Environmental and Aerosol Transmission of COVID-19, Monday 26th April -Wednesday 28th April 2021

Better understanding of the transmission of COVID-19 is a key factor in managing risk and designing practical interventions. With the reduction of lockdown restrictions over the next few months, insights into areas such as the role of ventilation and the impact of people moving around within buildings are particularly timely. This three-day science meeting reviewed existing work and identified where further research is most urgently needed. The meeting included a standalone public-facing component providing an accessible overview of the latest science, alongside scientific talks and discussion sessions targeting active researchers.

Each day, discussion sessions took place and the feedback from these is below

Day 1

1. Is 1m spacing between people on vehicles distant enough with regards to small droplet and aerosol transmission inside small spaces, and does this distance need to be smaller or greater than the conventions for office spaces?

- Dispersion is not uniform, and not 1 or 2 metre, is totally dependent on ventilation, physical environment and the source.
- Too many variables, artificial constraints.
- This suggest we are still discussing droplets and not considering aerosols – advice is still droplets (from government etc.) not aerosol.
- Is it more about airborne or ballistic droplets?
- There was a lengthy discussion on the link between aerosols numbers and the actual amount of active virus, and hence on the calculation of the actual viral load and calibration of the air flow models.

2. What would be the best “good enough” and achievable ventilation inside/on board vehicles and should this be expressed in terms of supply of fresh air per person or of internal CO_2 targets as a proxy for virus concentrations accumulating in a space?

- Can we model virus concentration to CO_2? It might be very difficult.
- High ppm correlated with poor mixing within buildings and suggestive of coming from someone breathing. Thus, it is possible this could be possible to measure this within vehicles theoretically. CO_2 is a proxy for ventilation.
- Use ventilation guidance from buildings.
- Would idling vehicles have higher CO_2? 400ppm ambient… what would be high?
- The type of ventilation is important. Recirculating air can significantly increase viral load.
- Assume complete mixing for airborne route with aerosols. Dose-response based on SARS rather than using Wells-Riley?

3. There is key evidence that is needed if we are to model the airborne route of transmission in a way that can be addressed in practice by Non-Pharmaceutical Interventions. How can we work with clinicians to design an experimental virus transmission study (for example an animal study) that would explicitly account for the ventilation in a space, and determine under which conditions a virus can truly be considered “airborne”, and quantify these conditions?

- Should not be just clinicians, but biologists and virologists. They should work out how to follow the virus - some / many still question whether the virus is truly airborne or aerosolised (or consensus of terminology).
- Hamster and Ferret models used to show aerosol transmission of other viral diseases and likely SARS-CoV-2, including sized aerosols.
- Fluid and Mechanical modelling might be useful (has been shown) for specific ventilation systems on vehicles.
- One group looked at a recent paper looking at viral contamination in a car over a 30min drive. This indicated that dust in the air can be important in viral transmission and that the 500nm size fraction was the most important.
- Some studies have been published where samples of airborne viruses have been collected in an intensive care unit and cultured.
- It is possible that the means of collecting the virus might damage it as well as the time between collection and of checking viability.
- PCR studies have also been made of virus contamination in the same locations. The link between PCR values and actual virus numbers is unclear.
- Face masks – no flu this winter, must mean that face masks and social distancing are working.
- SARS2 as influenza is sensitive to humidity and temperature and this could be accounted for in ventilation and aircon designs, see https://peerj.com/articles/11024/
- What is the infectious dose? Diluting the concentrations should be helpful even if not all particles are actually removed from the space.

4. What are the key data points on a train journey (getting on and off a train, mixing in the station - turnstiles etc are all areas where infection can occur)? Where should we be putting the most effort in to avoid risk?

- The answer is not known – only within a vicinity of an infected person.
- Enclosed space as opposed to passing someone who is infected.
- Modelling locations within enclosed spaces.
- Ventilation strategies / methods on trains are so varied / different that there is no real defined place on a particular train and assess a risk on any train.
- Limited to the journey, so it is about location to an infected person, not about a key points of a journey.
- Maintaining social distance may be impossible on public transport – the real question is the occupancy levels, passenger density.

5. Is it reasonable to structure passengers' train travel (e.g., only travel on certain days)?

- Assumed during pandemic as opposed to 'normality'.
- Not if it makes journeys worse – longer with multiple stages (modes) as opposed single shorter journeys.
- Hybrid models / working from home might alleviate / change people's working travel patterns, this is more optimistic due to people commuting less.
- 3-days week from office
- How would this work with season tickets (previous 5 days system – to 3 days system)? Trains or Underground (sealed system is different risk).
- Air pollution problems and the challenges and trade-offs between reducing exposure to COVID and increasing exposure to outdoor air pollution, especially in traffic. Consider emissions of VOCs or other emissions internally from other vehicle parts too.

Day 2

1. When can the fomite transmission pathway carry a significant risk?

- There is a lack of experimental measurements and evidence of fomite transmission leading to infection.
- However, Infection risk increases when shared objects acquire high viral loads through touching and/or deposition of large droplets over extended periods of time.

2. What can we tell about the survival of the virus in the environment and relevant mitigation strategies?

- While SARS-CoV-2 has been shown to survive for hours or days on surfaces and in air in lab experiments, there is a lack of data on its survival in real situations.
- The survival on a particular surface also strongly depends on the (changing) environmental conditions.
- Cleaning of smooth surfaces is effective while half-life of viable virus is lower on porous surfaces. Transfer from the latter to hand is also less effective.
- Soap and water is typically good enough to disrupt its protein.
- Alcohol gels are effective.
- Contamination on hands.
- It's important not to touch your face!
- TB is predominantly transmitted in droplet form, so inhalation is the overriding factor. For COVID-19, what are the different response levels to whether the virus is transferred via the mouth, nose, eyes, or ears?
- UV light is important, does the strength of the sun matter? In the warmer months, opening windows and taking advantage of the sunlight can be helpful mitigation strategies, however this is more difficult in winter.

3. What are the challenges and perspectives on measurements of respiratory emissions and their modelling? How do these depend upon different environments (e.g., a school room/lecture theatre, a concert hall, a dense crowd etc.)?

- Relying on particle size distributions that others produced is a challenge for modellers in an interdisciplinary setting. Important variation in quality of data and how it was collected and processed. Highly heterogeneous reporting of parameters and conditions of data collection hiding underlying physics of the process. Key to develop a gold-standard or just a minimum standard for the publication and reporting of these datasets, so studies can be compared.
- One effort discussed was the need to have a call to action paper to call for such standards in the field.
- Key to have these details to model the underlying physics and inform experiments and measurements.
- Importance of synergies to communicate and discuss how measurements are done and to collaborate to clarify these from the start – team building early and not during a time of pandemic but also in between epidemics and pandemics, so team are already in place and with a history of doing this work for true prevention and preparation.
- Bimodal or multimodal distributions have been mentioned many times, yet there are many experimental challenges and approaches that could be leading to these modalities as artefacts of measurements. Not enough information to support these features in the distribution as true and very few studies and protocols enable to compare distributions between events (speaking,

coughing, etc) due to the lack of homogeneous measurement approaches. Great caution is needed when using these in models of respiratory emissions or multiscale models, and sensitivity analysis is a must.

- Important to consider worst-case scenario, and not average scenario due to such high heterogeneity.
- It is challenging to trace infections back to sources in large settings with high occupancy.
- CFD simulations for specific conditions may not be general enough.
- On the other hand, an individual's risk depends on the specific flow pattern and viral concentration/plumes/jets.
- Statistical CFD approaches are needed for average risk estimation in an environment.
- The use of CO2 as a proxy for aerosols may not be fully justified.
- The location of sensors for measurement is very important, especially in environments with large spatial variability.
- There is a lot of variability in the time spent in different environments, e.g., office or school versus a shop.
- There is a lot of variability in seemingly comparable environments, e.g., a modern concert hall with excellent ventilation versus a medieval concert hall.
- Lots of existing studies focus on specific environments, e.g., public transport, schools, shops etc. Perhaps a typology of indoor environments - understanding and categorising
- rooms depending on size, length and density of occupancy, type of activity (e.g., talking, singing, coughing), ventilation etc. – would be more generalisable.

4. What processes determine the timescales for purging a space or determining the frequency of cleaning and which environmental conditions affect these?

- The nature of ventilation: mechanical or natural, and the exact flow pattern including any dead zones in a given space.
- Shared objects should ideally be cleaned after each user.

5. Can we quantify, understand and predict, the importance of multiscale and multiphase flow physics in modelling respiratory emissions and their spatio-temporal evolution?

- To build multiscale models, one approach is to homogenize scales. Implication of that? How to assess validity? Limitations in insights gained?
- DNS or more detailed simulations that capture more underlying physics than CFD and so can provide further important insights, but trade-off between details and ability to use for rapid decision making is a challenge.
- Averaged modelling vs. details in general is a challenge. There are important limitations with average models and inaccuracies. But they are rapid to obtain. Is speed more important than insight? It depends on the question, how such models are used, the care taken by those making them and those communicating their results, and those using such communication to make decisions and their ability to handle this trade off. Importance of understanding and acknowledging limitations and great uncertainties and not over claiming.
- The evolution of flow structures at different scales arising as a result of small and fast intermittent jets (coughs and sneezes) interacting with larger-scale flow structures requires further study. Non-resolved spatio-temporal scales and turbulence in current numerical simulations should not be ignored.
- The assumption of rapid homogenisation of aerosol concentrations may need to be revisited.

Day 3

1. How can we derive better, faster models of a room/building “structure” which take into account both fixed elements such as walls, but also of movable elements such as people desks, tables, chairs, screens? What is the trade-off between detailed CFD models and averaged advection-diffusion-reaction equation models?

- Advantages of CFD include – detailed special distributions – build up in specific areas, precision for accurate relation to risk.
- Challenges posed by flexibility and sensitivity of CFD vs simplicity and computational efficiency of averages.
- Averaged advection-diffusion-reaction equation models provide a framework for informing policy.
- CFD models really useful for calibration of averaged models.
- Could speed up the CFD using specific hardware designed for video games and using sensor data to correct simulation.
- DSTL developed eddy diffusivity models, which can sit in between these two extremes
- Picking the right model depending on the question your trying to answer) CFD and average models going hand in hand. Average models allow large numbers of calculations to be performed in a short time in order to derive conclusions of practical importance. However, they are approximate and subject to large uncertainty. CFD calculations are needed to develop and calibrate the averaged models. Integration with agent-based models opens up new possibilities.

2. How can we model semi-enclosed spaces? (A review of the literature indicates that not much has been done to measure concentrations or to develop models for semi-enclosed spaces (such as marquees, gazebos, tents, etc). How effective are localized outdoor air supplies and/or purification methods, and what factors affect their results?

- Current work on modelling semi-enclosed spaces is on-going by AIRBODS consortium and UCL (Liora Malki-Epshtein) and Cardiff and Oxford collaboration (Katerina Kaouri)
- This would be more complex because boundary conditions you have to apply to open up your space becomes more difficult – have to bring in assumptions
- Look to indoor/outdoor air pollution modelling where have thought about this – as a starting point.
- If you’re having to make assumptions specific assumptions around boundary conditions how uncertain would your predictions be?

3. How can we predict indoor transmission risk for new variants?

- Hazard approach – to take into account variability and other observational data.
- In terms of transmission pathways, they would be the same – it would just be different data – survival or new variants, etc – risk would be dose/response (and this is something we still don’t know, which is why human trials are still being conducted)
- Can we link understanding of microstructure of the virus? – Very difficult
- Concentration of viral particles may be different – but beyond what we’ve been discussing
- If know something about how much more transmissibly new variants are (but can’t solve inverse problem).

4. What is a good way of designing, and building, the pandemic-proof buildings of the future?

- Ventilation is crucial. CO_2 detection systems provide information on how much exhaled air is in the room and can be used to control the level of ventilation. Sensors are being developed that can detect the presence of virus in filters and it may be possible to use data from these to control ventilation rates in future.

5. How can risk and severity of infection of an individual be determined from the nature of viral exposure (i.e., how and where droplets or viral particles are deposited in the respiratory system of an individual, their frequency, the peak/cumulative dose, etc.)?

- Know about on how particles are created by breathing / coughing etc but no/little data on how/ where it is absorbed in the respiratory tract.
- There is some work on agent-based modelling on in-host behaviour in animals.
- There is a RAMP group on in-host behaviour that can hopefully shed light on this issue.
- Where a particle deposits in the respiratory tract will be sensitive to the physiology of the individual and also to the size of the particle. The location of deposition will in-turn influence the likelihood of infection.
- Work is required to determine how the location of the deposit affects the likelihood of infection and where particles of a given size deposit in the respiratory tract.
- Studies of particle deposition in the airways from asthma inhalers may provide some relevant information where particles are deposited in the respiratory tract?

6. Is there anything else from the event which you think is particularly important?

- Spatial dependence of infection is difficult to model numerically for large populations but possibly could address it using asymptotic people.
- Clarity as to pulse or continuous source from Andy Wood presentation with regard to how well mixed – suggest to discuss directly
- Important to differentiate types of terminology used: source quantification; viral load, quanta emission rates for activities, dose-response, concentrations vs risk, etc