Fire development and fire chemistry
Conference about cancer among firefighters

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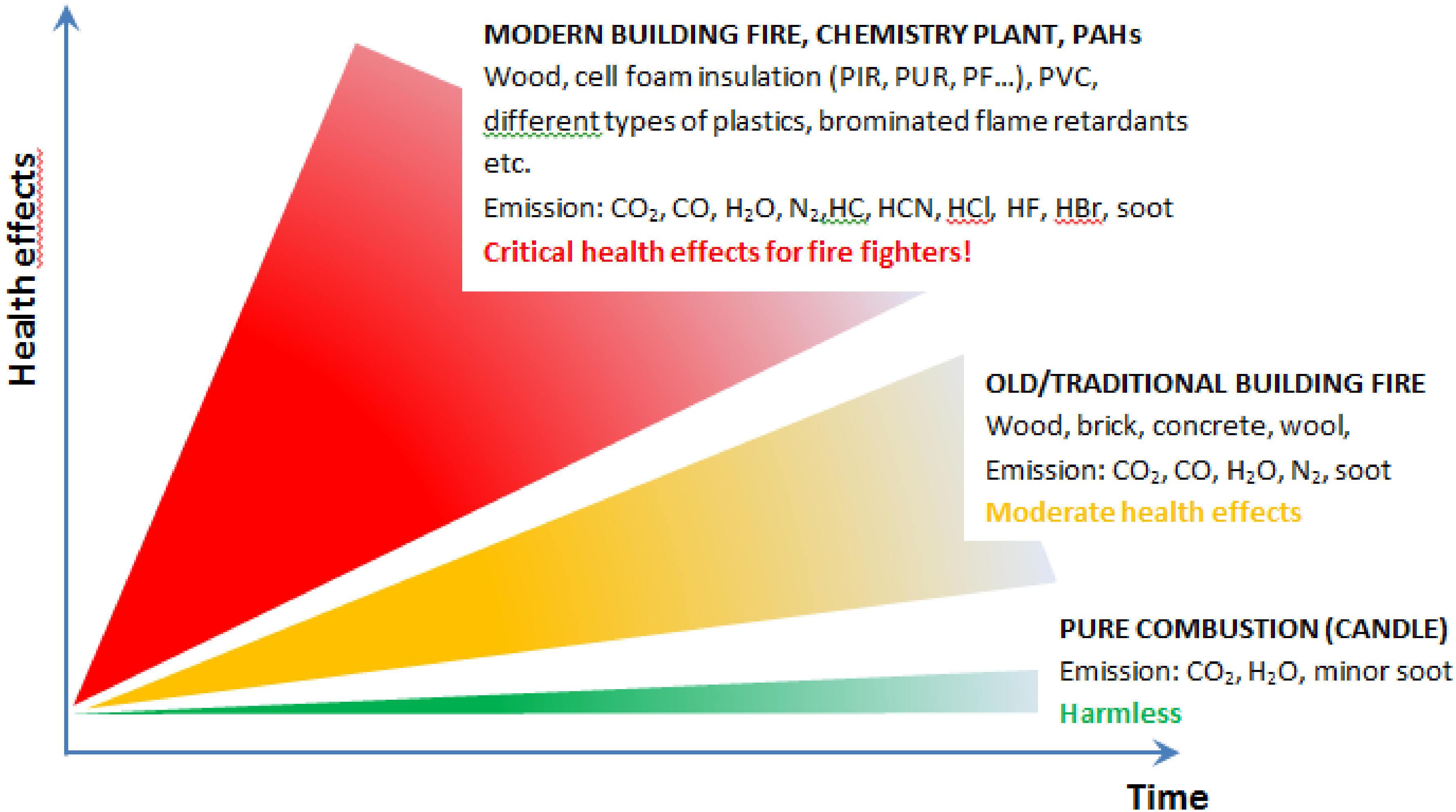

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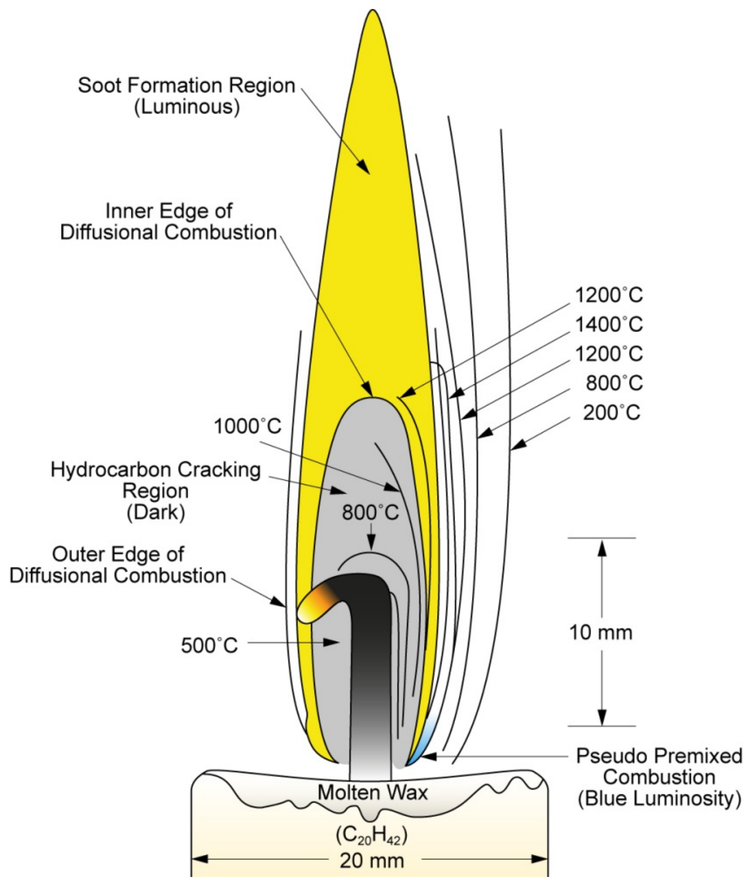

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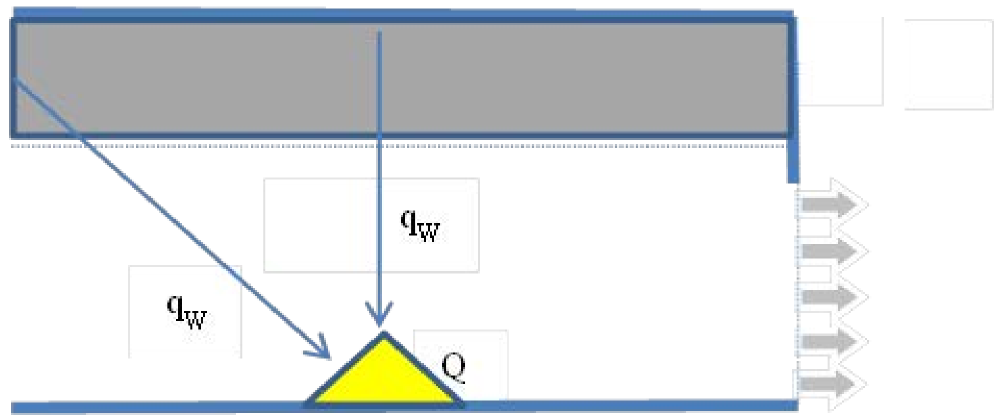

Figure 1 Enclosure fire with different “feedback” heat sources compared to a free burn fire.

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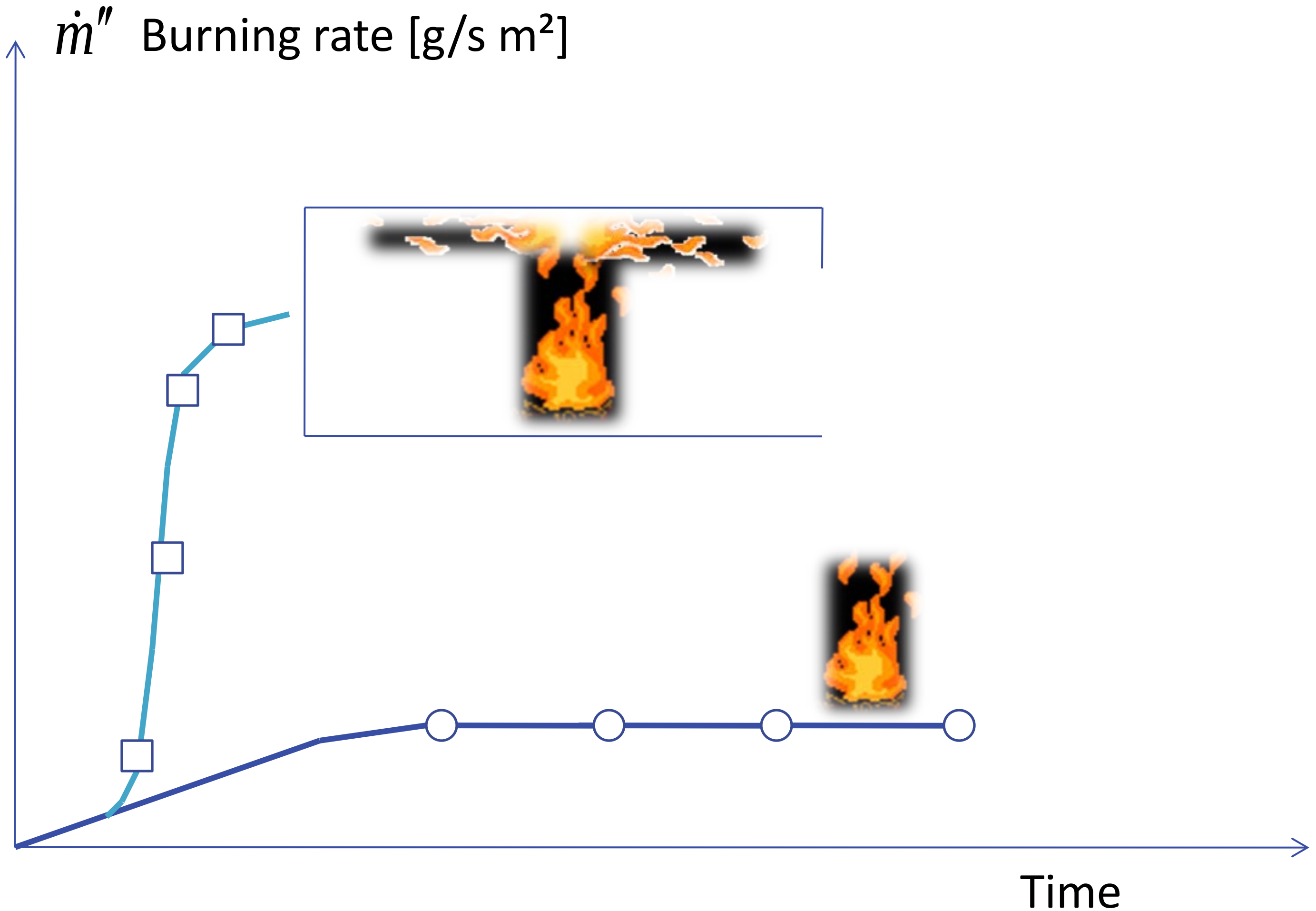
Enclosure fire versus free burn

Test with a burning block acrylic (Drysdale)



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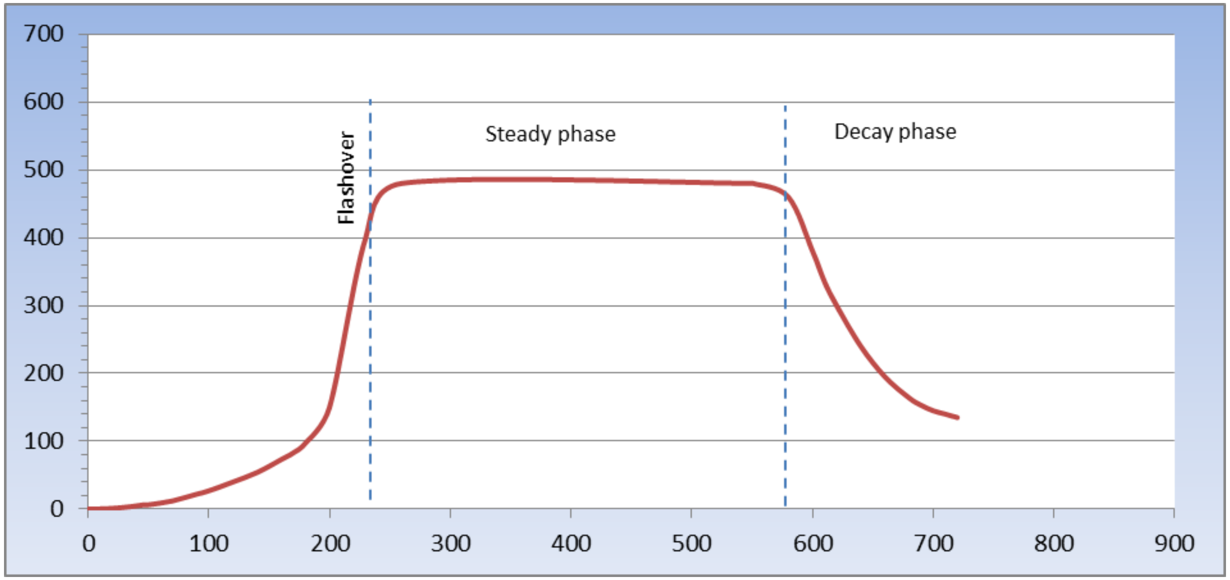
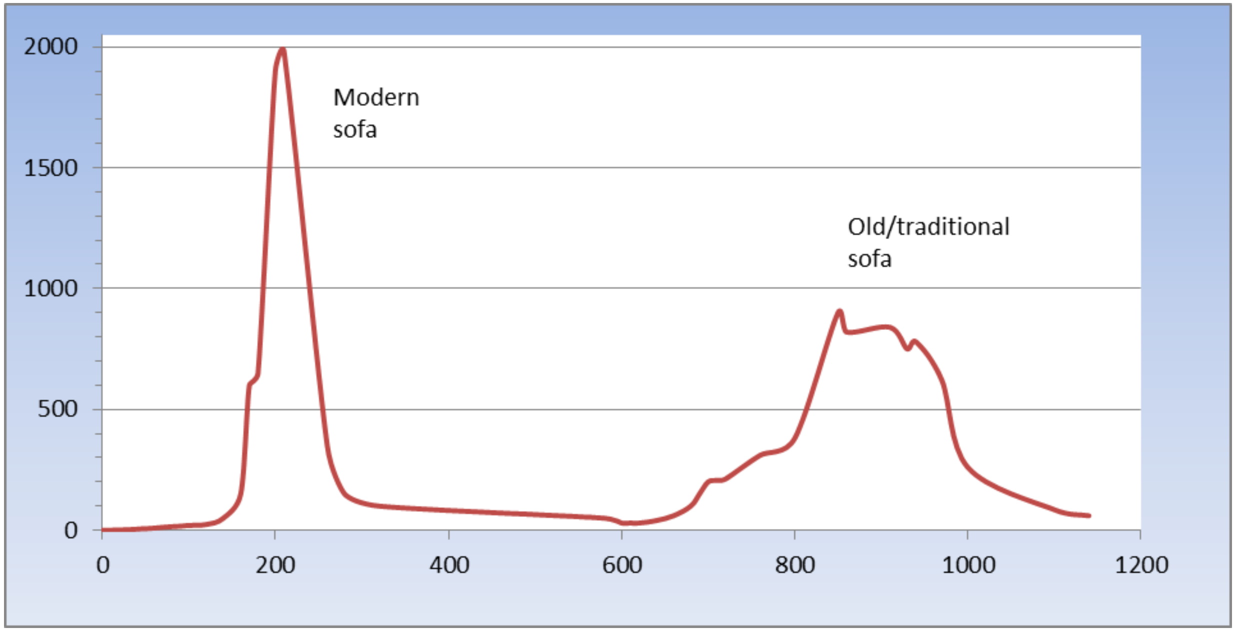
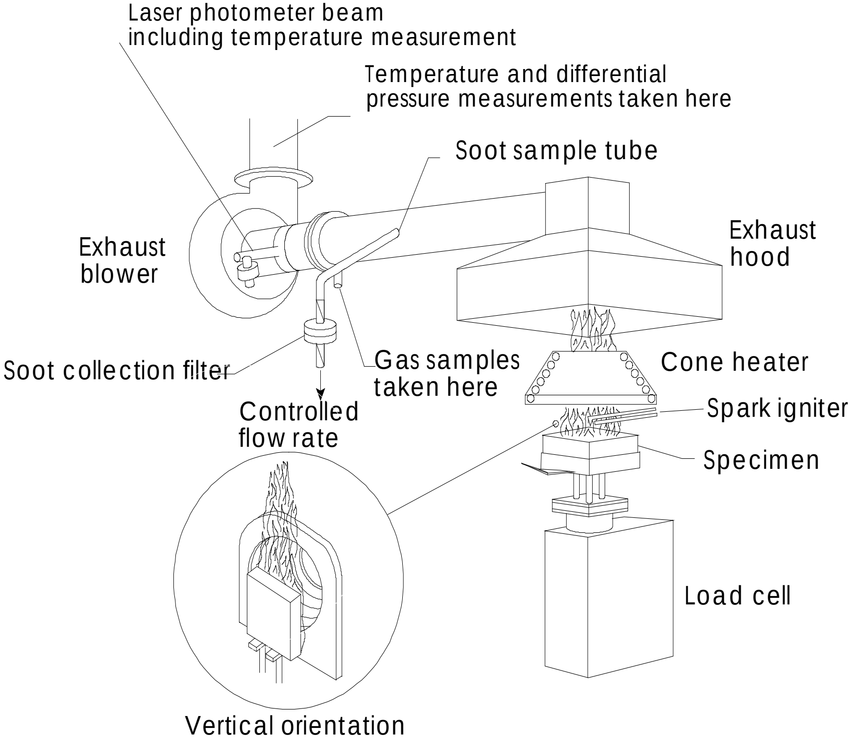
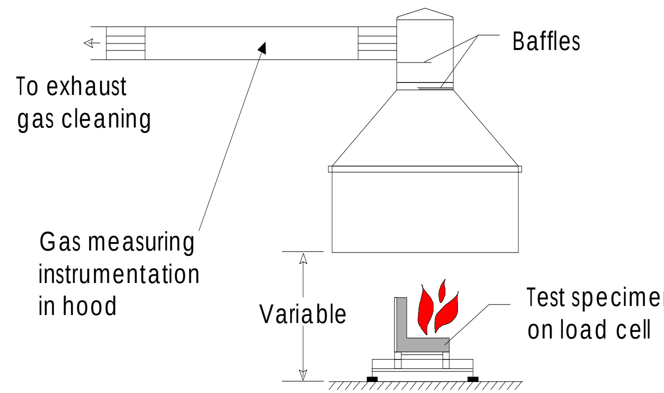

700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Flashover
Steady phase
Decay phase


2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Modern
sofa
Old/traditional
sofa



To the right: NORDTEST NT Fire 032 Calorimeter



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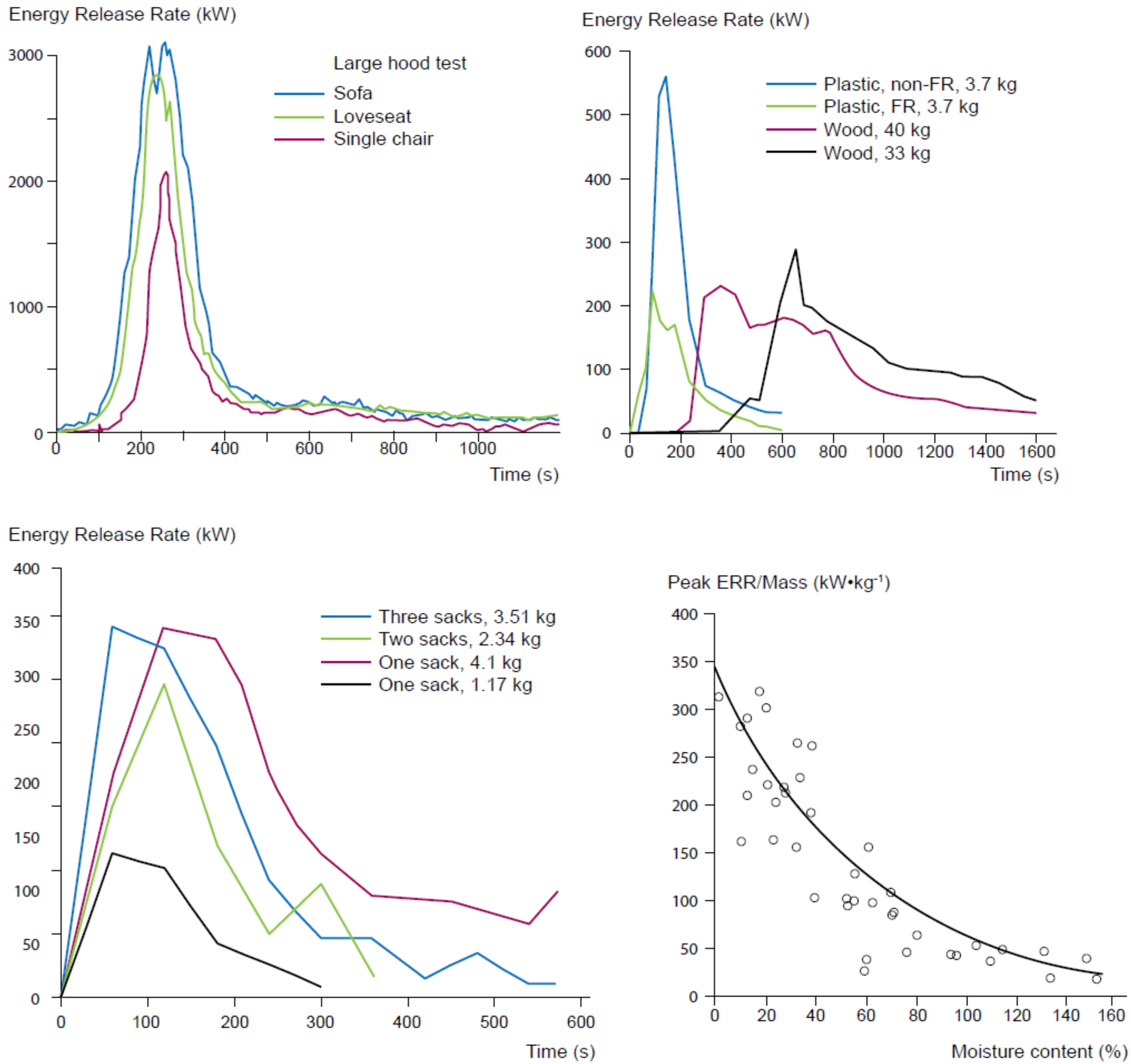
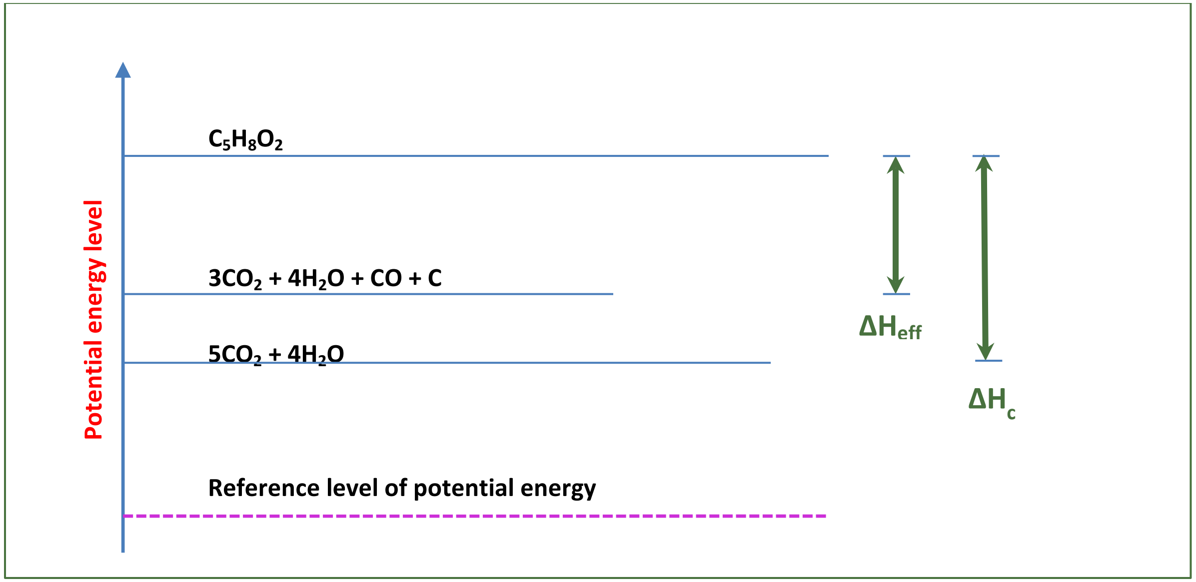
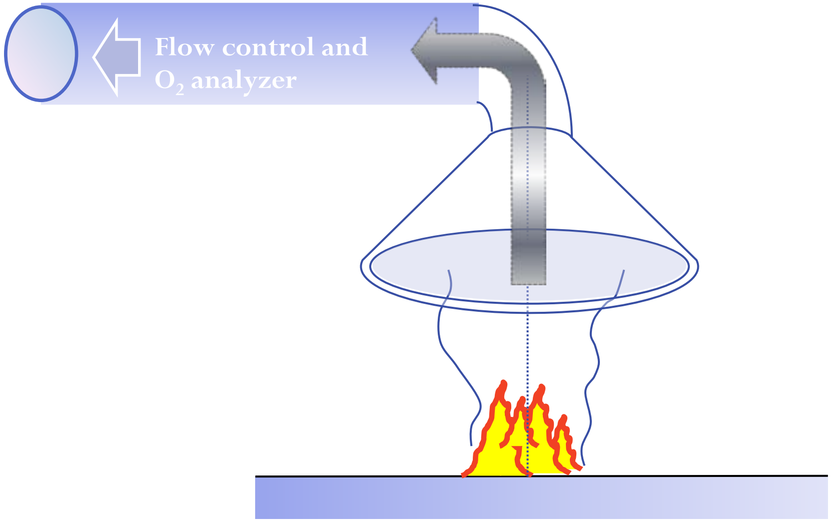

Energy Release Rate (kW)
Large hood test
Sofa
Loveseat
Single chair
3000
2000
1000
0
0
200
400
600
800
1000
Time (s)
Energy Release Rate (kW)
Plastic, non-FR, 3.7 kg
Plastic, FR, 3.7 kg
Wood, 40 kg
Wood, 33 kg
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
Time (s)
Energy Release Rate (kW)
Three sacks, 3.51 kg
Two sacks, 2.34 kg
One sack, 4.1 kg
One sack, 1.17 kg
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (s)
Peak ERR/Mass (kW•kg⁻¹)
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Moisture content (%)

Energy Release Rate (ERR):

$$\dot{Q} = 13100 \cdot \left(0{,}23 - o_{2M\AA LT}\right) \cdot \dot{m}_{GAS}$$


Potential energy level
$C_5H_8O_2$
$3CO_2 + 4H_2O + CO + C$
$5CO_2 + 4H_2O$
Reference level of potential energy
ΔH_{eff}
ΔH_c



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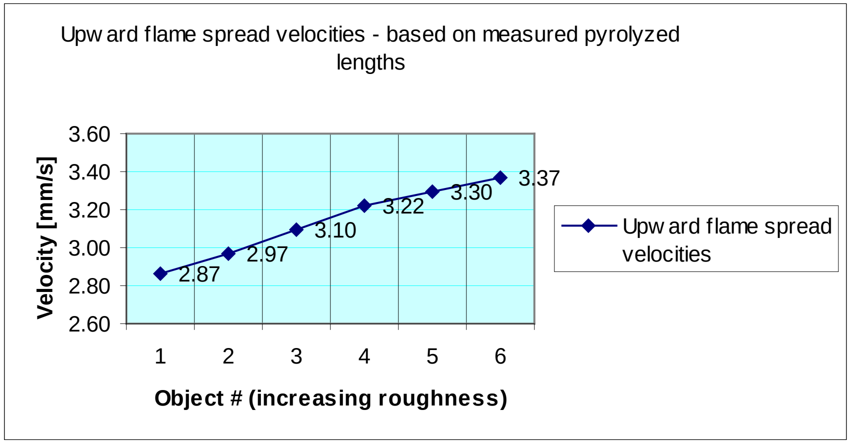
Fire Growth factor:

$$\dot{Q} = \alpha \cdot t^2$$

Flame spread

Upward flame spread velocities



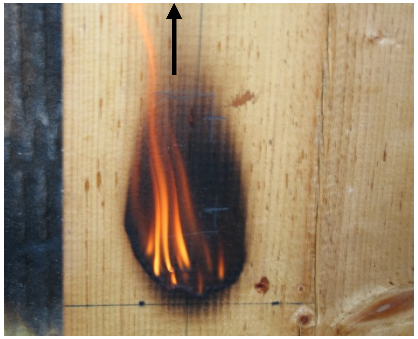


Figure 1 Upward flame spread

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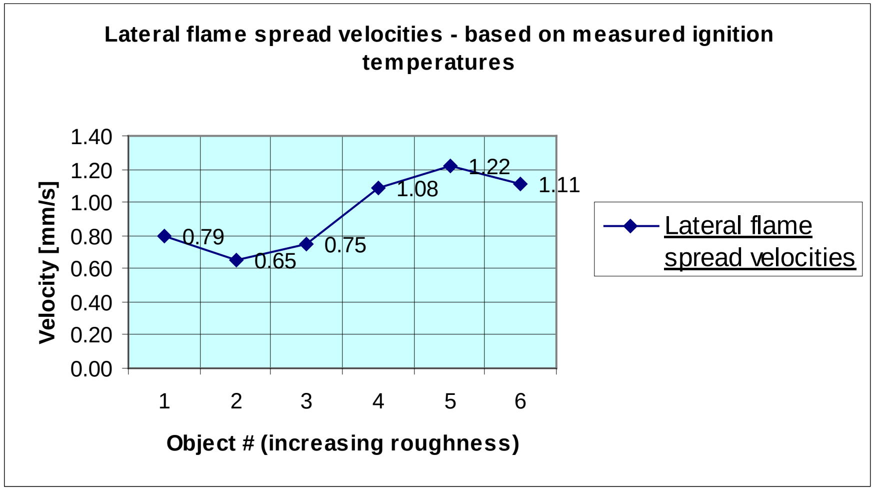
Lateral flame spread velocities



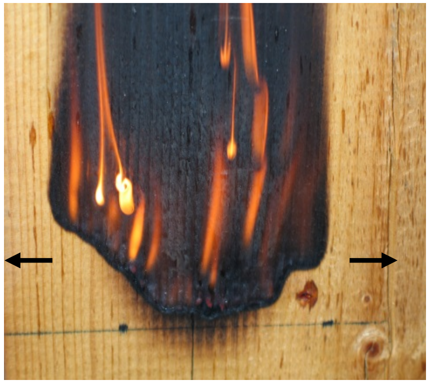
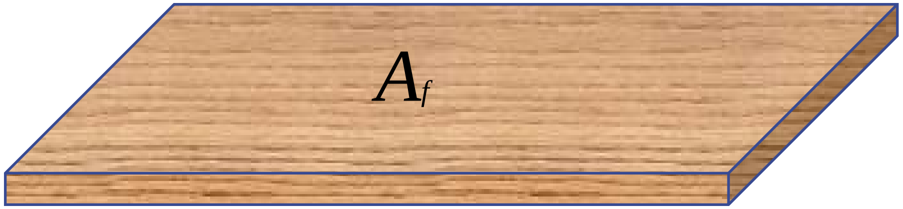


Figure 2 Lateral flame spread

Combustion controlled fire

… typical in the early fire process

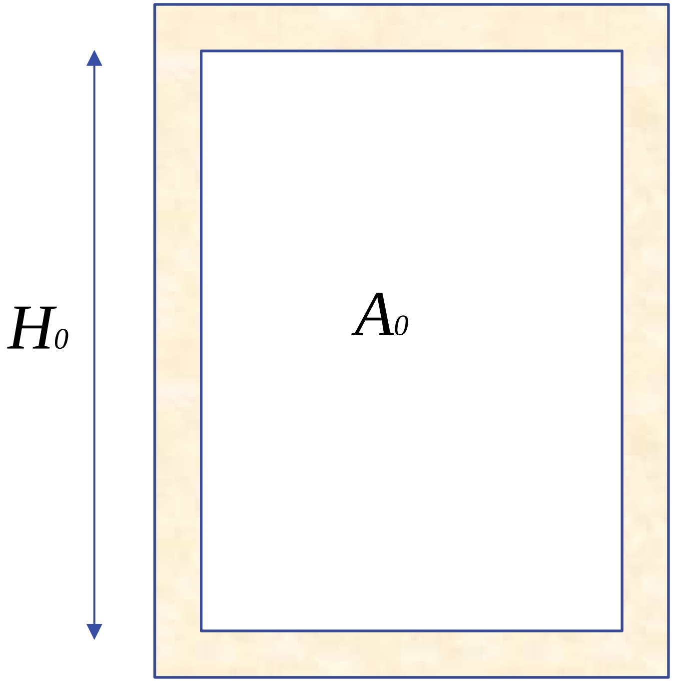
$$\dot{Q}_b = \dot{m}'' \cdot \Delta H_c \cdot \chi \cdot A_f$$



Ventilation controlled fire

(….is there enough oxygen available?)

$$\dot{Q}_v = 1{,}518 \cdot A_0 \sqrt{H_0}$$



Pictures of fire development until flashover. Fire in a living room with plastic foam upholstered furniture (NIST). A door to the test hall was open.

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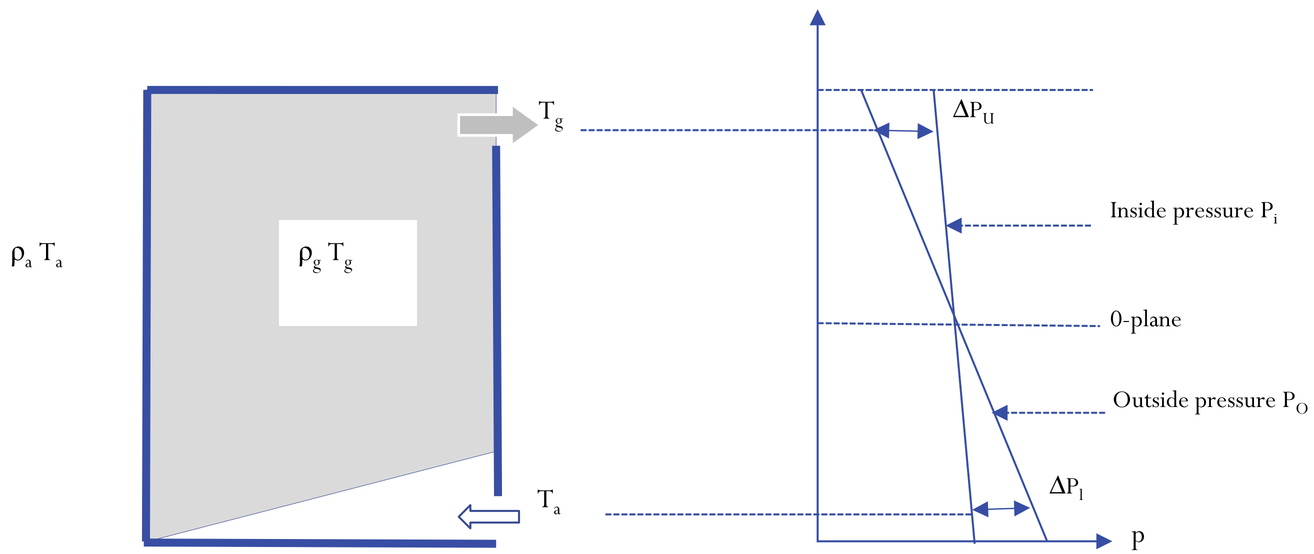
Pressure profile during fire



Smoke gases out of openings

The well-mixed case

$$\dot{m}_g = \frac{2}{3} \cdot C_d \cdot W \cdot \rho_g \cdot \sqrt{\frac{2 \cdot (\rho_a - \rho_g) \cdot g}{\rho_g}} \cdot hu^{3/2} \quad \Rightarrow$$

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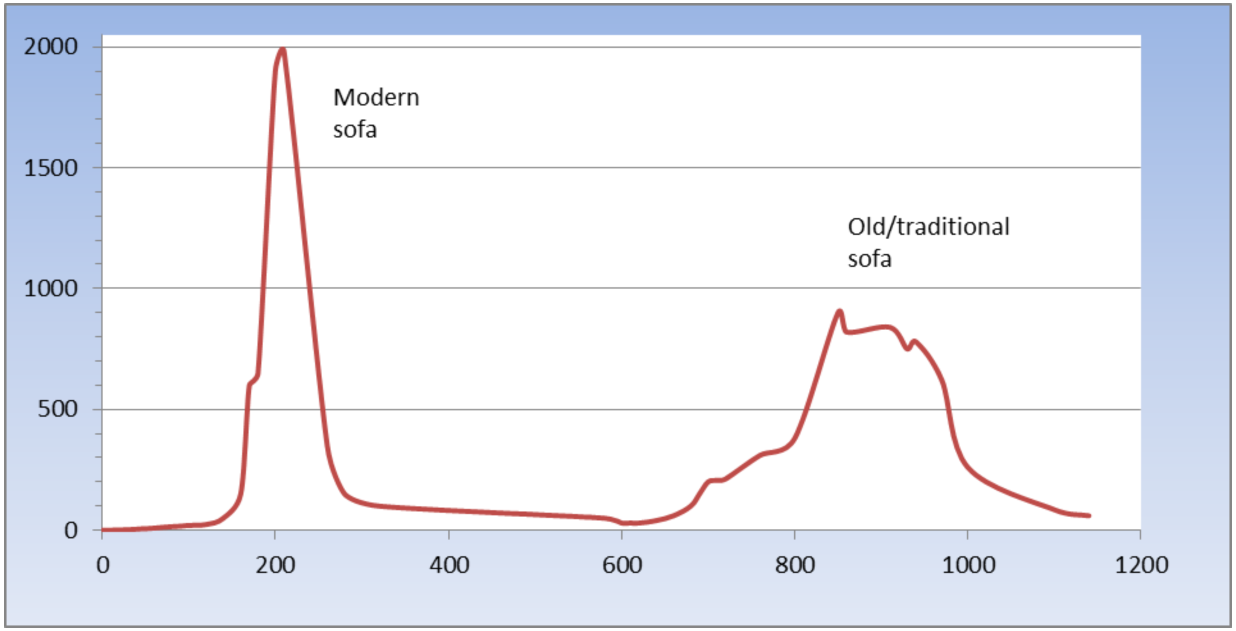
Flashover (NIST).wmv



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Cell foam (plastic insulation)

PIR	Polyisocyanurate
PUR	Polyurethane
PF	Phenol Foam
EPS	Extruded Polystyrene

Toxicity related to cell foam plastic

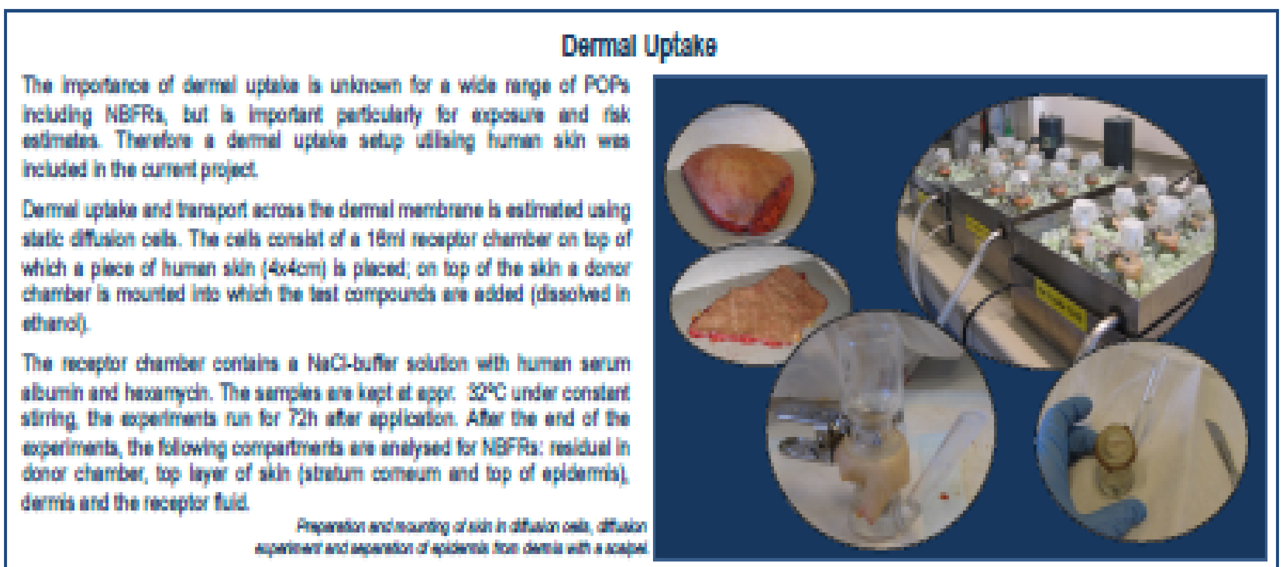
	Lethal exposure time[1]		Debilitating and lethal effects [2]				
	Temperatures[3] increased from 200 to 800 °C	Permanent temperature at 800 °C	Combustion with flames		Combustion without flames		Temperature [°C]
			IC_{50}[4]	LC_{50}[5]	IC_{50}[4]	LC_{50}[5]	
PIR	19.8-21.2	5.6-6.0	-	-	-	-	-
PUR	23.7-25.7	7.6-12.2	5.3 ±1.0	16.9 ±3.3	9.6 ±3.0	55.0 ±14.2	570/540
PF	17.2	6.5	2.0	8.4 ±1.1	1.5	5.9 ±1.1	750/730
EPS/XPS	26.3	15.4	15.3 ±3.3	29.0 ±4.9	27.0 ±3.1	66.0 ±13.0	540/480

Tabel 4. Toxicity of combustion products. The lower the values of IC_{50} and LC_{50} the more toxic are the combustion products. Table values for IC_{50} and LC_{50} are in minutes.

1) Pál and Macskásy, 1991
2) Landrock, 1983
3) Angiver hvilken temperatur testmaterialet bliver afbrændt ved, dvs. ikke den temperatur, som forsøgsdyrene blev udsat for
4) IC_{50} Tiden i minutter til 50 % af forsøgsrotterne er invaliderede
5) LC_{50} Tiden i minutter til 50 % af forsøgsrotterne er døde.

DERMAL UPTAKE OF NOVEL BROMINATED FLAME RETARDANTS (NBFRs) AND HBCD USING AN *EX VIVO* HUMAN SKIN MODEL (NoFlame)

Since the ban of most polybrominated diphenyl ethers (PBDEs) the production pattern of flame retardants has changed and alternatives are increasingly being used. These are generally described as novel brominated flame retardants (NBFRs) and include e.g. EH-TBB and BEH-TEBP in Firemaster 550®, which is one of the PentaBDE replacement products. However, little is known about exposure pathways, not least dermal absorption, for NBFRs and other POPs. The aim of the current study was to estimate the extent of dermal transport of NBFRs and determine the rate of the transport.


Dermal Uptake

The importance of dermal uptake is unknown for a wide range of POPs including NBFRs, but is important particularly for exposure and risk estimates. Therefore a dermal uptake setup utilising human skin was included in the current project.

Dermal uptake and transport across the dermal membrane is estimated using static diffusion cells. The cells consist of a 16ml receptor chamber on top of which a piece of human skin (4x4cm) is placed; on top of the skin a donor chamber is mounted into which the test compounds are added (dissolved in ethanol).

The receptor chamber contains a NaCl-buffer solution with human serum albumin and hexamycin. The samples are kept at appr. 32°C under constant stirring, the experiments run for 72h after application. After the end of the experiments, the following compartments are analysed for NBFRs: residual in donor chamber, top layer of skin (stratum corneum and top of epidermis), dermis and the receptor fluid.

Preparation and mounting of skin in diffusion cells, diffusion experiment and separation of epidermis from dermis with a scalpel.

Firefighters protection against heat and smoke

Many of the substances mentioned in the presentation are carcinogenic. How is the firefighter protected?

Risks

- Smoke particles (also toxic) can enter through cracks and crevices, to the neck, along the neck sleeve
- The face is (partly) directly exposed to smoke particles
- If the firefighter suit is not washed thoroughly after each fire, the fire fighter can be exposed to more toxic particles (dermal uptake)
- If fire engines is not properly cleaned the firefighters can be exposed to toxic dirt
- If fire equipment on the fire station is not placed separately from people wearing civil clothes
- If separation (clean from not clean) in general is missing
- Poor mask/respiratory protection (old type, not tightly, bad cleaning)
- Poor or bad equipment in general

Sweden

Thank you for your attention

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