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TOXICITY ASSESSMENT

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TOXICITY ASSESSMENT

OUTLINE

- Introduction
- Species and their influence
- Methods of assessment
  - FED & FEC
- Test methods

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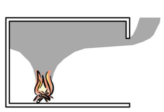
TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?

Required Safe Escape Time (RSET) < Available Safe Escape Time (ASET)



SAFE

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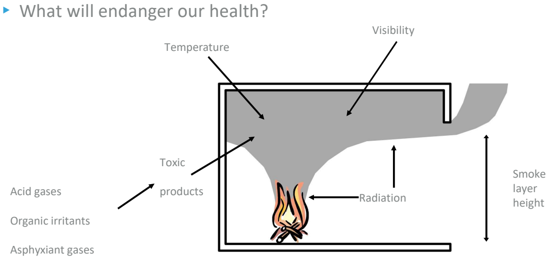
TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe
  - What will endanger our health?



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TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?
  - Critical conditions (values)

  or

  - Tenability assessment
    - FED - Fractional effective dose
    - FEC - Fractional effective concentration
    - Can be applied for
      - visibility, species, temperature, radiation

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TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?

BBRAD - Scenario analysis

Critical conditions (Swe)

Parameter	Value
Smoke layer height	1.6+(0,1·h) m
Visibility	10 m / 5 m
Radiation (long)	2.5 kW/m2
Radiation (short)	10 kW/m2
Radiation (dose)	60 kJ/m2
Temperature	80°C

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TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?

Critical conditions (Swe)

Parameter	Value
CO	< 2000 ppm
CO_2	< 5%
O_2	> 15%

BBRAD - Scenario analysis

…but is this all species that are ”dangerous”?

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TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?

Critical conditions (NZ)

Parameter	Value
CO	FED(CO) < 0.3
Thermal	FED(thermal) < 0.3
Visibility	> 10 m
Radiation	< 10 kW/m^2

C/VM2 - Verification Method: Framework for Fire Safety Design

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TOXICITY ASSESSMENT

INTRODUCTION

- How do we know that a building is safe?
  - Critical conditions (values)

  or

  - Tenability assessment
    - FED - Fractional effective dose
    - FEC - Fractional effective concentration
    - Can be applied for
      - visibility, species, temperature, radiation

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- Pathology vs. physiology
  - Pathological effects
    - slow to develop (hours, days, years)
    - affect longer term functions of organ systems, leading to adverse health effects and death due to failure of vital organs
  - Physiological effects
    - rapid development (seconds, minutes)
    - affect immediate vital functions (vision, pain, respiration, circulation, movement ability, consciousness, death)

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- Pathological effects (slow)
  - Fatal post-exposure lung condition
    - inflammation and pulmonary oedema (hours)
    - inflammation and infection (days)
    - inflammation of bronchioles (week)
  - Neuropathological effects
    - brain damage (weeks)
  - Cardiovascular effects
    - heart attack (days)
  - Sensitization

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- Physiological effects (fast)
  - Smoke makes it difficult to evacuate
  - Irritants attack sensory nerve endings
  - Asphyxiants give hypoxic effects
  - Irritants cause damage to lungs give hypoxic effects

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SPECIES AND THEIR INFLUENCE

- Most dangerous "things"
  - Smoke particles (soot)
  - Asphyxiants
    - CO
    - HCN
    - low O_2
    - CO_2
  - Irritants
    - Halogen acids
    - Organic irritants

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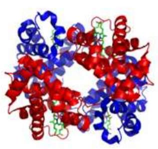
TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- CO - Carbon monoxide
  - Carbon based smouldering combustion and ventilation controlled flaming fires
  - Asphyxiant gas
    - combines with haemoglobin (Hb)
    - prevents oxygen from being carried with the blood
    - binds oxygen in Hb
    - follows Haber's law



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SPECIES AND THEIR INFLUENCE

- HCN - Hydrogen cyanide
  - From polymers with nitrogen
  - Material and temperature dependent
  - Asphyxiant gas
    - prevents oxygen metabolism in the mitochondrion
    - tissue hypoxia
    - does **not** follow Haber's law
  - Also influences breathing

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- low O_2 - low oxygen
  - Oxygen is consumed in the fire
  - Asphyxiant effect
    - >14% minor effects
    - 12-14% mild effects (difficult to work)
    - 9.5-12% mental process slower, dulled senses, increased heart rate and respiration
    - 8-9.5% unconsciousness, death

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- CO_2 - Carbondioxide
  - All carbon based fires
  - Influences breathing
    - CO_2 or acidity influences breathing rate
    - Increase uptake of asphyxiant gases
      - 5% CO_2 => x3
      - 10% CO_2 => x10
  - 5-10% CO_2 in fire plumes

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- Halogen acids - HCl, HF, HBr
  - Material dependent (contain halogen)
  - Flame retardants
  - Irritant gas (acid gas)
    - nose, eyes, upper respiratory tract
  - Can cause lethal effects, but irritant effect is more potent

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TOXICITY ASSESSMENT

SPECIES AND THEIR INFLUENCE

- Organic irritants - formaldehyde, unsaturated aldehydes (e.g. acrolein) and isocyanates
  - Pyrolysis and/or incomplete combustion of organic materials
  - Irritant gas (acid gas)
    - very small concentrations

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- ISO 13571:2012
  - Life-threatening components of fire: Guidelines for the estimation of time to compromised tenability in fires
    - Asphyxiants
    - Irritants
    - Heat
      - Hypothermia
      - Burns
    - Visibility

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- LC_{50} – volume fraction of toxic gas or smoke to produce lethality in 50 % of test animals within a specified exposure and post-exposure time
  - lethality – capable of causing death
  - exposure – while animals can inhale the gas or smoke
  - post-exposure – after that, when animals are breathing fresh air (e.g. 14 days)

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Self-rescue principle in most buildings
  - LC_{50} is less relevant
  - IC_{50} is more relevant
- IC_{50} is similarly defined for incapacitation
  - incapacitation – inability to take action to escape from a fire

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Asphyxiants

$$X_{\mathrm{FED}} = \sum_{t_1}^{t_2} \frac{\varphi_{\mathrm{CO}}}{35\,000}\Delta t + \sum_{t_1}^{t_2} \frac{\varphi_{\mathrm{HCN}}^{2,36}}{1{,}2\times 10^{6}}\Delta t$$

  - FED < 1.0 or FED < 0.3
  - FED = 1
    - would be incapacitating to 50% of exposed animals (IC_{50})

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Asphyxiants

$$X_{FED} = \sum_{t_1}^{t_2} \frac{\varphi_{CO}}{35\,000} \Delta t + \sum_{t_1}^{t_2} \frac{\varphi_{HCN}^{2,36}}{1,2 \times 10^6} \Delta t$$

  - FED < 1,0 or FED < 0,3
  - increased breathing…

$$v_{CO_2} = \exp\left(\frac{\varphi_{CO_2}}{5}\right)$$

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Irritants

$$X_{FEC} = \frac{\varphi_{HCl}}{F_{HCl}} + \frac{\varphi_{HBr}}{F_{HBr}} + \frac{\varphi_{HF}}{F_{HF}} + \frac{\varphi_{SO_2}}{F_{SO_2}} + \frac{\varphi_{NO_2}}{F_{NO_2}} + \frac{\varphi_{acrolein}}{F_{acrolein}} + \frac{\varphi_{formaldehyde}}{F_{formaldehyde}} + \sum \frac{\varphi_{irritant}}{F_{C_i}}$$

  - FEC < 1.0 or FEC < 0.3

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Irritants

$$X_{FEC} = \frac{\varphi_{HCl}}{F_{HCl}} + \frac{\varphi_{HBr}}{F_{HBr}} + \frac{\varphi_{HF}}{F_{HF}} + \frac{\varphi_{SO_2}}{F_{SO_2}} + \frac{\varphi_{NO_2}}{F_{NO_2}} + \frac{\varphi_{acrolein}}{F_{acrolein}} + \frac{\varphi_{formaldehyde}}{F_{formaldehyde}} + \sum \frac{\varphi_{irritant}}{F_{C_i}}$$

  - $F_{HCl} = F_{HBr} = 1000$ ppm, $F_{HF} = 500$ ppm
  - $F_{SO2} = 150$ ppm, $F_{NO2} = 250$ ppm
  - $F_{acrolein} = 30$ ppm, $F_{formaldehyde} = 250$ ppm

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- low Oxygen
  - only if <13%
  - only references to SFPE Handbook of Fire Protection Engineering

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Thermal
  - hyperthermia
  - body surface burns
  - respiratory tract burns

$t_{Iconv} = (5 \times 10^7) T^{-3,4}$ (fully clothed)

$t_{Iconv} = (4,1 \times 10^8) T^{-3,61}$ (lightly clothed or unclothed)

$t_{Irad} = 6,9 q^{-1,56}$ (burns, if >2.5 kW/m²)

$t_{Irad} = 4,2 q^{-1,9}$ (pain, if >2.5 kW/m²)

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Thermal
  - hyperthermia
  - body surface burns
  - respiratory tract burns

$$X_{FED} = \sum_{t_1}^{t_2} (1/t_{Irad} + 1/t_{Iconv}) \Delta t$$

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- FED or FEC = 1
  - ”sublethal effects that would incapacitate people of average susceptibility”
- FED or FEC = 0.3
  - ”11.4% susceptible to less severe exposures”
- A possible change is being discussed…

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TOXICITY ASSESSMENT

METHODS OF ASSESSMENT

- Comparison - Incapacitation of person of average susceptibility (FED=1)

Species	Exposure	
	5 min	30 min
CO (ppm)	6000–8000	1400–1700
HCN (ppm)	150–200	90–120
Low O2 (%)	10–13	< 12

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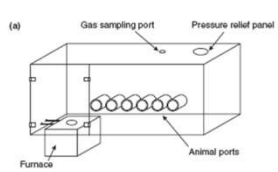
TOXICITY ASSESSMENT

TEST METHODS

- Based on experiments…
- …mainly with rats



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TOXICITY ASSESSMENT

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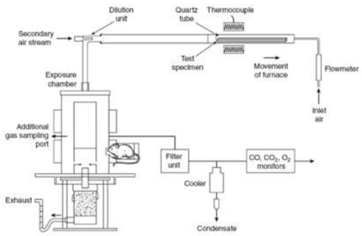

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TOXICITY ASSESSMENT

TEST METHODS

- Based on experiments…
- …mainly with rats

- …and also test with baboons (1985)…
  - FED for CO
  - trained to do tasks
  - given reward
  - exposure increased until no task was done

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TOXICITY ASSESSMENT

SUMMARY

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