Combustion Product Yields: Basic Principles and Examples from Large Fire Tests

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Fire Technology

Content

- **Introduction** of the factors governing the outcome of combustion products in fires
- Presenting the **groups of chemical species** produced and their main hazards
- Examples of product **yields from fire tests** with house content in fully furnished rooms (and other tests)

Combustion conditions

Main factors:

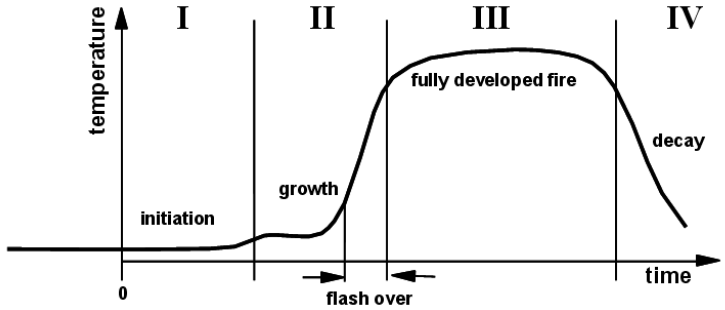
- **Fuel**
- **Temperature**
- **Ventilation**

Controlled combustion:

$Fuel + O_2 \Rightarrow CO_2 + H_2O$

Combustion in fires:

$Fuel + O_2 \Rightarrow CO_2 + H_2O + CO +$ soot +*multitude of additional species…*

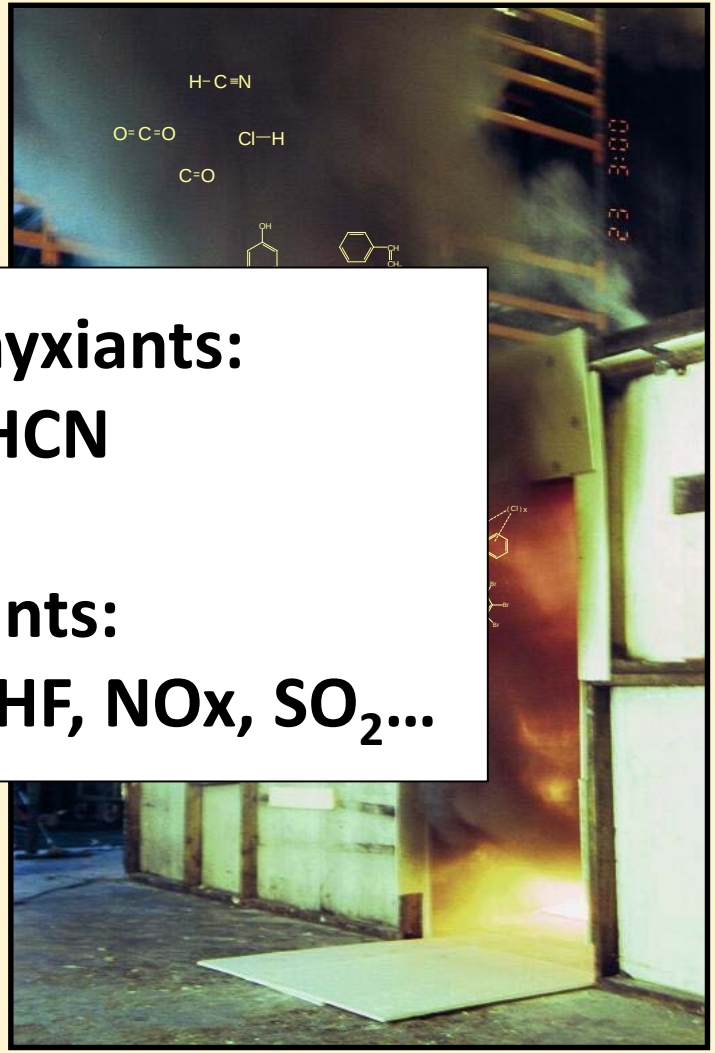


Fire gas composition

- **Inorganic gases**
- Smaller organics compounds
- Larger organic compounds
- Particulates (soot, inorganics, metals)

Asphyxiants:
CO, HCN

Irritants:
HCl, HF, NOx, SO_2…



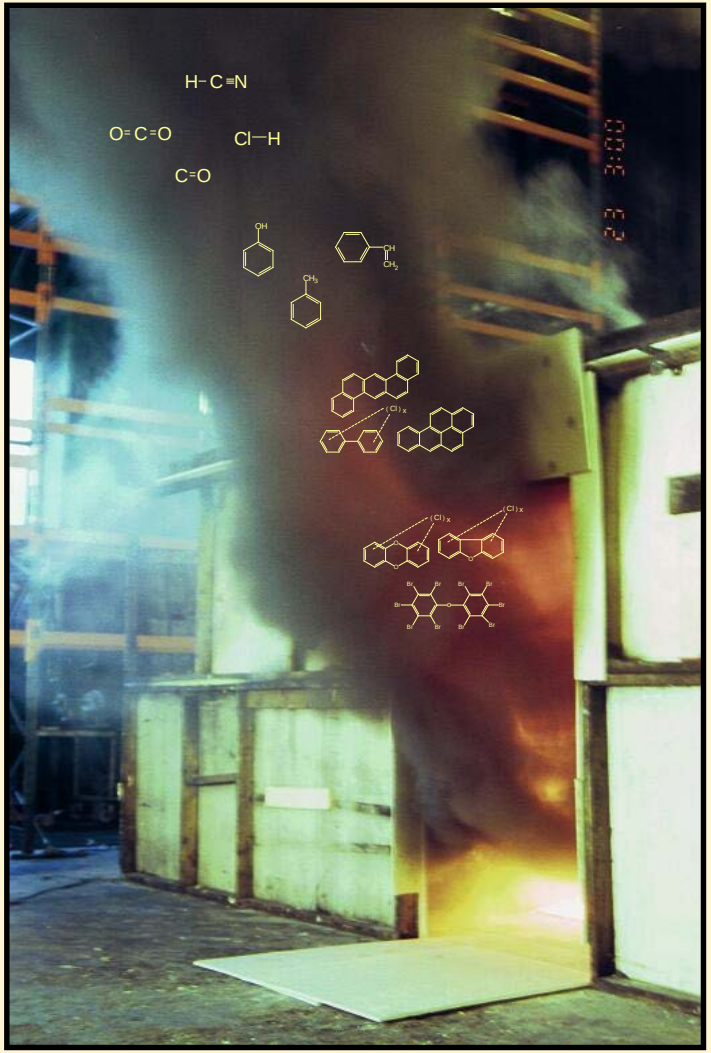
Ventilation conditions

$$\phi = \frac{\dot{m}_{fuel} \,/\, \dot{m}_{oxygen}}{\left(\dot{m}_{fuel} \,/\, \dot{m}_{oxygen}\right)_{stoich.}}$$

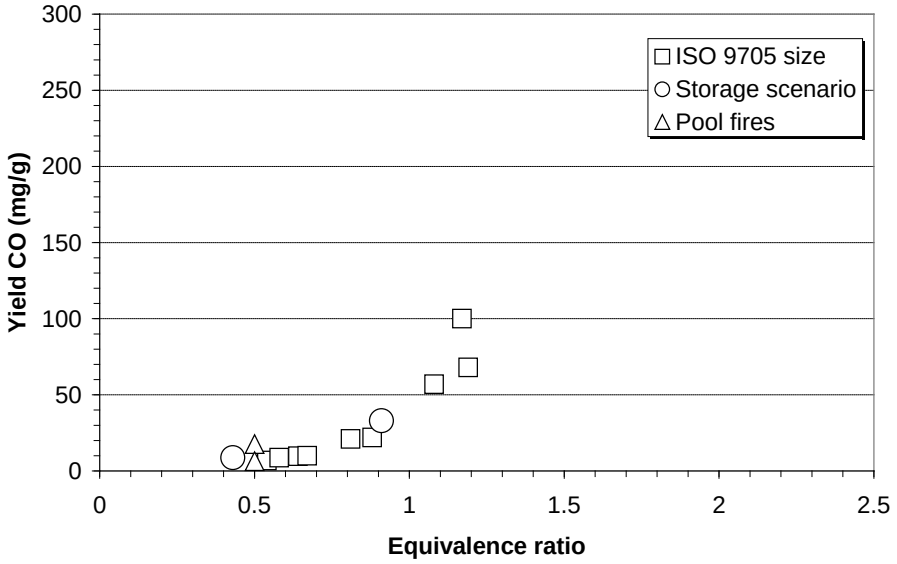
$\phi = 1$ stoichiometric combustion

$\phi < 1$ well ventilated combustion

$\phi > 1$ under-ventilated combustion



Ventilation conditions – carbon monoxide (CO)



Nylon-6,6: tests of different scales

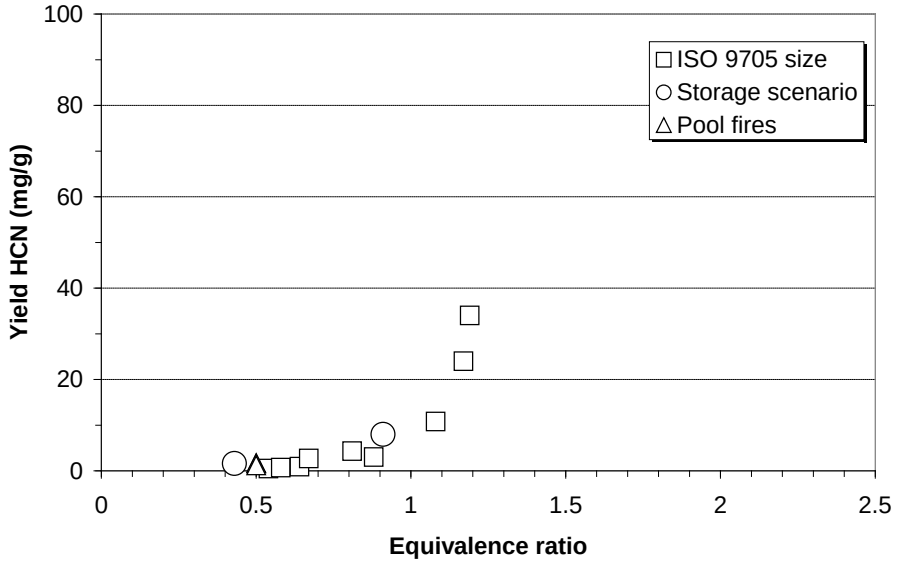
Data from reference [1].

ISO 9705 room
~75 kg Nylon

Storage scenario
160 kg Nylon

Pool fires
~90 kg

Ventilation conditions – hydrogen cyanide (HCN)



Nylon-6,6: tests of different scales

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Pool fires
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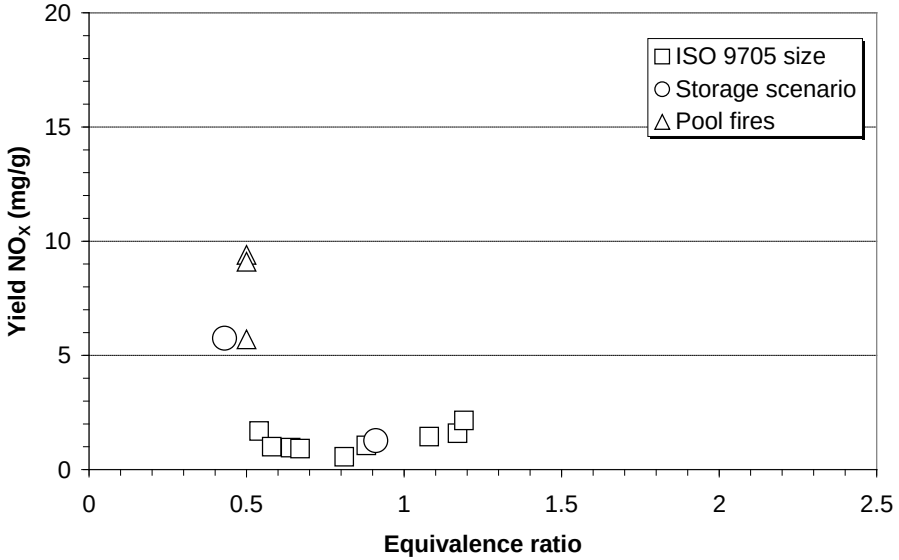
Ventilation conditions – nitrogen oxides (NOx)



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Fire gas composition

- Inorganic gases
- **Smaller organics compounds**
- Larger orga
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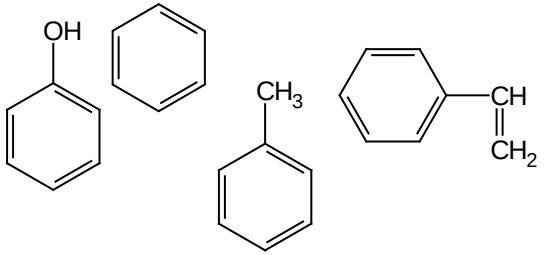
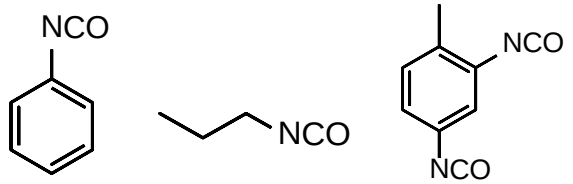
-

  - Irritants
  - Allergy
  - Cancer

Volatile organic compounds (VOC)

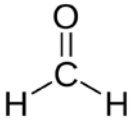


Isocyanates Ref. [2, 3, 4]



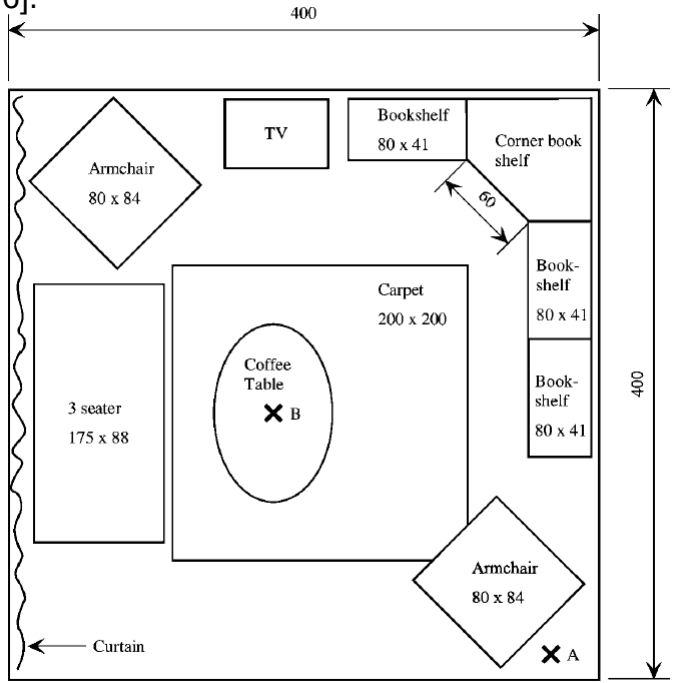
Ref. [3, 4]

Aldehydes



Furnished room test

From references [5, 6].



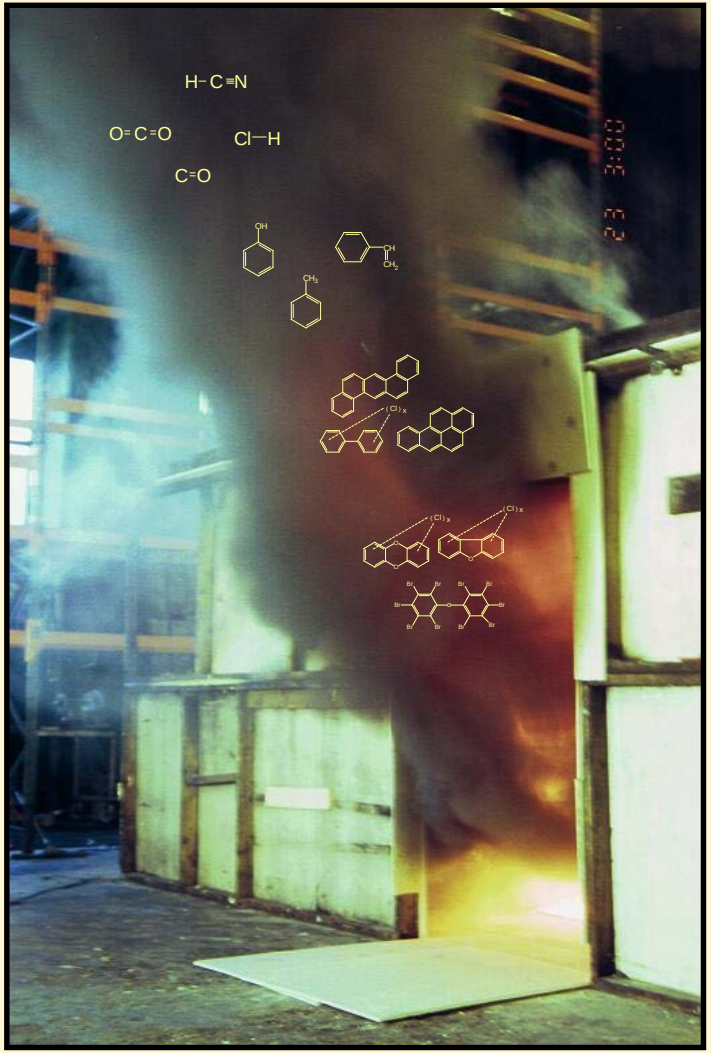
Item	#	Weight (kg)	Main Combustible Material
Sofa	1	72	Wood, PUR, cotton, feathers
Armchair	2	19 × 2 = 38	Wood, leather, filling
Corner bookshelf	1	52	Particleboard, veneer
Bookshelf	3	30 × 3 = 90	Particleboard, veneer
Coffee table	1	26	Wood
Carpet	2 m × 2 m	Approx. 20	Wool, synthetic
Curtains	10 m	5	Cotton
Books, Exp. 1	–	219	Paper
Books, Exp. 2	–	216	Paper
Books, Exp 3	–	No data	Paper
EU TV, Exp. 1 and 3	1	31.4	Polystyrene
US TV, Exp. 2	1	33.6	FR polystyrene

~550 kg combustible material in each room test, equals 34 kg/m^2 floor area.

Full-scale TV fire tests conducted separately.

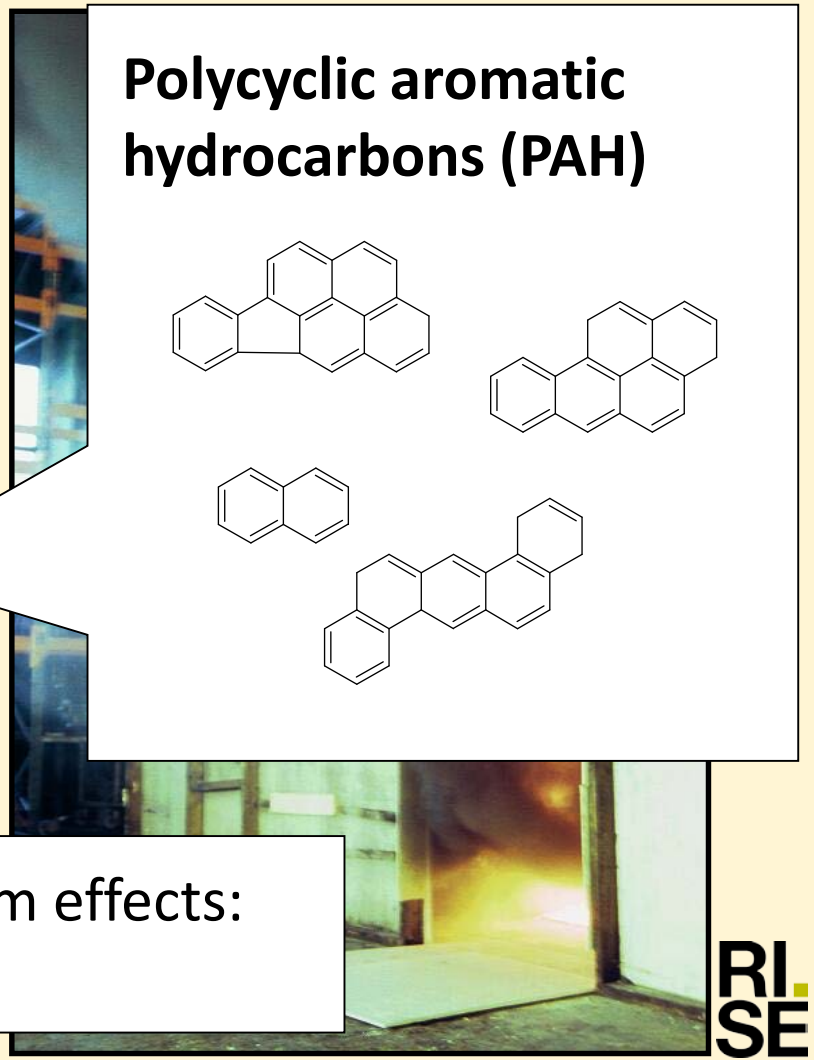
Example: VOC-yields

Order	**Room 1**	**Room 2**	**Room 3**	**nFR-TV**	**FR-TV**
1	Benzene 25 %	Benzene 46 %	Benzene 39 %	Styrene 37 %	Styrene 49 %
2	Benzo-nitrile	Toluene	Chloro-benzene	Benzene	Benzene
3	Styrene	Benzo-nitrile	Toluene	Toluene	Toluene
4	Toluene	Styrene	Benzo-nitrile	Phenol	Ethynyl-benzene
5	Phenol	Ethynyl-benzene	Styrene	Ethynyl-benzene	Phenol
Other	55 %	32 %	37 %	15 %	15 %
Total	344 g 0.69 g/kg	1164 g 2.4 g/kg	1278 g 2.6 g/kg	108 g 20 g/kg	286 g 91 g/kg



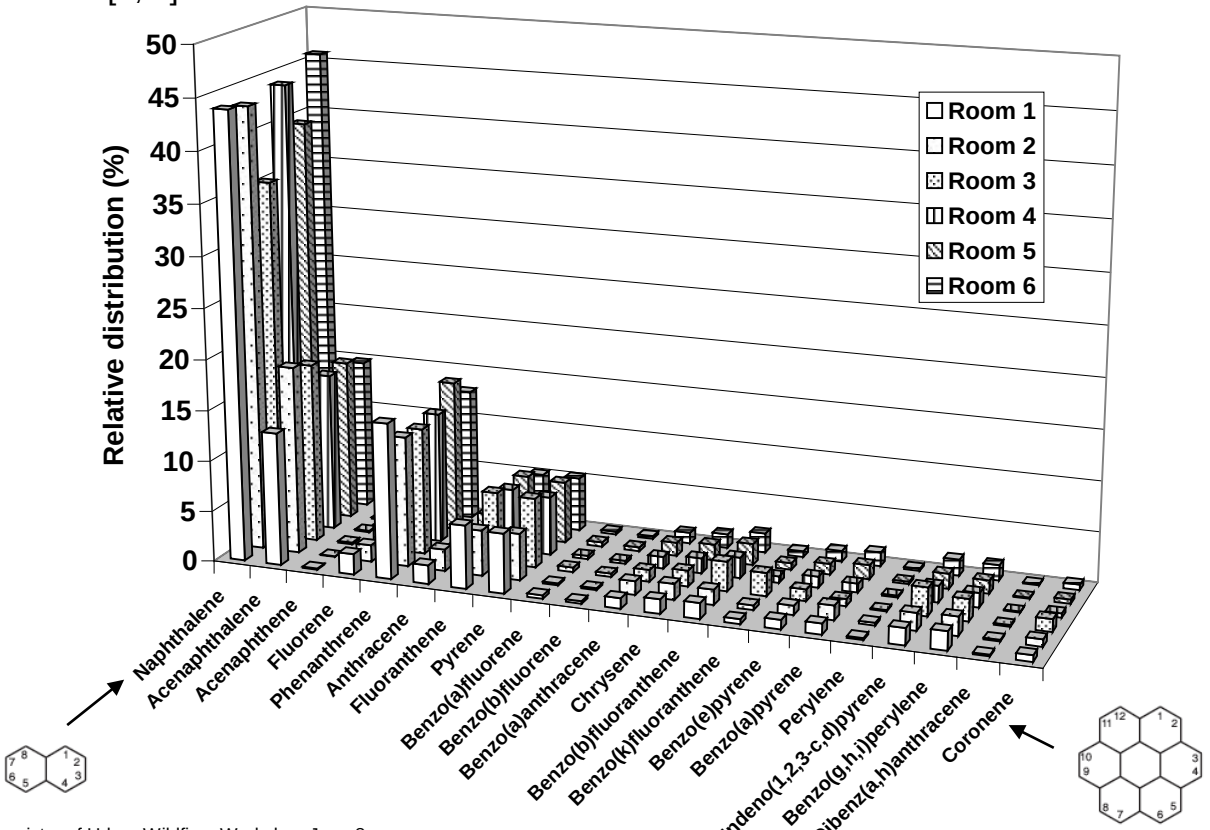
Fire gas composition

- Inorganic gases
- Smaller organics compounds
- **Larger organic compounds**
- Particulates (soot, inorganics, metals)



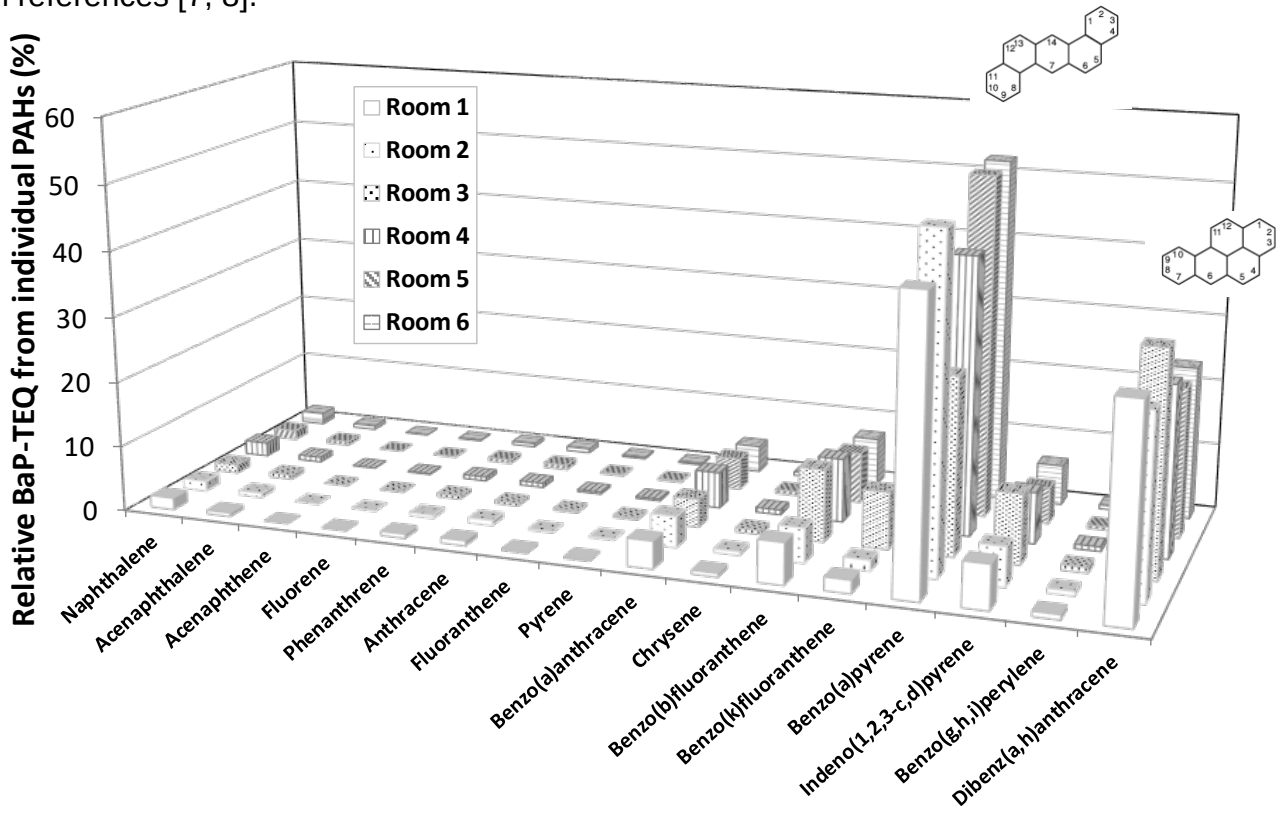
Example: PAHs in room fires

Data from references [7, 8].



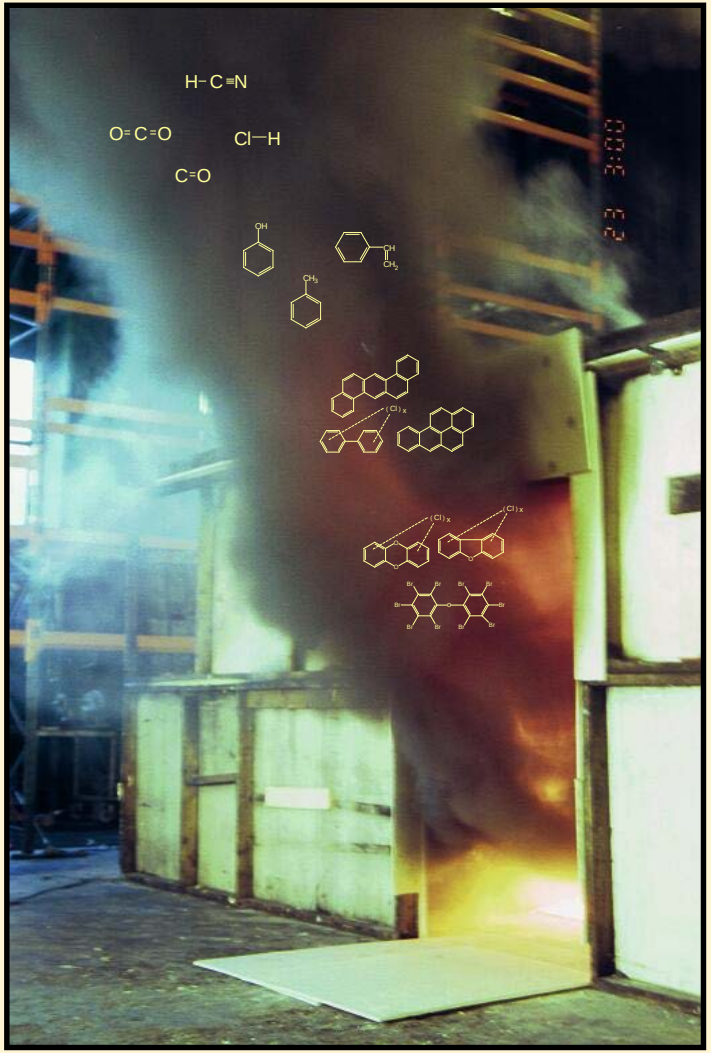
Example: PAHs toxicity weighted from room fires

Data from references [7, 8].



Example: PAH-yields

	Room fires	**nFR-TV**	**FR-TV**	**Car fire** [4]
Amount (g)	~500	33	35	119
Yields (g/kg)	0.60-1.7	6.1	11	1.1
BaP-TEQ yield (g/kg)	0.016-0.050	0.26	0.89	-



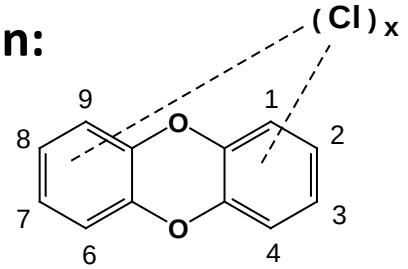
Fire gas composition

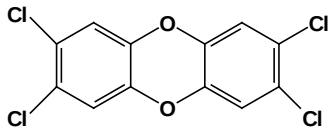
- Inorganic gases
- Smaller organics compounds
- **Larger organic compo**
- Particu
  inorgan

- DNA damages
- Immune defence
- Cancer
- Reproduction
- Bioaccumulation

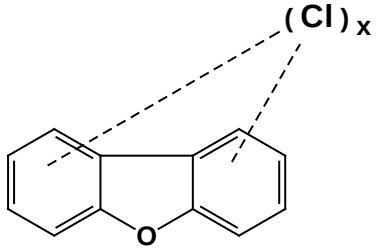
Polychlorinated dioxins

Dioxin:



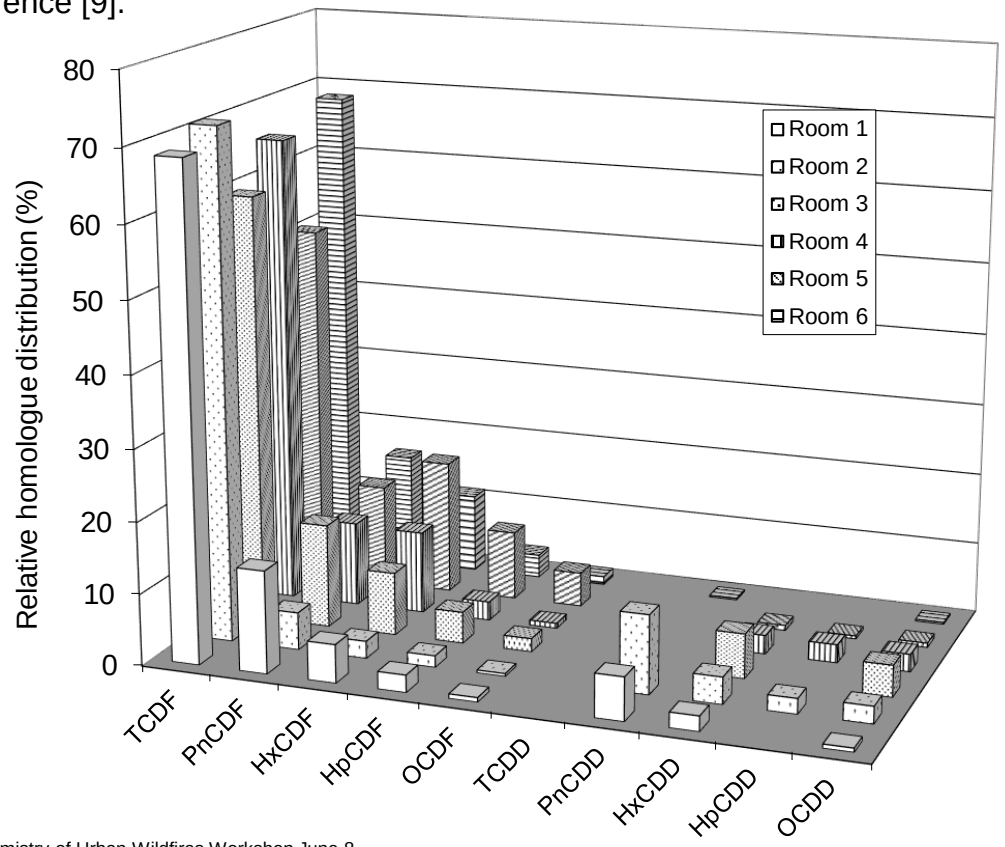


Furan:



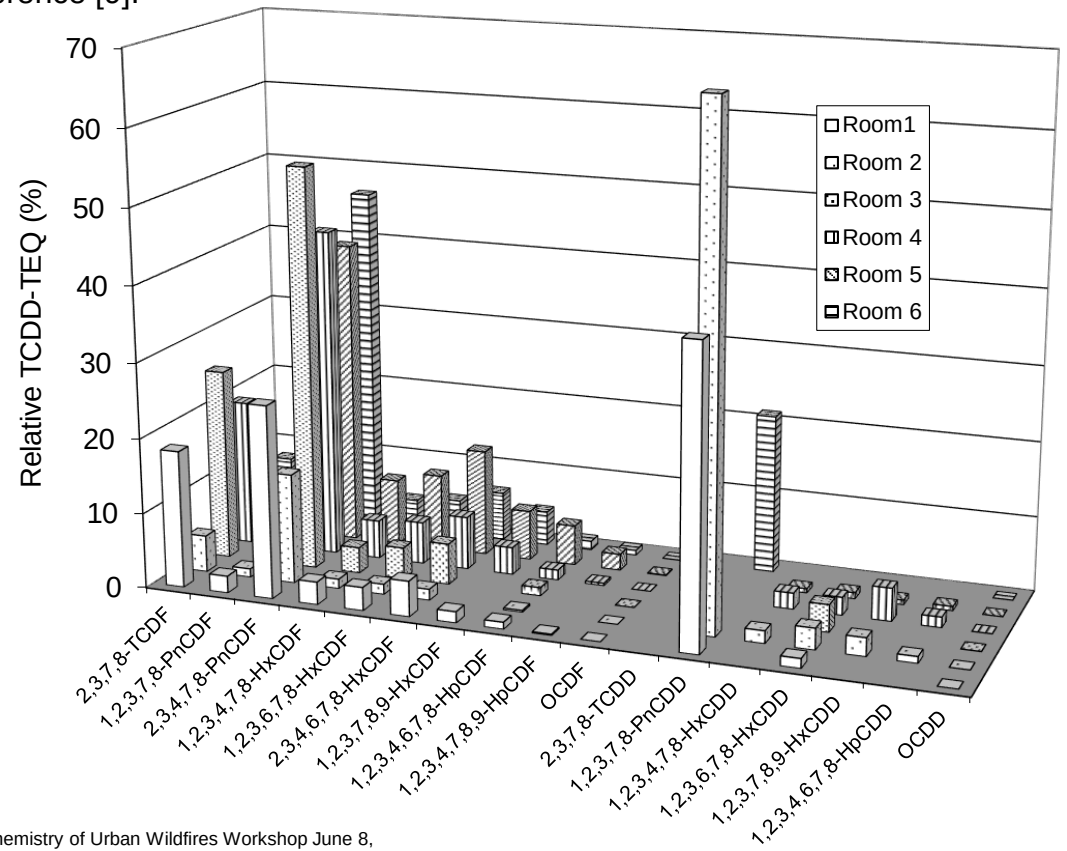
Example: dioxins from room tests

Data from reference [9].



Example: dioxins from room tests, toxicity weighted

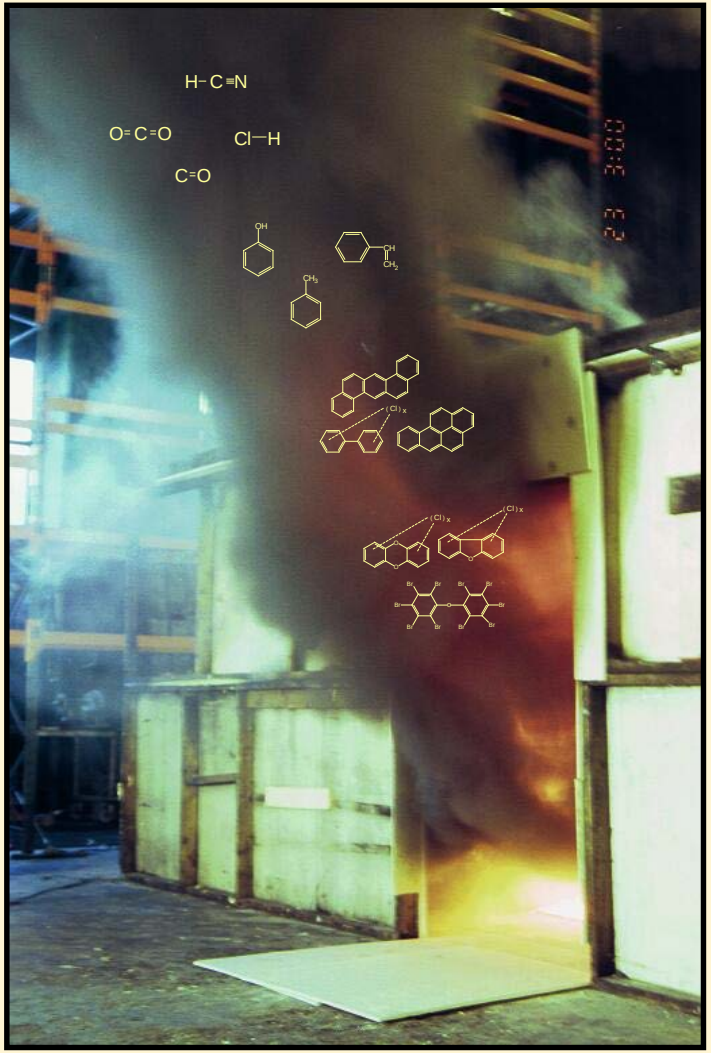
Data from reference [9].



Example: Dioxin-yields

Data from reference [9].

	Room fires	**nFR-TV**	**FR-TV**	**Car fire** [4]
Yield all homologues (µg/kg)	0.21-3.3	110	530	58
Yield 2,3,7,8-subst. (µg/kg)	0.028-0.26	7.5	25	-
TCDD-TEQ (µg/kg)	0.0022-0.033	1.0	10	0.65



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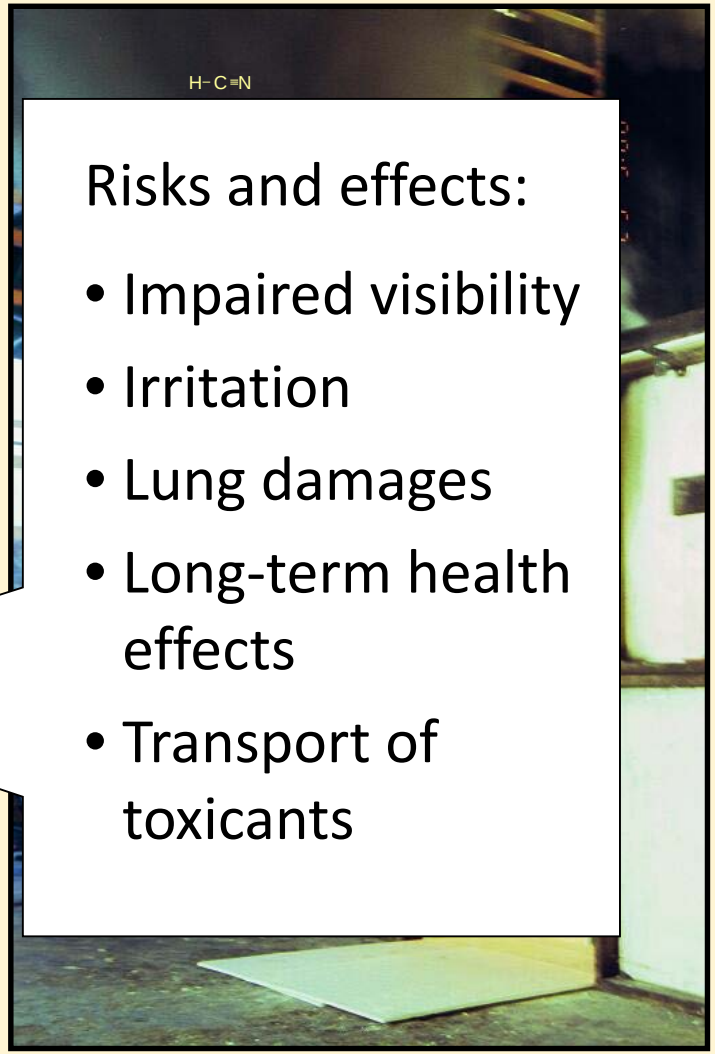
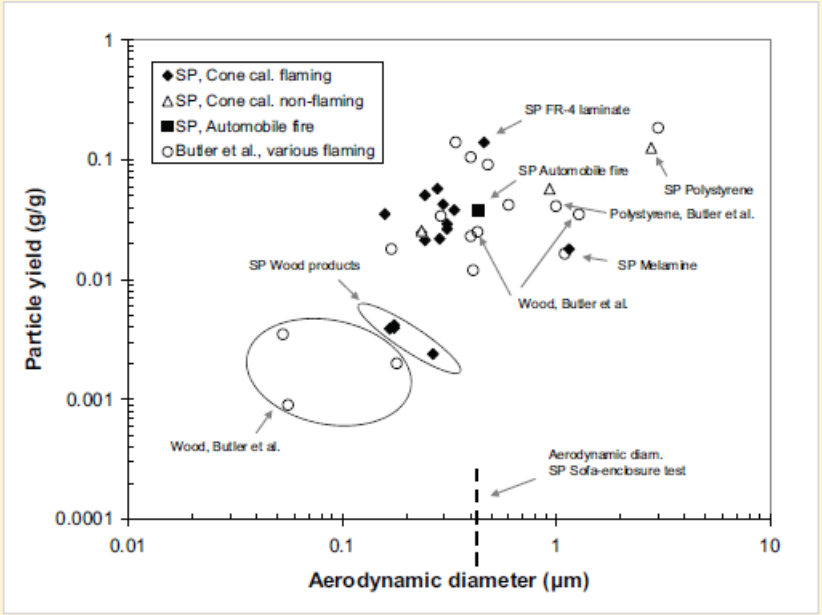
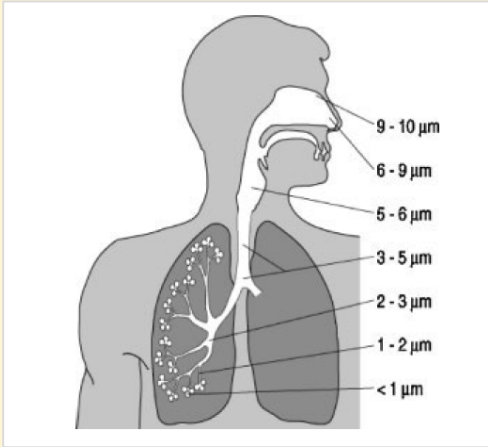


Particulates

References [9, 10].

- Type of fuel affect particle production
- Polystyrene, e.g., gives high production
- Wood, generally, gives lower
- Relationship between particle yield and particle size
- Fire generated particles can be transported deep into the lungs





References

1. **Blomqvist P. and Lönnermark A., ”Characterization of the combustion products in large-scale fire tests: comparison of three experimental configurations”, Fire and Materials 25 (2000) 71-81**
2. **Blomqvist P., Hertzberg T., Dalene M. and Skarping G., “Isocyanates and amines from fires – a screening over common materials found in buildings”, Fire and Materials 27 (2003) 275-294**
3. **Per Blomqvist, Tommy Hertzberg, Heimo Tuovinen, Karine Arrhenius, Lars Rosell, “Detailed determination of smoke gas contents using a small-scale controlled equivalence ratio tube furnace method”, Fire and Materials, 31 (2007) 495-521**
4. **Lönnermark A. and Blomqvist P., “Emissions from an Automobile Fire”, Chemosphere 62 (2006) 1043-1056**
5. **Blomqvist P., Rosell L. and Simonson M., “Emissions from Fires part I: Fire retarded and non-Fire retarded TV-sets”, Fire Technology 40 (2004) 39-58**
6. **Blomqvist P., Rosell L. and Simonson M., “Emissions from Fires part II: Simulated room fires”, Fire Technology 40 (2004) 59-73**

References, cont.

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8. **Andersson P., Blomqvist P., Rosell L. and Simonson M., “The environmental effect of furniture”, proceedings of Interflam ‘04, Edinburgh, Scotland, pp. 1467-1478**

9. **Blomqvist, P., “Emissions from fires – Consequences for Human Safety and the Environment”, doctoral thesis, Lund University, Sweden, 2005**

10. **Hertzberg T. and Blomqvist P., “Particles from fires – a screening over common materials found in buildings”, Fire and Materials 27 (2003) 295-314**

Useful references on emission from fires in Li-ion batteries and electric vehicles:

11. **Fredrik Larsson, Petra Andersson, Per Blomqvist and Bengt-Erik Mellander, “Toxic fluoride gas emissions from lithium-ion battery fires”, Scientific Reports 7, Article number: 10018, doi:10.1038/s41598-017-09784-z, 2017**

12. **Willstrand et al., “Toxic gases from Fire in Electric Vehicles”, RISE-report 2020:90, ISBN: 978-91-89167-75-9, URN: urn:nbn:se:ri:diva-52000**

Thank you!

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