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



Miss H. Mat Kiah, School of Chemical and Process Engineering, U.Leeds

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**FIRED-UP 2018**



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

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Fired-Up 2018

Thursday 17th to Friday 18th May 2018

The University of Edinburgh, UK



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## Contents

1. Toxic gases released from fires and their effects to human health
2. Experimental methods
3. Materials investigated
4. Toxic gas concentrations
5. Toxic level for COSHH, LC50 and AEGl-2
6. Total toxicity under restricted and free ventilations
7. Conclusions



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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 <sub>2</sub> | Formaldehyde CH <sub>2</sub> O        | Formic acid CH <sub>2</sub> O <sub>2</sub>               | Acrolein C <sub>3</sub> H <sub>4</sub> O |
| Carbon monoxide CO             | Benzene C <sub>6</sub> H <sub>6</sub> | Acetic acid C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> | Nitrogen dioxide NO <sub>2</sub>         |
| Hydrogen cyanide HCN           |                                       | Hydrogen chloride HCl                                    | Sulfur dioxide SO <sub>2</sub>           |
|                                |                                       | Hydrogen fluoride HF                                     | Ammonia NH <sub>3</sub>                  |
|                                |                                       | 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.



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## The Cone Calorimeter

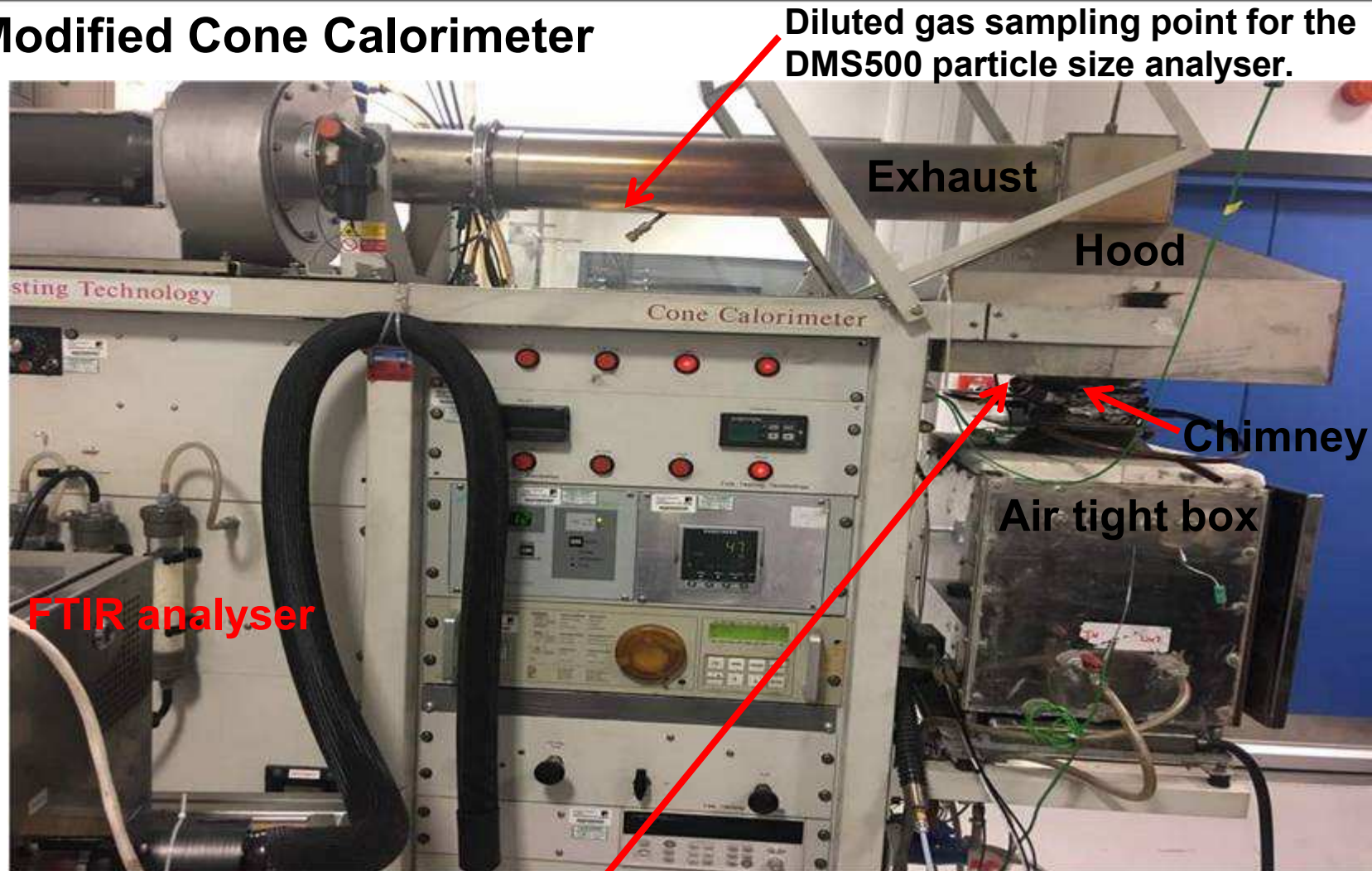
The Standard Cone calorimeter was modified to have an air tight box around the test specimen to simulate a compartment fire.

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

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



## Modified Cone Calorimeter



Diluted gas sampling point for the DMS500 particle size analyser.

Exhaust

Hood

Chimney

Air tight box

FTIR analyser

Raw gas sampling point for the FTIR gas analyser.



## PVC Electrical Cable Test

Test conditions: **35 kW/m<sup>2</sup> radiant heat and 0.192 g/s air flow rate.**

\* Fixed air flow ---> 19 g/sm<sup>2</sup> = 59 kW/m<sup>2</sup> 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 |                                      |                        |

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

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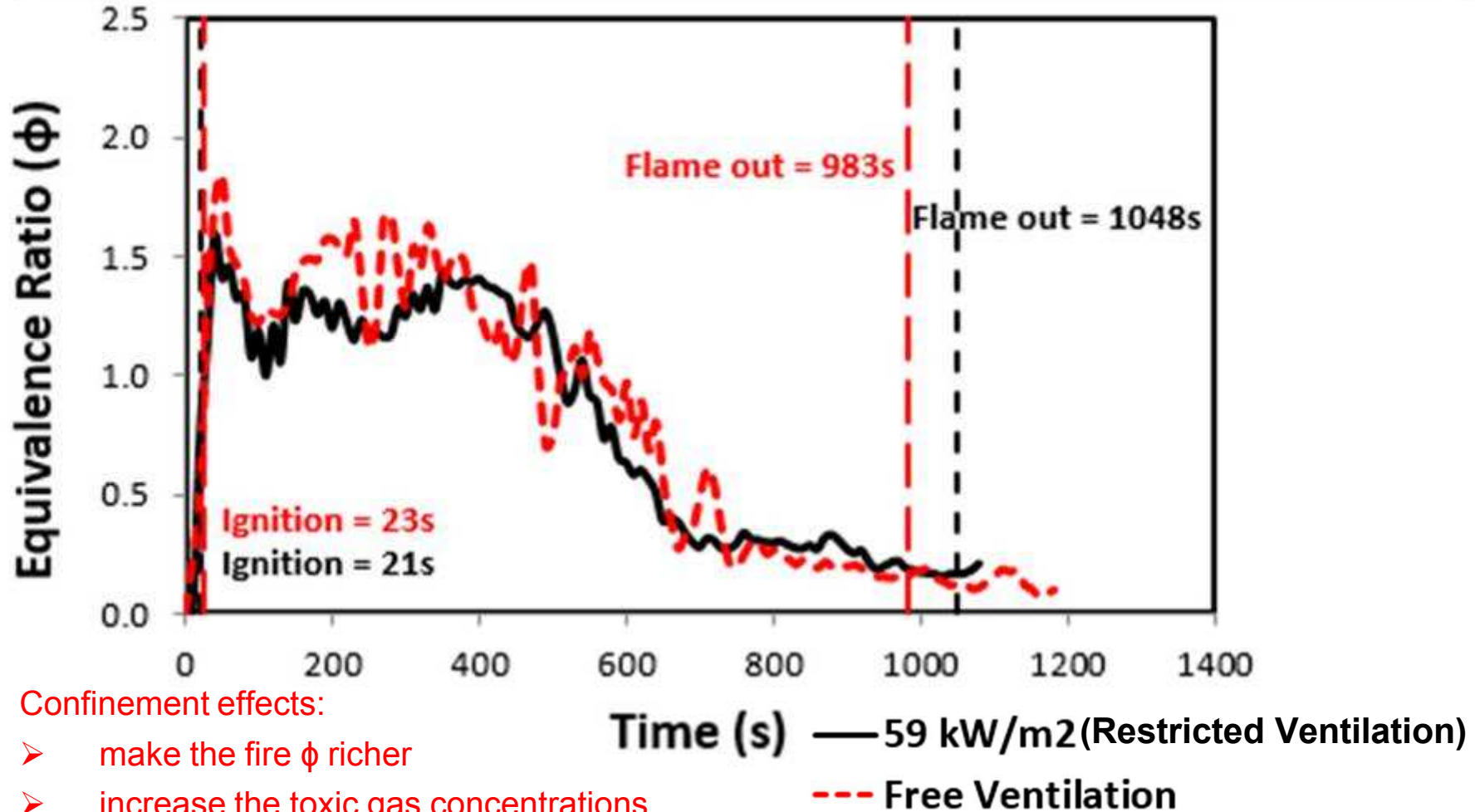
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Confinement effects:

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

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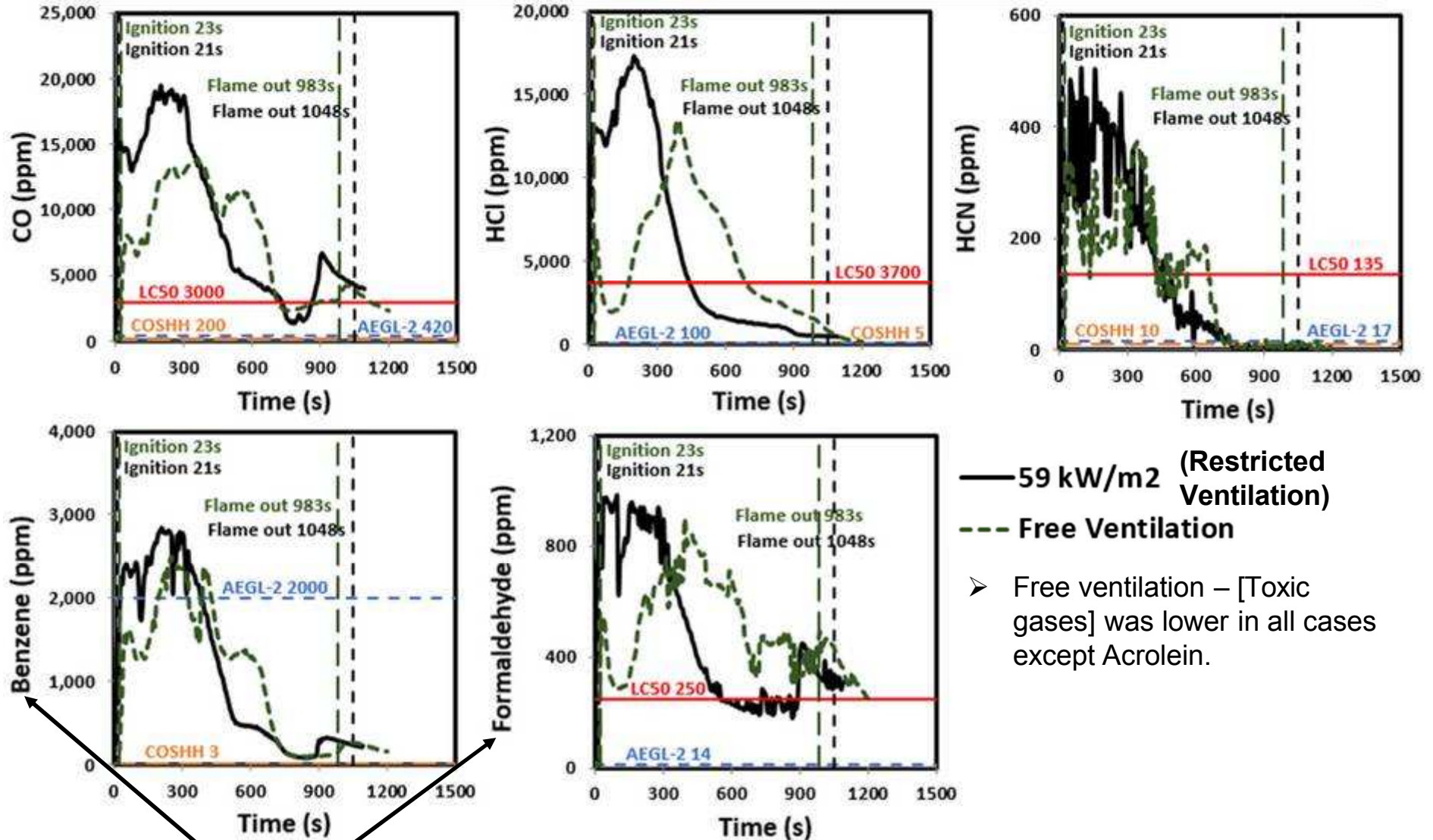
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— 59 kW/m<sup>2</sup> (Restricted Ventilation)  
 - - - Free Ventilation

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

**Carcinogenic**

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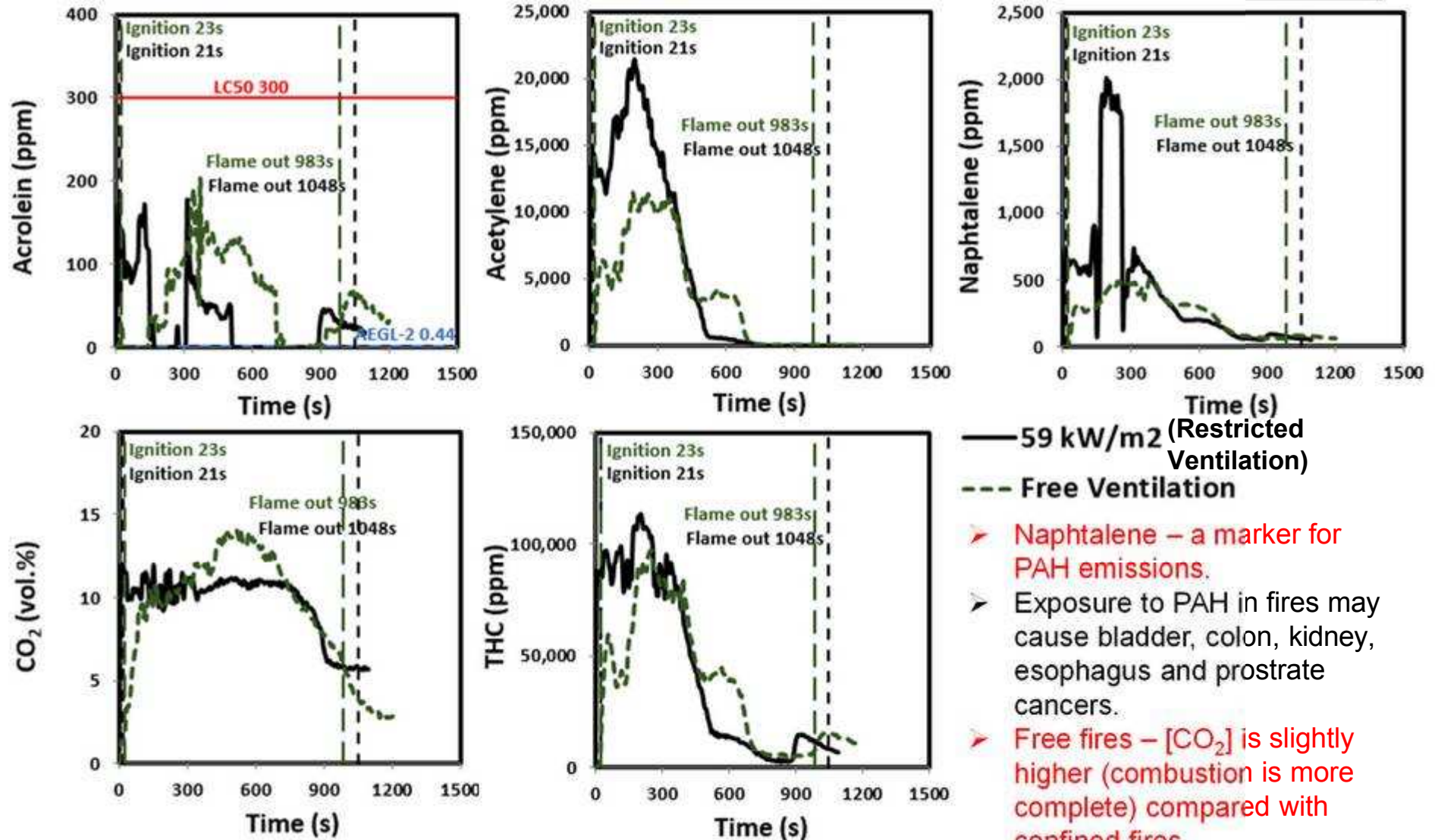
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- Naphtalene – a marker for PAH emissions.
- Exposure to PAH in fires may cause bladder, colon, kidney, esophagus and prostate cancers.
- Free fires – [CO<sub>2</sub>] is slightly higher (combustion is more complete) compared with confined fires.



**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**

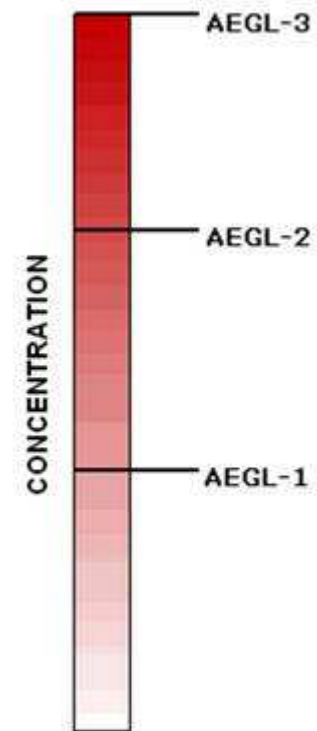
**COSHH 15 minutes exposure (EU) – Control of Substances Hazardous to Health in preventing ill health. This is taken as an impairment of escape concentration with 15 minutes exposure.**

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

**Toxicity level n (for each gas) =  $\frac{\text{Measured concentration}}{\text{Toxic limit concentration}}$**

**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).**

Most severe



Least severe  
(Source: US EPA)

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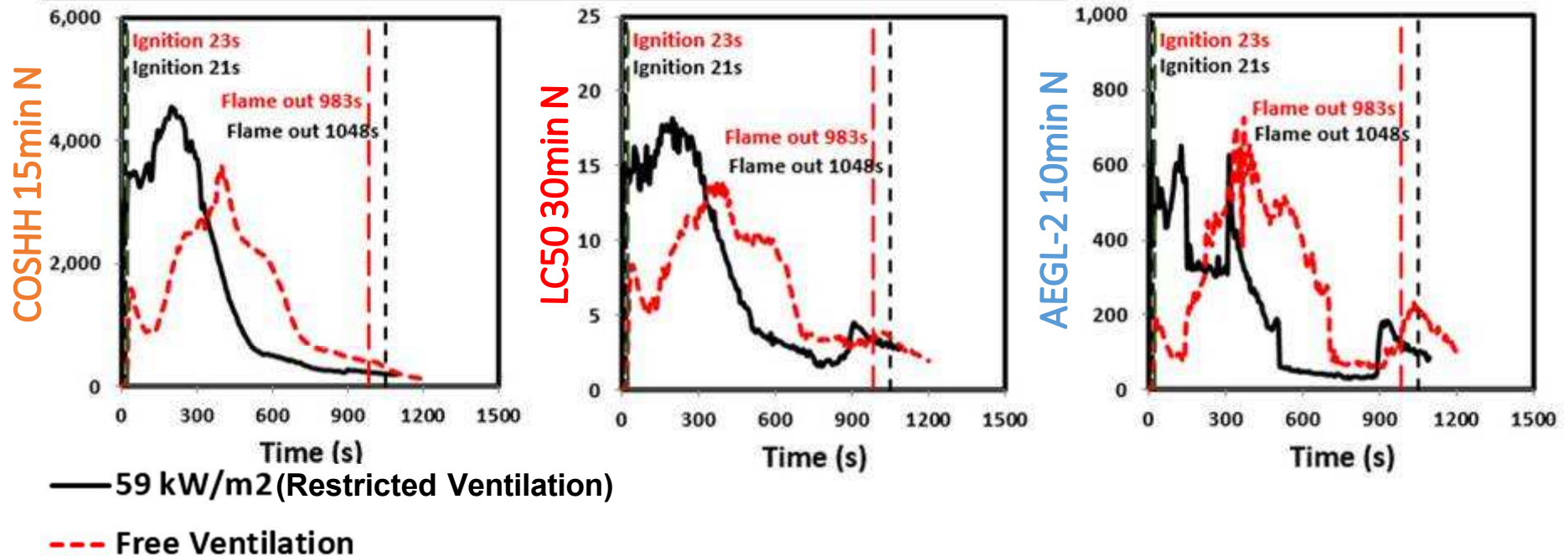
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For total COSHH and LC50, free ventilation fires give a lower toxicity level compared to restricted ventilation fires.

## 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<sub>2</sub>.**
- **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.**