Thinking about the Public Health Impacts of Reaerosolization Following a Large Outdoor Release

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Reaerosolization – Background (1 of 2)

- **Aerosols deposit on surfaces – the details about deposition rate and ultimate mass loading depend on:**
  - Aerosol characteristics (size, shape, form, charge, etc.)
  - Surface characteristics (type, roughness, temperature, etc)
  - Environmental characteristics (wind speed, precipitation, etc.)

- **Aerosols can be resuspended from surfaces (aka reaerosolization) – the details depend on:**
  - Aerosol characteristics (size, shape, form, etc.)
  - Surface characteristics (type, roughness, etc.)
  - Aerosol-surface interactions (binding forces, association with other materials, etc.)
  - Reaerosolization mechanisms (walking, traffic, wind, etc.)

- **Relative importance of these (and other, possibly unknown) factors is NOT well understood.**

Reaerosolization – Background (2 of 2)

- **Strong experimental/observational evidence for resuspension**
  - Outdoors – data collected over 50+ years:
    - Radioactive materials (e.g. Schmel, 1980; Nicholson, 1988, 2009)
    - ‘Dust’ storms – local to global in scale (e.g. Griffin, 2007)
    - Road and fugitive ‘dust’ (e.g. EPA AP-42)
    - Natural biological aerosols (e.g. Jones, 2004; Burrows, 2009)
  - Indoors – less data, much of the work recent (< 10 y)
    - ‘Real world’ observations – miscellaneous (but limited) sources (e.g., Thatcher and Layton, 1995; Ferro et al., 2004)
    - Published Hart SOB experiments showed significant BA reaerosolization from “normal” activities (Weis et al., 2002)
    - Limited laboratory-based experiments that provide better quantitative insights

- **Theory/Modeling lags experimental work**
  - Empirically based outdoor models exist and in common use (e.g. Loosmore, 2003; Maxwell and Anspaugh, 2011)

    But, models do not explain observations to high precision
  - No good, general models for indoors – driving forces poorly understood and/or defined
  - Lots of unknowns

Reaerosolization – Problem Statement

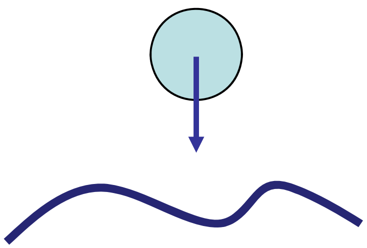
- **In the context of an aerosol ‘attack’, does resuspension matter?**
  - Does it affect the attack ‘footprint’?
  - Does it affect the size of the exposed population?
  - Does it result in ‘non-linear’ risks – e.g., spread of aerosol material along commuter corridors?
  - Does it complicate clean-up and return to service?

- **Under the right (wrong) circumstances, the answer to the above is almost certainly yes**
  - Abundant evidence for the spread of contamination via resuspension (mainly outdoors, but some indoors)
  - Lower individual exposures but a (potentially) larger exposed population
  - Collection and transport of aerosols on fomites is (qualitatively) recognized in the medical community
  - Answer is also directly coupled to the question of ‘how clean is safe?’

Outdoor Reaerosolization Discussion Points

Aerosol Fate and Transport Steps

Deposition



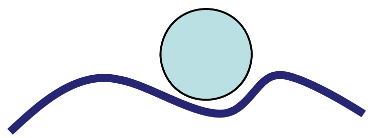
Depends on:

Aerosol

Surface

Environmental Conditions

Weathering (and transport)



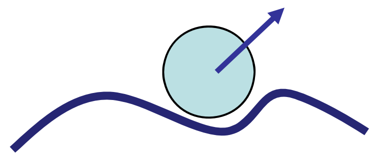
Potential Changes:

Physical/Chemical Interactions (inc combine with other particles)

Viability Changes

Transport to new locations (fomite, water run-off)

Re-aerosolization



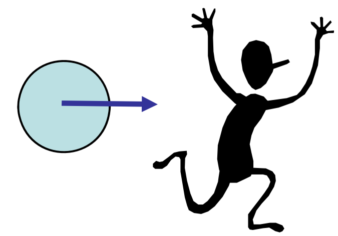
Potential mechanisms:

Mechanical (traffic)
Natural (Wind)
Biological

Mechanism affects:

Rate
Aerosol size

Exposure



Impact depends on:

Location (indoor/outdoor)

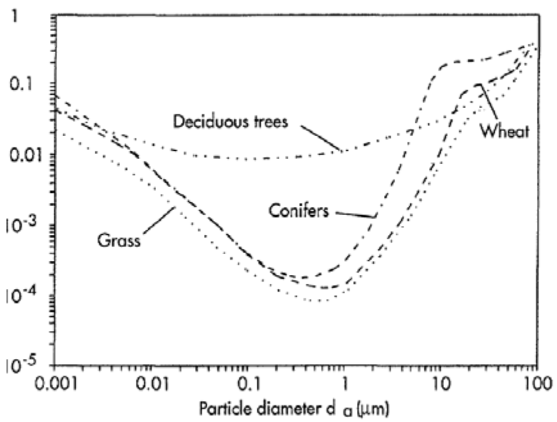
Concentration

Aerosol size

Viability

Deposition/Resuspension highly depends on surface type
Vegetation as an illustrative surface

High Deposition Rates



IAEA Techdoc 760 [1994]

Surface Widely Present

http://www.csc.noaa.gov/crs/lca/class_groups/mid.html

High Surface Area

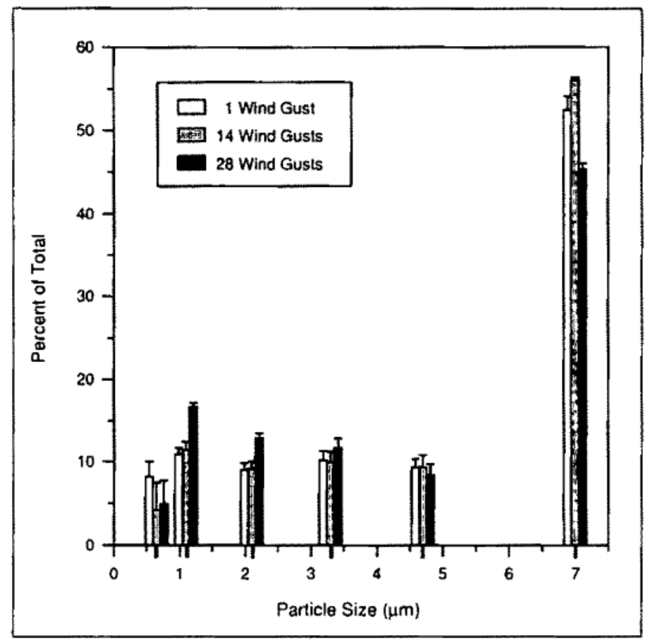
$$\frac{Leaf\ Area}{Ground\ Area} = 0\ to\ {\sim}6$$

(depends on season, vegetation)

Potentially Persistent

B.*anthracis* decreases rapidly with sunlight (e.g. EPA 2010)

Deposited Material Resuspendable in Small Aerosol Size

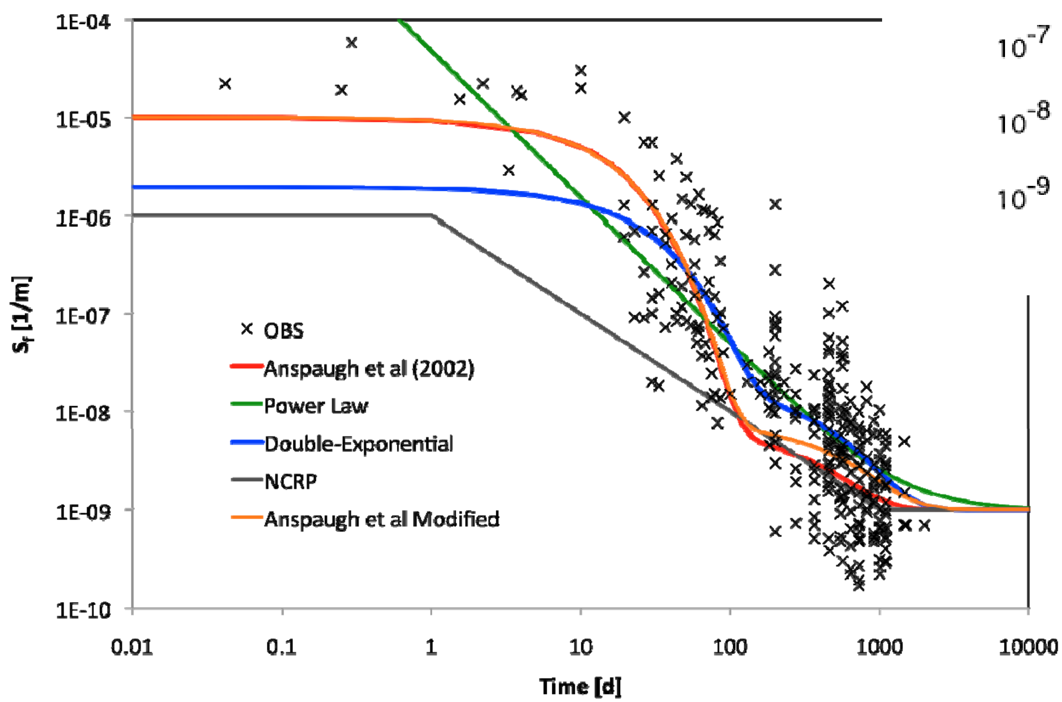


Lighthart [1993]

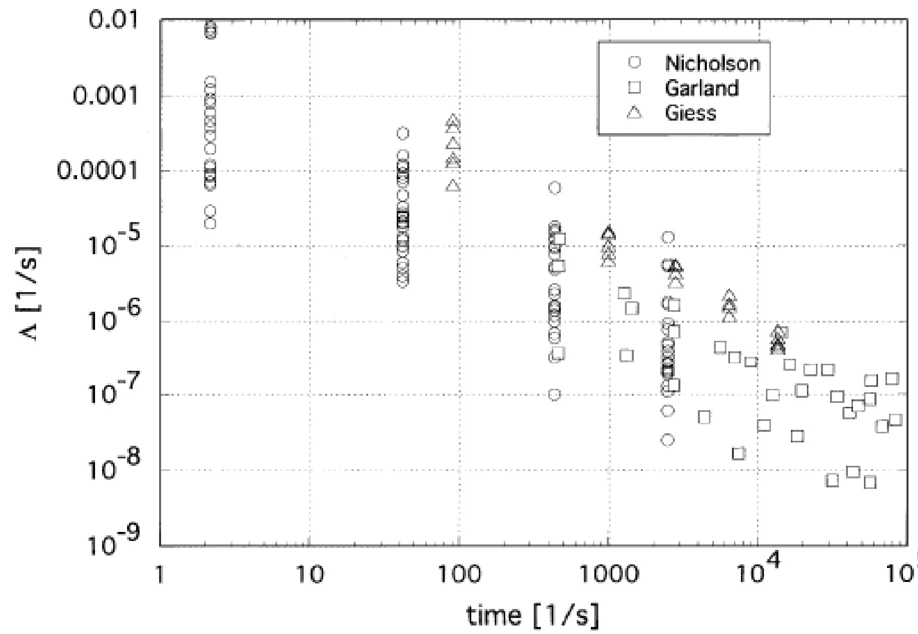
Wind Driven Reaerosolization Decreases with Time

note the y-axes are different

Long time scale



Maxwell and Anspaugh [2011]

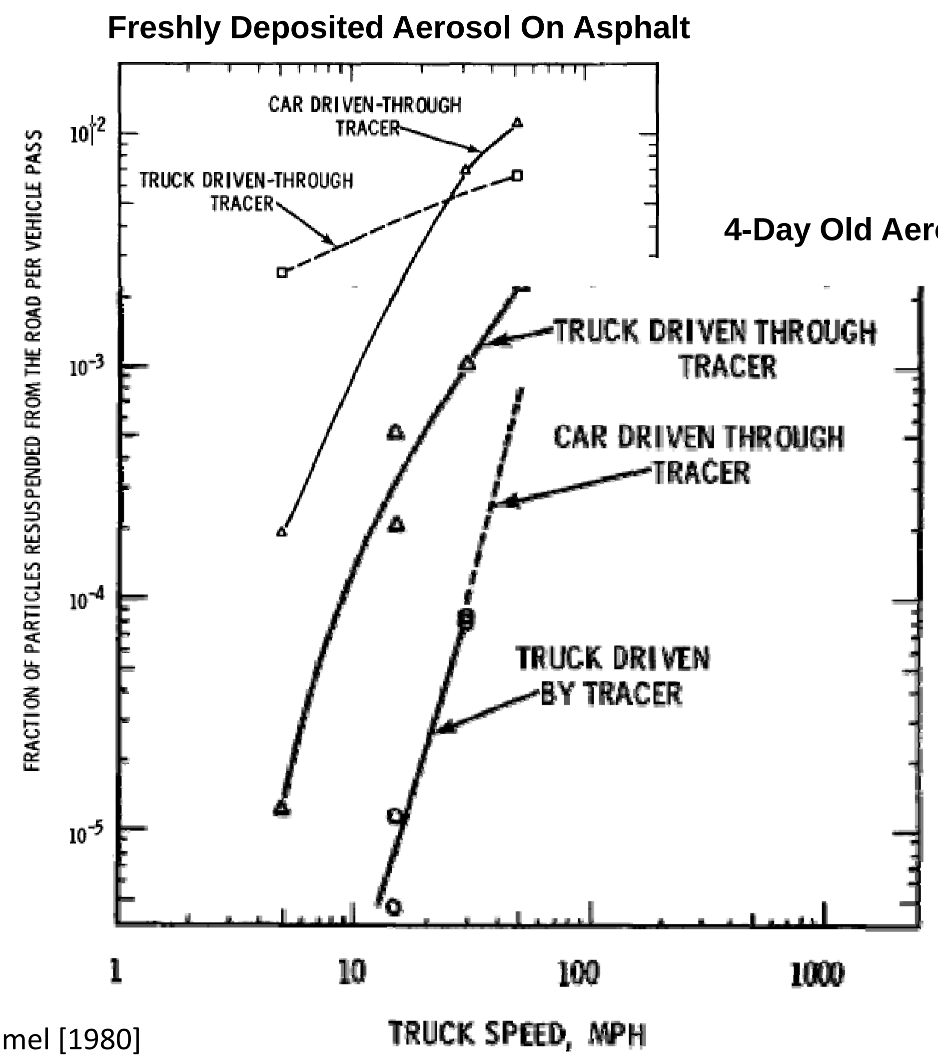


Short time scale

Loosmore [2003]

This is a loss in the 'availability' of resuspendable aerosol – NOT due to loss in viability (a separate consideration)

Vehicle Reaerosolization



Sehmel [1980]

Increases with vehicle speed

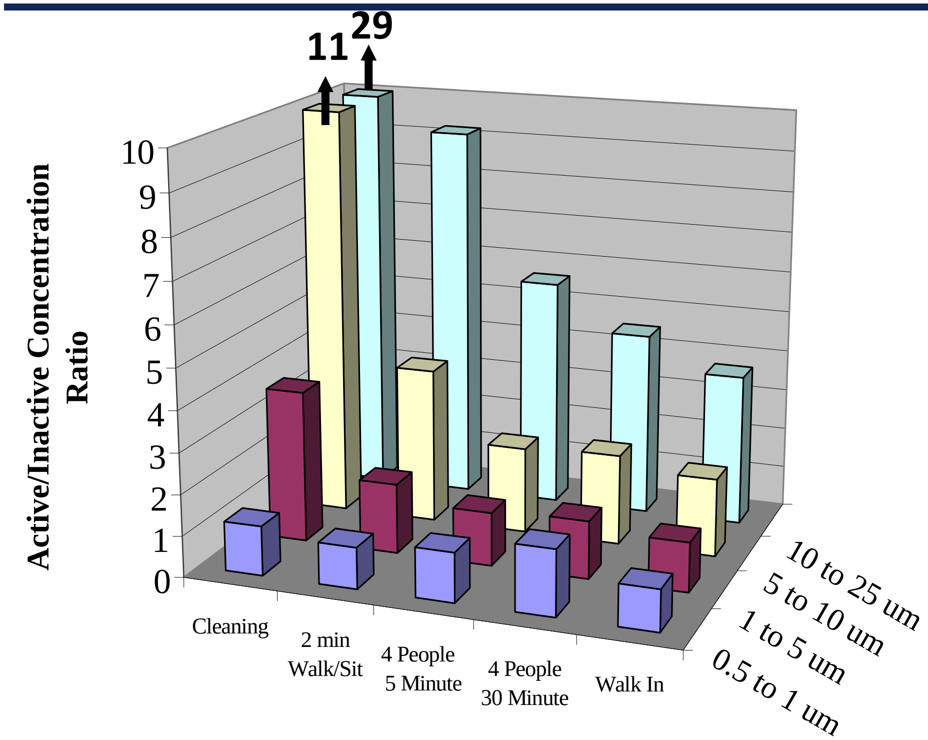
Decreases with time since deposition

Indoor Reaerosolization Discussion Points

Indoor Resuspension

- **Resuspension indoors strongly driven by mechanical forces – air flow over surfaces much smaller consideration – except in ducts or possibly 'wake effects' in subways**
- **Lots of surface area indoors (S/V ratios much higher indoors than out) – a fraction of it is accessible**
- **Indoor 'sources' are potent – fraction of mass inhaled is >1000 times higher indoors than outdoors per unit release**
- **Resuspension is strongly coupled to aerosol mass transport, e.g., transport on shoes or clothing**

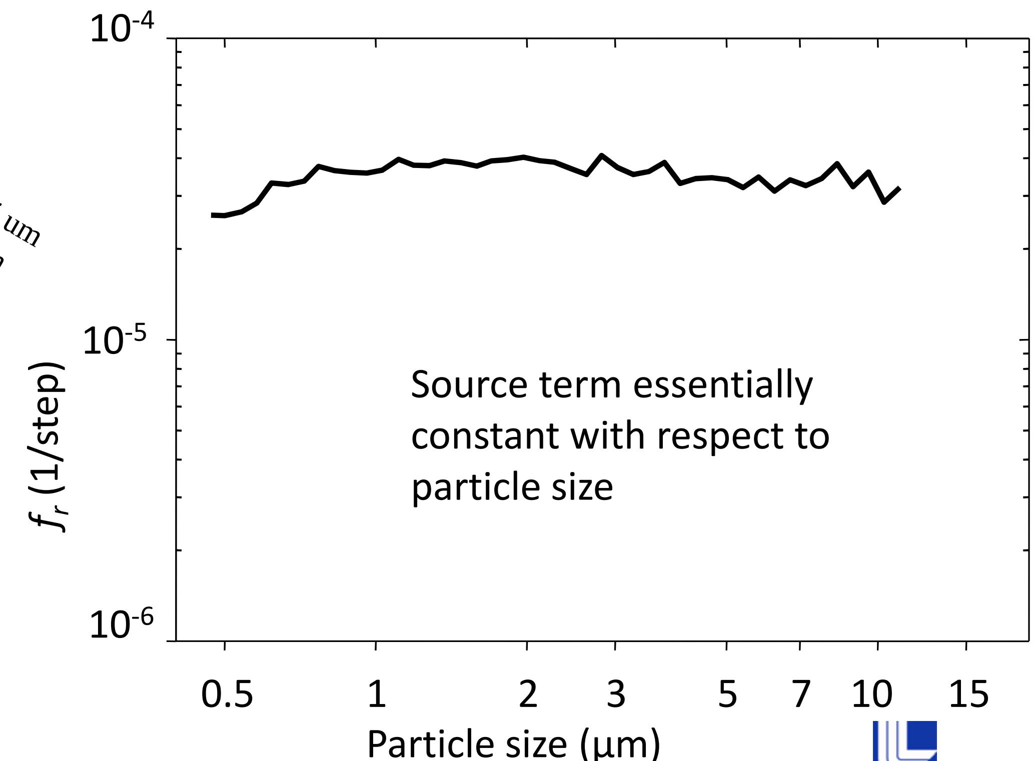
Indoor Resuspension experiments



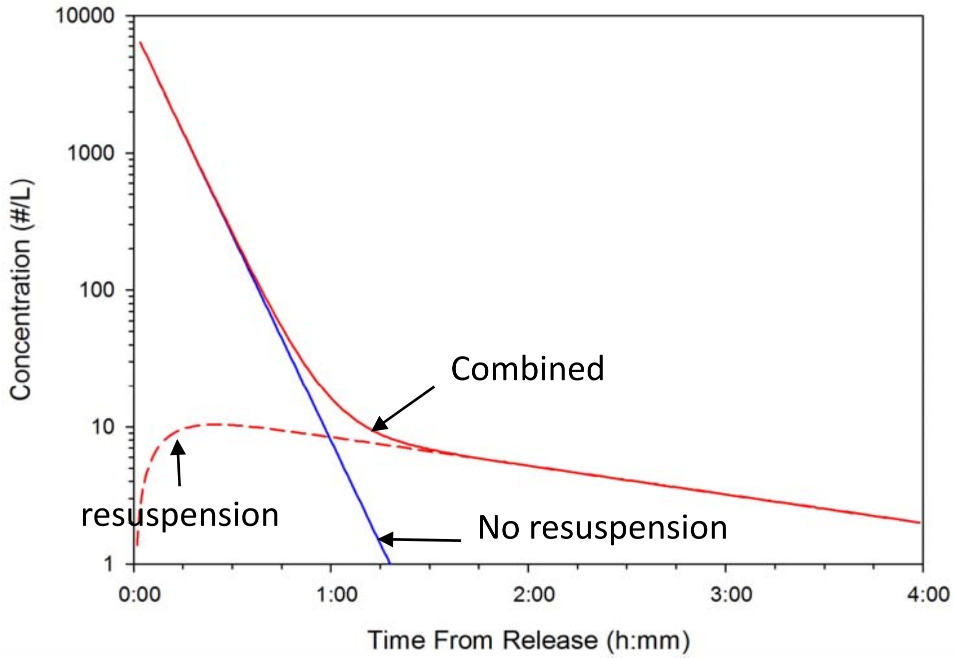
Residential Observations
(Thatcher et al, 1995)

Chamber Measurements with known resuspendable mass (LBNL)

Fraction in footprint area resuspended per step, f_r (1/step)

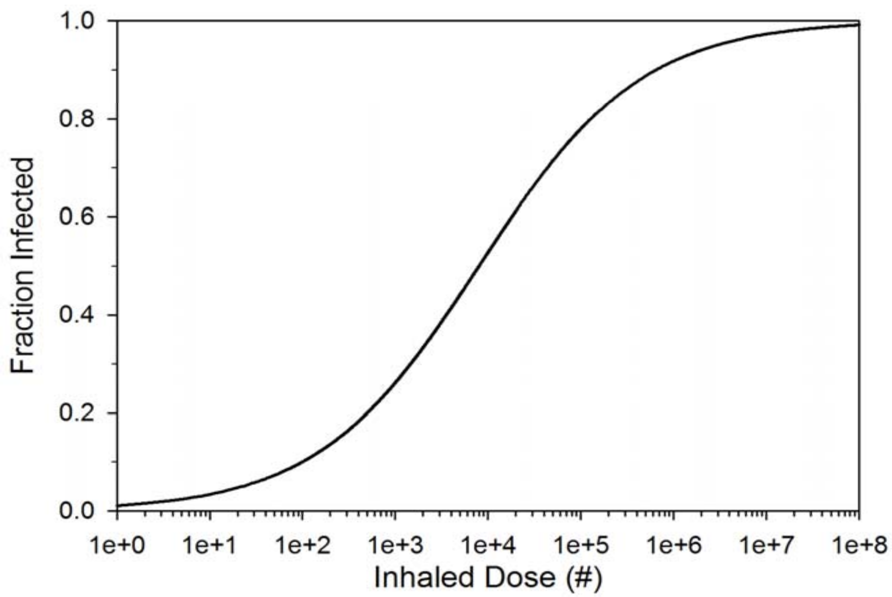


Combining resuspension and dose-response

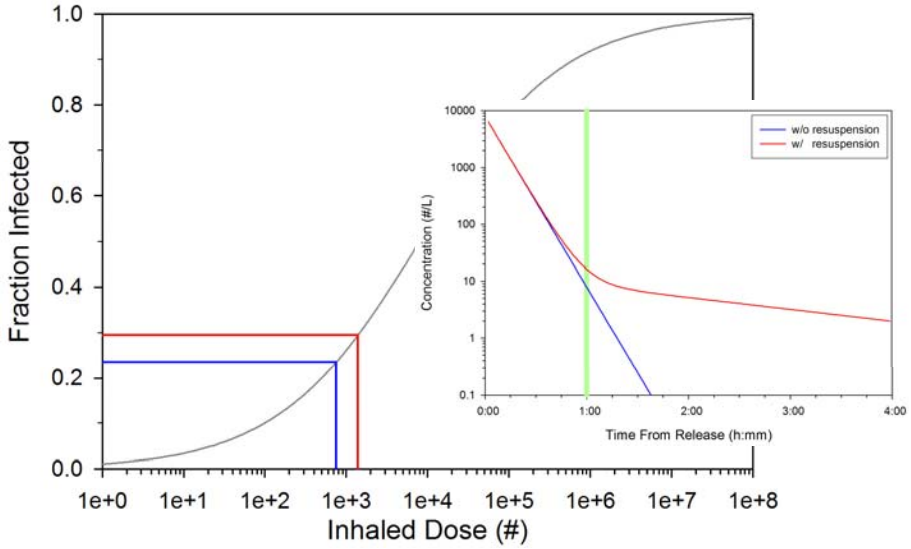


Indoor concentration profile – with and without resuspension

Hypothetical dose-response curve

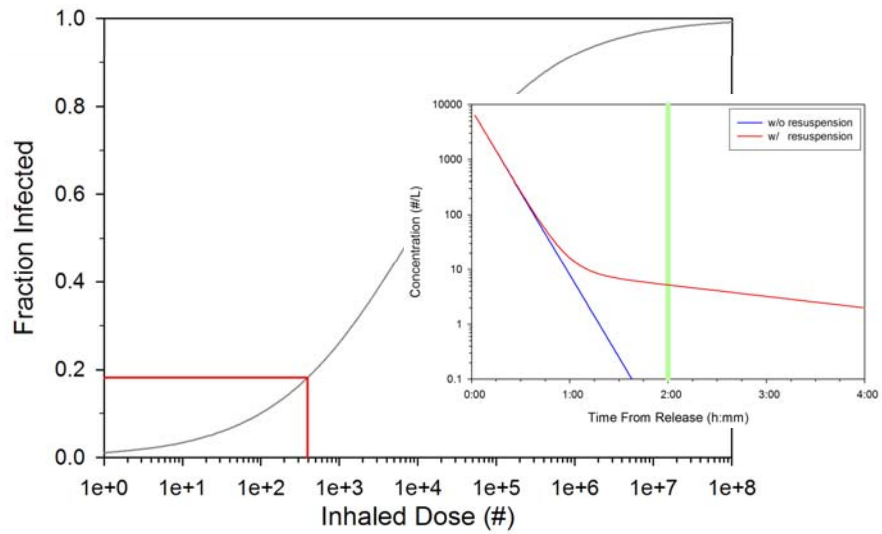


Potential for infections – 5 min inhalation

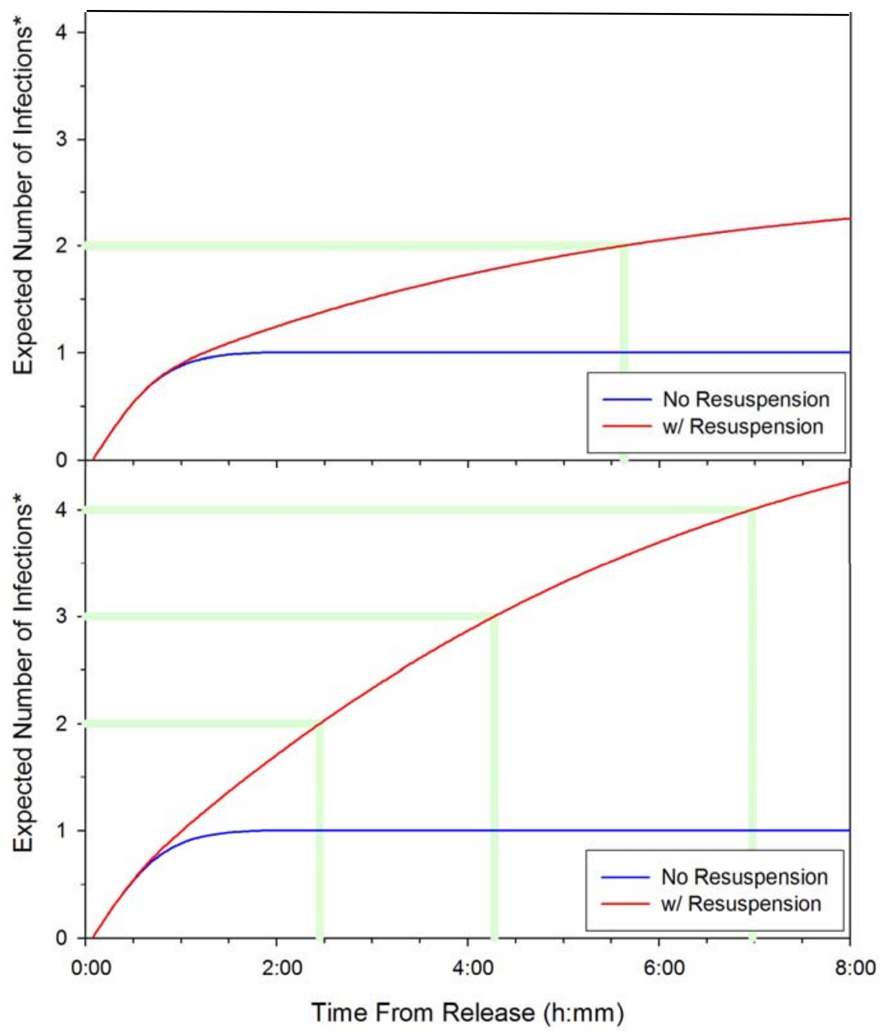


5 minute exposure at 1 hour after release

5 minute exposure at 2 hours after release



Expected Number of Infections – with and without resuspension



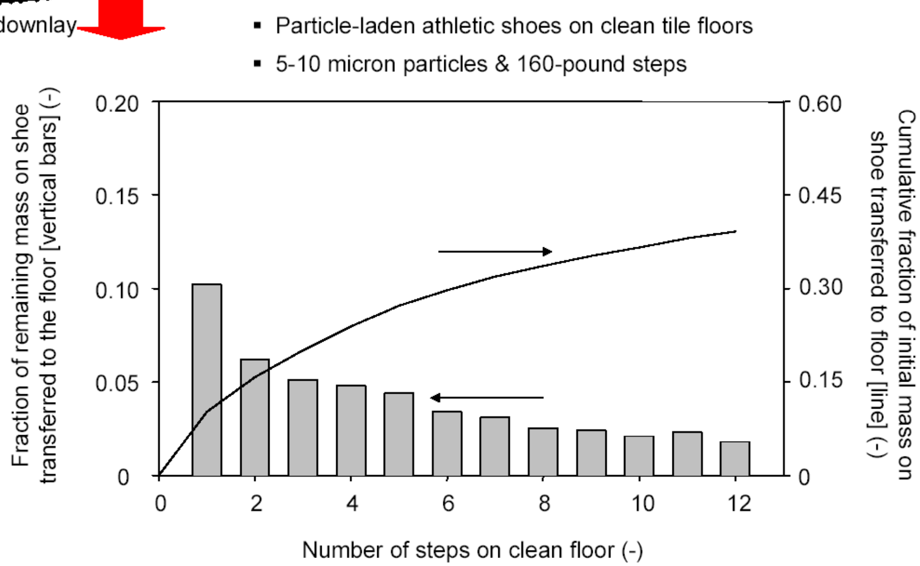
Assuming no detection/awareness and population ‘flow’ through indoor space is constant:

Total number of infections doubles* after ~5.5 hours

With increased resuspension rate (e.g., carpeted floor instead of hard surface), number of infections doubles* ~2.5 hours and quadruples* in 7 hours

*relative to no resuspension case

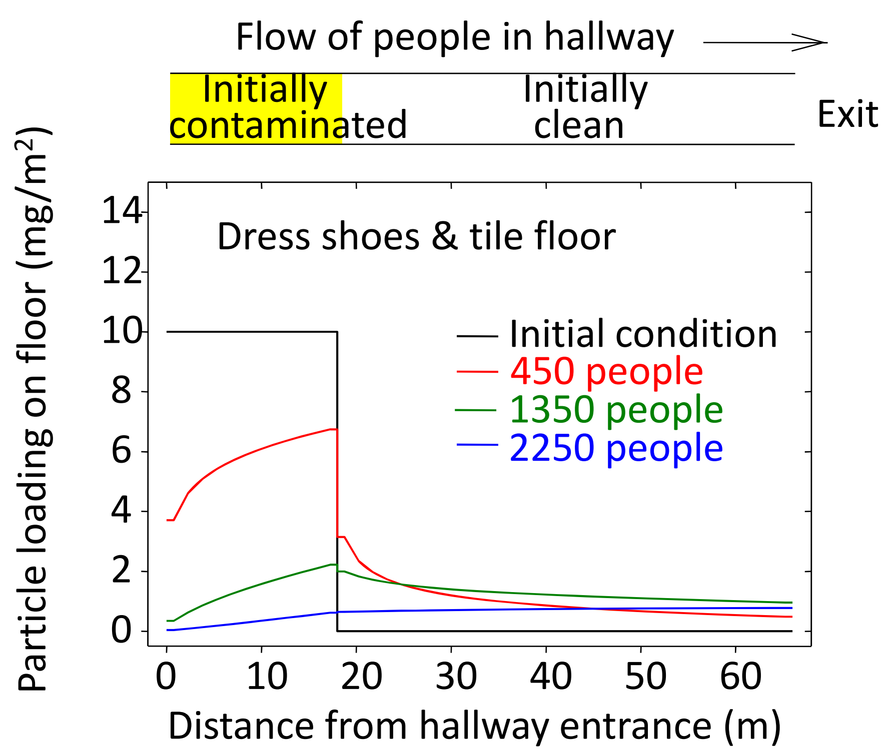
Mass transport via tracking



Small stepping chamber experiments to give multiple step transfer fraction

Modeling mass transport down hypothetical hallway

After 2250 people, only ~20% of original mass remains in the 60 m hallway



Broad Technical and Policy Discussion

Technical Considerations

- **Potential for wide-spread, spotty contamination**
  - Complicates risk management and clean-up decisions
- **Potentially hard to characterize and may evolve with time**
  - Risk likely to decrease with time – but … lots may happen <u>before</u> detection/analysis
  - Characterization of (changing) contamination zones includes spreading to previously clean regions
- **Potential importance of low-dose exposures**
  - Need to better understand health effects arising from low dose exposures
  - Impacts on medical countermeasures efficacy
  - Management of sensitive populations may be key

Policy Considerations

- **The science is unsettled**
  - Expect surprises and avoid definitive statements
- **Consider multi-jurisdiction implications**
  - Alert connected communities to potential contamination/infection
- **Consider decision criteria carefully**
  - Total exposures? Avoidable exposures?
  - Maintain public trust in government?
  - Economic impacts? Time to return to service?
  - Degree of conservatism in decision making?
  - Can sensitive populations be identified and protected?
- **Clearance criteria: given the potential for spottiness…**
  - Is there some degree of acceptable risk/impacts?

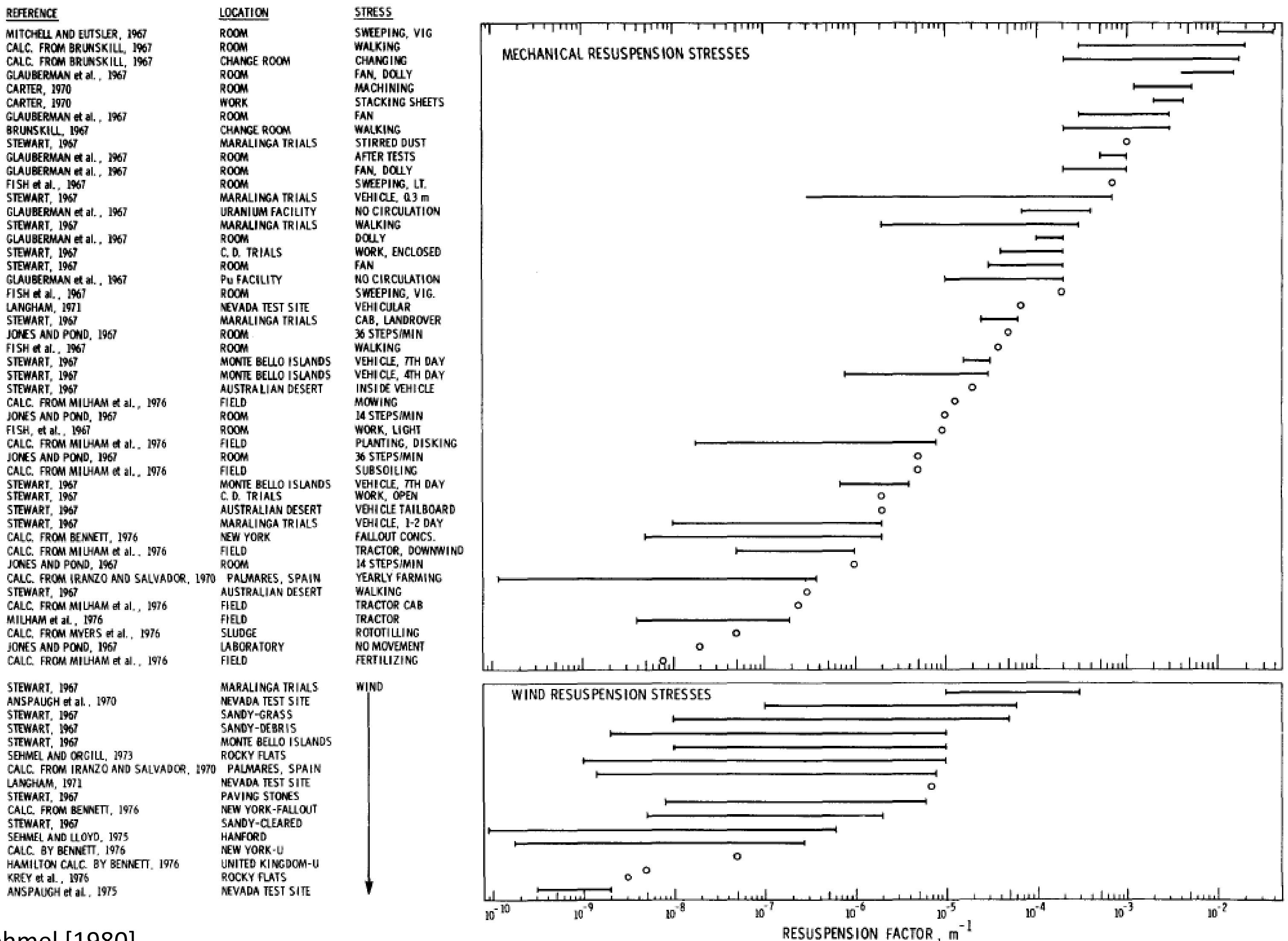
Outstanding Technical Questions

- **To what degree does secondary transport constitute a hazard?**
  - What are the dominant transport mechanisms?
  - How can secondary transport be detected (operationally)?
  - How can secondary transport be minimized/mitigated?

- **How well do we understand this problem?**
  - To what extent can we leverage prior science?
    - When do (viable) biological aerosols behave differently than other aerosols (e.g. radioactive particles)?
    - Applicability of prior outdoor work to non-arid regions
  - What would a constitute a “closure” experiment?

Backup Charts

Wide Range in Observed Reaerosolization Rates



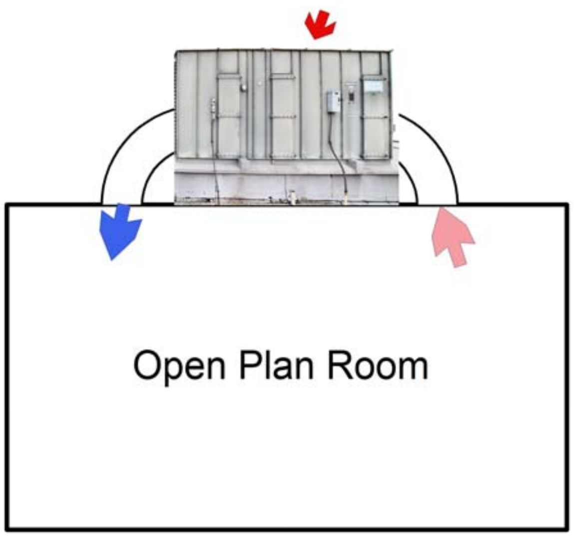
Sehmel [1980]

Use of Simple Resuspension Results

- **Nominal fractional resuspension rate of ~3x10^{-5} per step for hard surfaces.**

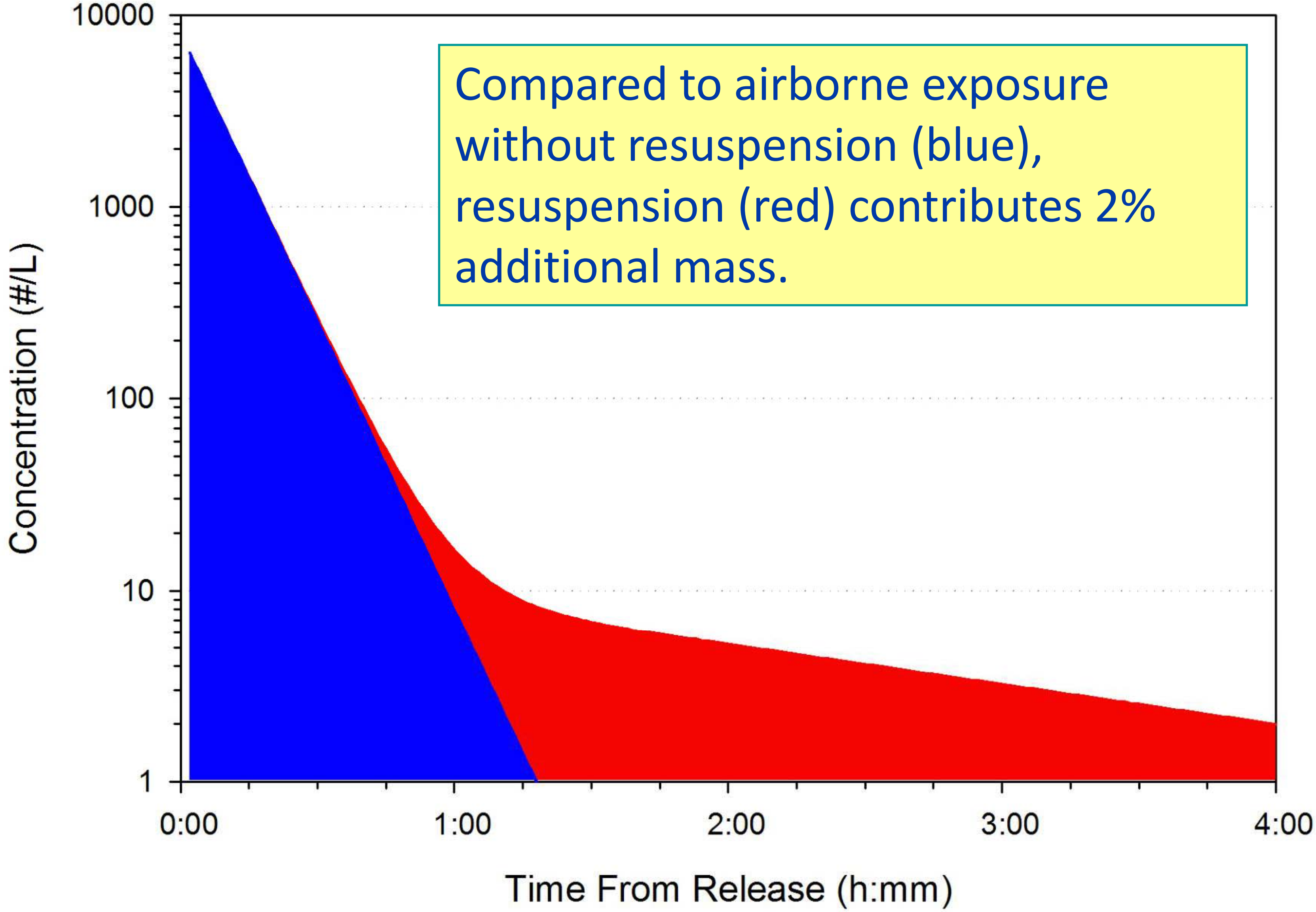
Simple Box Model
100,000 ft2
1 cfm/ft2
10% OA
80% Filters
Puff release, 3µm aerosols

Resuspension Source Term



Initially this results in—
22% Deposited on the floor
70% Trapped in the filters
The rest ventilated to the outside or deposited on the walls

Mass Collected over Four Hours (Based on a Simple Box Model)



Even single aerosols can matter