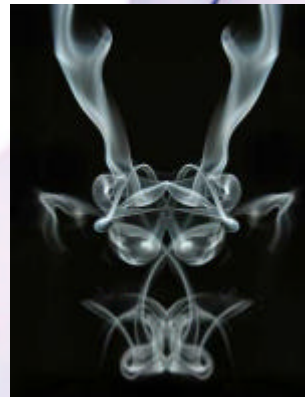


# **Toxic Emissions from Air Starved Enclosure Fires**



**A presentation by Paul Yeomans**

**3<sup>rd</sup> Year, Fire and Explosions MEng, Leeds University**



# **Introduction**

**This was a study concerned with small scale, yet highly toxic enclosure fires.**

**These are of significant hazard in modern buildings equipped with passive fire protection, insulation and hence, little means of ventilation.**

**In the past, great emphasis has been placed on the danger of fast growing, well ventilated fires.**

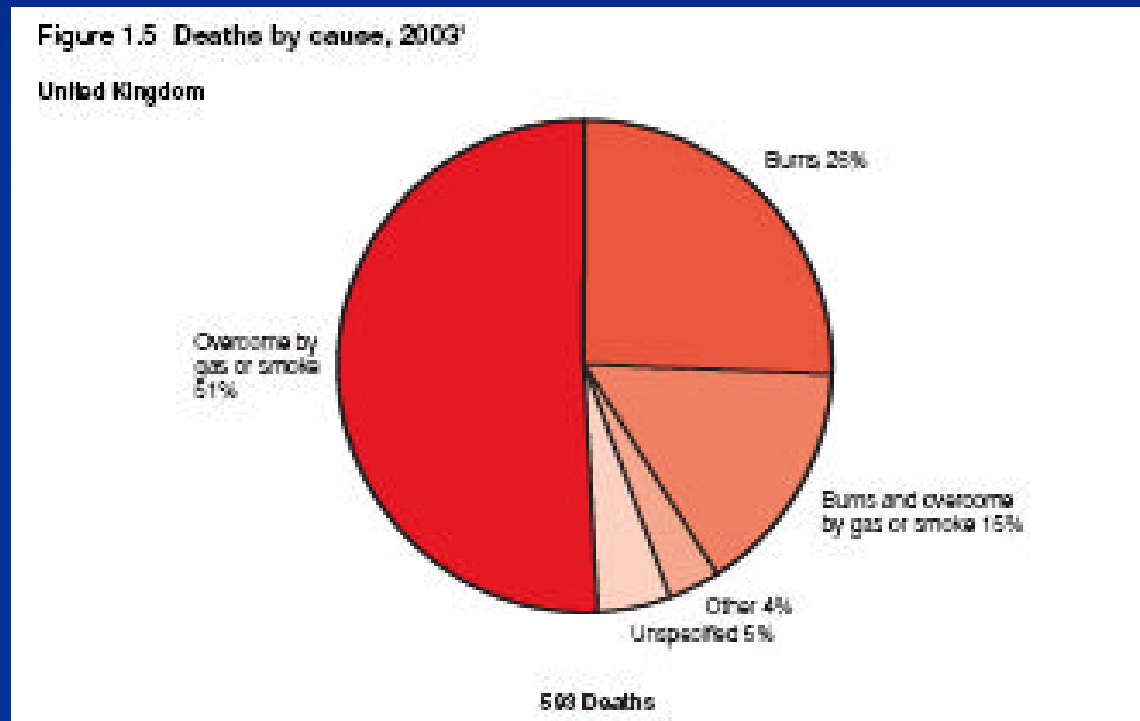
**The concept of a very small fire in a room with very little ventilation is not a hazard that people would usually identify.**



# Vital Statistics



- ✦ In 2007/2008 over 500 deaths were of the result of fires in the UK. Over 300 of these were accidental dwelling fires.
- ✦ In 2003, roughly 50% of fire deaths were due to smoke inhalation.



- ✦ Similar studies were carried out in the USA using autopsy results. Older studies concluded that around 66% of fire deaths were due to smoke inhalation. In more recent years the fraction is thought to be growing to around 75%.

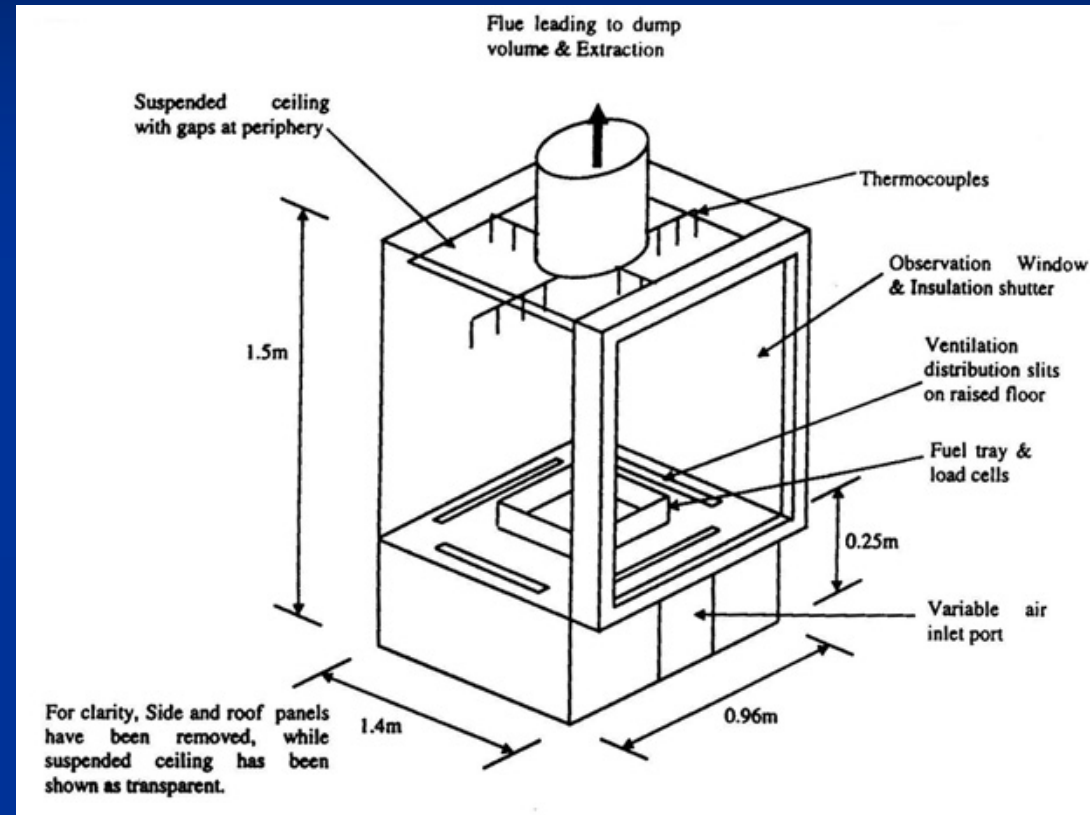


## **Objectives**

- o Perform simple air starved enclosure combustion experiments using cotton towels and monitor toxic emissions.**
- o Quantify toxic emissions against recognised toxicity limits.**
- o Calculate toxic yields & compare to established recommended values used in CFD and zone modelling fire codes.**

# The Experiment

- o Two focal experiments were carried out in a  $1.57\text{m}^3$
- o The air flow rate was set to 5.7 air changes per hour.
- o This air flow rate is low enough to be comparable to the type of ventilation that was present in linen room of the Rose Park Nursing Home fire.



**The Combustion Rig**

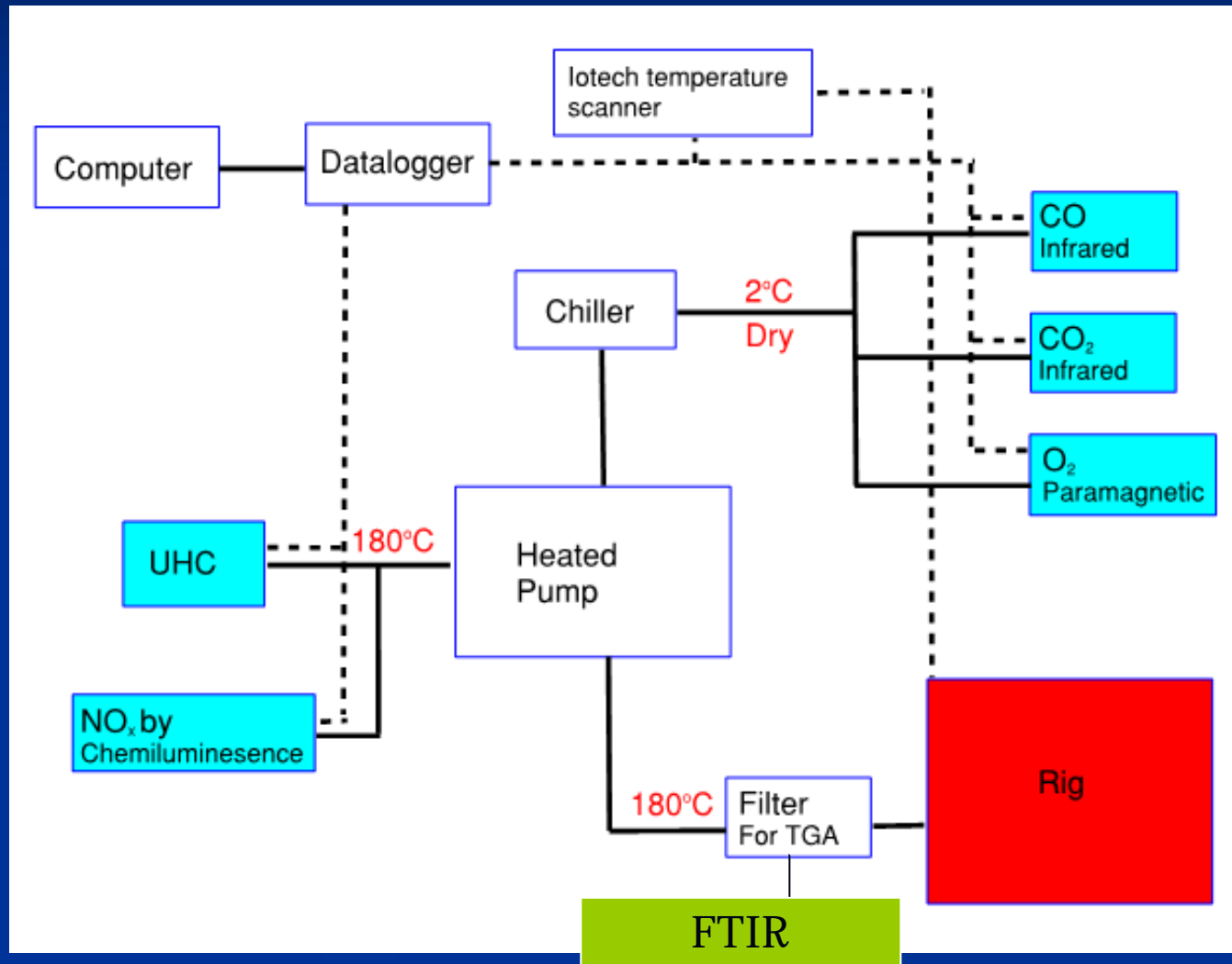
A 10cc cup of accelerant was used to start the fire

Various online gas analysers monitored the combustion products at small intervals.

A large number of thermocouples were located around the rig, allowing temperature to be measured



# Simple diagram of Rig and Analysers



# **Significant Toxic Species present in FTIR data.**

## **Carbon monoxide (CO)**

- ✎ A odorless, colourless, tasteless and poisonous gas produced by incomplete burning of carbon based fuels.
- ✎ When CO enters the body, it prevents the blood from bringing oxygen to cells, tissues and organs, ultimately suffocating its victims.
- ✎ The British Standard 5 minutes to incapacitation limit is **6000ppm**.

## **Formaldehyde (HCHO)**

- ✎ Can be detected by odor and eye irritation. It can irritate the eyes with redness pain and blurred vision.
- ✎ Concentrations of **25 to 30ppm** can cause severe respiratory tract injury leading to pulmonary edema and pneumonitis.
- ✎ In high concentrations it can be fatal.

## **Acrolein (C<sub>3</sub>H<sub>4</sub>O)**

- ✎ Has a unpleasant odor threshold at a concentration of around 0.2 ppm.
- ✎ Acute inhalation exposure to high levels (**10ppm**) of Acrolein in humans can result in death.

# Quantifying the FTIR data



## **COSHH (Control of Substances Hazardous to Health), 15 minute limits**

These limits are relevant to fire protection design due to the fact that levels of greater than 100% will impair a persons ability to escape. They are widely accepted and often employed in work place legislation.

## **LC<sub>50</sub> (lethal concentration), 30 minutes**

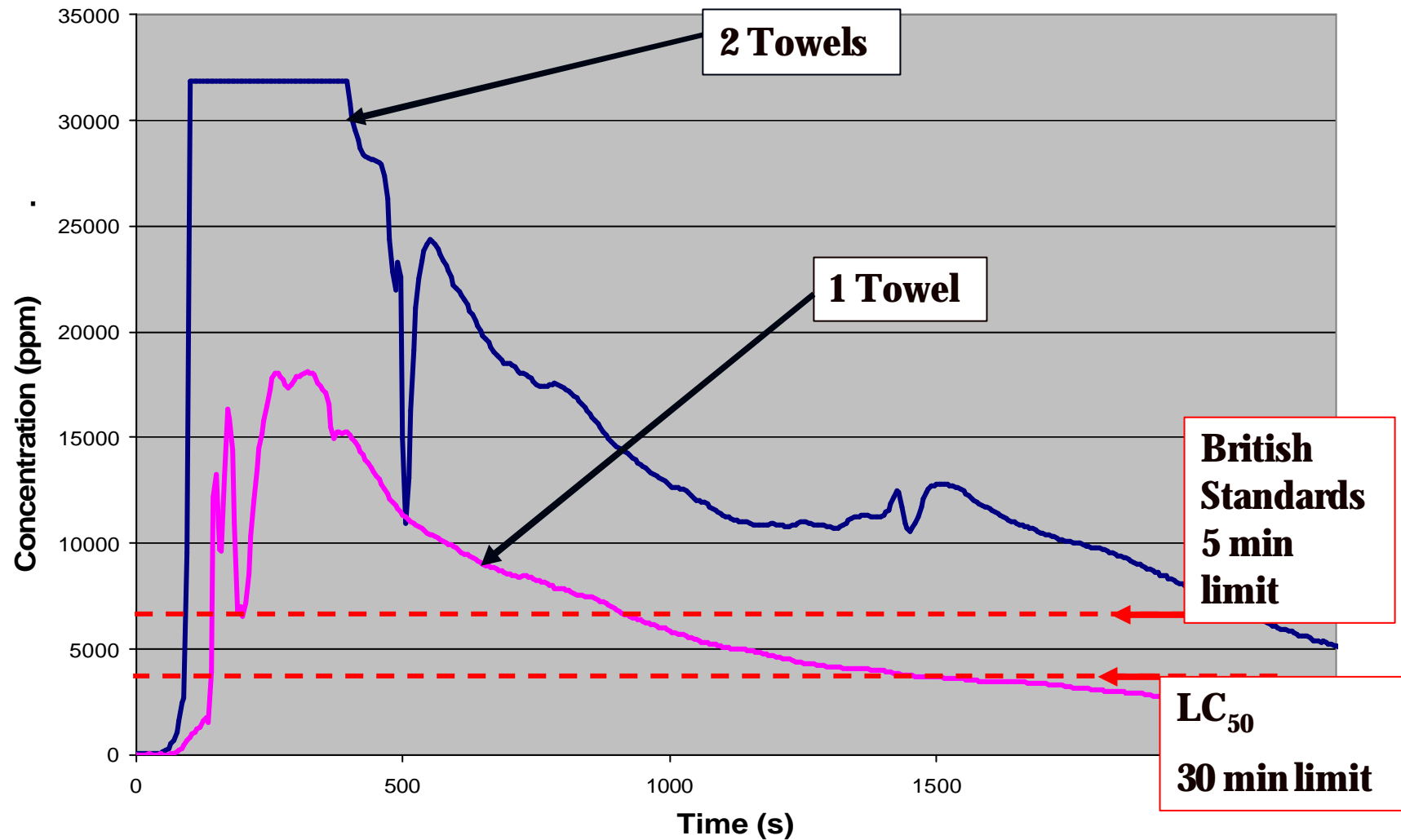
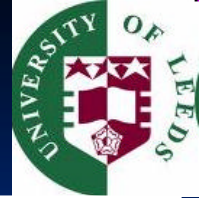
Provides a reference point for the deadly concentration that will kill 50% of test animals in a given time. This is a useful limit in terms of fire investigation, such as the case of the Rose Park Nursing home.

## **Only Dominant gases were analysed**

The amounts were normalised against two of the established limits and trace amounts were ignored.

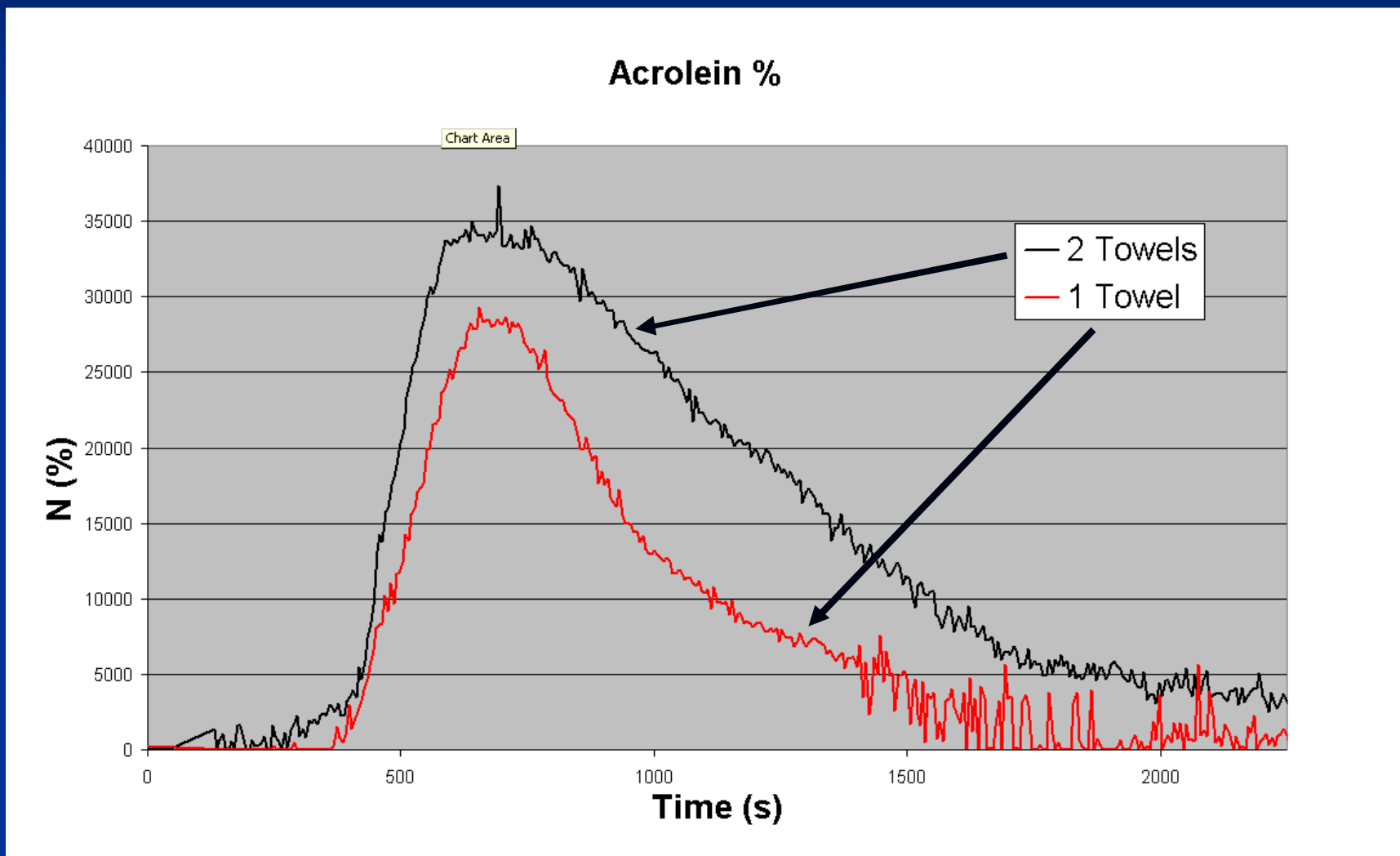
$$\text{Normalised Value (N\%)} = \text{Toxic Concentration} / \text{Toxic Limit}$$

# Carbon Monoxide Infra-red Online Analyser results



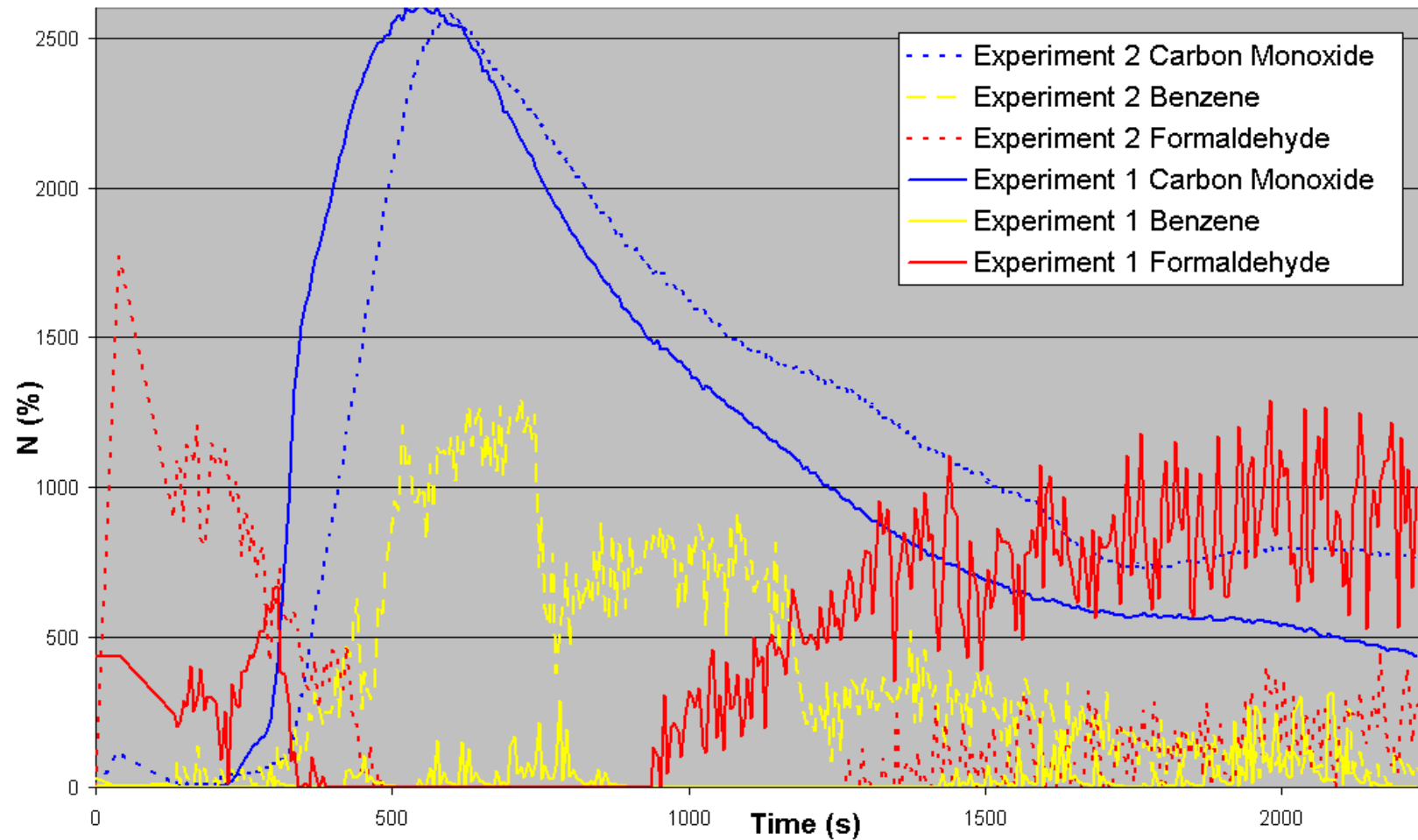
# COSHH N%

Acrolein was produced far in excess of all other species relative to COSHH limits.



# FTIR - COSHH N%

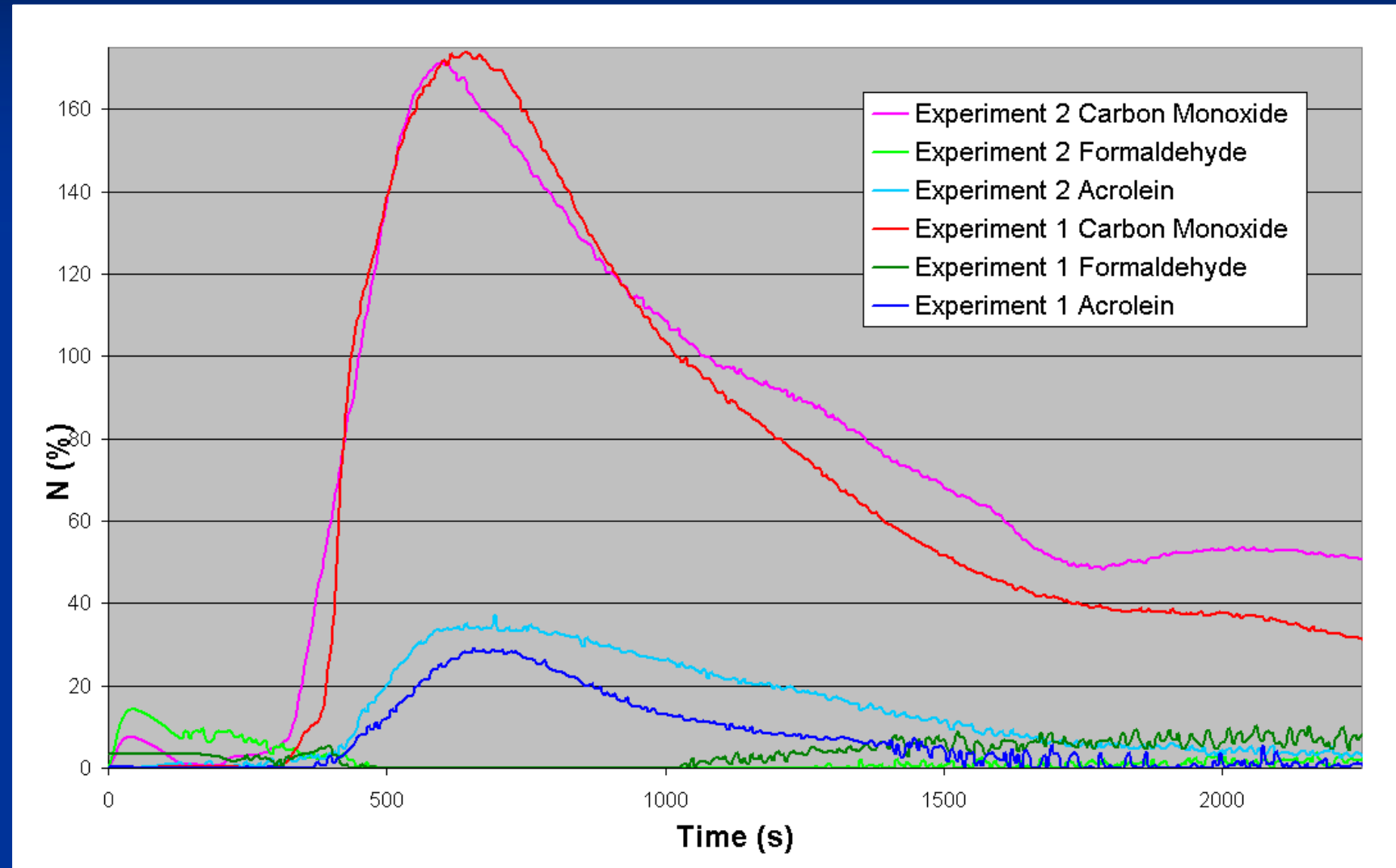
Less dominant species. Carbon Monoxide peaks at 2500% COSHH limitations.



# *LC<sub>50</sub>, 30 minutes (Lethal Concentration)*



**Carbon Monoxide is the only species which breaches the 100% mark.**





# Conclusions from FTIR toxicity Results

- ✍ In both experiments, the COSHH and LC<sub>50</sub> limits are breached, meaning that a potentially lethal volume of toxic gases are being produced.
- ✍ The COSHH limits place a much greater emphasis on Acrolein than LC<sub>50</sub>, which favours Carbon Monoxide as most lethal gas.
- ✍ This allows a conclusion that air starved fires involving simple cellulosic materials can easily produce significantly lethal amounts of toxic gases.
- ✍ To take this further, it is necessary to consider the **toxic yield**.

# Toxic Yields

**(mass of products released per mass of fuel consumed)**

- **In the application of CFD and zone modelling fire codes, there is text book data in place for estimating CO yields.**
- **This data is based on experimental, Cone Calorimeter type tests, with infinite air supply.**
- **Clearly, this will not predict accurate yields for toxic species in air starved conditions.**

# Toxic Yields

**(continued)**

- **Currently, for a given fire size, the accepted CO concentration modelling method is to:**

**Take the fire load mass burn rate and multiply that by the toxic product yield.**

**This give a mass flow rate of each of the toxic products**

- **Lets see how these text book toxic yields compare to those from the burning cotton towel experiments.**

# **Toxic Yields**

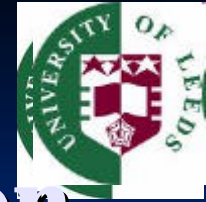


**British Standard Fire Products for well ventilated flaming combustion**

<b>Material</b>	<b>Carbon Monoxide mass conversion rate (<math>Y_{co}</math>) g/kg</b>
<b>Timber</b>	<b>4</b>
<b>Polyvinyl chloride (PVC)</b>	<b>63</b>
<b>Polystyrene</b>	<b>51</b>
<b>Generic Building Contents</b>	<b>13</b>

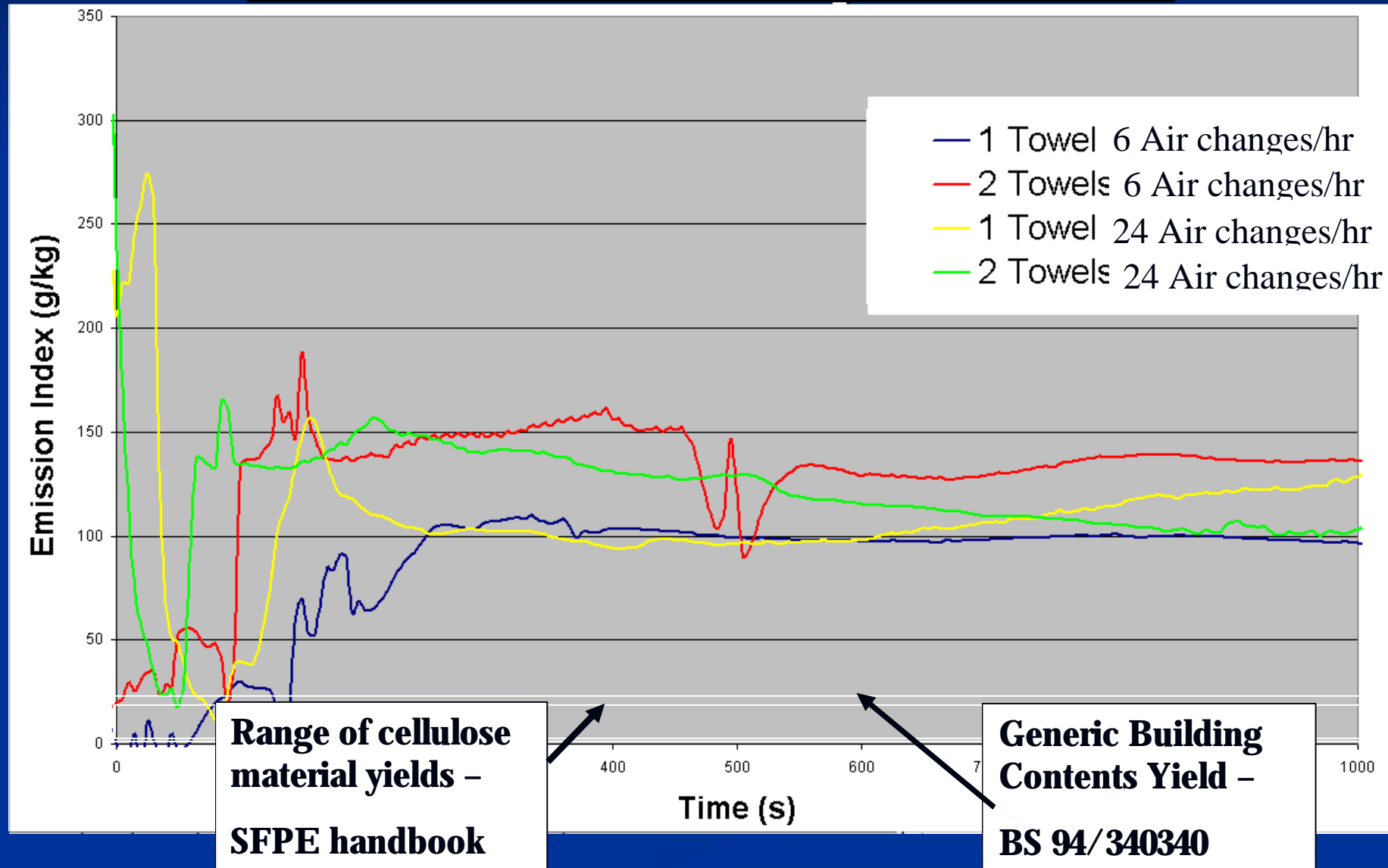
Taken from BS 94/340340 DC

# The SFPE Handbook of Fire Protection Engineering 2<sup>nd</sup> Edition



- ✍ In this book are CO yields for a large number of materials.
- ✍ The ranges of yields for a cellulosic materials are **1 – 10 g/kg.**
- ✍ Now lets compare these text book values to those obtained in the cotton towel experiments.

# Carbon Monoxide toxic yield for Cotton Towel Experiments

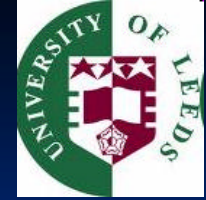


# Comparison between Experimental Data and CFD fire code CO predictions.



The Previous plot shows:

- ✎ The BS recommendations for generic building contents (13g/kg) are roughly 10% of the average yields in the towel fires.
- ✎ Comparing the results to a whole range of yields for materials' CO yields in SFPE Fire Protection Engineering handbook predict maximum yields of only 50% those taken from the cotton towel experiments.
- ✎ In conclusion, these experiments have shown that ventilation is clearly a factor that needs to be added in CFD and zone modelling applications in terms of toxic yield.



# *Further Work*

- ✍ The results gained from these experiments serve merely to highlight an area of concern.
- ✍ Further study should be carried out using a range of materials/air flow rates/fire loads in order for recommendations to be conclusive.
- ✍ Also need to include information about soot and particulate yields.

**The end**

Thank you for listening