Toxicity of electrical cable fires under restricted and free ventilations in the Cone Calorimeter

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Toxic smoke from fires

60% fire deaths in UK (1980-2014) – due to smoke inhalation (i.e. Grenfell Towers Fire 2017).

Fire smoke – solid and liquid particulates and gases.

Smoke composition depends on

- nature of the burning fuel
- conditions of combustion

High smoke production – high concentrations of toxic gases and particulates.

Asphyxiant and irritant gases in fire gases

Asphyxiants	Irritants		
	Carcinogens	Acidic gases	Other irritants
Carbon dioxide CO_2	Formaldehyde CH2O	Formic acid CH_2O_2	Acrolein C_3H_4O
Carbon monoxide CO	Benzene C6H6	Acetic acid $C_2H_4O_2$	Nitrogen dioxide NO2
Hydrogen cyanide HCN		Hydrogen chloride HCl	Sulfur dioxide SO2
		Hydrogen fluoride HF	Ammonia NH3
		Hydrogen bromide HBr	Fine particulates

References: Fraser 1996, Purser 2000, Tan and Wang 2005, Alarifi et al 2015 & Witty 2017

Asphyxiant – choking effect (immediate death) -------> SHORT term effects
Irritants – cause irritancy (impair escape) -------> SHORT/LONG term effects

Toxic gases and nano particles (<100nm) – can kill and act as irritants depending to the concentration.

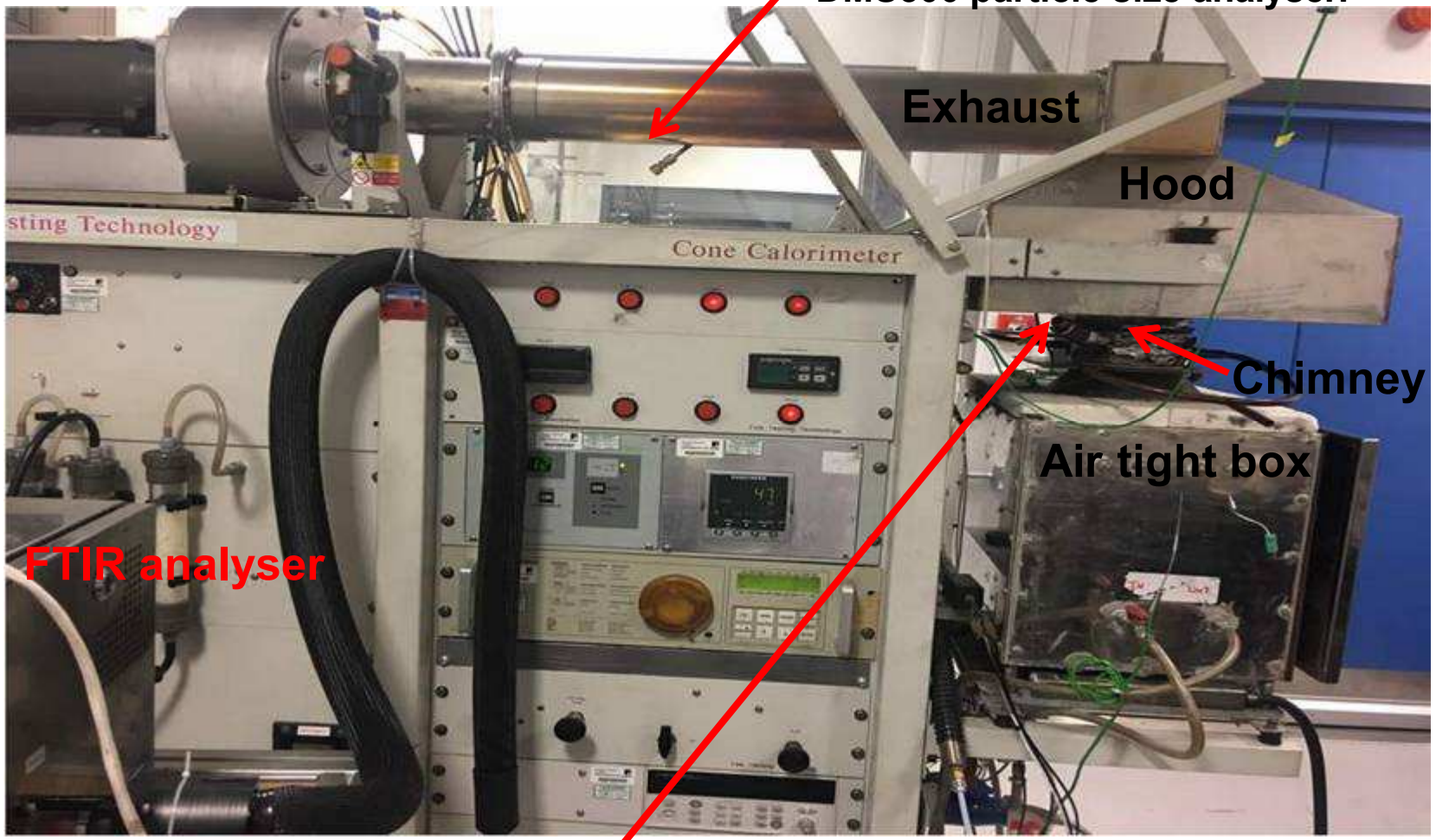
The Cone Calorimeter

The Standard Cone calorimeter was modified to have an air tight box around the test specimen to simulate a compartment fire.

- The Gasmet FTIR analyser – measure concentration of gases (up to 55 species).
- The Cambustion DMS500 – measure particle size distribution in fires.

>40 synthetic materials covered in this research programme (electrical cables and polymers).

Modified Cone Calorimeter



PVC Electrical Cable Test

Test conditions: 35 kW/m^2 radiant heat and 0.192 g/s air flow rate.

* Fixed air flow ---> 19 g/sm^2 = 59 kW/m^2 primary HRR

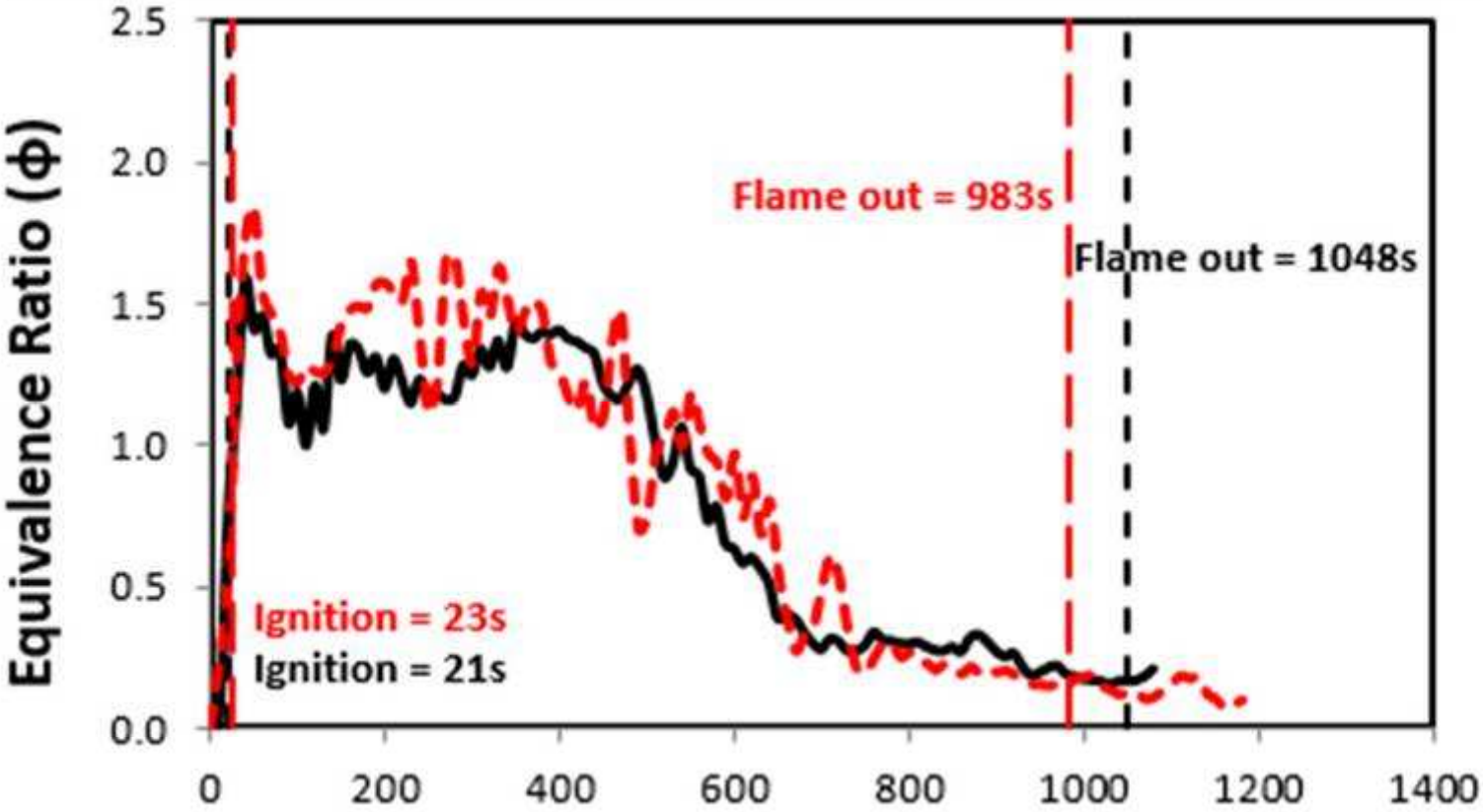
Raw sample

Burned sample

- PVC cable – fire retarded material
- Blue flame – due to presence of chloride compounds.

Materials Investigated: PVC Electrical Cable

Pre-analysis results			
Proximate analysis (wt.%)(daf)			
TGA		**Other information**	
Volatile matter	96.36	Stoichiometric A/F by carbon balance	4.85
Fixed carbon	3.64	Chemical formula	$C_1H_{1.29}Cl_{0.57}$
Moisture (as received)	0.40	Cable Type	PVC Prysmian A
Ash (as received)	28.91	Cable Standard	BS 6004
Ultimate analysis (wt.%)(daf)			
CHNS		**SEM**	
Carbon	35.63	Element	Wt%
Hydrogen	3.84	Oxygen	58.46
Nitrogen	0.00	Aluminium	0.33
Sulfur	0.00	Silicon	0.27
Oxygen	0.00	Chlorine	20.57
Chlorine	60.53	Calcium	20.37
Bomb Calorimeter		Total:	100
GCV (MJ/kg)	17.95		



Confinement effects:

- make the fire ϕ richer
- increase the toxic gas concentrations
- Refer to the ϕ of these confined and free fires, the difference of confinement was not large.

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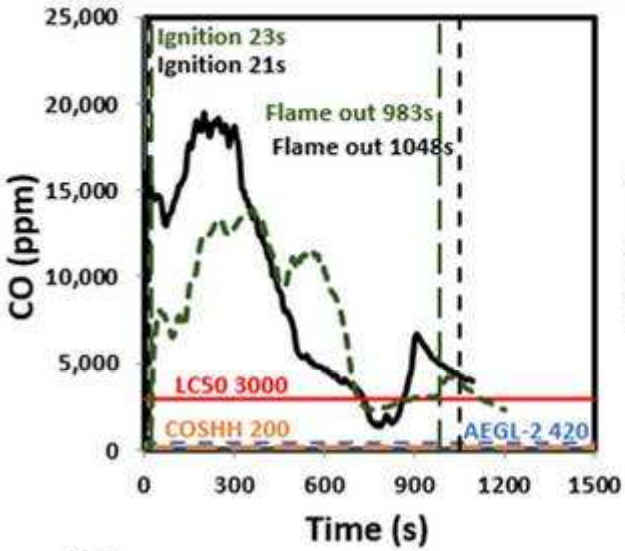

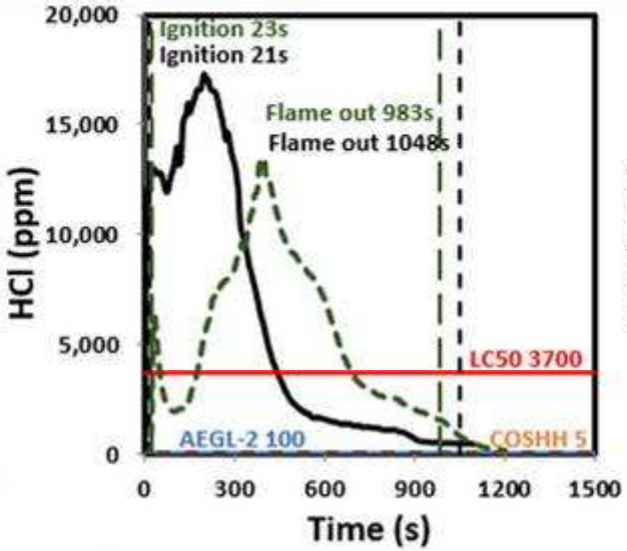

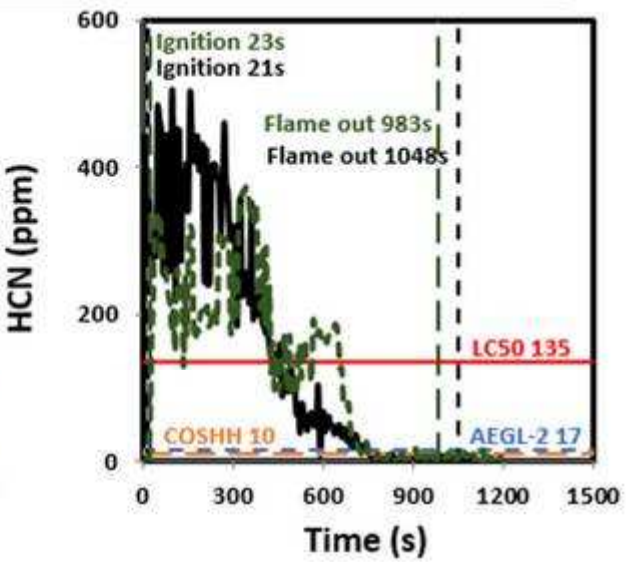

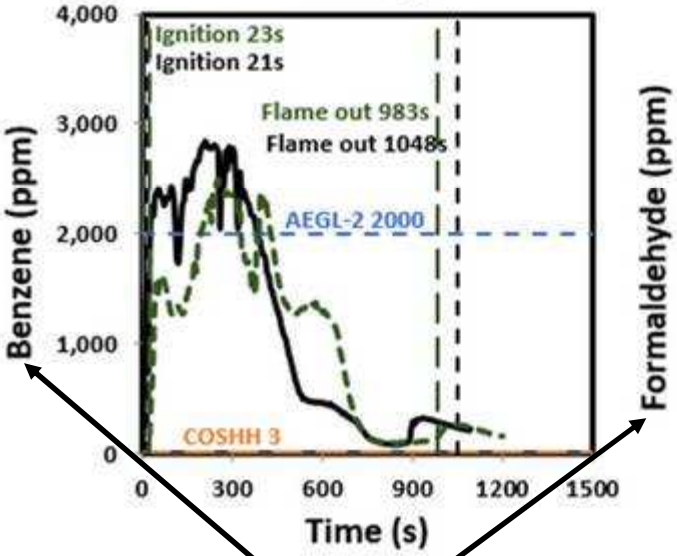

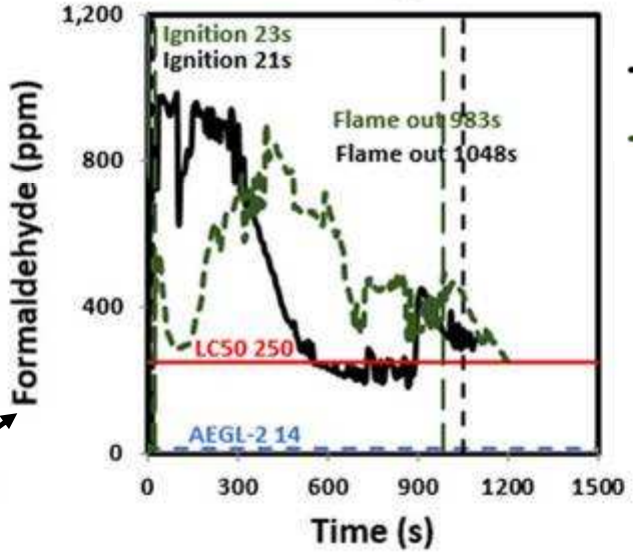

Carcinogenic

——59 kW/m2 **(Restricted Ventilation)**

- - - **Free Ventilation**

- Free ventilation – [Toxic gases] was lower in all cases except Acrolein.

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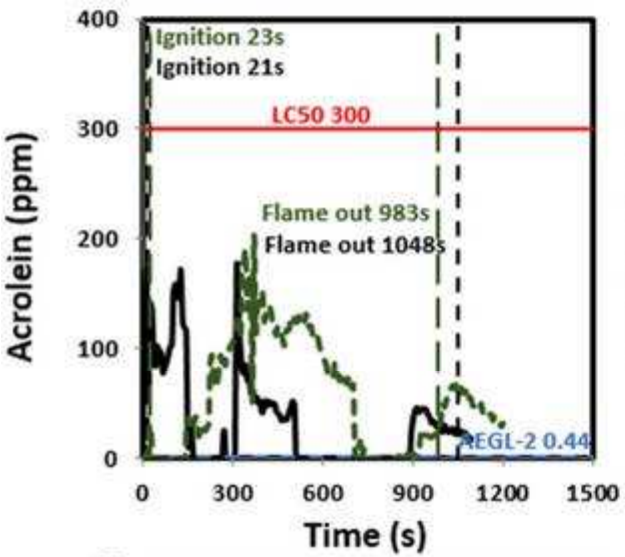
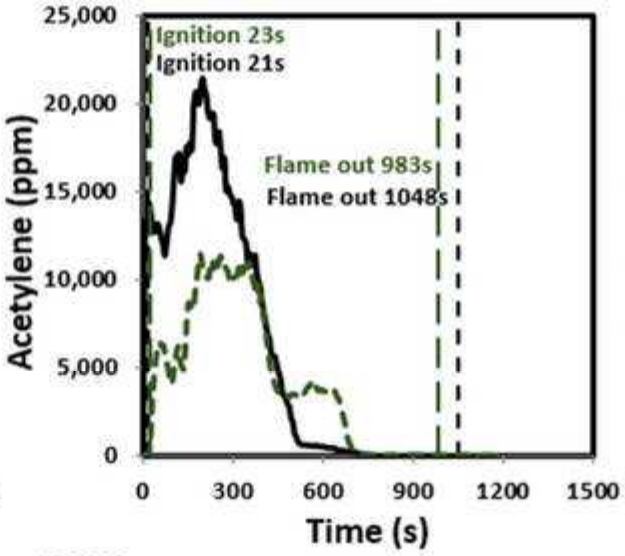
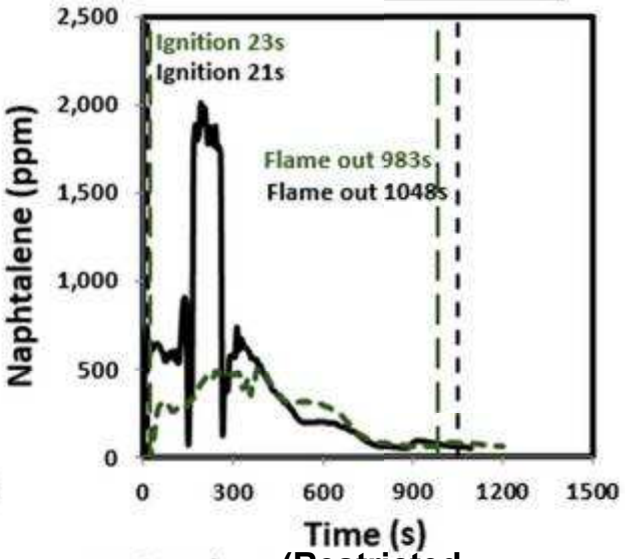
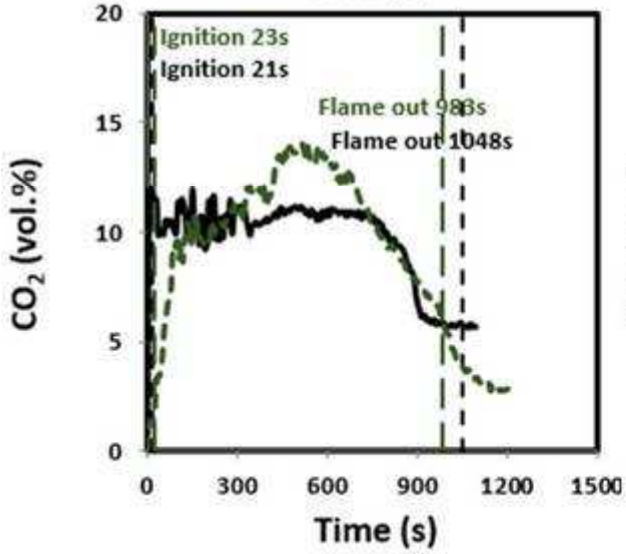
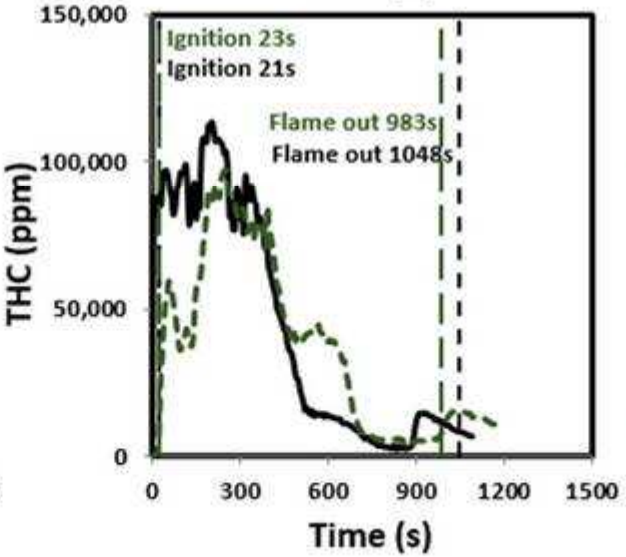










—— 59 kW/m2 (Restricted Ventilation)

--- Free Ventilation

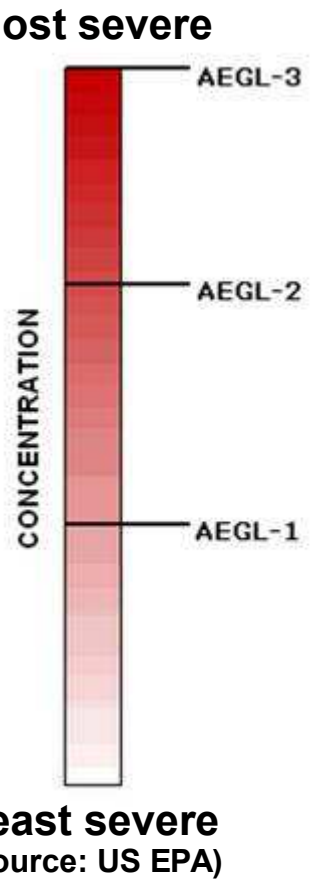
- Naphtalene – a marker for PAH emissions.
- Exposure to PAH in fires may cause bladder, colon, kidney, esophagus and prostrate cancers.
- Free fires – [CO_2] is slightly higher (combustion is more complete) compared with confined fires.

LC50 – Lethal Concentration: 50% die after 30 minutes exposure (Equivalent to AEGL-3)

AEGL-2 – (USA) Impairment of Escape after 10 minutes exposure. Also known as Acute Exposure Guideline Levels

COSHH 15 minutes exposure (EU) – Control of Substances Hazardous to Health in preventing ill health. This is taken as an impairment of escape concentration with 15 minutes exposure.

AEGL – 1 and COSHH 8 hours are workplace exposure guidelines for the no-harm limit.



Toxicity level n (for each gas) = Measured concentration / Toxic limit concentration

Total toxicity N – the sum of all the determined n (it is the dilution required to make the gases safe from death or impairment of escape).

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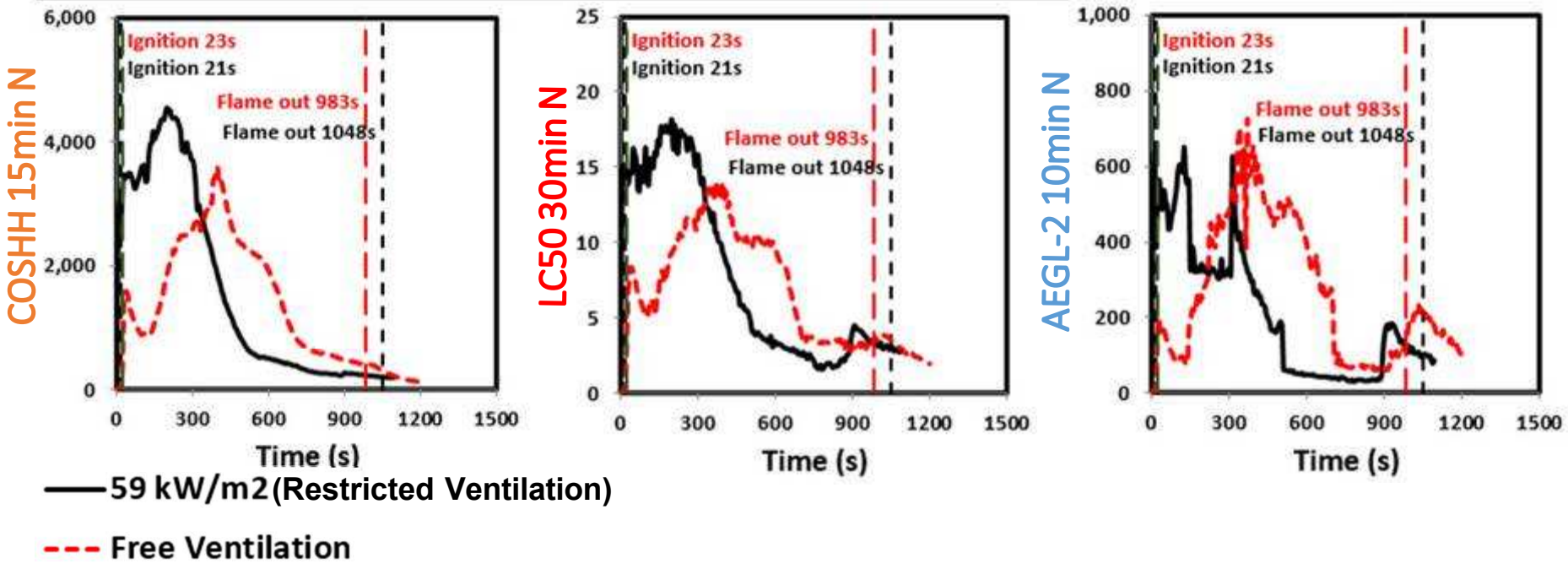

For total COSHH and LC50, free ventilation fires give a lower toxicity level compared to restricted ventilation fires.

Free ventilation compared to restricted ventilation:

– cable burning tends to be more complete – more sufficient air

– decrease the production of toxic gases – decrease level of toxicity.

No significant different for total AEGL-2 for both ventilation conditions.

Conclusions

- PVC electrical cable fires in free ventilation produce a lower concentration of toxic gases due to lean burning compared with restricted ventilation condition.
- HCl is the major toxic gas released from the PVC cable burning. It is irritant, can cause irritancy to human skin, eyes and respiration tract and reduce their ability of escape.
- Free ventilation gave a more complete combustion of the PVC electrical cable compared to the controlled ventilation with producing a higher concentration of CO_2.
- In overall, total toxicity N related to COSHH, LC50 and AEGL-2 assessments for PVC cable fires show a good agreement as early prediction which confined fires would give a higher gaseous toxicity.
- The cone calorimeter is a good test method to access fire materials for gaseous toxicity measurement by the FTIR analyser as well as particle size measurement by the DMS500.