APPENDIX 3.F – What We Know About Particulates Resulting from Fires

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The smoke aerosol is described in more detail in this presentation. Particulates may be either solid particles or liquid droplets. Flaming results in large agglomerates of primary spheres that are roughly 30 nm in diameter, and smoldering results in liquid droplets about 2 μm in diameter. Information on smoke yield and particle size from various fuels is presented. Deposition in the lungs is a strong function of particle diameter. Non-flaming smoke scatters more than 90 % of light. Its composition is related to the fuel, and gases may adsorb to its surface. This raises the question of what materials would be appropriate for a standard smolder smoke.

What We know About Particulates Resulting from Fires

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Workshop on Real-Time Particulate Monitoring:
Respiratory Threats for First Responders
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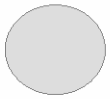
Overview of Non-flaming Smoke Aerosol Properties

- Terminology
- Demonstration of non-flaming smoke aerosol
- Production of smoke
- Light transmission through smoke
- Size and shape of smoke
- Size Distribution of smoke
- Smoke deposition in the respiratory system
- Chemistry of smoke

Terminology

- Smoke aerosol – the condensed phase component (solid and liquid) of the products of combustion. In this presentation the smoke aerosol will be simply referred to as smoke.
- Particulate matter – either solid particles or liquid droplets.

smolder smoke

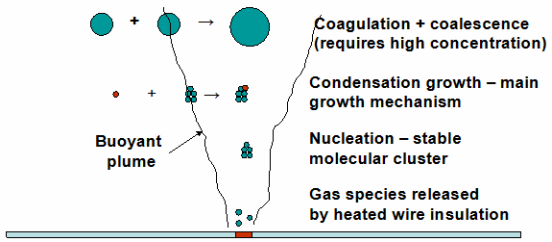


diameter = 2 μm

soot

primary sphere diameter = 30 nm

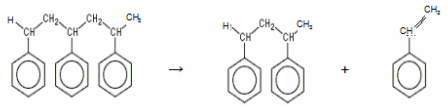
Mechanism of Smoke Formation and Growth



Insulated wire with a short resulting in a hot spot

Generation of Non-flaming Smoke

- Evaporation and condensation – candle wax
- Pyrolysis – fuel molecule undergoes reaction when heated.
  Example: pyrolysis of polystyrene



- Smolder – enough heat release via oxidation for the process to be self-propagating without external heat.
  Examples: newspaper, polyurethane foam cushion, pile of rubble with wood or paper.

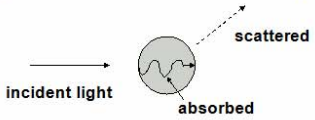
Smoke Yield

Smoke yield = mass of smoke produced per mass loss of fuel

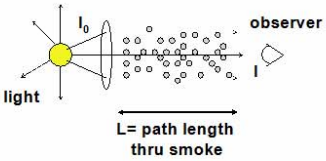
Fuel	Yield
Cellulose (paper)	0.06
Douglas fir – low flux - high flux	0.03 0.15
Polyurethane foam	0.15
PVC	0.12
Polypropylene	0.12

K.M. Butler and G.W. Mulholland, *Fire Tech.*, 40, 149-177(2004)

Light Transmission Through Smoke



For non-flaming smoke, more than 90 % of the light is scattered. For there to be significant scattering, $\pi D_m/\lambda > 1$.



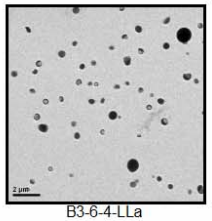
Transmitted Intensity

$I/I_0 = \exp(-\sigma mL)$

σ(avg) = 4.4 m²/g for white light; Range from 2.5 m²/g to 8 m²/g.

TEM Images of Non-flaming Smoke

Cylinders of various materials were heated with a coiled tungsten wire. The voltage to the wire was controlled so each test was run at a fixed temperature.



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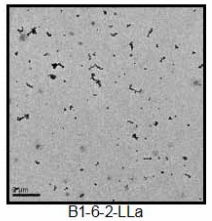
Lamp-wick smoke



B1-6-2-LLa

Kapton smoke

TEM photos by NASA Glenn Research Center

Size Distribution of Non-flaming Smoke: Lognormal Parameters

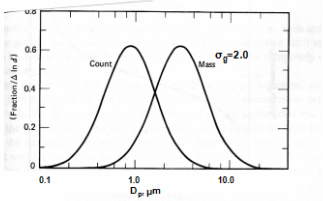
Fuel	D_{gm}, µm	σ_g
Cellulose	2-3	
Douglas Fir	0.8 – 1.8	1.9
PU foam	1.1 – 1.6	2.0
PVC	1.5	1.6
PP	2.1	1.8
Range	1 - 3	1.6-2.0

Geometric mass median diameter

$$\ln D_{gm} = \frac{\sum m_i \ln D_i}{m_t}$$

Geometric standard deviation

$$\ln \sigma_g = \left(\frac{\sum m_i (\ln D_i - \ln D_{gm})^2}{m_t} \right)^{1/2}$$

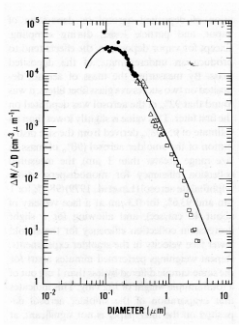


Count and mass distributions (logarithmic size scale).

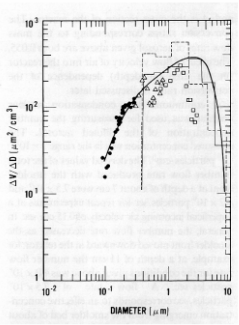
From *Aerosol Technology*, W. C. Hinds

Size Distribution of Cellulose Smoke

- Broad size distribution from < 0.09 µm to 5 µm
- Requires 2 instruments to obtain both number and volume dist.



Number distribution with optical particle counter (OPC)

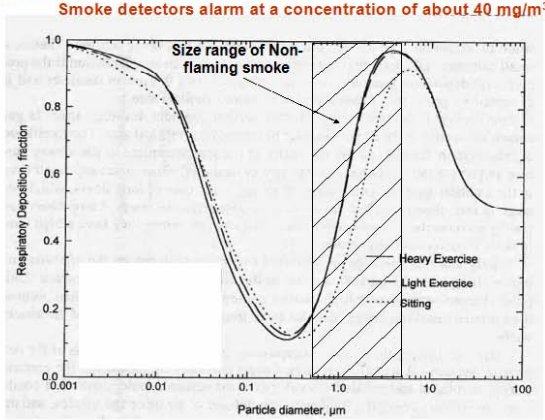


Volume distribution with OPC and 2 impactors (solid and dashed lines)

G.W.Mulholland and T.J. Ohlemiller, Aer. Sci. Tech., 1, 59 (1982).

Total Respiratory Deposition

Note: OSHA 8 hour exposure limit = 5 mg/m^3 for nuisance particulate. Smoke detectors alarm at a concentration of about 40 mg/m^3.



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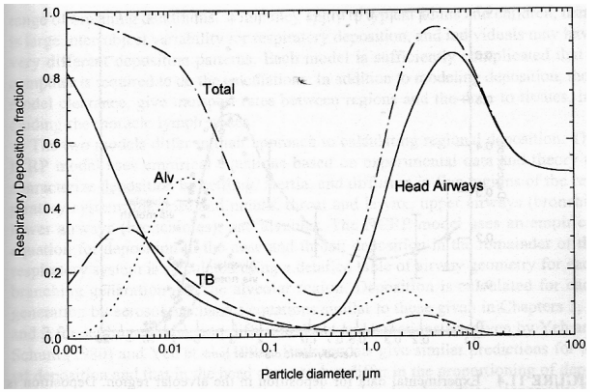
Chemistry of Non-flaming Smoke Aerosol

- Related to fuel – each with its own set of pyrolysis products
- Possibility of adsorbed gases such as HCl from PVC
- Other materials could generate particulate from prolonged exposure to heat:
  a. metals such as lead and mercury
  b. Transformer fluids
  c. Asbestos from tiles and insulation
- Acute toxicity tests performed at NIST on a range of materials found in buildings for exposure to both particulate and gases; indication that particulate produced by pyrolyzing Teflon may be highly toxic.
- Key Question – What should be the exposure limit to non-flaming smoke aerosol?

Total and Regional Deposition for Light Exercise (nose breathing) based on ICRP Model



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Respiratory System

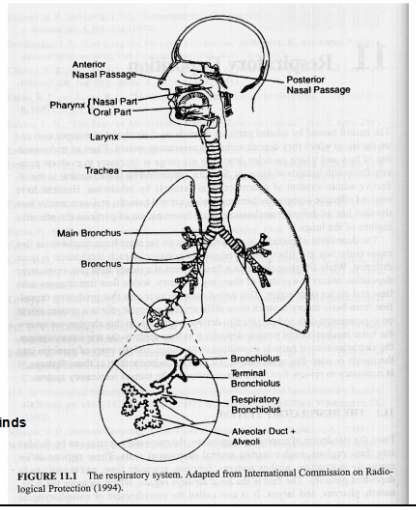

FIGURE 11.1 The respiratory system. Adapted from International Commission on Radiological Protection (1994).

From *Aerosol Technology*, W. C. Hinds