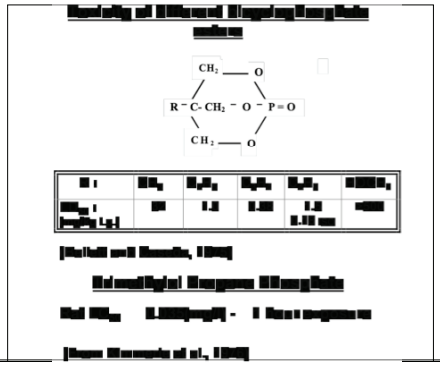
*David Purser*

## Extreme neurotoxicity from phosphate fire retardant and foam

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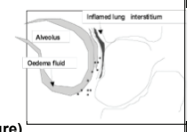
## Toxicity of thermal decomposition and combustion products of fluoropolymers




**Polytetrafluroethylene (PTFE)**

$$-(CF_2 - CF_2)_n-$$

**Toxic potency: 0.015 - 14 g/m$^3$ (30- minute exposure)**

**Most fires: potency 10 x wood**

**Extreme toxicity conditions: 1000 x wood (e.g. 2 g in this room lethal to all occupants). Decomposition at 450-650ºC and recirculation through hot zone**

**Extreme toxicity due to ultrafine fluropolymer particles 0.01-0.15 µm**

**deposit in lung interstitium causing inflammation and oedema**

*David Purser*

## The Equivalence Ratio $\phi$

For well-ventilated fires, $\phi < 1$,

For fuel-rich (vitiated) combustion, $\phi > 1$

Further factors affecting yields of CO and other products:
- Oxygen concentration
- Temperature
- Fire retardants

*David Purser*

## Effect of $\phi$ on CO yield (new data)

*David Purser*

## Bench-scale "toxicity" tests

NES 713

ISO Smoke chamber

NFX 70-100 tube furnace – decomposes 1g and collect gases

None of these produce combustion conditions relevant to actual defined fire conditions

Cannot measure yields as a function of equivalence ratio

Do not measure decomposition mode (flaming or non-flaming)

Do not measure "upper layer" temperature

All use simplistic toxicity index

Static boxes result in losses to walls

*Richard Hull - UCLAN - is speaking about the performance of these tests this afternoon*

*David Purser*

## Simplistic toxicity test index

**Table B.1 BS 6853-1 — IDLH values**

**Gases IDLH values: "Immediately dangerous to life or health" after 30 minutes**

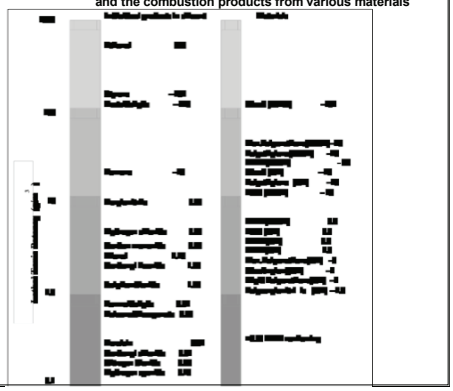
| | p.p.m. | mgm–3 |
|---|---|---|
| Carbon dioxide | 40 000 | 73 000 |
| Carbon monoxide | 1 200 | 1 400 |
| Hydrogen fluoride | 30 | 25 |
| Hydrogen chloride | 50 | 76 |
| Hydrogen bromide | 30 | 101 |
| Hydrogen cyanide | 50 | 56 |
| Nitrogen dioxide + Nitric oxide | 20 | 38 |
| Sulfur dioxide | 100 | 270 |

Individual gases expressed as fractions of limit concentration then summed to find overall index

- Does relate to effects in humans
- Does not take into account development time of effects – not time-based
- Does not take into account realistic interactions between gases
- No relationship between test decomposition conditions and specific fire conditions

*David Purser*

**Lethal toxic potencies (g/m³) of individual compounds and the combustion products from various materials**



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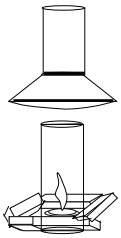
Factory Mutual ASTM E2058 fire propation apparatus

Bench-scale methods enabling toxic product yields to be measured as a function of equivalence ratio

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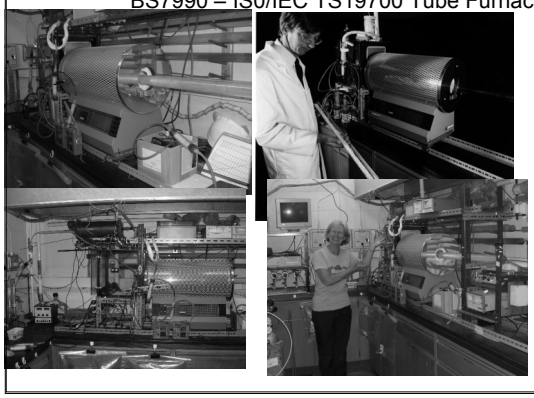
BS7990 – IS0/IEC TS19700 Tube Furnace



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## Toxic fire hazards

**Toxic hazard evaluation for buildings or products:**

1. **Time-concentration curves for major products in full-scale scenario which depends on:**
   - **Fire growth curve (mass loss rate of fuel [kg/s])**
     **Cone calorimeter, SBI, large-scale test, heat of gasification, heat of combustion**
   - **Yields of toxic products under a range of combustion conditions (e.g. kg CO/kg material burned)**
     **ISO TS19700 tube furnace, ASTM E2058 flammability apparatus**

   **Input data into CFAST or FDS to calculate time concentration curves for different specific fire scenarios with specified boundary conditions**
2. **Physiological effects of the products**

   **exposure concentrations [kg.m$^{-3}$] or exposure doses [kg.m$^{-3}$.min] required to cause toxic effects (pain or burns from heat) in terms of :**
   - **concentrations or doses likely to impair escape efficiency**
   - **incapacitating exposure concentrations or doses**
   - **lethal exposure concentrations or doses**

**Physiological FED methods in ISO 13571, Purser SFPE Handbook, BS7899-2**

**Combine 1 and 2 to calculate time to incapacitation.**

**Compare with specified acceptable tenability time for the end use scenario**

*David Purser*

## Sequence of fire hazards

ACUTE SURVIVAL HAZARDS DURING FIRES

- Impaired vision from smoke obscuration
- Impaired vision, pain and breathing difficulties from effects of smoke irritants on eyes and respiratory tract.
- Asphyxiation from toxic gases leading to confusion and loss consciousness
- Pain to exposed skin and respiratory tract followed by burns from exposure to radiant and convected heat leading to collapse

SURVIVAL AND HEALTH HAZARDS AFTER FIRE EXPOSURE

- Lung inflammation and oedema
- Neuropathological and neuropsychological sequelae
- Cardiovascular problems
- Sensitization

*David Purser*

## Fire Hazard Toxicology

**In fires the important toxicity concerns are:**

- Acute incapacitating and lethal effects occurring during or within a few days of the fire - these determine immediate survival
- Long term effects on health resulting from a single fire exposure
- Chronic health hazards arising from long term exposure to environmental fire pollutants, inside buildings and outside in food, air and water

*David Purser*

## Main concerns

- Time when effects occur which might affect behaviour and delay escape
- Time when escape is prevented by incapacitation
- Time when exposure is likely to result in permanent injury or death

*David Purser*

## Long Term Health Hazards and Target Organs

**Long term effects following a single fire exposure include:**

- Post traumatic stress syndrome
- Central nervous system pathology (hypoxic brain damage), leucoencephalopathy
- Cardiovascular pathology including angina and atherosclerosis
- Permanent damage to airways and deep lung
- Sensitization and RADS (reactive airway distress syndrome) resulting in asthma
- Non-specific: memory loss, tremors, flu-like symptoms

*David Purser*

## Quantification of physiological effects?

How can physiological effects be quantified for application in hazard assessments?

- Smoke and irritants
- Asphyxiants

How can effects be validated?

- By detailed investigation of actual fire incidents for which fire conditions have been re-created experimentally or modelled and information is available for effects on victims
- Limited experimental exposures of humans to individual fire gases
- Animal experiments
- Consideration of range of sensitivity in human population

*David Purser*

## Hazards from Smoke particulates

- Smoke is usually the first fire hazard encountered
- Effect depend somewhat on location of occupant and behavioural characteristics
  - Not in fire enclosure: Open door and see smoke: may decide to shut door and await rescue – tend to turn back if OD/m > 0.3 (~ 4 m visibility)
  - In fire enclosure and exposed: more likely to attempt to move through smoke no matter how dense – then physiological effects on movement speed and wayfinding ability
  - Physiological effects depend on visibility (direct obscuration and obscuration of lighting from above) and irritancy of smoke
  - Therefore affect both ASET and RSET
    ASET: concentration at which trapped so cannot escape
    RSET: if escaping walking speed and increased wayfinding time
  - If smoke layer is above 2 m and upper layer temperature < 200ºC (where venting used) then may be considered acceptable
  - If OD/m < 0.1 (~10 m visibility) then concentrations of other toxic gases unlikely to be hazardous for up to 60 minutes.

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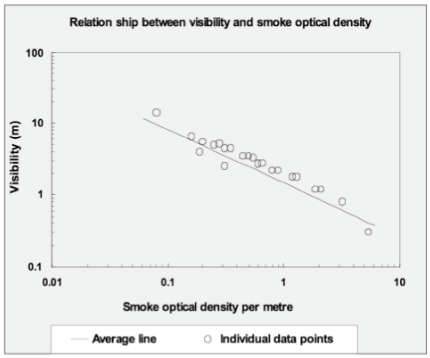


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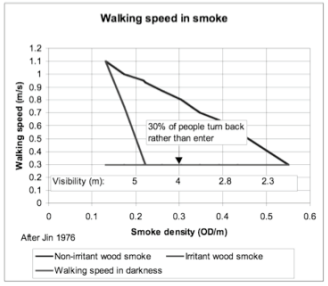
## Hazards from smoke

Effects of acid gases and organic irritants on escape capability

- Bonfire smoke or side-stream cigarette smoke: eye pain, blepharospasm, breathing difficulties and chest pain
- Incident reports of escape difficulties due to irritancy




Effects:

- Impaired vision, eye pain, eye closure and tears
- Pain to nose, throat and chest
- Bronchoconstriction
- At low-moderate concentrations slow movement and turning back
- At high concentrations incapacitation
- Lung oedema and inflammation after exposure

*David Purser*

[redacted]

Equations for the relationship between walking speed and smoke optical density (OD·m$^{-1}$) is given by:

Walking speed in non-irritant smoke (m/s) = 1.36 – 1.9 × smoke optical density (OD·m$^{-1}$) [1]

Walking speed in irritant smoke (m/s) = 2.27 – 9 × smoke optical density (OD·m$^{-1}$) [2]

If high concentrations of acid gases likely to be present then effects may be greater

*David Purser*

**Effects of irritants: the trigeminal and vagus nerves**

For smoke and irritants the main concern is the exposure concentration.

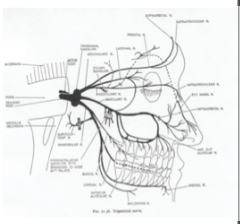
The surface of the eye, the skin of the face and inside the nose, mouth and throat contain sensory nerve endings which provide a sensation of irritation or pain when they are stimulated by chemical substances such as acid gases or organic smoke irritants or by intense heat.

The irritant effects of chemicals in smoke lie on a continuous scale from mild eye and upper respiratory tract irritation to severe eye and respiratory tract pain, coughing, breathing difficulties and collapse. The pain probably lies on a logarithmic scale in that for example with the acid gas hydrogen chloride (HCl - which is given off by burning) PVC:

*David Purser*

## Why concentration?

- Immediate painful stimulation of trigeminal nerve endings in the eyes, nose and throat – a sensory effect (like light or sound)
- Effect proportional to the log of the exposure concentration
- Effect does not increase with time as do dose-related effects
- Similar in all mammals for all irritant compounds



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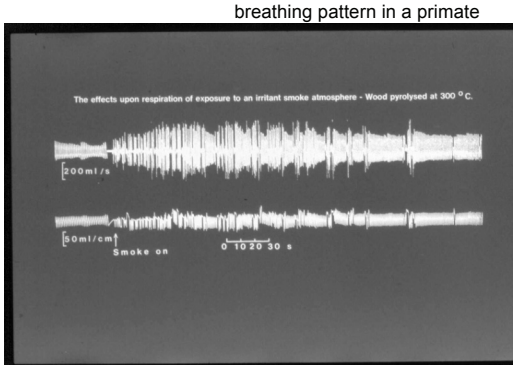
*David Purser*

Effect of irritant wood smoke on breathing pattern in a primate

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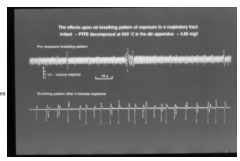
Concentration - effect relationships for irritants

**Effect of exposure on mouse breathing rate of thermal decomposition products from PVC-J (0.72 g.m$^{-3}$)**



**% breathing rate depression is proportional to log concentration**

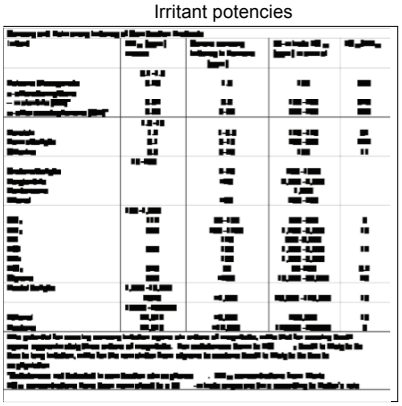
**$RD_{50}$ PVC-I 0.57 g.m$^{-3}$**

*David Purser*

## Irritant potencies

Irritant potencies

In smoke:
acrolein,
formaldehyde
crotonaldehyde
phenol,
styrene
HF, HCl, HBr
$SO_2$, NO, $H_3PO_4$



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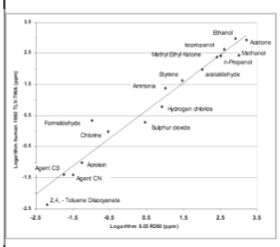
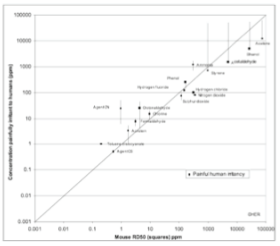
## Irritant concentrations of common substances in mice and humans

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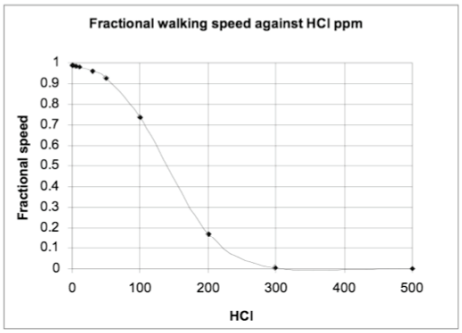
## Lung irritation in a primate

*David Purser*

## Suggested effect of hydrogen chloride on walking speed

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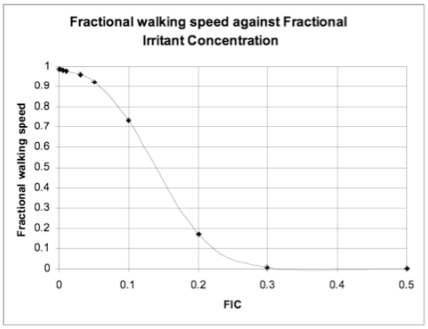
## Suggested effect of any sensory irritant on walking speed




*David Purser*

## Effects of irritant gases

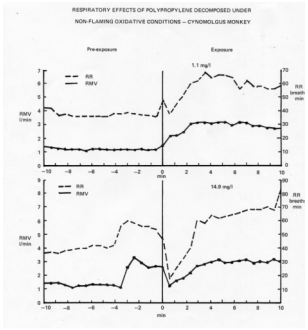
**An equation that can be applied to any individual irritant compound, or to the fractional irritant concentrations for a mixture of compounds, is given by:**

**Where**
**$W_{irr}$ = Walking speed**
**b = 160**
**x = FIC**

**The overall effect of exposure to an irritant smoke on walking speed ($W_{sirr}$) would then be given by:**
**$W_{sirr} = 1.2 – (1.2\text{-}W_s) – (1.2\text{-}W_{virr})$**
**Where:**
**$W_{sirr}$ = Overall walking speed in irritant smoke**
**$W_s$ = Walking speed adjusted for smoke visibility effects**
**$W_{virr}$ = Walking speed adjusted for effects for irritants compounds 1 to n**

*David Purser*

Lung irritation in a primate

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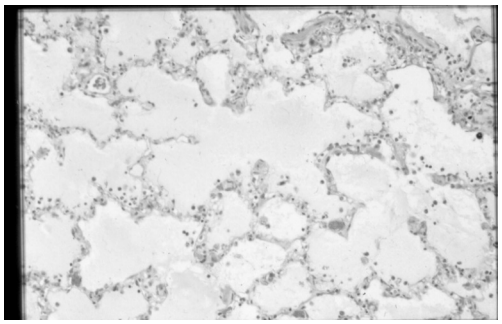
Pulmonary oedema - rat



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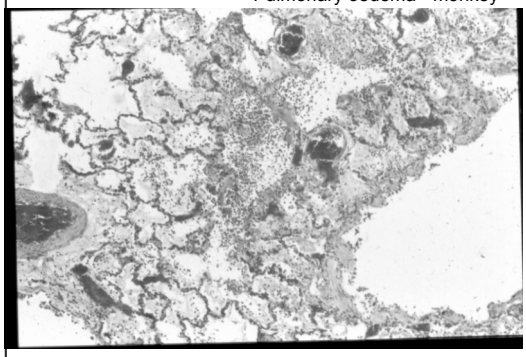
Pulmonary oedema - monkey



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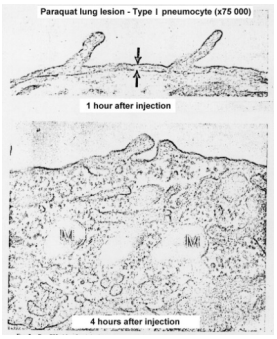
Acute lung inflammation

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Lethal exposure doses of irritants

[redacted]