Estimating the Risk of Exposure to SARS-CoV-2 by Airborne Aerosols

Work for the UK Government’s Pandemic Response
Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in well mixed indoor air

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Virus Transmission

Short-range
<1.5 m

Close contact

Proximity inhalation

Spray

Proximity touch

Long-range
>1.5 m

Distant inhalation

Distant touch

Resuspension (dust)

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THE RELATIVE SIZE OF PARTICLES

From the COVID-19 pandemic to the U.S. West Coast wildfires, some of the biggest threats now are also the most microscopic. A particle needs to be 10 microns (µm) or less before it can be inhaled into your respiratory tract. But just how small are these specs?

Here’s a look at the relative sizes of some familiar particles:

- HUMAN HAIR FOR SCALE
  - 50-180 µm

- FINE BEACH SAND
  - 90 µm

- GRAIN OF SALT
  - 60 µm

- WHITE BLOOD CELL
  - 25 µm

- GRAIN OF POLLEN
  - 15 µm

- DUST PARTICLE (PM10)
  - <10 µm

- DUST PARTICLE (PM2.5)
  - 2.5 µm

- RESPIRATORY DROPLETS
  - 5-10 µm

- RED BLOOD CELL
  - 7.8 µm

- BACTERIUM
  - 1-3 µm

- WILDFIRE SMOKE
  - 0.5-0.7 µm

- CORONAVIRUS
  - 0.1-0.5 µm

- T. BACTERIOPHAGE
  - 0.225 µm

- ZIKA VIRUS
  - 0.045 µm

Wildfire smoke can persist in the air for several days, and even months.

Pollen can trigger allergic reactions and hay fever—which 1 in 5 Americans experience every year.

Respiratory droplets have the potential to carry smaller particles within them, such as dust or coronavirus.

Source: Howard Schultz

SOURCES: California, National Laboratories, EPA, Financial Times, Harvard Medical School, Science Direct, SCDOT, Susan Sadowski, Patrick US, Dept of Energy

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1. Gains
   1. Emission from a person
   2. Entry from outside via ventilation
   3. Entry from outside via infiltration
   4. Virus already present in the space

2. Losses
   1. Dilution via ventilation
   2. Surface deposition
   3. Biological decay and UVC denaturing
   4. Respiratory tract absorption
   5. Filtration
1. **Gains**
   1. Emission from a person, $G$ (RNA copies/s)
   2. Entry from outside via ventilation [none]
   3. Entry from outside via infiltration [none]
   4. Virus already present in the space [none]

2. **Losses**
   1. Dilution via ventilation, $\psi$ (s$^{-1}$)
   2. Surface deposition, $\Upsilon$ (s$^{-1}$)
   3. Biological decay and UVC denaturing, $\lambda$ (s$^{-1}$)
   4. Respiratory tract absorption, $\zeta$ (s$^{-1}$)
   5. Filtration, $\omega$ (s$^{-1}$)

Here, $\phi = \psi + \Upsilon + \lambda + \zeta + \omega$

And, $\phi$ is known as an *equivalent* air change rate
For a step response scenario where \( n(0) = 0 \),

\[
\sum n = \frac{kq_{sus}GT}{\phi^2V} (T\phi + e^{-\phi T} - 1)
\]

- \( k \) ratio ratio of the number of aerosol particles that are absorbed by the respiratory tract to the total number of aerosol particles that are passed through it [-]
- \( q_{sus} \) volume flow rate through the respiratory tract of a susceptible person [m\(^3\) s\(^{-1}\)]
- \( G \) is the emission rate of RNA copies [RNA copies s\(^{-1}\)]
- \( T \) is the exposure period [s]
- \( V \) is the room volume [m\(^3\)]
- \( \phi \) is the dilution rate [s\(^{-1}\)]
The reference scenario

- **School classroom**
  - Geometry and ventilation provision described by guidance documents (BB103 and BB101, respectively)
  - Minimum floor area of 55m² for a junior school
  - 30 students and 2 teachers
    - Occupancy density of 1.7m² per person
  - Floor to ceiling height of 2.7m
    - Volume of 149m³
  - Maximum CO₂ concentration of 1500ppm averaged over the school day
    - Corresponds to minimum of 5ls⁻¹ per person
  - Occupied for 7 hours continuously
    - Models a worst case scenario (like a rainy day with no play time)
  - Occupants breathe for 75% of the time and talk for 25% of the time
Reference scenario: school classroom

- Dashed line
- Smooth line

The graph shows the trend of RNA copies over time in a school classroom scenario. The x-axis represents time in hours, and the y-axis represents the number of RNA copies present (×10^2). The lines labeled A, B, C, and D illustrate different scenarios or conditions within the classroom environment.
Uncertainty in metrics

Monte-Carlo

VirusVent Model

Multiple samples using bootstrap techniques to ensure convergence

Inputs

Outputs
Reference scenario
Comparing different scenarios

- To compare two different scenarios we can simply determine the ratio of the $\Sigma n$ predicted for each scenario.
- This gives a *Relative Exposure Index* (REI) where

$$REI = \frac{\Sigma n_2}{\Sigma n_1}$$

- Then if $\Sigma n_1$ is a reference scenario,
  - $REI>1$ indicates a higher exposure risk
  - $REI=1$ indicates identical exposure risk
  - $REI<1$ indicates a lower exposure risk
Relative Exposure Risk [all scenarios]
Key findings

1. Uncertainty in our predictions is high
2. The REI is a measure of the risk of a space relative to the geometry, occupant activities, and exposure times of the reference scenario
3. The REI is not a measure of the probability of infection
4. $\Sigma n$ is effected by the
   • The emission rate of RNA copies
   • Respiratory rate of a susceptible person
   • The exposure time
   • Space volume
   • Removal rate
5. A sensitivity analysis shows it is most sensitive to the emission rate.

6. Activities such as exercise and singing increase the emission rate.

7. To achieve \( \text{REI} \leq 1 \), a space must preserve the removal rate of the reference scenario (\(0.21 \text{ m}^3/\text{s per infected person}\)) as a minimum rate irrespective of the number of people present.

8. Using a fixed air change rate will lead to \( \text{REI} > 1 \) when the volume is smaller than that of the reference space.

9. Using *per capita* flow rates can only be used with a minimum airflow rate.

10. Therefore, using \( \text{CO}_2 \) sensors is problematic in some circumstances, particularly if a space is under-occupied or the volume is large.
Sources of information

- Supporting paper: dx.doi.org/10.13140/RG.2.2.16867.99361
- CIBSE: https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000HsaFtQAJ
- ASHRAE: https://www.ashrae.org/technical-resources/resources
- AIVC: https://www.aivc.org/keywords/sars-cov-2
- NIST CO₂ Metric Analysis Tool: https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/
- Longer version of the talk via CIBSE #WeChampion: https://tinyurl.com/jaxu9mf3
The End

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