Fire Toxicity:
Silent Killer

Presented by:-

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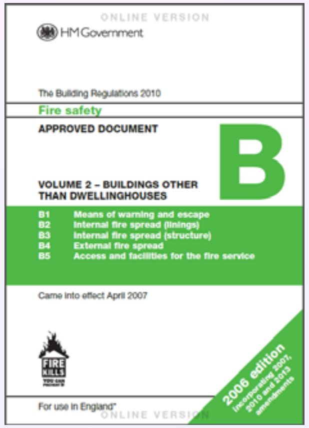
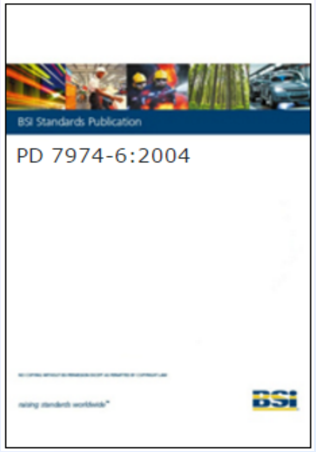
UK fire regulations



Means of warning and escape

B1. The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times.



6 Occupant condition

6.1 Effects fire effluent and heat on ASET and RSET

Exposure of building occupants to fire effluent or heat affects both ASET and RSET. These depend on:

a) the time-concentration (or intensity) curves for the major toxic products, optically dense smoke and heat in the fire at the breathing zone of the occupants, which in turn depend upon:

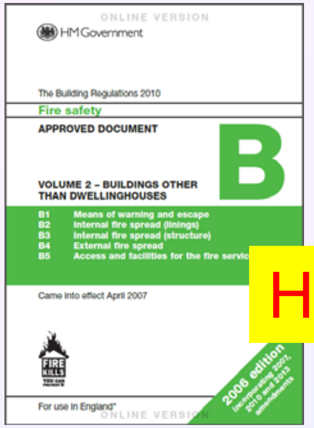
1) the fire growth curve in terms of the mass loss rate of the fuel (kg/s) and the volume into which it is dispersed (kg/m^3) with time;

2) the yield of toxic products, smoke and heat in the fire (for example kg CO per kg of material burned).

Guidance on calculation methods for these terms is given in PD 7974-0 to PD 7974-3.

b) The toxic or physiological potency of the heat and effluent (the exposure concentration (kg/m^3), or exposure dose (kg·m^{-3}·min or ppm·min) required to cause toxic effects (and the equivalent effects of heat and smoke obscuration).

UK fire regulations

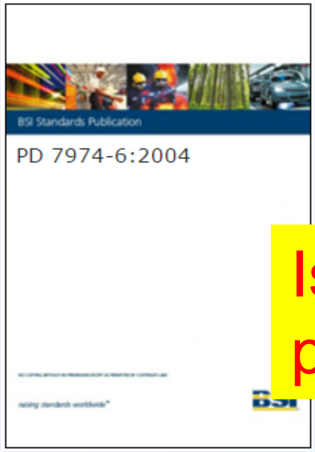


Means of warning and escape

B1. The building shall be designed and constructed so that there are appropriate provisions for the early warning of

How much smoke is acceptable if it is highly toxic?

of being safely and effectively used at all material times.



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Is "*minimising smoke ingress*" good enough in the presence of highly toxic combustion products?

b) The toxic or physiological potency of the heat and effluent (the exposure concentration (kg/m^3), or exposure dose (kg·m^{-3}·min or ppm·min) required to cause toxic effects (and the equivalent effects of heat and smoke obscuration).

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The need for toxicity assessment

- Toxic gases cause most fire deaths ▶
- Longer term the effects are unknown ▶
- Fire adds lethal particulates to the environment
- ..and fires do not look less likely in future ▲




Smoke inhalation in Nightclub Fires

Gothenburg disco fire 1998, (63 deaths)

Station nightclub fire, RI, US, 2003 (100 deaths);

República Cromañón in Buenos Aires, Argentina, 2004 (194 deaths);

Santika Club fire in Bangkok, Thailand, 2009 (61 deaths); and

Lame Horse fire in Perm, Russia, 2009 (156 deaths).

Kiss Nightclub fire Brazil (2013) – Pyrotechnics ignite PU foam – 242 deaths – 90% toxic gases!

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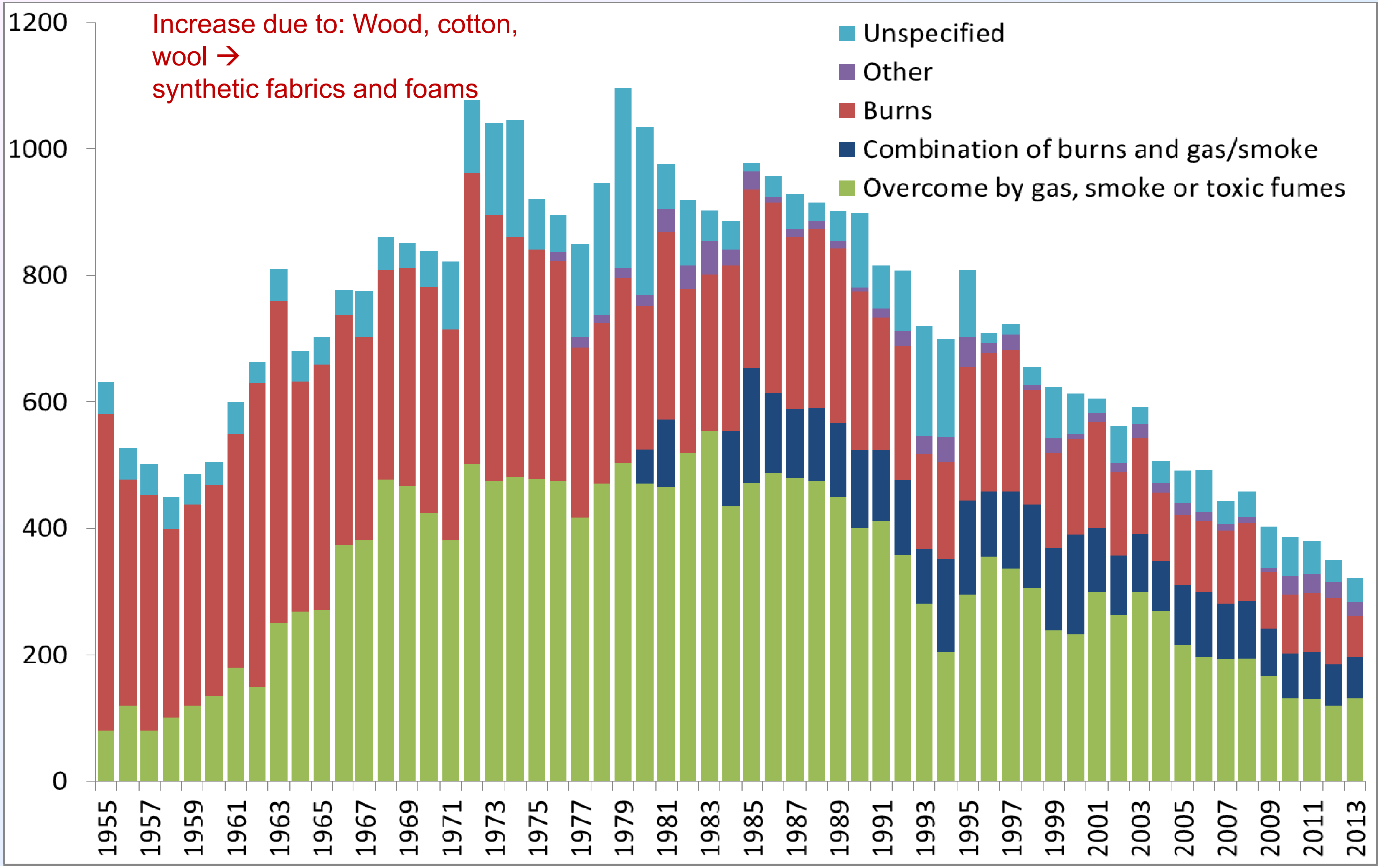
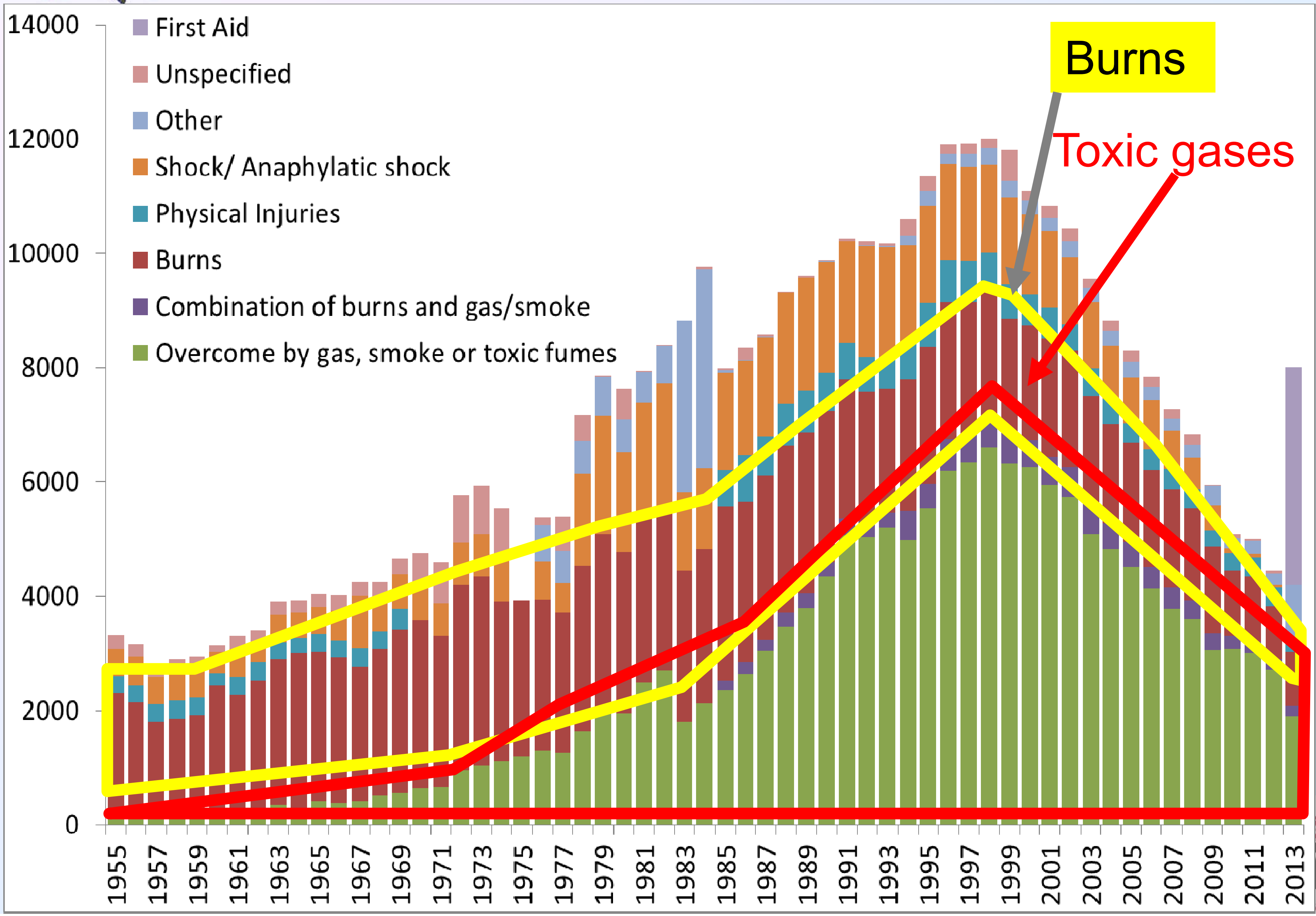
UK Fire Deaths (1955-2014)



UK Fire Injuries (1955-2014)



Toxic product yields in fires

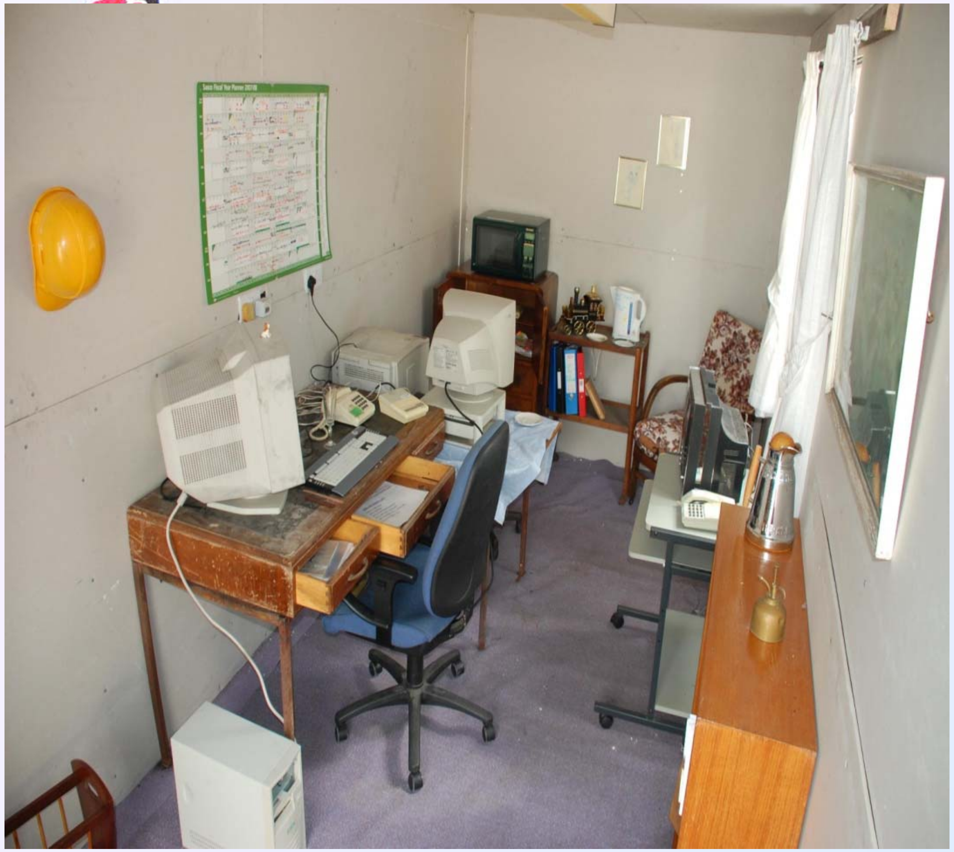
Depend upon:

1. Ventilation (fire scenarios/conditions)

- **Flaming/non-flaming, ventilation, temperature**

2. Chemical composition of material (fuel type)

- **C, N,Cl,Br,S, (Fire Retardants)**
- **Organic composition (Aliphatic or aromatic)**



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Fire Conditions

Immediate effects, less than 30 s.
disorientation because of smoke obscuration, sensory irritation, impaired normal breathing, etc., but the natural reaction is to attempt to extinguish the fire, warn others, and try to escape.

Fire Conditions

Immediate effects, within 2 min -All of the above present and intensifying. spreading smoke, accumulating and forming a hot layer at the ceiling level but rapidly descending toward the floor.

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Fire Conditions

•The combination of low O_2 and heat are extremely fast acting and above smoke also contains carbon dioxide and carbon monoxide.

•If the burning material contains nitrogen (as in polyurethane or polyisocyanurate foam) the smoke will contain hydrogen cyanide (HCN), nitrogen oxides (NO, NO_2), ammonia etc.

•If the burning materials contain chlorine, bromine, or fluorine (as PVC), hydrogen chloride (HCl), hydrogen fluoride (HF), and hydrogen bromide (HBr) are released.

•These inorganic irritants are always present, and exacerbate the irritating and choking effects of the smoke.

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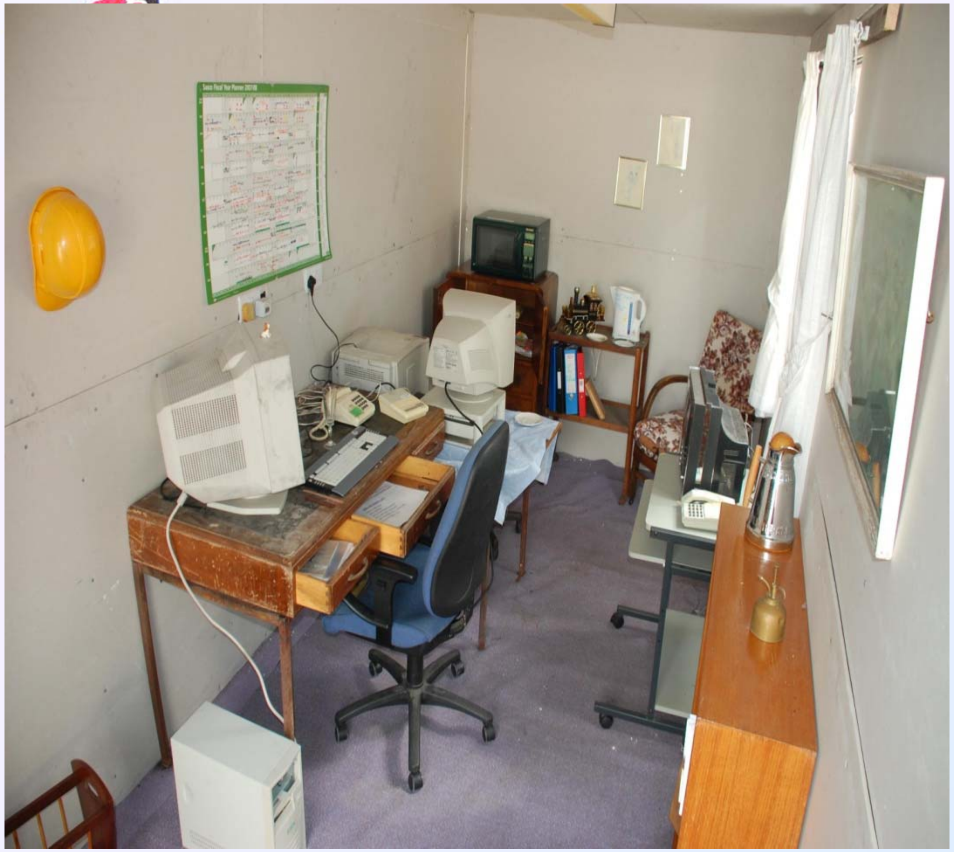


Harmful Effects

- **Smoke obscuration** - impaired vision due to the smoke and particulates presence

Harmful Effects

- **Irritant gases**
  - HCl, HBr, HF, NOx, Acrolein, Formaldehyde
  - Depending upon the concentration cause painful stimulation of the eyes, nose, mouth, throat and lungs with some hypoxia due to breathing difficulties which impedes escape and can be fatal
  - Depending upon dose inhaled cause lung inflammation and oedema which may be fatal usually some hours after exposure

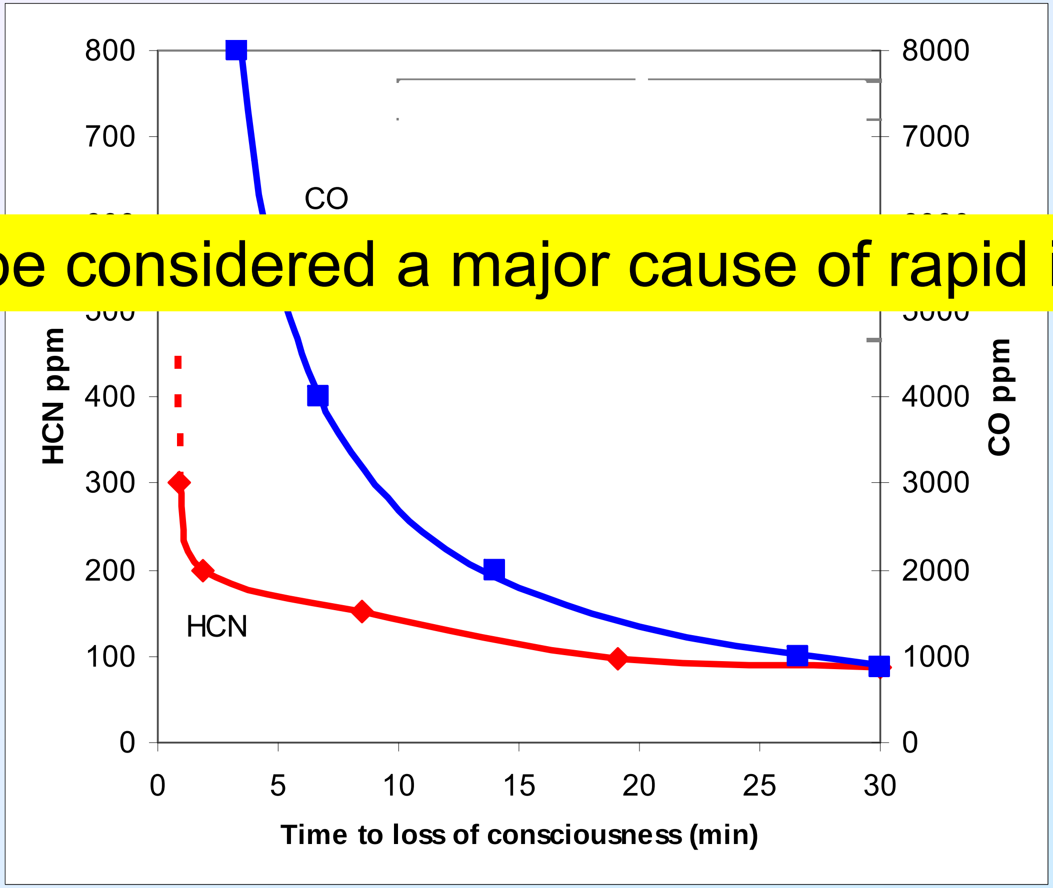
Harmful Effects

- **Asphyxiation gases**

- CO, HCN, CO_2, Low Oxygen
- Cause confusion and loss of consciousness followed by death from asphyxia when a sufficient dose has been inhaled
- For asphyxiants effects depend upon an exposure dose. There is little effect until a threshold dose is inhaled after which confusion occurs rapidly followed by collapse

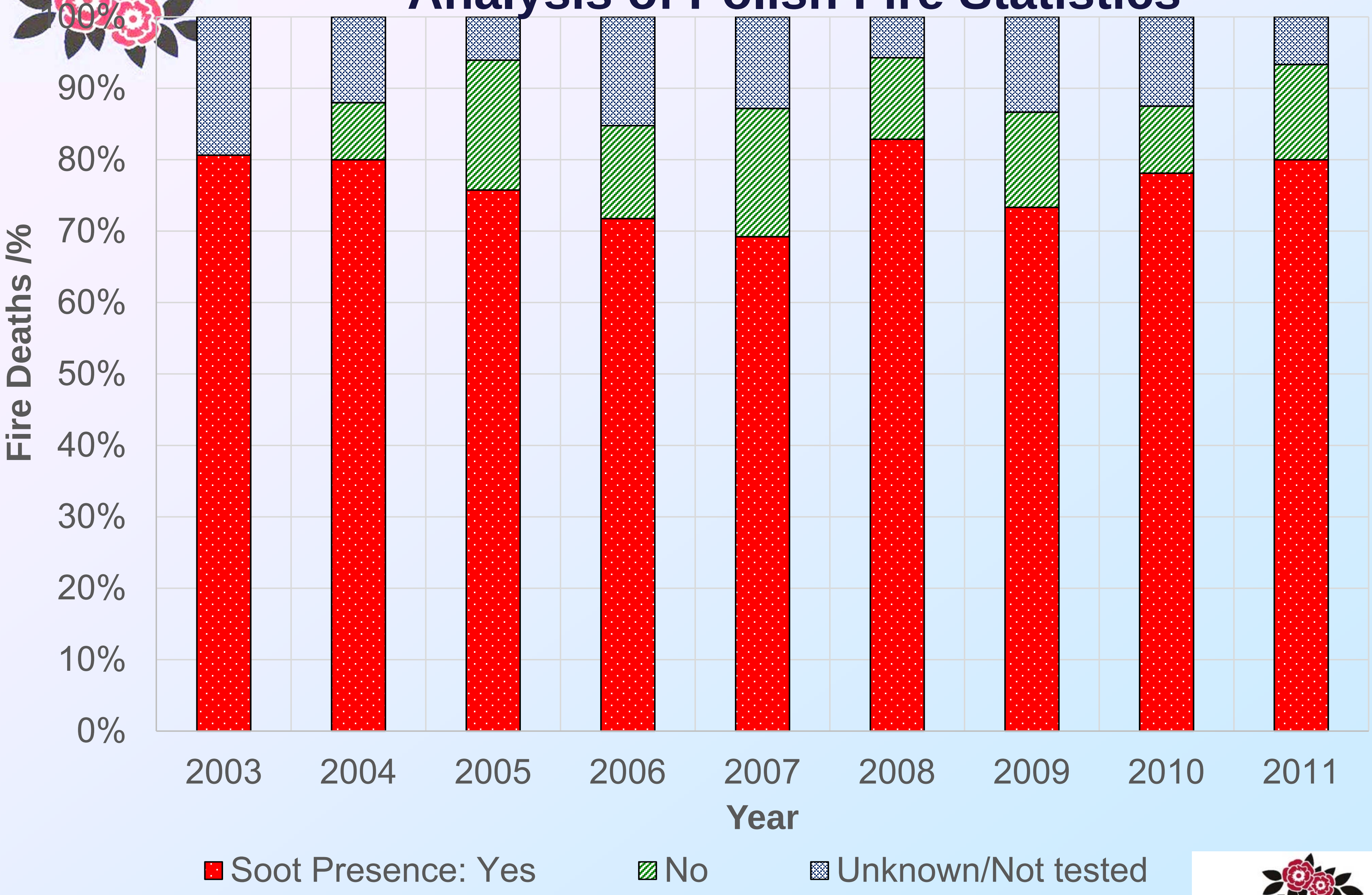
Asphyxiants: CO and HCN

- CO stays in the blood as COHb
- The uptake of HCN decreases (rapidly dispersed into the tissues, the intracellular fluids etc.).



HCN can be considered a major cause of rapid incapacitation.

Analysis of Polish Fire Statistics



Stec et al. Analysis of Fire Deaths in Poland and Influence of Smoke Toxicity, Forensic Science International .

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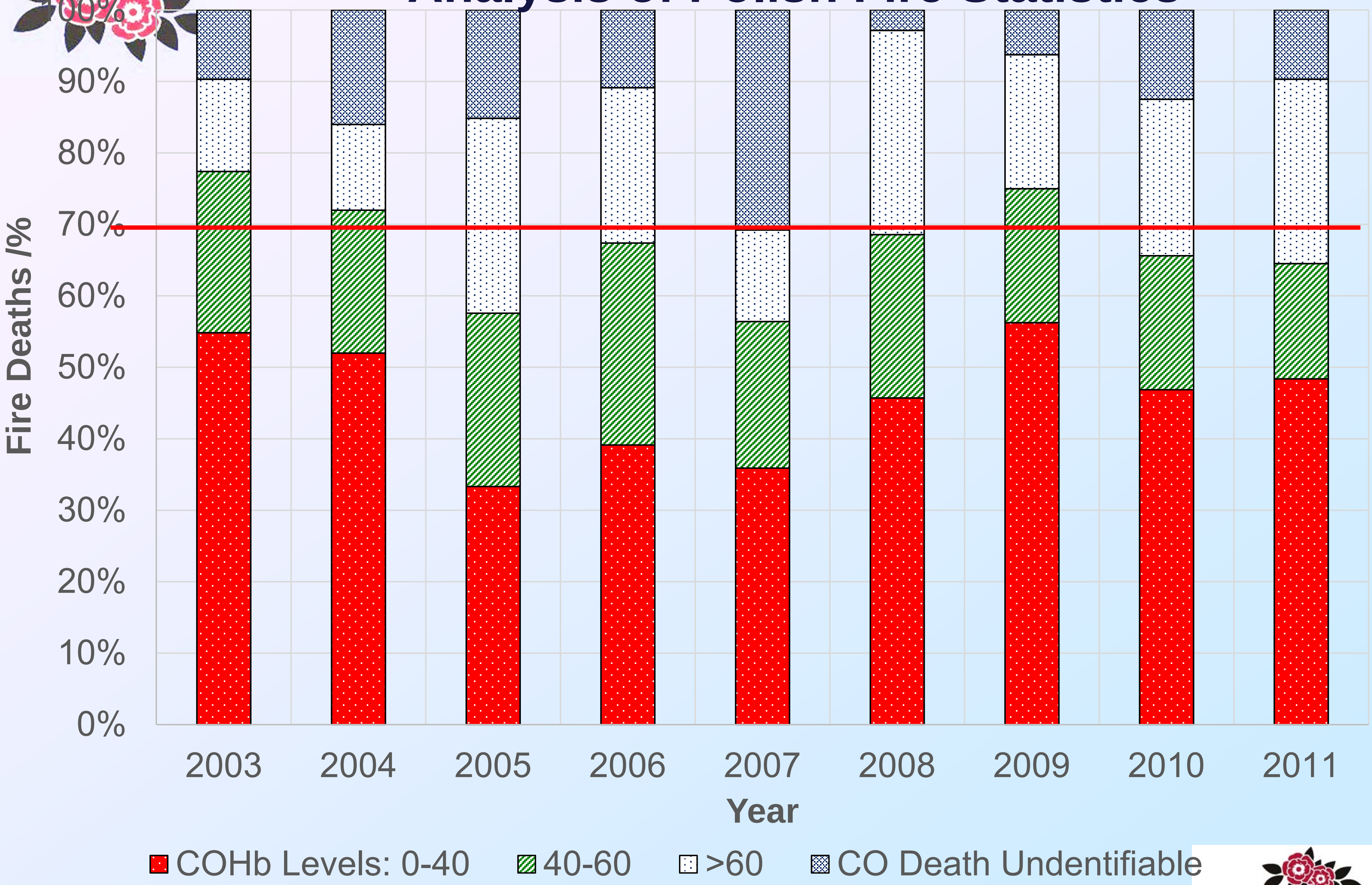

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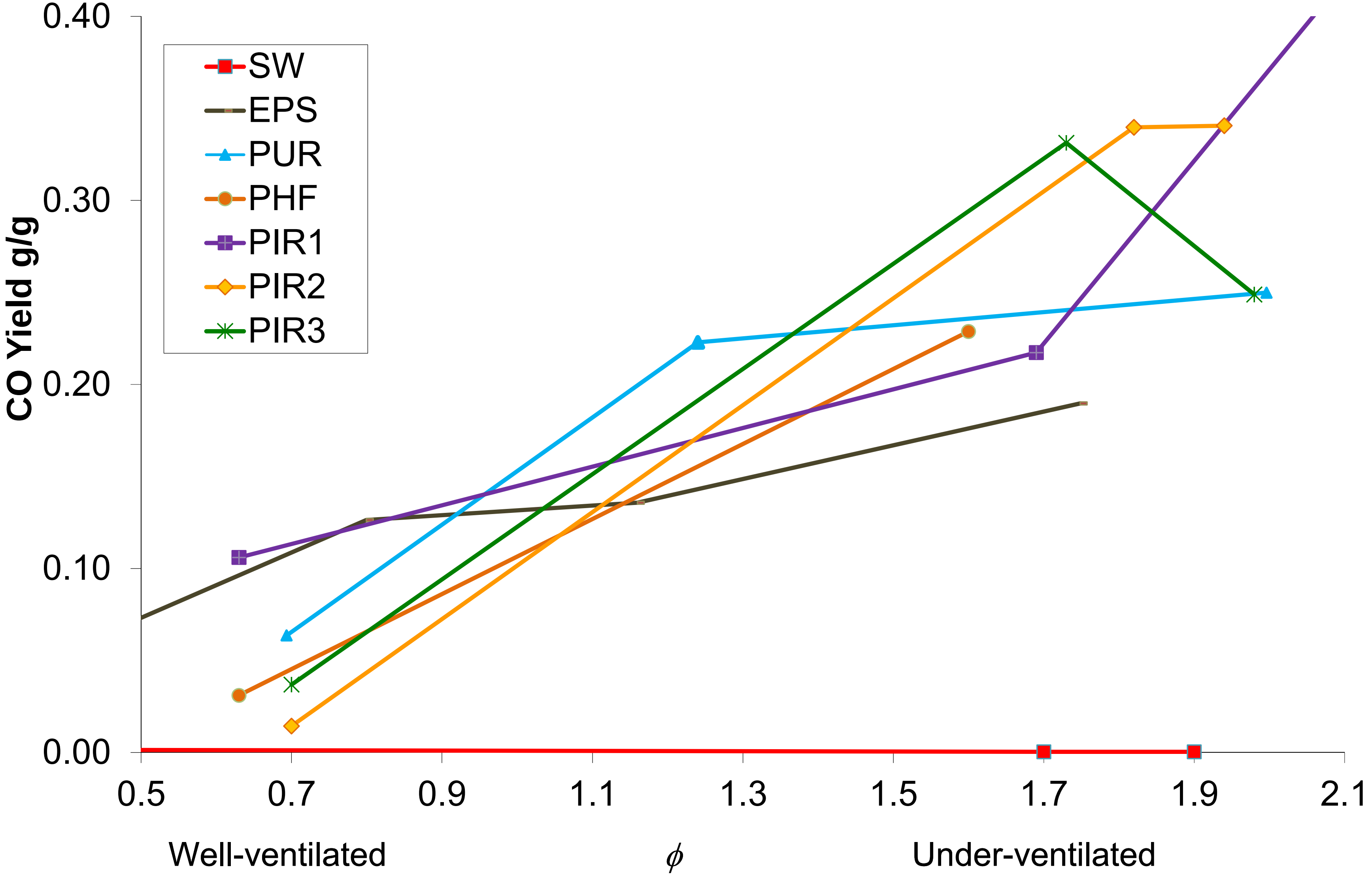
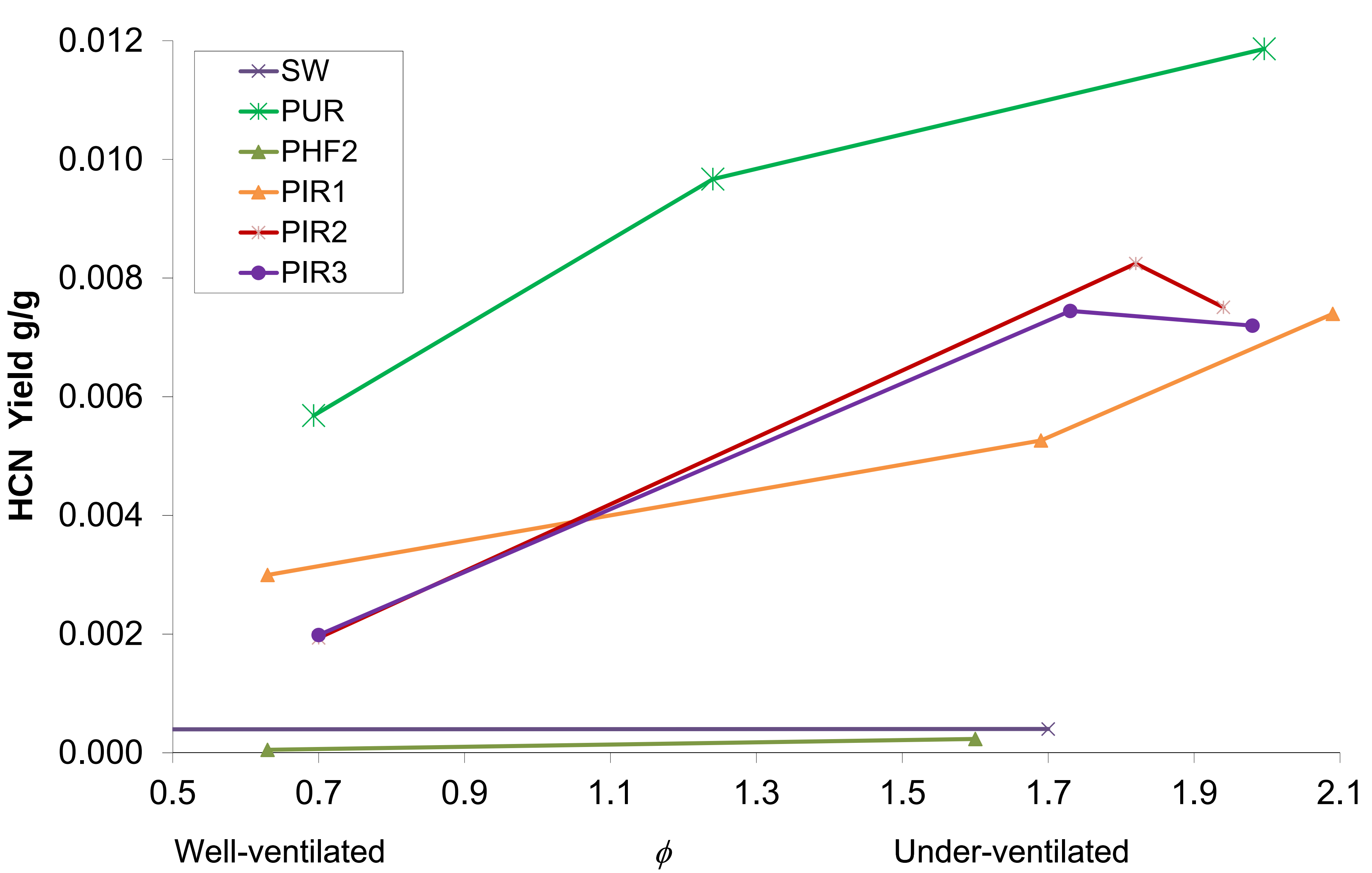
CO yields from construction materials



Stec A.A and Hull T.R Assessment of the fire toxicity of building insulation materials. Energy and Buildings, 43 (2-3). pp. 498-506

HCN yields from construction materials



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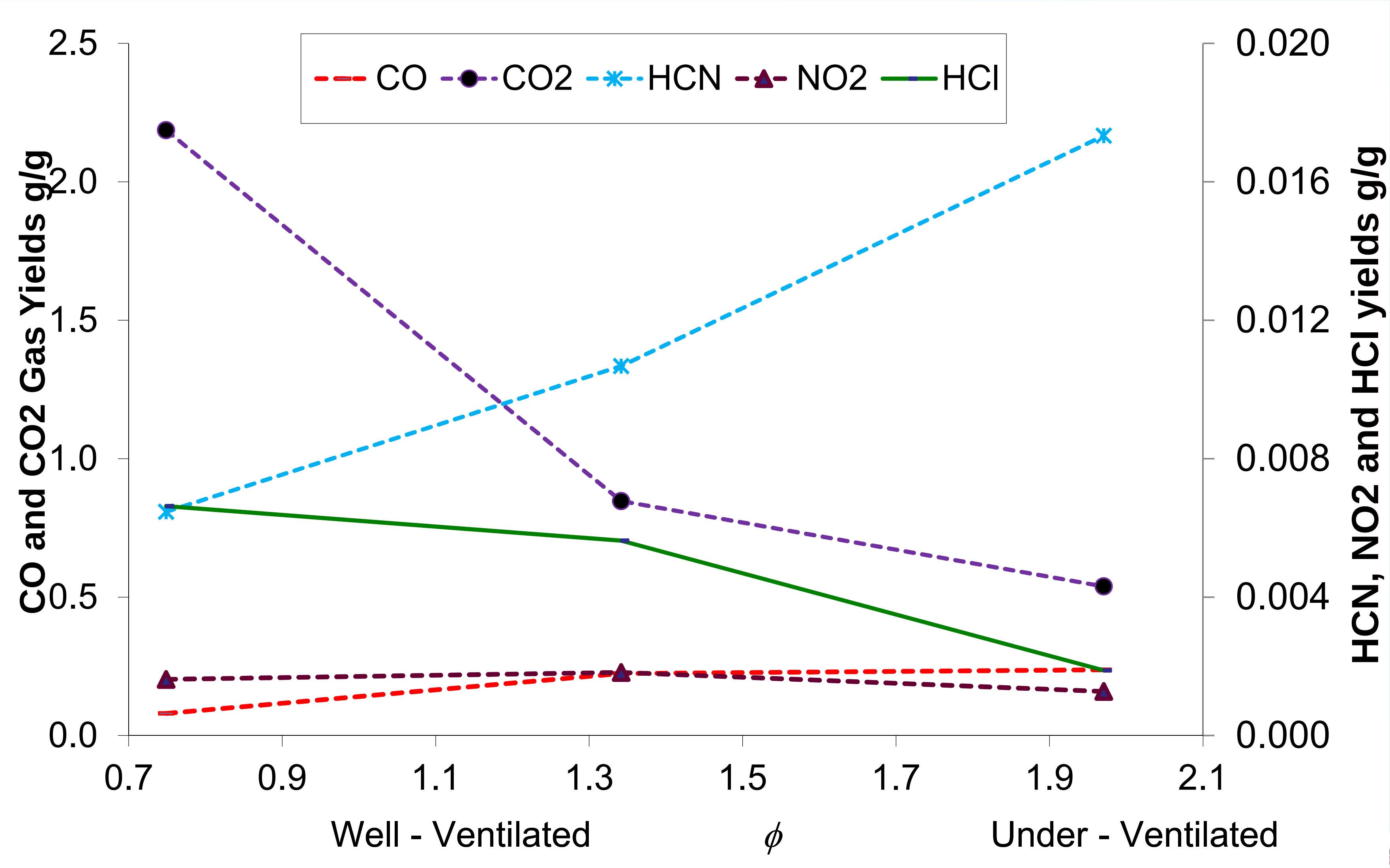
PIR yields g/g



Stec A.A and Hull T.R Fire Toxicity, CRC Press, Elsevier, 2010

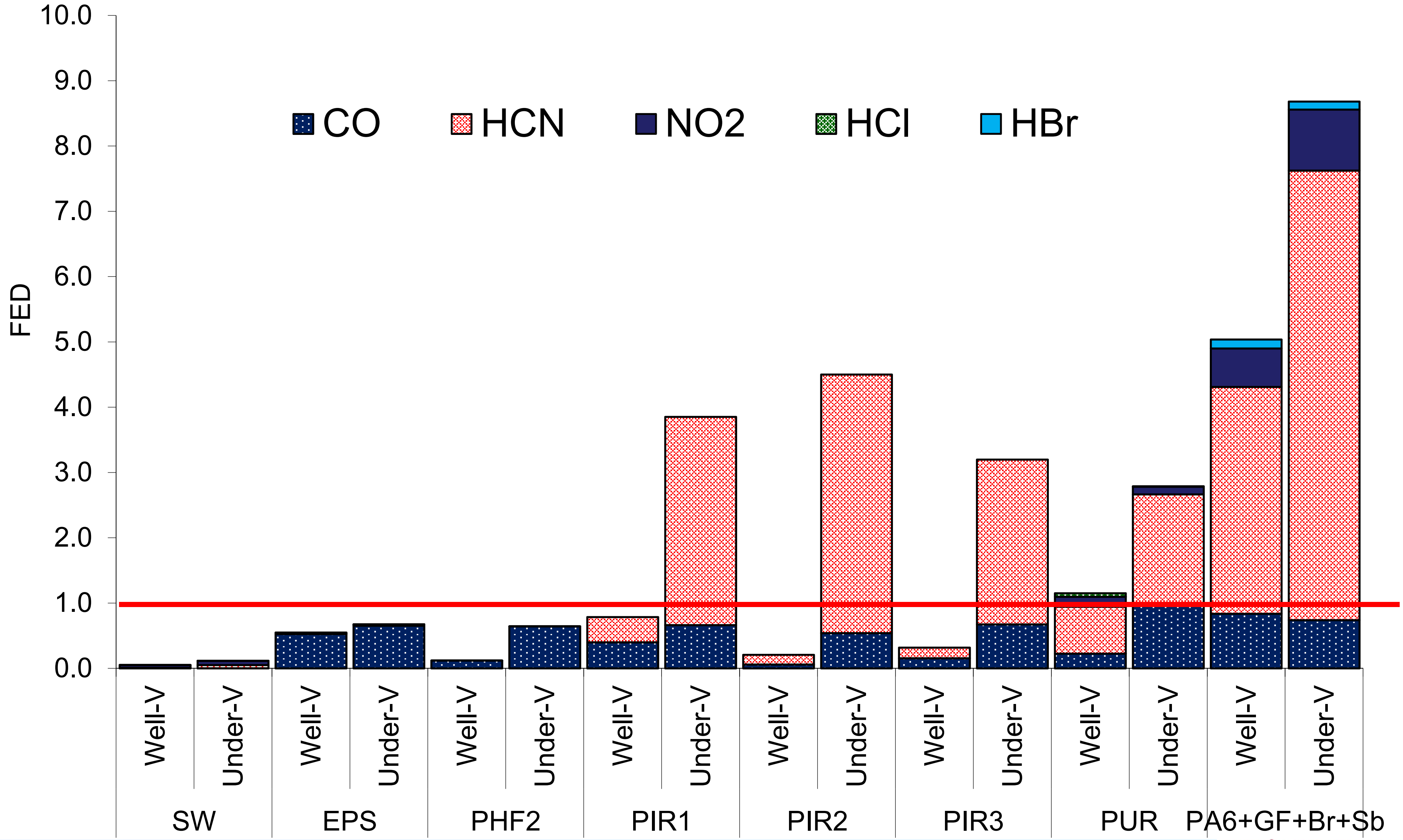
Estimation of fire toxicity- ISO 13344

FED - the fraction of a lethal dose (for 50% of the population)
When FED = 1 then 50% of the population will die.

$$FED = \frac{m[CO]}{[CO_2]-b} + \frac{21-[O_2]}{21-LC_{50,O_2}} + \frac{[HCN]}{LC_{50,HCN}} + \frac{[HCl]}{LC_{50,HCl}} + \frac{[HBr]}{LC_{50,HBr}} + \frac{[SO_2]}{LC_{50,SO_2}} ....$$

$$FED = \frac{m[CO]}{[CO_2]-b} + \frac{21-[O_2]}{(21-5,4)\,\%} + \frac{[HCN]}{150} + \frac{[HCl]}{3\,700} + \frac{[HBr]}{3\,000}$$

Fire toxicity of Common Polymers at 20 g/m^3 loading

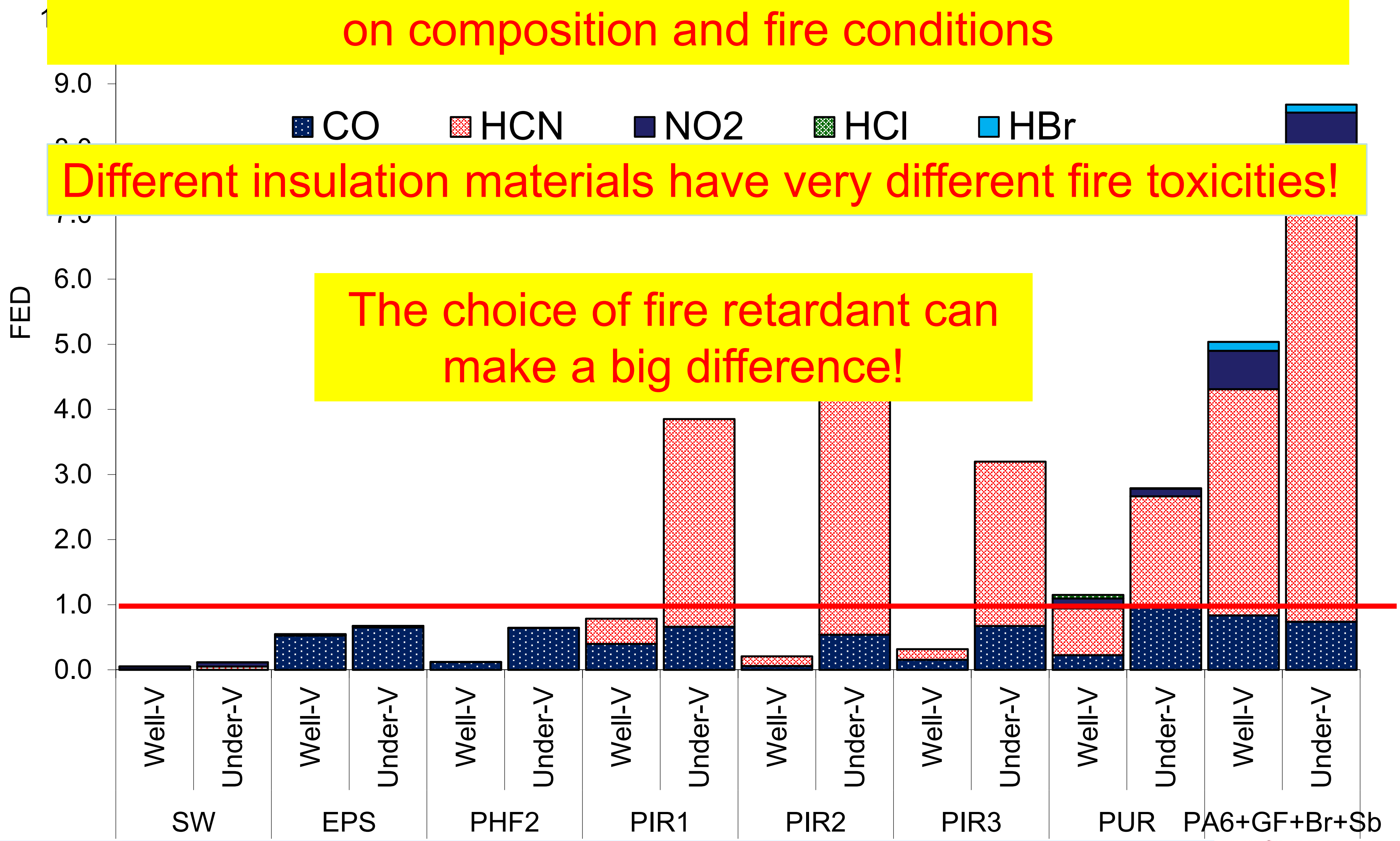


Fire toxicity of Common Polymers at 20 g/m^3 loading

Toxicity of common plastics depends on composition and fire conditions

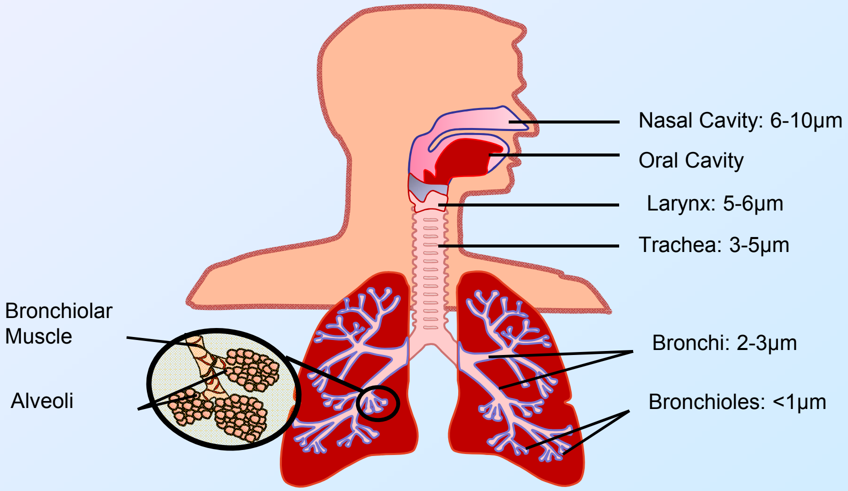
Different insulation materials have very different fire toxicities!

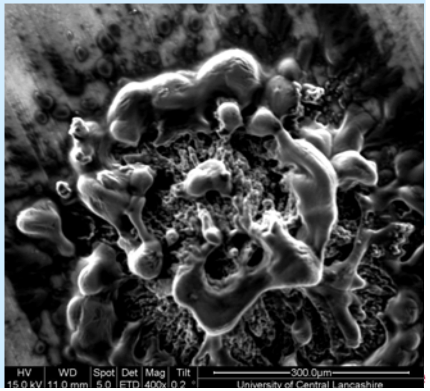
The choice of fire retardant can make a big difference!



Harmful Effects: Chronic Toxicants

- Particulates
- Polycyclic aromatic hydrocarbons
- Organophosphates
- Metals
- Polychlorinated and polybrominated dioxins and furans





Conclusions

- Fire toxicity is the biggest cause of death and injury in fires, but is unregulated.
- Material composition has a big effect on fire toxicity.
- CO is a good indicator of incomplete combustion however, it is not always the major toxicant.
- Fire retardants which act in the gas phase often increase fire effluent toxicity.
- We need a method which can quantify fire toxicity under each fire condition and assessment of fire toxicity must replicate under-ventilated flaming.

Thank you for your attention

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