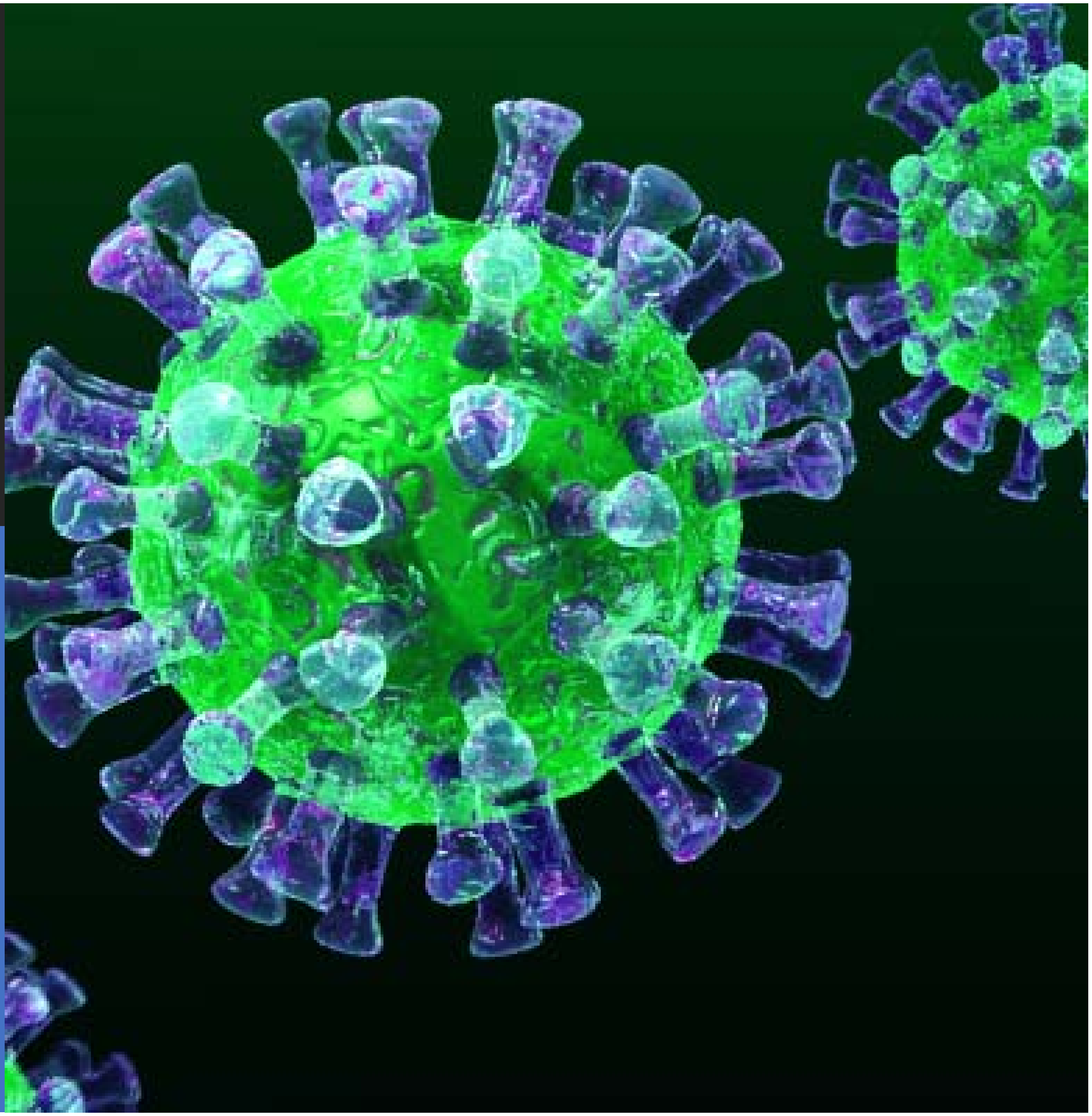

Using Infectious Dose to Understand Risk

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What About Dose?

- For SARS, highest risk of infection occurred during aerosol-generating medical procedures
- COVID-19 shows higher attack rates in indoor clusters
- Suggests that SARS and COVID-19 infections may be related to dose
  - Concentration & Time

Aerosol Transmission = Inhalation of Infectious Particles

- The probability of getting infected depends on inhaling an “infectious dose” = the number of virions needed to make infection likely
  - Function of where particles land in the lung
  - Likelihood of deposition
- Infectious dose does not necessarily imply illness (symptoms and disease)
- Don’t know infectious dose for COVID-19, but might estimate 1000 virions by analogy to influenza and other coronaviruses

Matthew Evans. Avoiding COVID-19: Aerosol Guidelines. Preprint 2020 https://www.medrxiv.org/content/10.1101/2020.05.21.20108894v2

Infectious Dose

- Viral load (RNA copies per mL) in sputum = viral load in particles emitted during breathing, talking, coughing, sneezing, etc.
- Viral emission rate is a function of:
  - Viral load in sputum
  - Volume of air exhaled per breath
  - Breathing rate
  - Number of particles emitted per breath
  - Volume of a particle (function of particle diameter)

Buonanno, Giorgio, Luca Stabile, and Lidia Morawska. "Estimation of airborne viral emission: quanta emission rate of SARS-CoV-2 for infection risk assessment." *Environment International* (2020): 105794.

STEADY STATE CONCENTRATION

Steady state concentration of infectious virus in the air (C, virions/m^3) is a function of*

- Generation rate of virions by infectious person (G, virions/min)
- Ventilation rate (Q, m^3/min)

$$C = G/Q$$

Person infected with SARS-CoV-2 generates 1000 virions/nL saliva.**

Human Activity	Volume of Saliva	virions/min (G)
Sneeze	1 μL (1000 nL)	10^6 (1 sneeze/min = 1,001,000/min)
Cough	100 nL	10^5 (1 cough/min = 101,000/min)
Talking	10 nL/min	10^4
Breathing	1 nL/min	10^3

*Hewett, Paul, and Gary H. Ganser. "Models for nearly every occasion: Part I-One box models." Journal of occupational and environmental hygiene 14.1 (2017): 49-57.
** Evans, Matthew. "Avoiding COVID-19: Aerosol Guidelines." *arXiv preprint arXiv:2005.10988* (2020).

STEADY STATE CONCENTRATION

Ventilation rate (Q, m^3/hr) is function of:*

- Number of Air Changes per Hour (ACH) (n)
- Volume of the room (V, m^3)

$$Q = nV$$

<u>Example</u>

Room volume (V) = 300 m^3 and ACH = 5

Q = 1500 m^3/hr or 26 m^3/min

*Hewett, Paul, and Gary H. Ganser. "Models for nearly every occasion: Part I-One box models." Journal of occupational and environmental hygiene 14.1 (2017): 49-57.

EXAMPLE – HOTEL ROOM

What's the concentration in a 300 m^3 hotel room with 5 ACH if an infectious guest stays overnight (12 hrs)?

Assume mostly breathing (90%), some talking (10%) & periodic coughing (1/hr).

Activity	**Calculation**	**G (virions/min)**
Breathing	0.9×10^3 virions/min	900
Talking	0.1×10^4 virions/min	1000
1 cough/hr	10^5/hr x (hr/60 min)	1667
Overall		3567

$C = G/Q$ = 3567 virions/min ÷ 26 m^3/min = **137 virions/m^3**

HOW LONG TO WAIT FOR ROOM TO CLEAR?

Time to wait for a room to clear is a function of the room volume, ventilation rate, and initial concentration:

$$t_2 = -\frac{V}{Q}\ln(\frac{c_2}{c_1})$$

Example: If we want the concentration to be no more than 0.1 virions/m^3 (c_2), then the wait time is:

$$-\frac{300\ m^3}{26\ m^3/min}\ln(\frac{0.1\ virions/m^3}{137\ virions/m^3}) = 84\ \text{min}$$

TABLE 1. Air changes per hour (ACH) and time required for removal efficiencies of 99% and 99.9% of airborne contaminants*

	Minutes required for removal efficiency†	
ACH	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Centers for Disease Control and Prevention. Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis*
in Health-Care Settings, 2005. MMWR 2005;54(No. RR-17)

MIXING FACTOR

- The well-mixed box model assumes perfect mixing, which may not always be the case
- Some guidelines suggest using a mixing factor (m) to adjust the ventilation rate (Q) where m could range from 0 (no mixing) to 1 (perfect mixing)

$$C = \frac{G}{mQ}$$

- Typically, values for m range from 0.1 to 0.5
- Not entirely correct to use a mixing factor, because it violates the mass balance principle. Not used much in modeling.

WHAT'S THE EXPOSURE?

- What if one person in the room is infectious and the other is not?
- Steady state concentration = 137 virions/m^3
- Dose (D) is a function of concentration (C), breathing rate (Q_{BR}) and time (t):

$$D = CQ_{BR}\mathrm{t}$$

Someone sharing the room with this person, for 12 hours, breathing at a rate of 10 L/min (0.01 m^3/min) will have a dose of 986 virions.

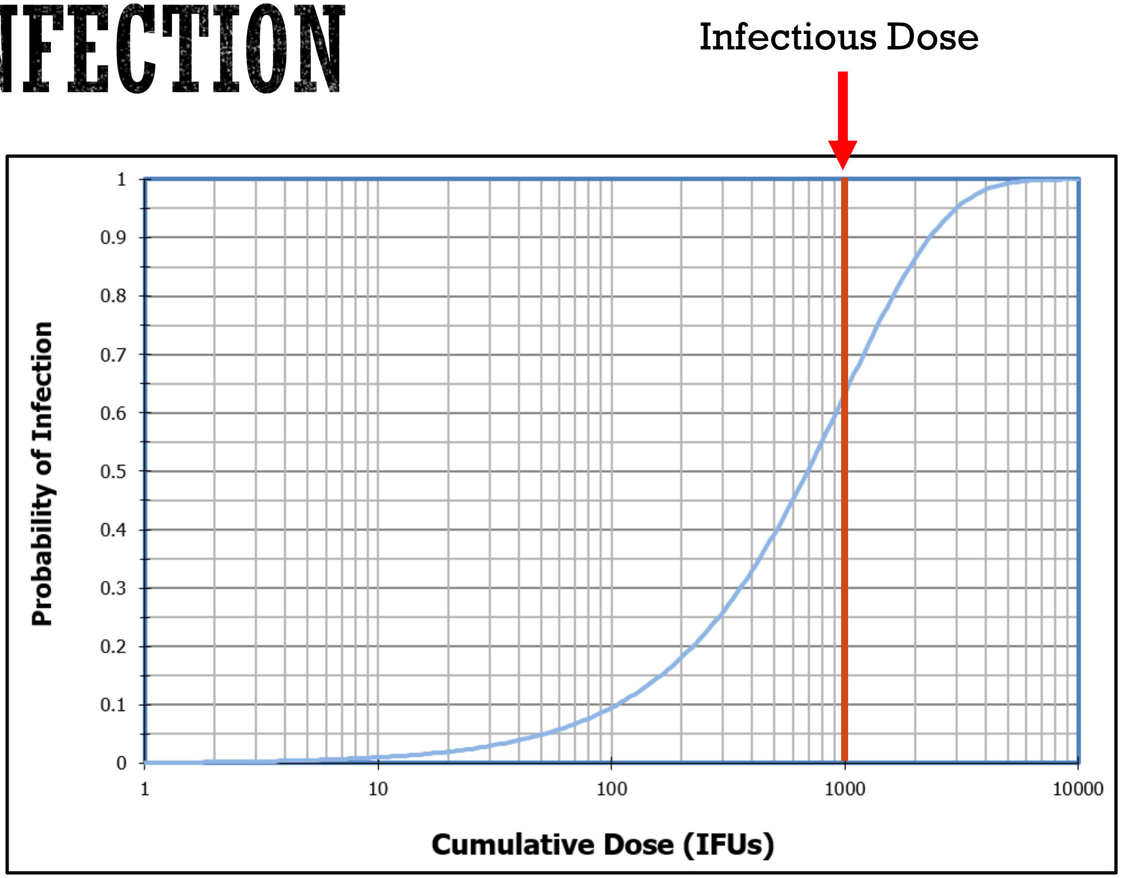
PROBABILITY OF INFECTION

- Estimate the probability of infection*

$$P(infection) = 1 - \exp(-\frac{D}{D_{infectious}})$$

$D_{infectious}$ = infectious dose = 1000 virions (estimated; not known for SARS-CoV-2)

A dose of 986 virions has a 62% chance of leading to an infection



* Evans, Matthew. "Avoiding COVID-19: Aerosol Guidelines." *arXiv preprint arXiv:2005.10988* (2020).

INTERVENTIONS

- Source controls:
  - Limit the number of people staying in a room
  - Screen guests
- Pathway controls:
  - Increase HVAC ventilation rate (ACH) to decrease wait time [not always possible]
  - Add a portable air cleaner to the room to increase ventilation rate & decrease wait time [should have a high-efficiency filter]
  - Limit the amount of time a worker spends in a room
  - Limit the number of rooms cleaned