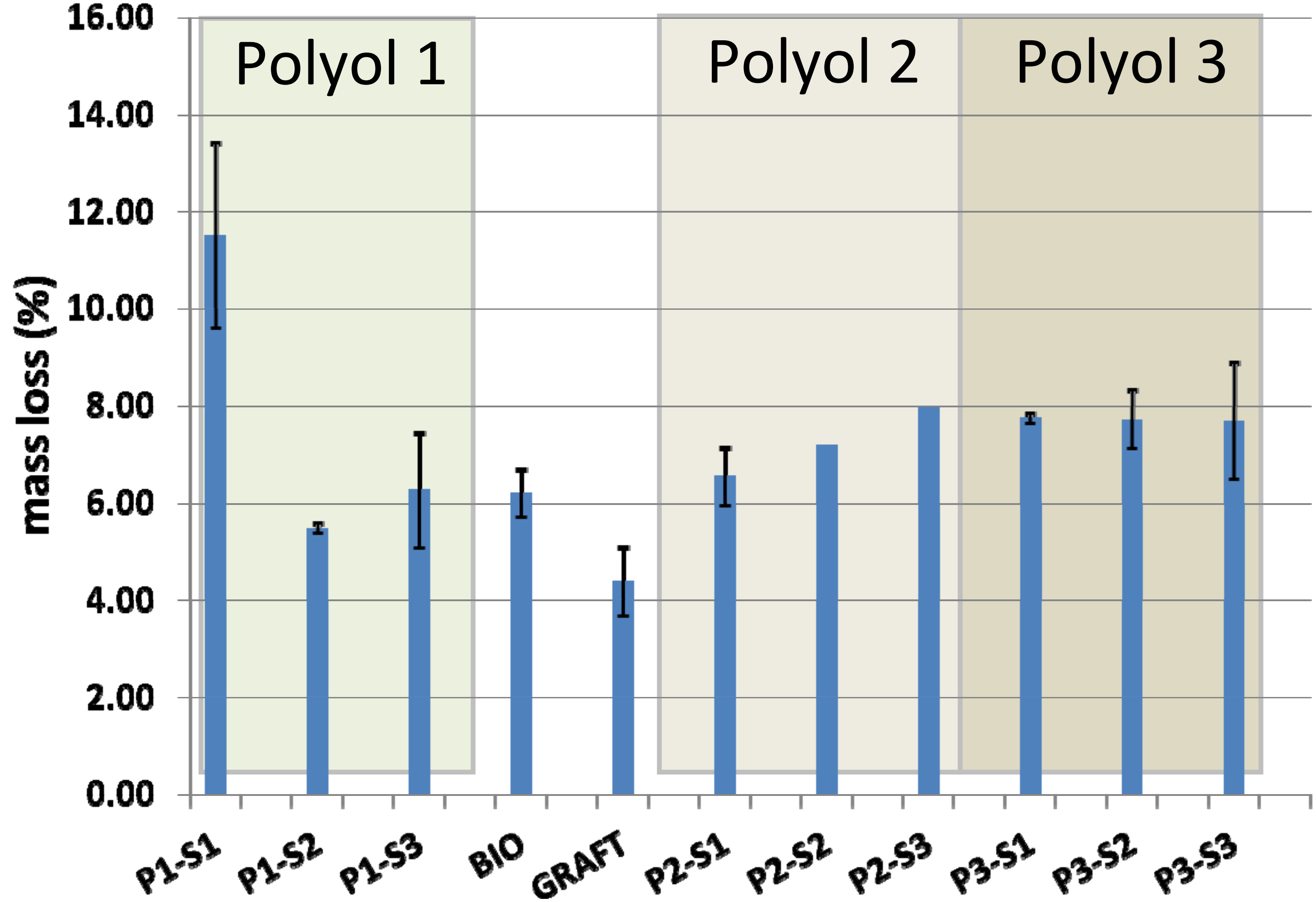
	Average	Same sample type deviation	Same sample type deviation %
Mass loss (%)	7.2	0.6	8 %
Temperature at 4 in distance (°C)	179	24	13 %
Power to maintain Set point (W)	12.9	0.9	7 %
Energy supplied (W×h)	24.7	0.7	3 %
Heating rate (°C min^{-1})	5.7	0.1	2 %

Initiation of continuous smolder in box test



Smolder Box Results

T_{heater} = 340 °C

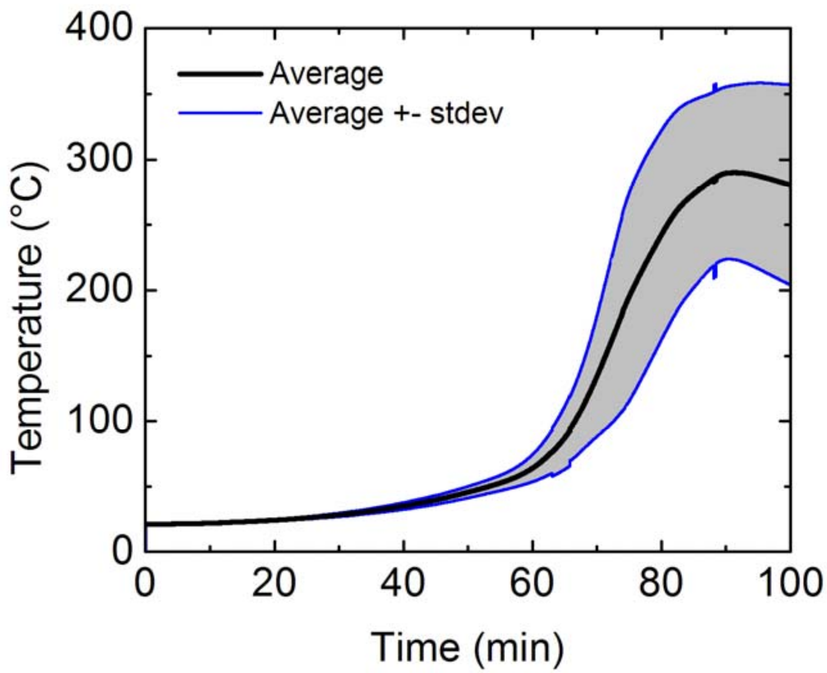


Variability of reference formulations T_{heater} = 360 °C

Commercial foams

Mass loss

9 % ± 7 %

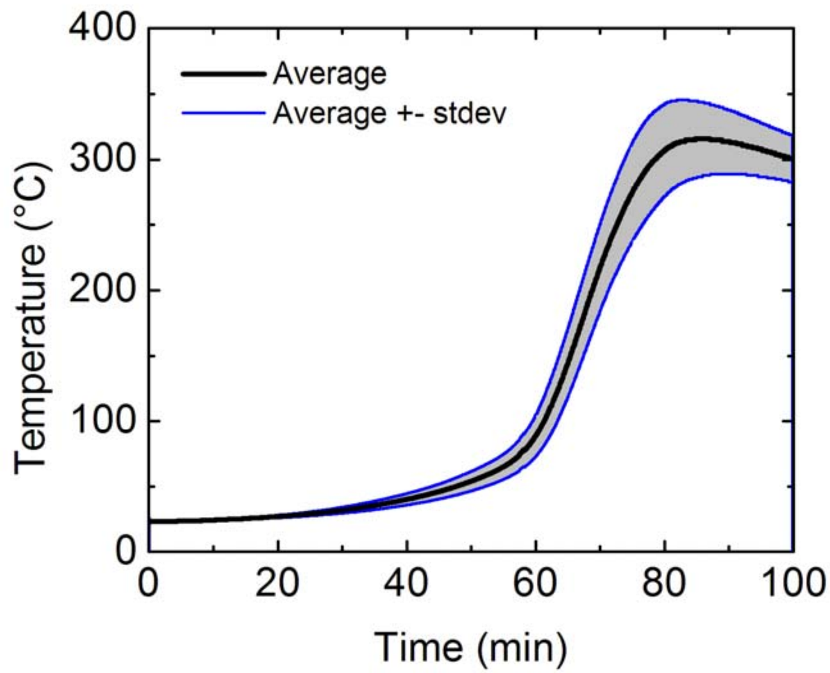


SRM evaluation

3 surfactants x 3 polyols

Mass loss

8 % ± 2 %



Effect of chemical composition on smoldering propensity

- The smolder box test method was continuously improved and showed a satisfactory reproducibility of results.
- An acceptable foam quality and level of control over known nuisance parameters was achieved using a pilot foam production line.
- The variability of the smolder box test results of the custom-made samples was significantly lower than that of commercial samples.
- The nature of the polyether polyols and silicone surfactants chosen for this sample set did not significantly affect the outcome of the smolder box test.

BACKGROUND: Feasibility study

Composition

Morphology

Reference Material Flexible Polyurethane Foam

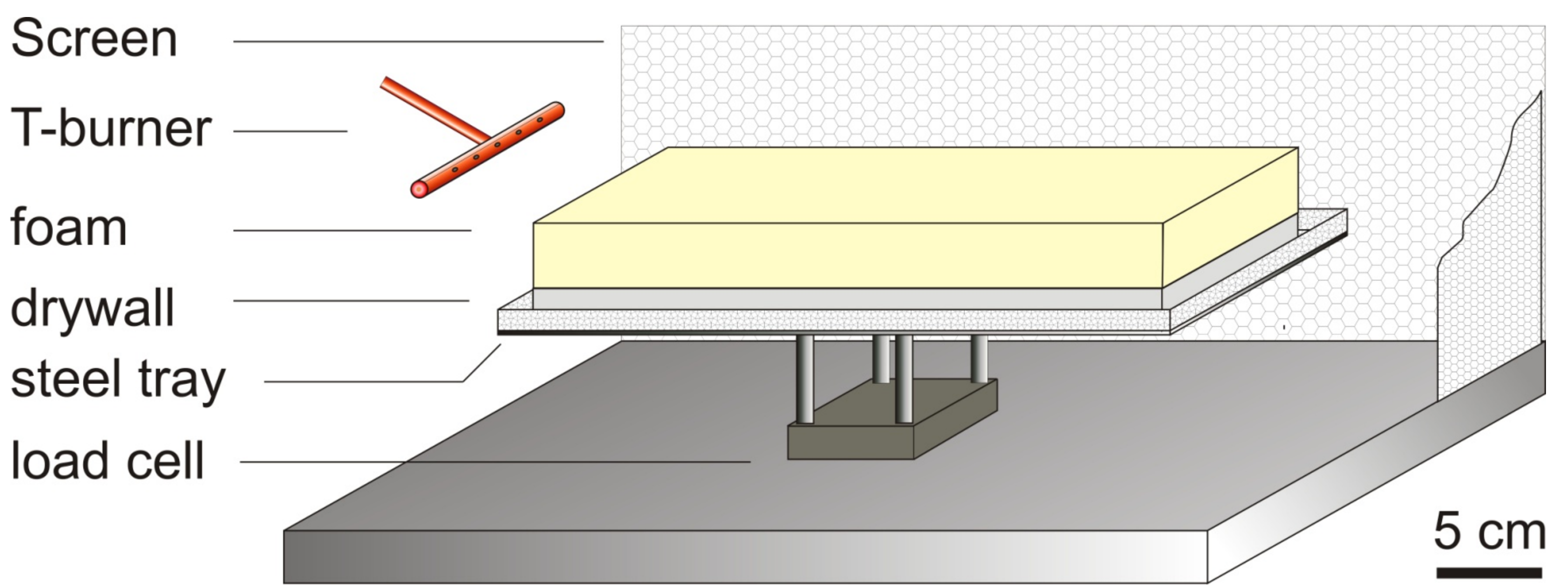
Flame spread

Smoldering propensity

Heat release

Measurement Tools

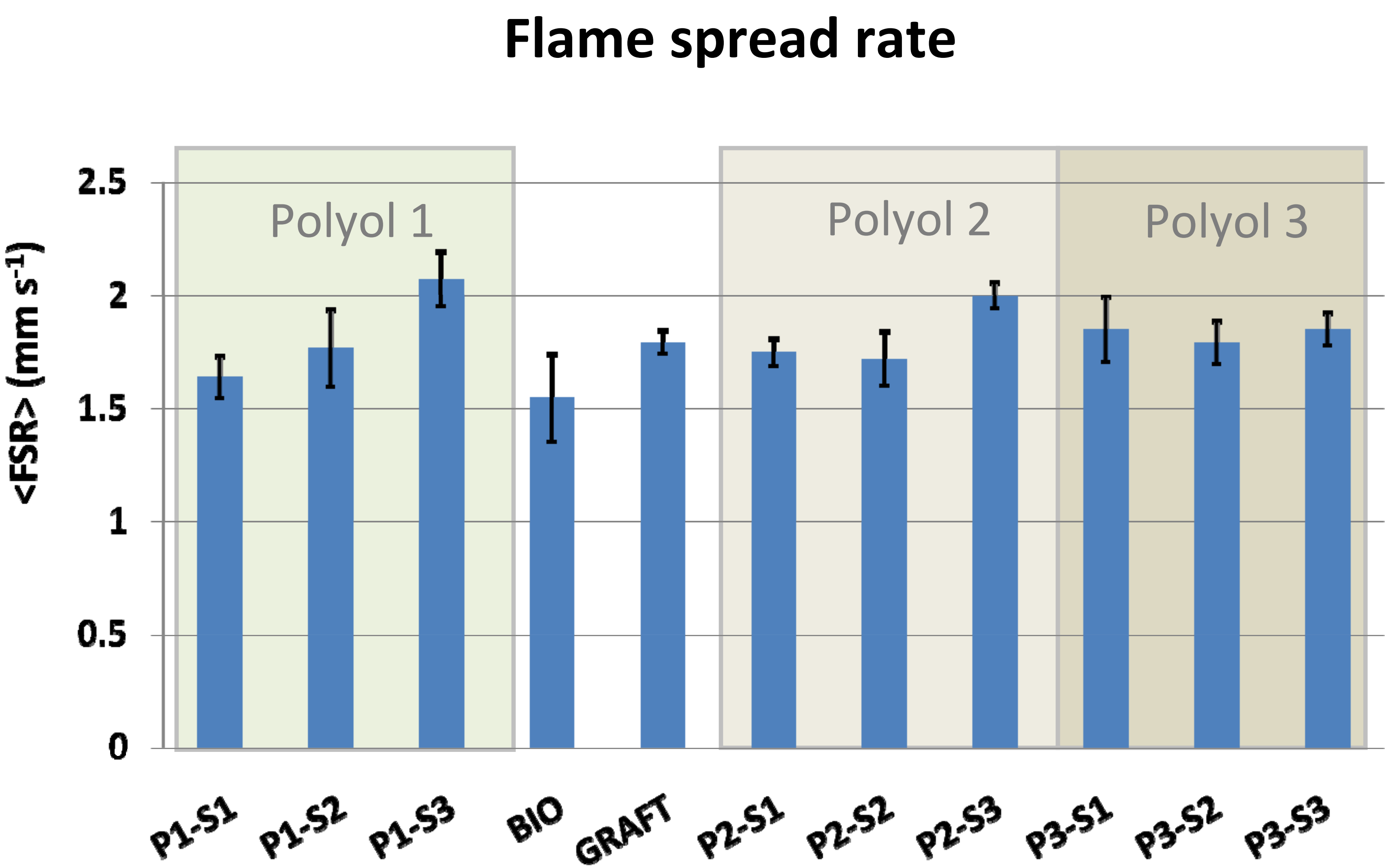
Flame spread test

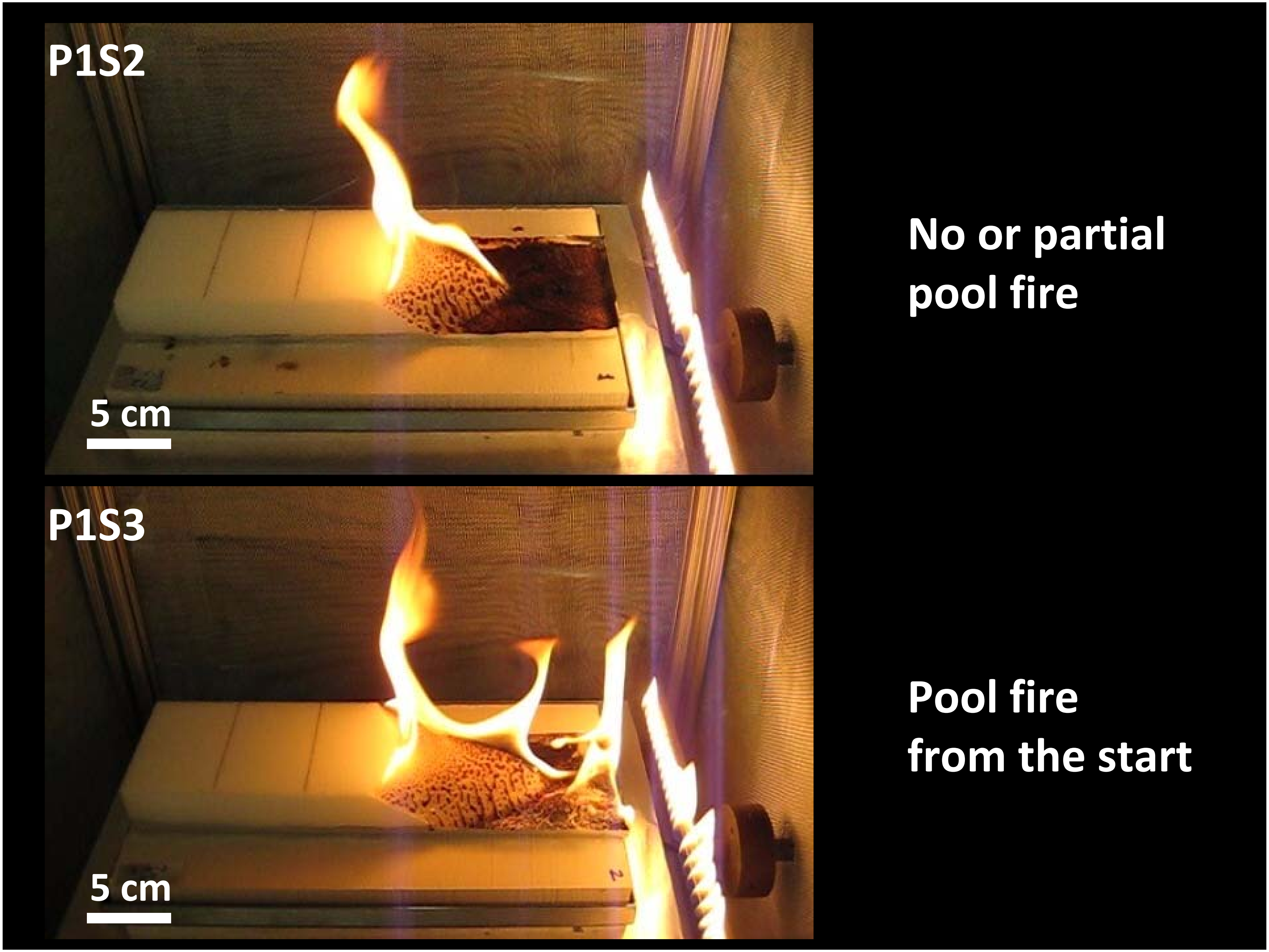


Sample size: 28 cm × 7.5 cm × 3 cm

Flame application: 20 s

Flame spread test

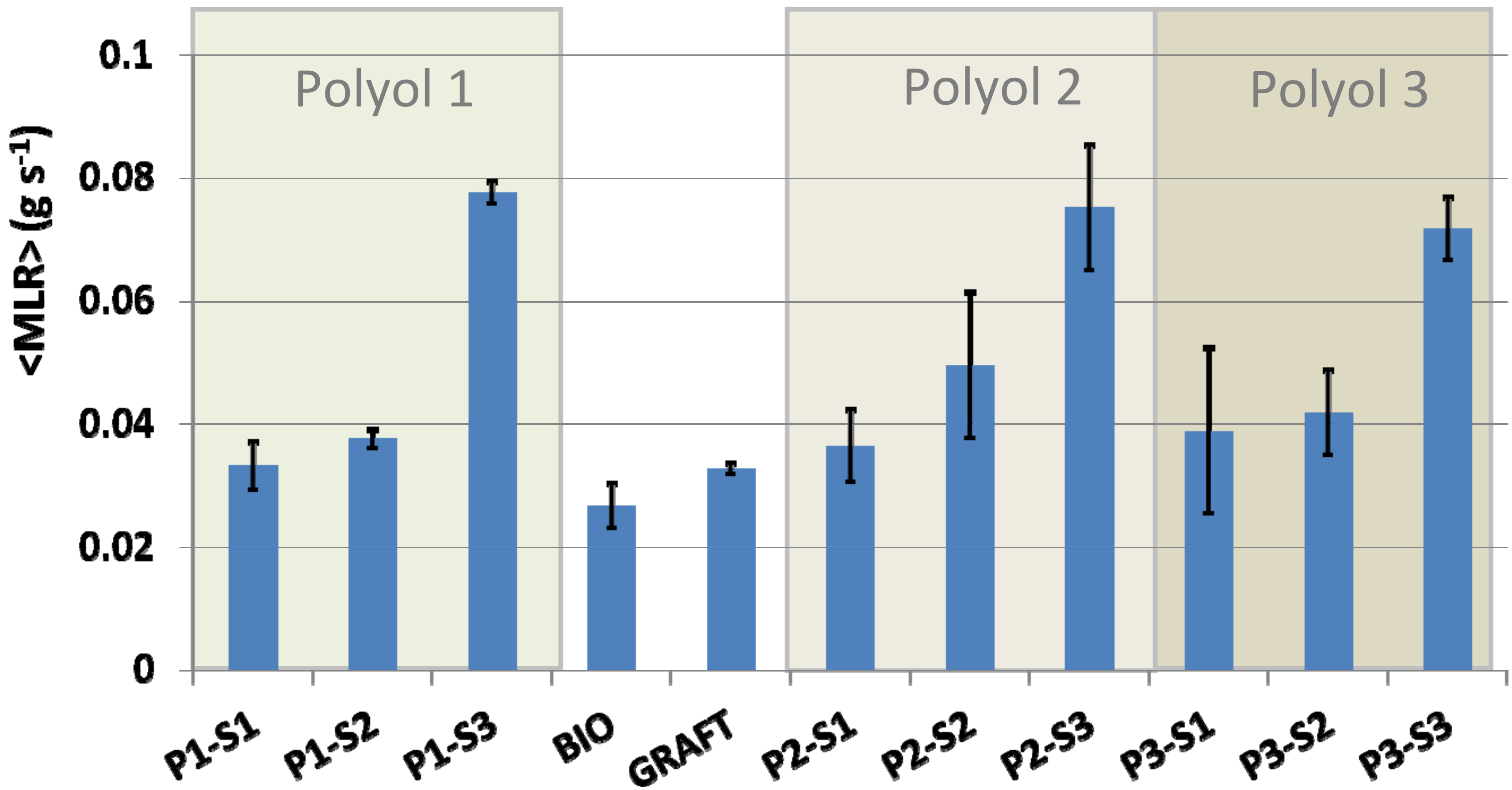



P1S2
5 cm
No or partial pool fire
P1S3
5 cm
Pool fire from the start

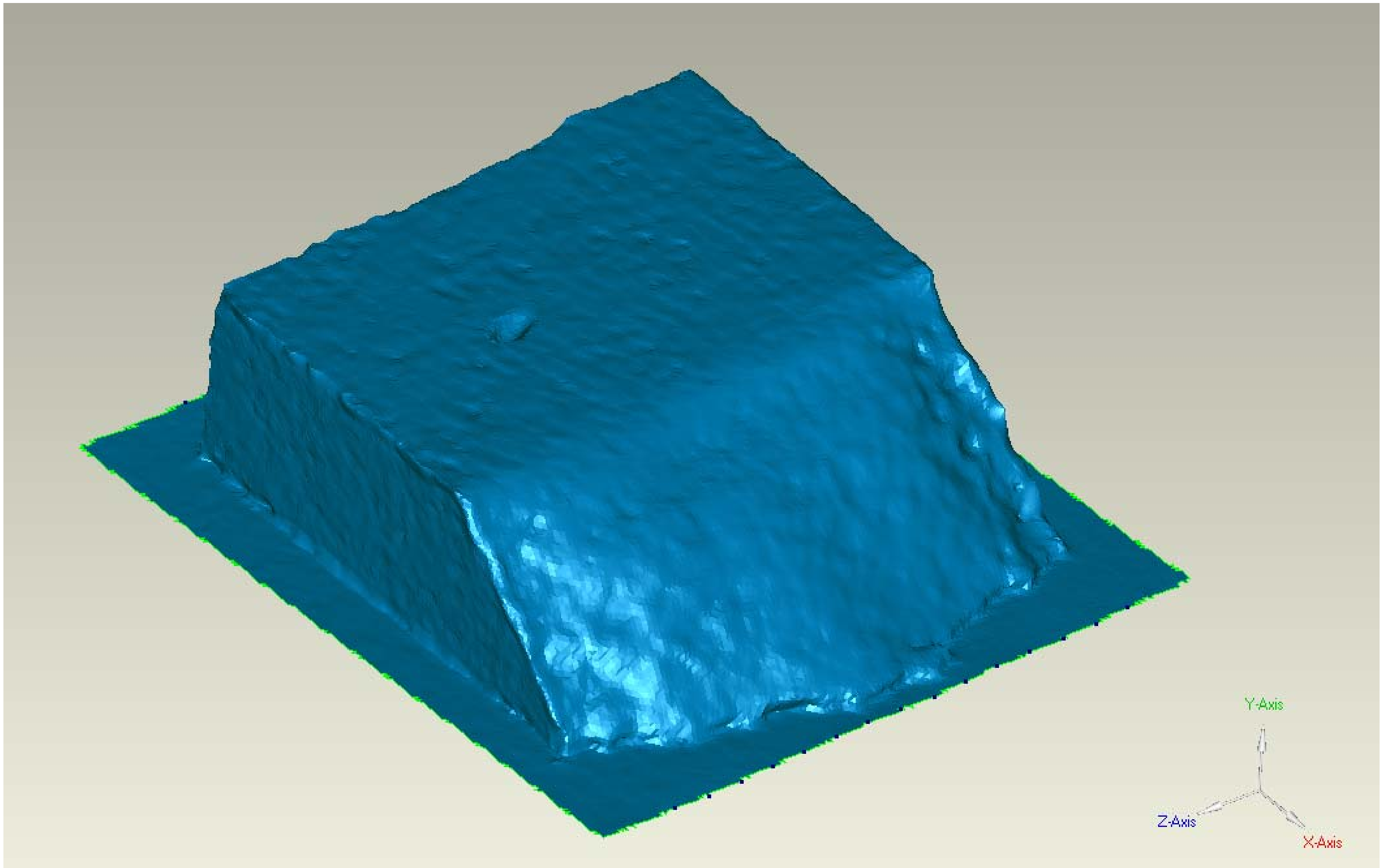
Flame spread test

Link

Mass loss rate during flame spread

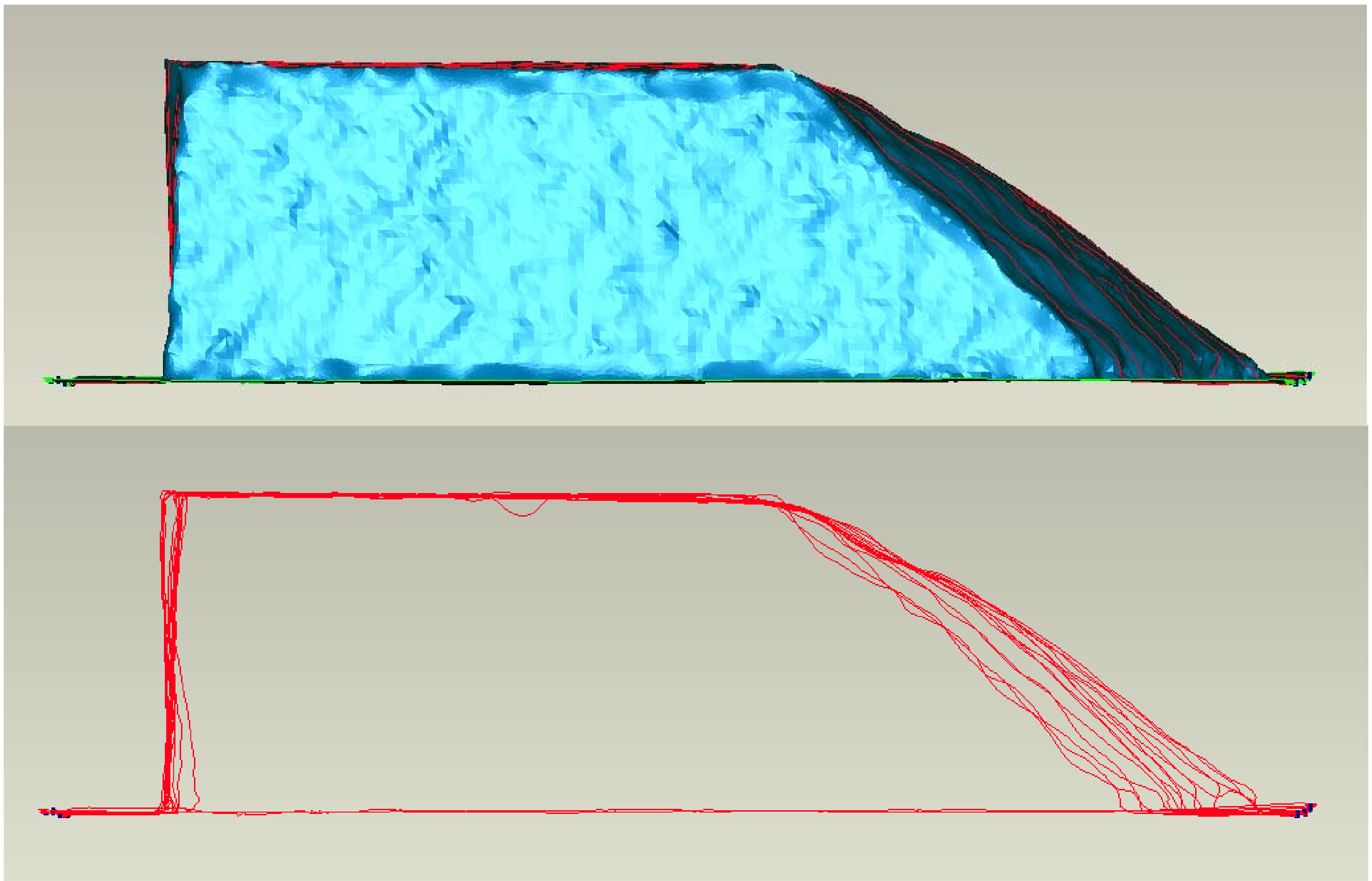


Flame spread test – Shape change of foam



2 cm

Flame spread test – Shape change of foam



2 cm

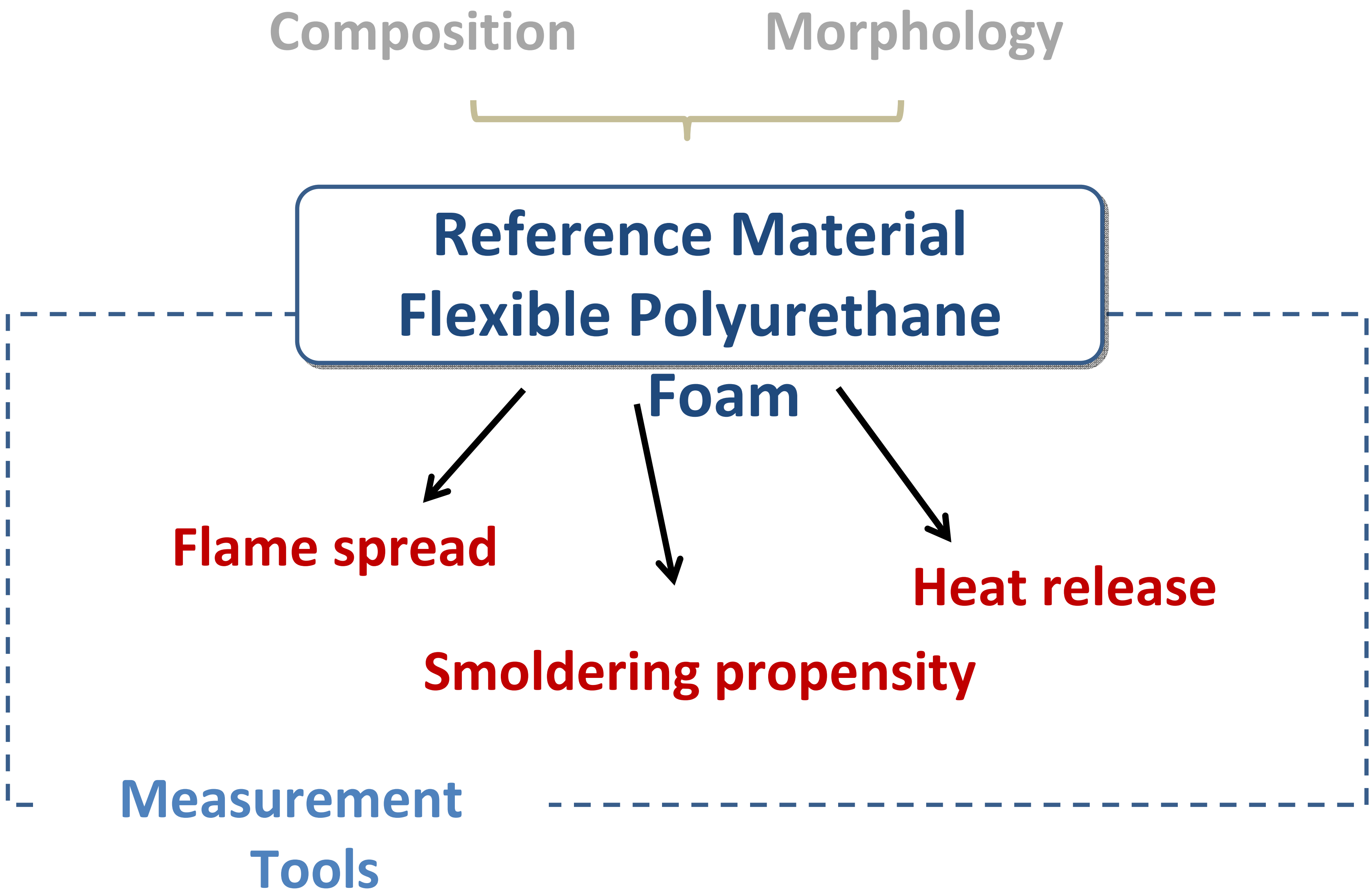
Effect of chemical composition on flame spread behavior

- The nature of the polyether polyols tested did not significantly affect the outcome of the flame spread test.

- The type of silicone surfactant had a strong impact on the burning rate of the pool of degraded material formed during the collapse of the foam following the initial flame spread over the sample surface.

- The flame spread rate in the given test configuration showed little variation for the foam formulations tested. The formation of pool fires led to a small increase in the flame spread rate.

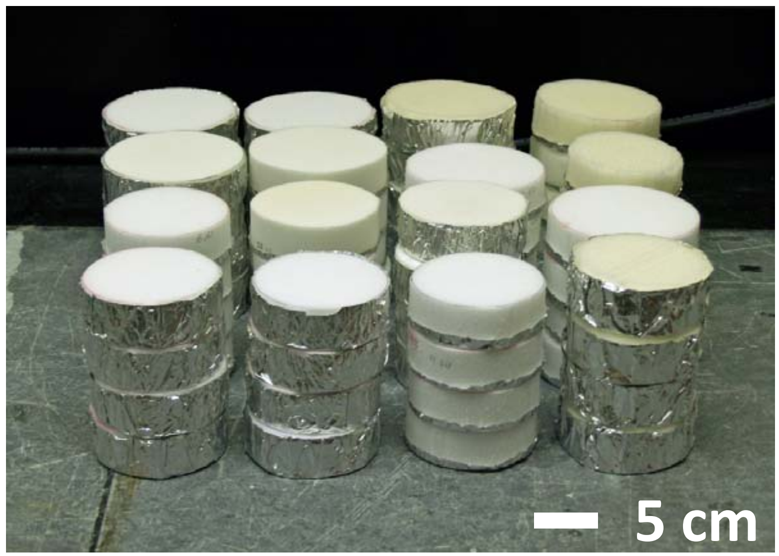
BACKGROUND: Feasibility study



Cone calorimeter - Combinatorial Evaluation

foam types – PUR-29, LDPE-29, LDPE-39, PA6-58

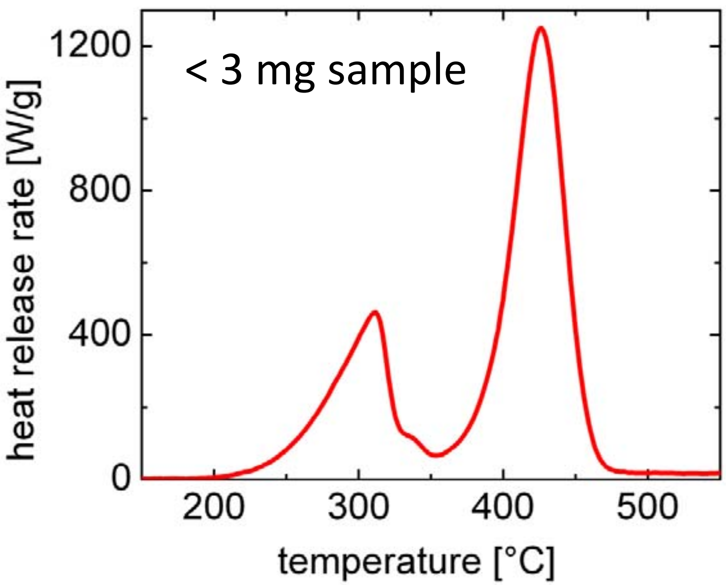
2^3 full factorial experimental design



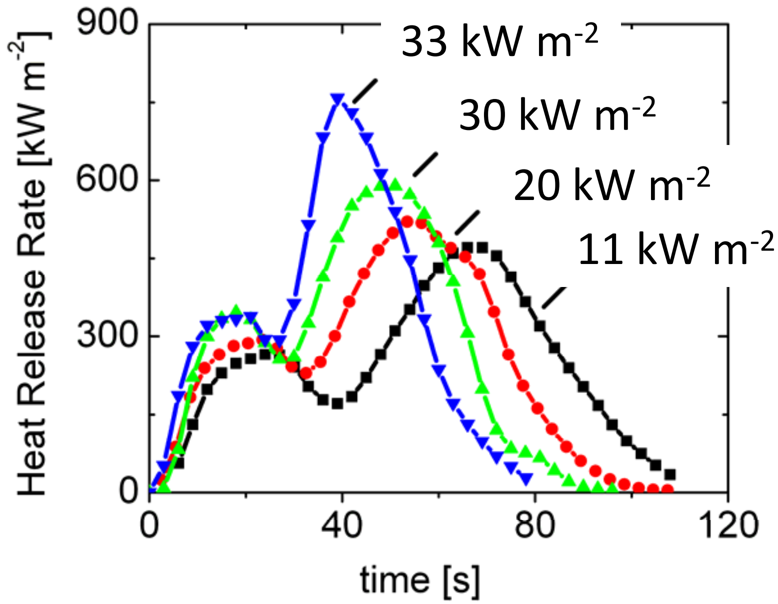
Diameter	86 mm	/	100 mm
Edge	5 mm	/	30 mm
Heat flux	10 kW m^{-2}	/	30 kW m^{-2}

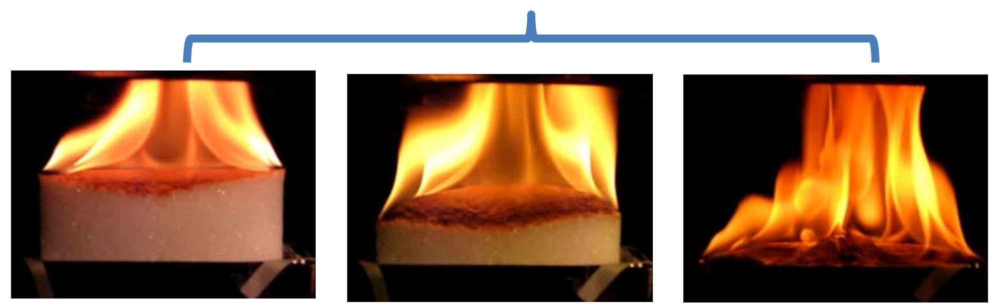
Two-stage foam burning – example Polyurethane foam

Micro-Combustion Calorimeter



Cone Calorimeter

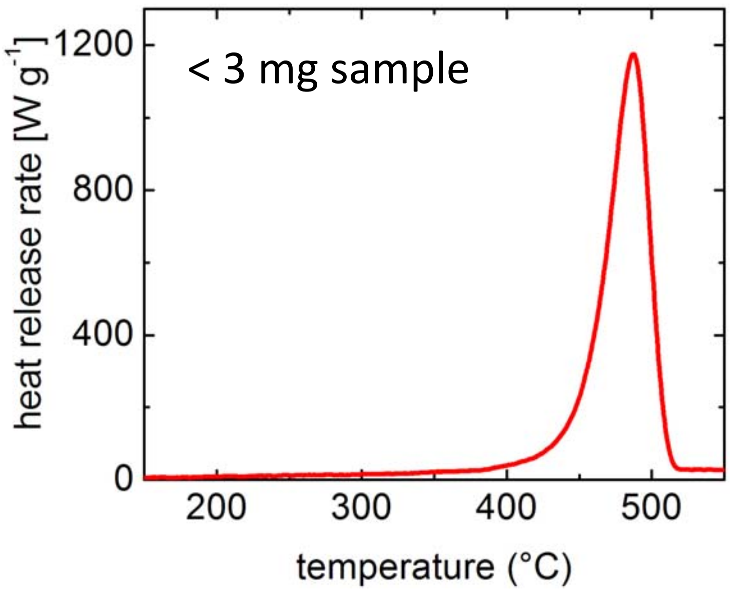




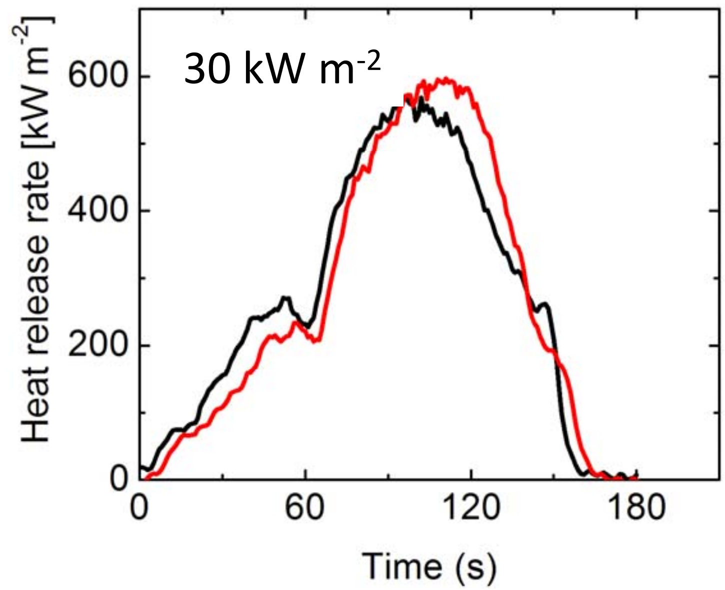
mm **cm**

Two-stage foam burning – example LDPE foam

Microcombustion calorimeter

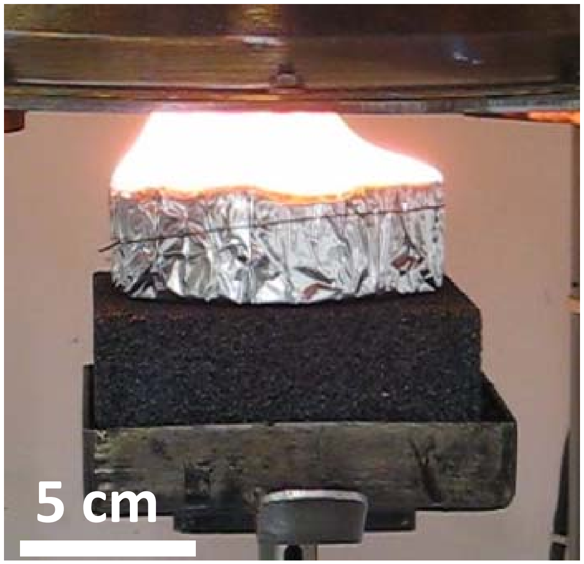


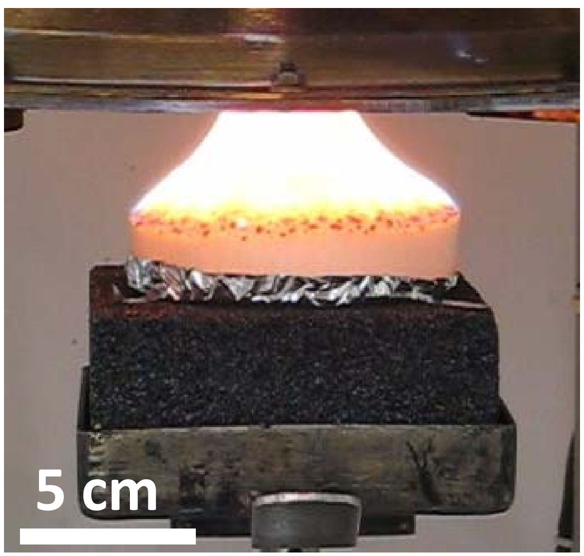
Cone calorimeter



mm **cm**

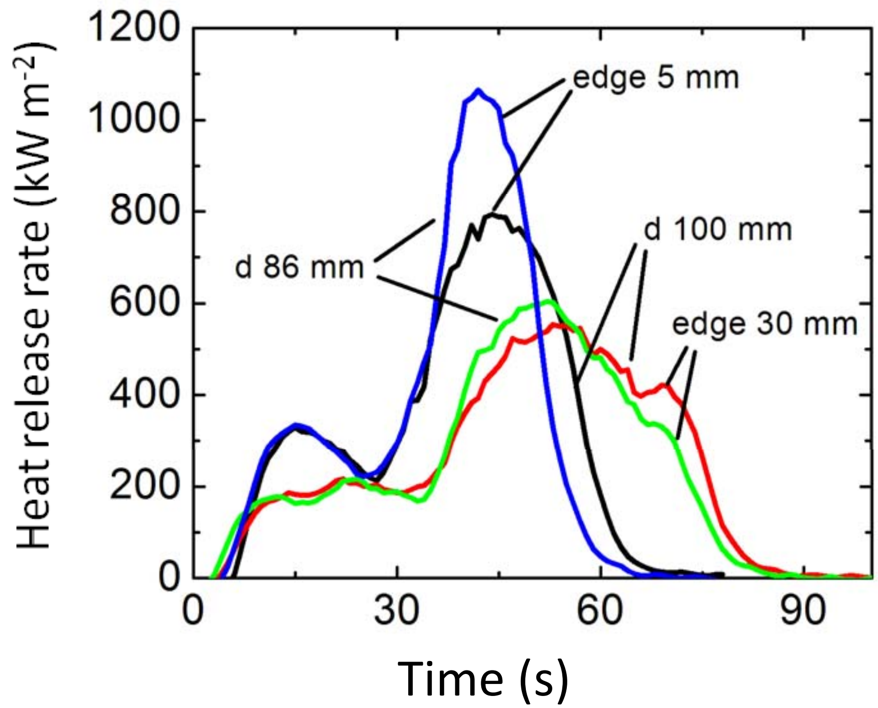
Effect of edge condition on burning rate





Incident heat flux 30 kW m^{-2}

PUR-29 kg m^{-3}



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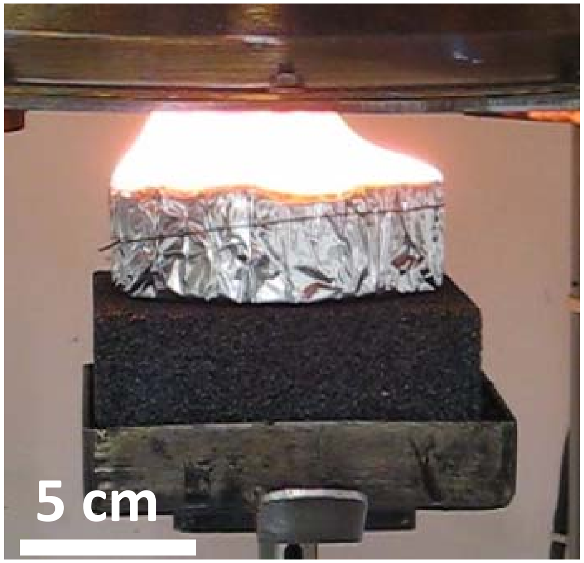
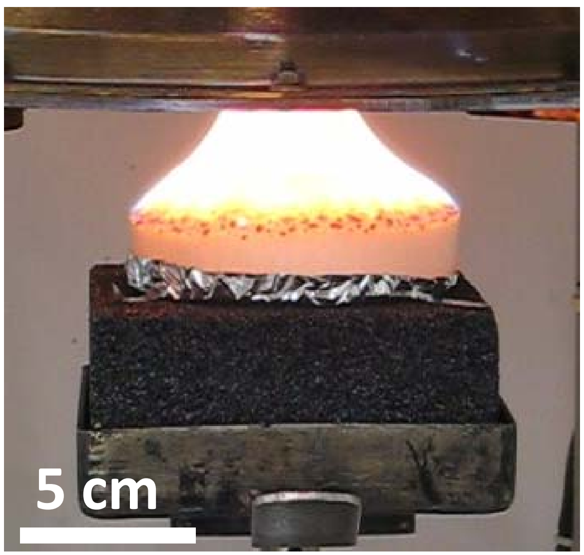
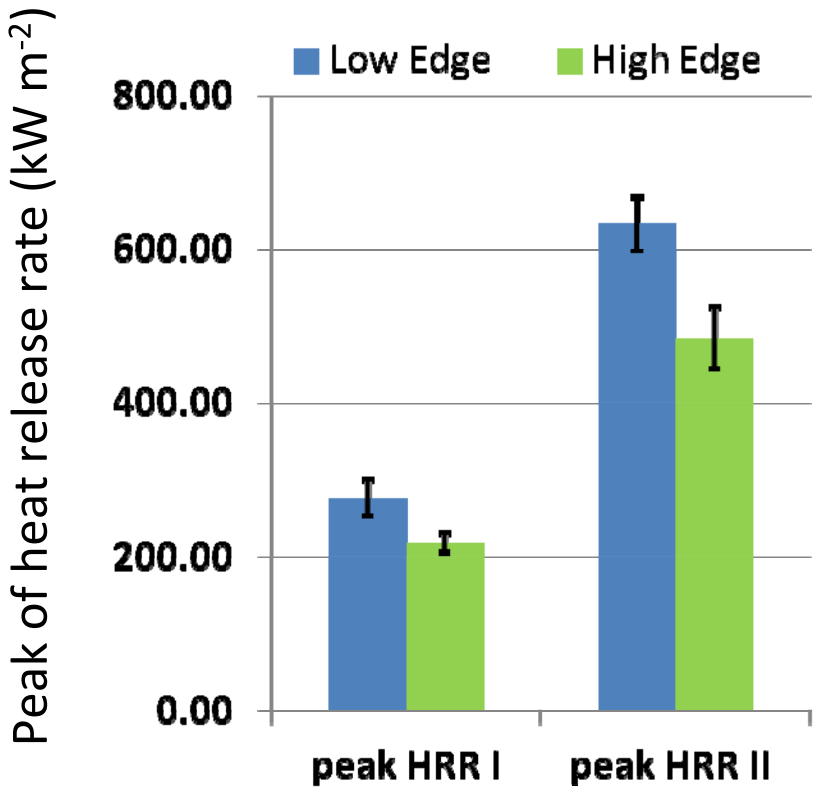




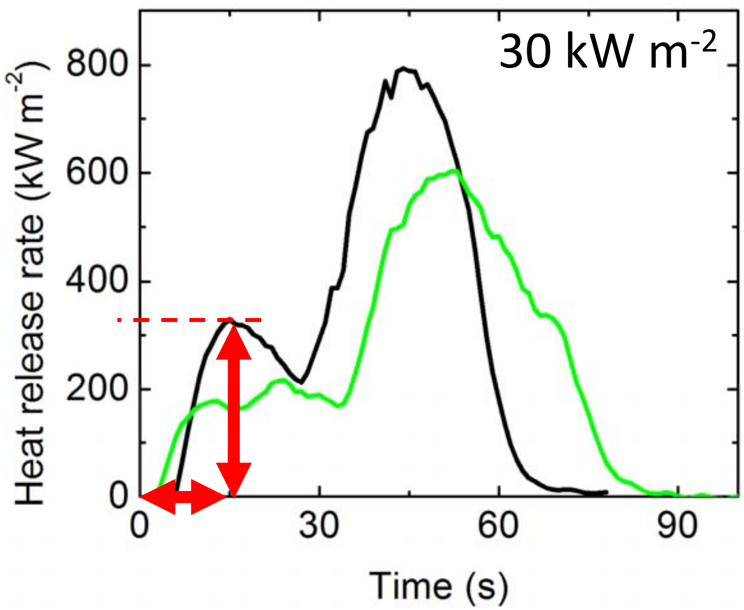


Incident heat flux: 30 kW m^{-2}
32 runs, 8 formulations

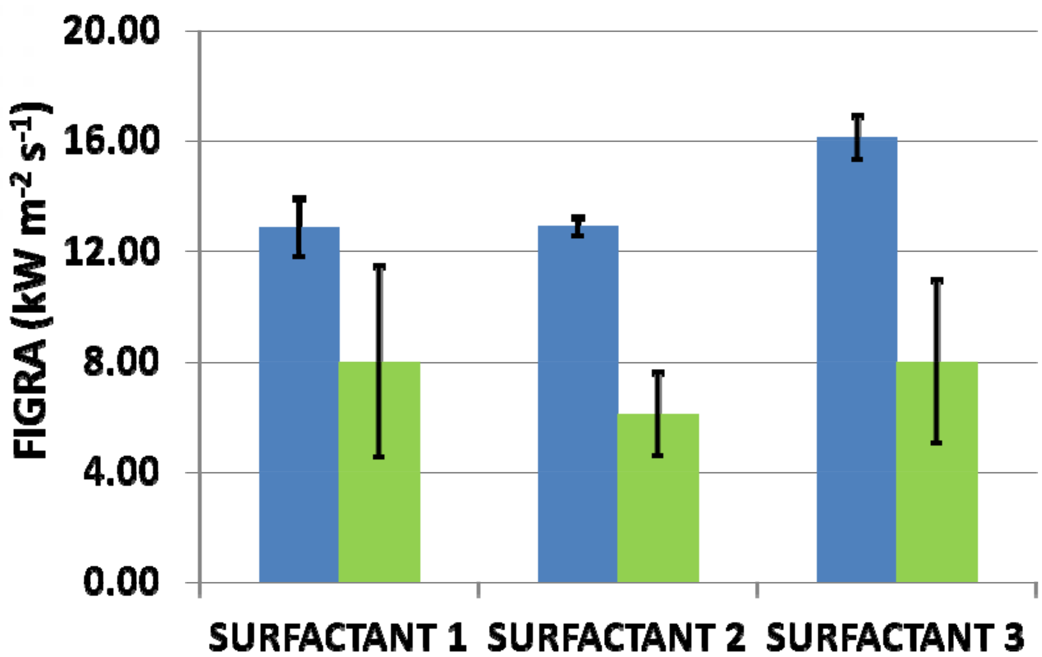
Sample to sample variation
Low edge ± 4 %
High edge ± 10 %

Effect of edge condition on test results

PUR-29 kg m^{-3}



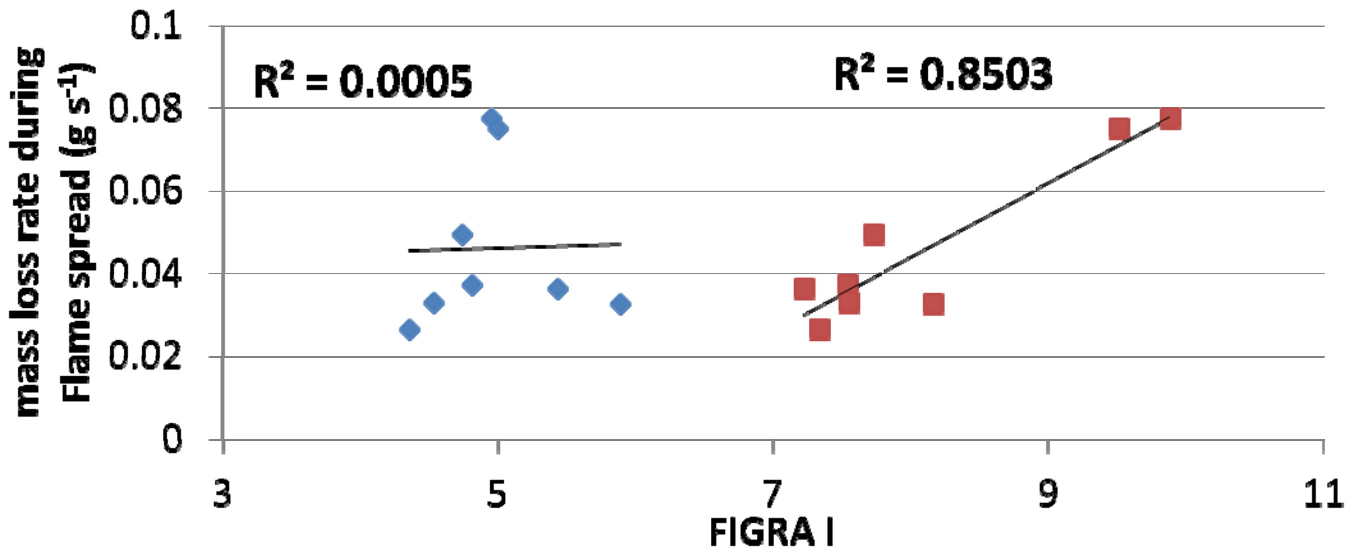
$$\text{FIGRA} = \frac{\text{Peak of heat release rate}}{\text{time to peak}}$$



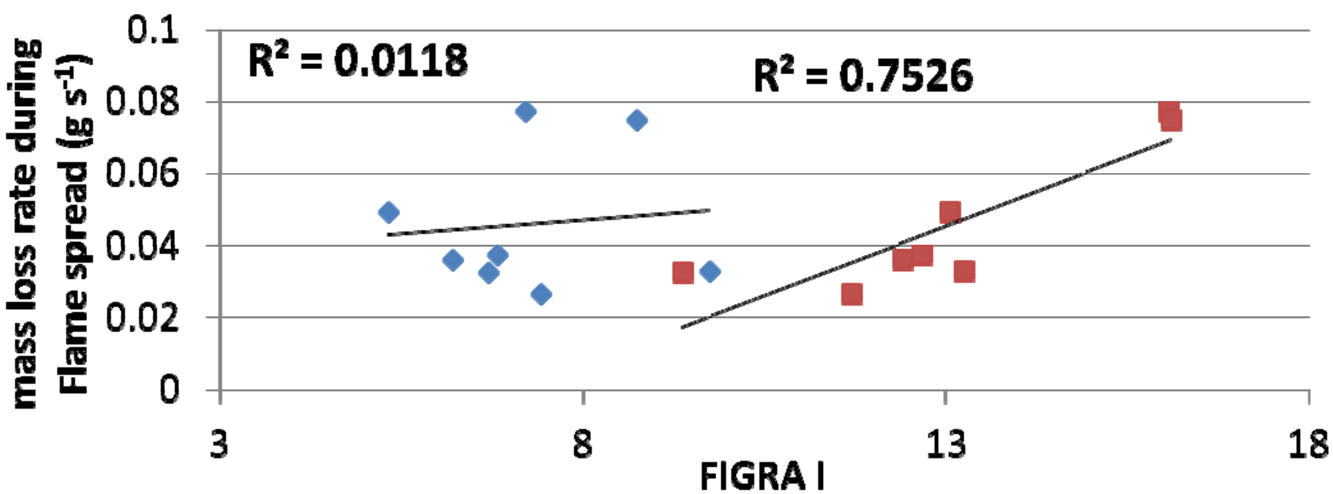
Comparison: cone calorimeter vs. flame spread test

standard edge low edge

Incid. Heat flux
15 kW m^{-2}



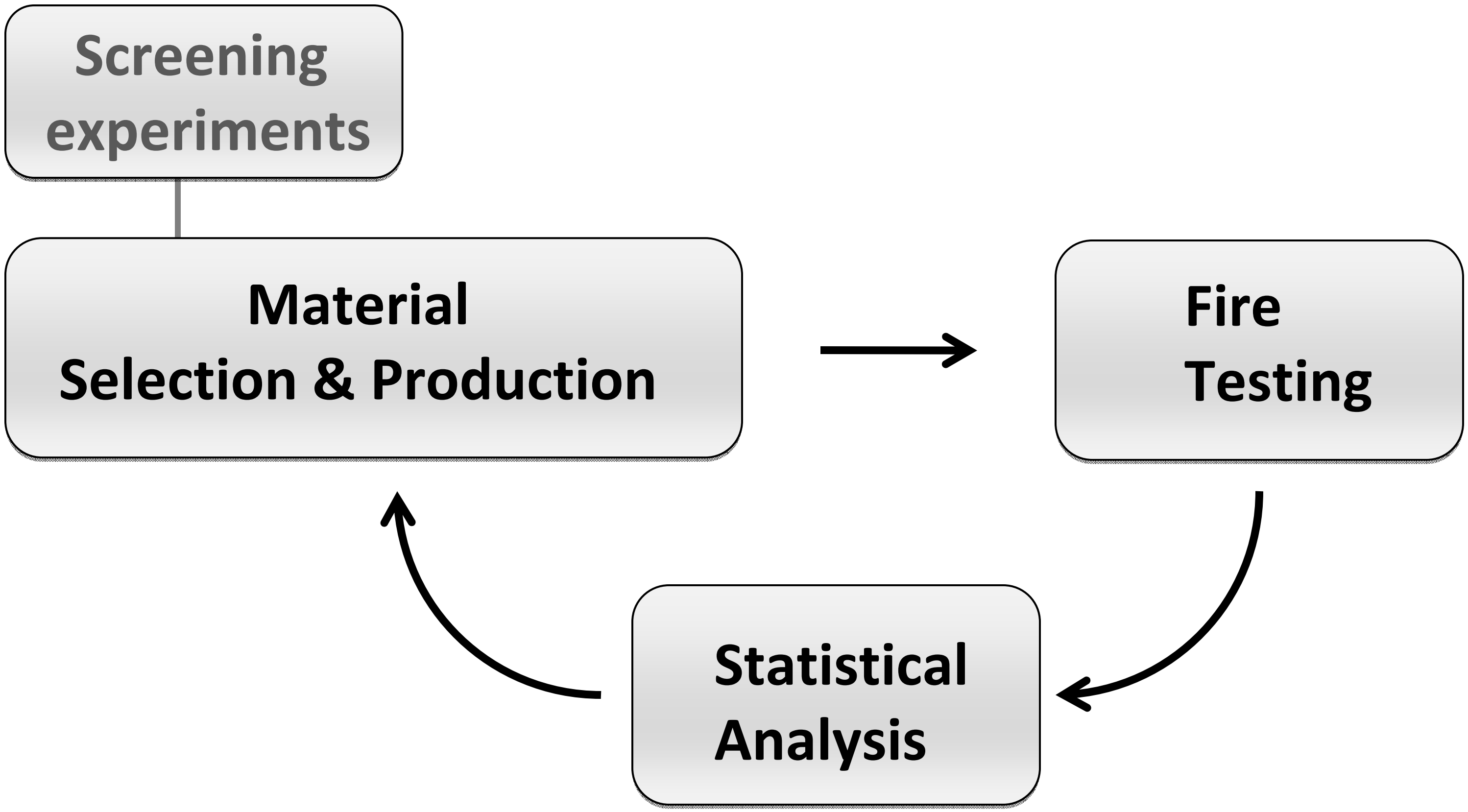
Incid. Heat flux
30 kW m^{-2}



Summary – cone calorimeter tests

- The test conditions severely affect the shape of the heat release rate curve and measured parameters.
- Under well-control conditions, very well-reproducible results can be achieved to compare different foam formulations.
- Eight foam formulations (3 surfactants, 2 polyols, graft- and bio-polyol) did not show significant differences in standard cone calorimeter test with a covered edge.
- Testing samples with an exposed edge allows to capture the physical behavior of the foam, which affected the ease of pool fire formation in the flame spread tests.

Experimental design with 3 iterations



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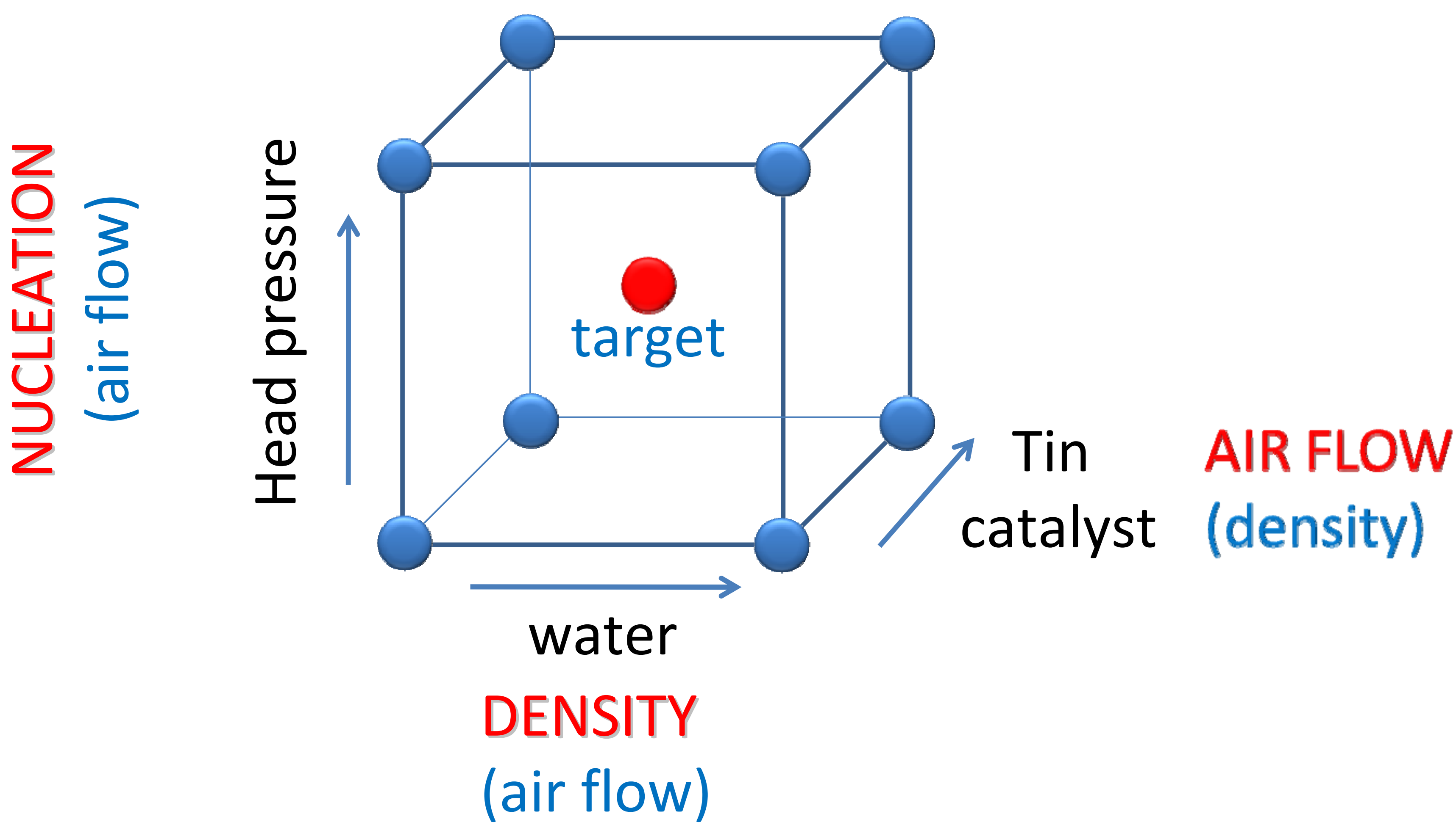
2nd Iteration: Morphology



THANK YOU!

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THANK YOU!

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