Witness Name:

Professor Catherine Noakes

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UK COVID-19 INQUIRY – MODULE 2

WITNESS STATEMENT OF PROFESSOR CATHERINE NOAKES

I, **Professor Catherine Noakes**, of the School of Civil Engineering at the University of Leeds, Woodhouse Ln., Leeds LS2 9JT will say as follows:

1: Introduction:

1.1. I make this statement pursuant to the UK Covid-19 Inquiry's Rule 9 request of 23 February 2023.

1.2. The matters I set out within this statement are within my own knowledge save for where I state otherwise. Where I refer to facts not within my own knowledge, I will provide the source for those facts to the best of my knowledge. The contents of this statement are to the best of my knowledge and belief both true and correct.

1.3. This statement sets out my expertise, my role during the COVID-19 pandemic response and my views on the effectiveness of parts of said response. I was involved in the response in a number of ways including: as a participant of SAGE; chair of the SAGE sub-group Environment and Modelling Group (EMG); participant in several other SAGE sub-groups; carrying out research studies with collaborators in the UK and internationally, including studies that have directly involved and informed policy makers; engagement with a number of other advisory and working groups led by

different organisations including the World Health Organisation (WHO), Royal Academy of Engineering, Academy of Medical Sciences, Institution of Mechanical Engineers (IMechE), Chartered Institution of Building Services Engineers (CIBSE), NHS England, NHS Scotland, the UK, Scottish and Welsh governments; engagement with the media both through support to official government communications and as an individual expert.

1.4. Within this statement I have summarised the key activities of my involvement, my views on the approach to how evidence was used and how evidence evolved through the pandemic, how groups worked together, how the advice provided supported policy, and how understanding supported public understanding of transmission of SARS-CoV-2 and how it could be mitigated. Where it is appropriate and feasible to do so, I have provided supporting evidence in the form of publicly available papers and in some cases I have disclosed emails and other documents. However, over the period of the pandemic response I was involved in a huge number of activities, was involved in authoring large numbers of documents, and have many thousands of emails. It is not feasible to capture the detail of every activity that I was involved in (and indeed I don't have all of the information). Therefore, this statement provides a focused overview of what I recall as my key activities and my views focusing on the areas that I believe are important from the perspective of my involvement.

2: Background Expertise and Role of the University of Leeds:

2.1. I am currently a Professor of Environmental Engineering in the School of Civil Engineering at the University of Leeds. I am a chartered mechanical engineer with a background in fluid dynamics. Prior to the pandemic I had led or worked on several studies that focused on environmental transmission of disease within the built environment with focus on exposure to pathogens in air and on surfaces as well as the role of engineering approaches (ventilation, air cleaning and disinfection technology) and behavioural and management responses to mitigating transmission. These studies primarily focused on modelling the indoor environment and its interaction with pathogens including zonal airflow models, computational fluid dynamics models and transmission risk models. Studies also involved laboratory experiments with microorganisms including aerosol experiments carried out in a room sized bioaerosol chamber at the University of Leeds, and field measurements for microorganisms and human behaviour in hospital environments. I have continued to work on similar research studies during and beyond the pandemic.

2.2. By way of a limited explanation, fluid dynamics is the study of how liquids and gasses behave, using mathematical, experimental and computational techniques. The principles of fluid dynamics can be applied to study a wide range of problems, from the weather and climate in our atmosphere through to blood flow in the human body. With respect to transmission of infectious respiratory disease, fluid dynamics can play a role in understanding how virus carrying liquid particles are formed in the respiratory system and released through the mouth and nose into the environment. Fluid dynamics can also provide an understanding of how air moves in buildings to evaluate the role that ventilation plays in exposing people to pathogens in air. Fluid dynamics cannot on its own be used to analyse disease transmission and needs to be applied alongside information from many other sources as is discussed within this statement.

2.3. The Inquiry has asked me to explain the contribution of Leeds Institute for Fluid Dynamics (LIFD) during the pandemic. I am currently the Deputy Director of LIFD and was throughout the pandemic. LIFD is a virtual institute that brings together staff and PhD students across 12 different academic departments at the University of Leeds with interests across the breadth of fluid dynamics. Some of the research I carried out during the pandemic aligned to fluid dynamics, my connections through LIFD allowed me to identify collaborators on certain research questions, and LIFD promoted my research on social media during the pandemic.

2.4. Throughout the pandemic I collaborated on research studies with other academic staff at the University of Leeds, including colleagues in Mathematics, Civil Engineering, Mechanical Engineering, Institute for Transport Studies and Earth and Environment. Some of these were long established collaborations, while others were newly established. A small number of academic colleagues, postdoctoral researchers and PhD students contributed to some of the modelling and literature review contained within scientific advice papers that were prepared for SAGE.

2.5. Despite this however, my research and advisory activities were independent of LIFD. LIFD did not coordinate or directly support my research or advisory role and none of my immediate collaborators at the University of Leeds were participants in SAGE or its sub-groups.

3: Role of Engineering in a Pandemic:

3.1. Managing infectious disease is widely regarded as a challenge for health professionals, however engineering and physical sciences can play an important but often overlooked role.

3.2. As some examples of the important role of engineers through COVID-19: the early hospital response in ensuring sufficient oxygen supply; repurposing hospital wards; and the high profile (but ultimately unnecessary) nightingale ward construction. The ventilator challenge in response to high demand for intensive care beds is a further example of the engineering sector's creativity in rapidly coming up with innovative solutions. Engineering is also a critical but overlooked part of the pharmaceutical and vaccine response, in terms of manufacturing and supply chains.

3.3. Related to my area of expertise, engineering design of buildings and the systems within them (heating, ventilation, cooling, water, waste), together with our civil infrastructure for water, wastewater and waste are all baseline essential engineering measures with public health as a primary purpose. Infection control is a key consideration in ventilation design and maintenance guidance for healthcare buildings. In public, domestic, and commercial buildings, comfort requirements tend to dominate over infection transmission, however guidance for ventilation rates in buildings and design of heating and water systems have health and air quality embedded in the recommendations. Evidence collected through the pandemic, and pre-pandemic suggests although there are some well performing buildings, it is widely recognised that many buildings, including a large proportion of hospitals do not meet current design standards particularly for ventilation rates, and therefore do not offer indoor environments that are healthy for occupants.

3.4. Within the engineering sector a large number of organisations proposed technology solutions during the pandemic, including new mask and respirator designs, air cleaning technologies for buildings, sensors for measuring and monitoring contact between people, technologies for cleaning surfaces, technologies to enable a range of devices and processes for contactless use. Some of these innovations were well designed and were effective, simultaneously however there have also been a number of technologies that were ineffective, addressing the wrong question, or in some cases harmful. A need exists for higher standards and regulation for many of these technology solutions as well as a greater expectation of integrity within the sector to ensure that approaches work and are safe.

3.5. Engineers were called upon in an official capacity to support the pandemic, including, in the UK, input from the Royal Academy of Engineering (RAEng) in the early days in identifying potential mitigation approaches, and then in 2021-2023 leading work around Infection Resilient Environments (IRE) (see section 8), CIBSE who set out guidance for buildings emerging from lockdown, and IMechE who led a number of actions (see section 8).

3.6. The engineering pandemic response does appear to be more hidden and has less visibility than frontline health responses. Many of the engineering responses to managing transmission involve changes to how buildings are operated, and this requires specialist knowledge and may involve substantial financial investment. Although evidence such as the IRE work and studies from around the world suggest that investing in better building systems such as ventilation can be a cost-effective long term public health measure, this does not appear to be taken seriously as the focus is too often on short term gains.

3.7. The limitations from the lack of engineering expertise at a sufficiently strategic level were evident a number of times through the response to the pandemic. As an example, Infection prevention and control (IPC) guidance for healthcare is dominated by administrative and behaviour driven actions such as hand hygiene, use of PPE, surface cleaning and cohorting of patients with considerable detail in guidance documents on these elements. But aspects around ventilation (or other building systems such as water/wastewater) often receive scant attention in IPC documents and are "assumed" to be delivered by estates professionals. However, as many buildings rely on opening windows or local operation of ventilation/air conditioning units to support ventilation and thermal comfort, it is critical that guidance for front line healthcare staff also includes information on how to manage ventilation and which devices/approaches to use when. I hope that one of the lessons from the pandemic can be the better joining up of engineering, microbiological and behavioural expertise to improve infection control strategies in healthcare and other buildings.

3.8. On several occasions I have supported UK Health Security Agency (UKHSA) (replaced Public Health England (PHE) on 1st April 2021) and others in government to draft guidance on ventilation, ranging from a simple guidance document prepared by EMG that informed a UKHSA guidance document through to more specific input to the drafting of guidance documents for care homes and other healthcare settings {CN/01 – INQ000192045}. The small number of "in-house" engineering professionals with UKHSA and NHS England and Improvement means these staff can be rapidly

overloaded, and that development of guidance is often delayed and relies very significantly on outside help to get it right. This may also mean that engineering aspects are missed when considering outbreak investigations or where there may be a need for policy responses to support the use of technology. A better consideration of where engineering and design expertise has played an important role during the pandemic, and how to sustain that going forward, would likely be very beneficial for responding more effectively to future infectious diseases.

3.9. With respect to SAGE, I believe that I was the only independent engineer who participated on a regular basis. However, there were engineers in the SAGE Environment and Modelling Group and some task and finish groups, some other engineers participated at SAGE on an occasional basis, and at least one of the departmental Chief Scientific Advisors was an engineer. SAGE / Sir Patrick Vallance (Government Chief Scientific Adviser (GCSA)) also requested information via organisations such as RAEng when required.

4: Participation in SAGE:

Joining SAGE

4.1. My first interaction with SAGE was an email that I received on 7th April 2020 from the SAGE secretariat {CN/02 – INQ000192046}. Such email indicated an urgent need to better understand environmental dispersion of the SARS-CoV-2 virus and asking whether I had availability to provide expertise on this. Following my positive response, a further email was received the same day indicating that SAGE would like to commission a small group to answer a discrete set of questions, requiring modelling from a physics/engineering angle as opposed to epidemiological, and whether I might be willing to lead the sub-group.

4.2. On 8th April 2020 I had a phone call with the SAGE secretariat, followed by an email confirming the scope of the paper requested was '*evidence of environmental dispersion for different mechanisms and the risks and potential mitigations/measures of control within different environments from what we know about COVID19'* {CN/02 – INQ000192046}. This brief evidence summary, including areas for further research and any potential next steps in modelling these unknowns, was requested for presentation at SAGE on 14th April 2020.

4.3. As a new request with a timeline of less than 6 days and no prior interaction with SAGE participants or sub-groups, it was not feasible or appropriate at this stage to establish

a sub-group. I therefore contacted colleagues at University of Leeds, including PhD students and postdoctoral researchers, and requested assistance in pulling together an evidence paper. Together we rapidly drafted a paper, drawing on our pooled expertise and prior research, knowledge of relevant pre-pandemic literature and rapid review of emerging evidence from pre-print and newly published papers on transmission of SARS-CoV-2.

4.4. This paper covered understanding of respiratory virus transmission from both a physics and microbiology perspective, potential mechanisms of transmission, potential mitigation methods, and an indication of how transmission at the local scale (between people in the same room) could be evaluated through experimental and modelling studies {CN/03 – INQ000192047}. The evidence for how the SARS-CoV-2 was transmitted was uncertain at this stage and understanding evolved during the pandemic (see sections 9 and 10). Although much of the evidence within this paper had to draw on evidence of transmission of other viruses, particularly influenza and SARS, I feel that the majority of the evidence presented has remained correct throughout the pandemic.

My role in SAGE through the pandemic

4.5. I attended 71 SAGE meetings overall from 14 April 2020 onwards. I was involved in discussion around the majority of papers and agenda items at meetings, informing SAGE of new evidence relating to transmission and mitigations (this was through both EMG papers and highlighting new research studies that were important but did not merit a paper) and working with other participants to identify evidence gaps to inform sub-group activities and research and evidence priorities. Some of this activity informed the UK Research and Innovation (UKRI) and the National Institute for Health and Care Research (NIHR) funding priorities.

4.6. On several occasions I lead the presentation of a paper that had come to SAGE from EMG or from a Task and Finish group. Here I provided a verbal summary of the paper including the consensus view from EMG or the relevant group.

4.7. Within SAGE and across all groups I provided expertise relating to evidence on transmission of the virus and mitigation strategies, predominantly on non-pharmaceutical interventions (NPIs) focusing on the environment and behaviour such as ventilation, distancing, hygiene, masks etc. This involved drawing from my own research experience, published scientific literature worldwide (pre and during

pandemic), knowledge from other groups in the UK and ongoing research studies worldwide.

4.8. I provided technical expertise on the emission of virus from respiratory sources, the dispersion of virus in different environments, and the factors that influenced exposure to the virus through inhalation, direct exposure to droplets and indirect exposure through contaminated surfaces (fomites). I provided knowledge of the built environment and factors relating to building design and operation, as well as the interface with human behaviour.

4.9. I also provided connecting expertise between a range of expertise to work with others across SAGE sub-groups to consider the complexities, uncertainties and trade-offs associated with different strategies. Much of the information and advice which I, and others in EMG, provided supported the practical guidance that was issued by government departments to enable both the public and those who led organisations to understand how the virus is transmitted, carry out risk assessments and implement measures in different settings.

4.10. All my involvement with SAGE, sub-groups and other activities with government departments were carried out remotely. All meetings were via online platforms (MS Teams, Zoom, Google Meet), and other interactions via email or phone/messaging. EMG held an in-person meeting in May 2022 as a final review of our activity.

My experience of SAGE

4.11. SAGE meetings were well chaired and in every meeting I attended I felt that participants were treated with respect, there was opportunity for people to express their views and that all discussion was allowed. I never felt that my opinion was dismissed or not valued and I never felt that I was not allowed to speak up. While there were a range of views expressed and sometimes differences of opinion, I never felt that we were pressured into adopting a particular viewpoint or that there was any significant conflict or mistrust among SAGE participants. I also felt that the group on several occasions took time to step back, reflect and ask ourselves whether we were experiencing "group think", especially during times when opinion of other scientists in the UK or worldwide, or public opinion appeared to be different to the views within SAGE.

4.12. I was very pleased when the decision was taken to release SAGE papers in May 2020, and like many other SAGE participants I was very supportive and wished they could

have been released earlier. Papers are usually released without author names included and minutes are relatively brief. However, I feel that this was appropriate as highlighting authors or including expansive comments on discussion in minutes would have raised the level of public and media scrutiny looking for divisions and conspiracy, which would likely have significantly hampered the work of the group.

5: Operation of the Environment and Modelling Group (EMG):

5.1. In this section I cover how EMG was established and some of my thoughts on how it operated during the pandemic, mainly from a process perspective. The detail of the work that EMG carried with respect to scientific evidence on transmission and mitigation is covered separately in sections 9 and 10.

Establishing EMG

5.2. At my first SAGE meeting on 14th April 2020, I was asked by the GCSA to set up and chair a new sub-group to respond to specific questions around transmission and the environment {CN/04 – INQ000061533}. This group became the Environment and Modelling group, referred to throughout as EMG and focused primarily on transmission mechanisms and mitigation of the virus in enclosed (largely indoor) environments. A number of SAGE participants from different areas of expertise expressed interest in being involved in EMG and within 24 hours I had set about ascertaining the scope of cover and expertise that was needed within EMG.

5.3. Professor Andrew Curran (Chief Scientific Adviser (CSA) for Health & Safety Executive (HSE)) confirmed after discussions that HSE had capacity to fulfil a secretariat function {CN/05 – INQ000192048}. He also agreed to co-chair EMG.

5.4. Initial discussion between myself, Professor Andrew Curran and other SAGE sub-group leads considered the remit of the new group and how it should interact with others. We agreed that it was valuable to have a representative from each existing sub-group of the Scientific Pandemic Infections Group on Modelling (SPI-M), the Independent Scientific Pandemic Insights Group on Behaviours (SPI-B) and the New and Emerging Respiratory Virus Threats Advisory Group (NERVTAG), whose representatives are indicated in Annex A {CN/06 – INQ000192050}, which enabled EMG access to wider expertise when necessary for a particular commission.

5.5. There was discussion around how EMG would interact with the Healthcare Onset COVID Working Group (HOCWG). As a number of the key concerns in April 2020 related to hospitals and HOCWG already had some representation from Royal Academy of Engineering, it was considered whether to subsume EMG within HOCWG. Ultimately, we recognised that many of the key questions would be relevant across multiple areas of policy and the guidance given to the public, and therefore the decision was taken to keep the two groups separate. In the light of this, several representatives from HOCWG became part of EMG (see Annex A {CN/06 – INQ000192050}), and I agreed to attend HOCWG meetings (see section 7) to ensure that questions relevant to both groups could be joined up effectively.

5.6. Along with co-opting other SAGE sub-group members, there was a need within EMG for wider expertise that was not currently represented within SAGE or its sub-groups. The urgency of the questions was such that there was not time to follow a typical committee recruitment process, and we had to rely on drawing from expertise based on our knowledge of people who were carrying out scientific activities in relevant areas and recommendations from SAGE participants. Together with Professor Andrew Curran, I drew up an initial list of people from academia, UKHSA (PHE at the time), HSE and the Defence Science and Technology Laboratory (Dstl) covering expertise relating to microbiology, aerosol science, mathematical modelling, architecture and health and safety. Following recommendations from co-opted SAGE sub-group members and RAEng we also identified further expertise in public health and ventilation. Chief Scientific Advisors (CSAs) from the Ministry of Housing, Communities & Local Government (MHCLG) (now the Department for Levelling Up, Housing and Communities (DLUCH)) and Department for Transport (DfT) were involved in EMG from early May 2020, and we had representation from NHS England (Healthcare estates) and NHS Scotland (Engineering and Infection Control).

5.7. The initial membership were contacted by email. Together with the HSE secretariat, Professor Andrew Curran and I drafted terms of reference and agreed an initial plan for meetings {CN/07 – INQ000192051}. The first meeting was on 21st April 2020, where we coined the name EMG, agreed the terms of reference, requested declarations of interest, and discussed our first commission {CN/08 – INQ000192053}.

5.8. Membership of EMG evolved slightly over the pandemic based on the priorities for policy makers. Additional expertise around water and sanitation joined in early May 2020, with further expertise on risk assessment and risk visualisation in July 2020. Further CSAs from Department for Business, Energy and Industrial Strategy (BEIS),

Department for Culture, Media and Sport (DCMS) and Department for Environment Food and Rural Affairs (Defra) joined EMG in May and June 2020. Some members left as areas of priority and their time availability changed. Meetings were observed by a range of officials from various government departments, GO-Science and devolved nations; these participants changed regularly over the course of the pandemic.

Structure and Governance of EMG

5.9. I attended 38 of 39 EMG meetings and I chaired most of these meetings. As one of the co-chairs of EMG my primary role and responsibilities included: working with the EMG secretariat, SAGE secretariat and co-chairs to agree agendas and priorities; chairing main EMG meetings; coordinating the approach to preparing evidence papers including, nominating leads when appropriate; leadership and/or contribution to papers including, carrying out simple modelling and analysis, review of research literature, drafting and finalising papers; coordinating liaison with other sub-groups; representing EMG on SAGE and in science coordination groups; representing EMG in ad-hoc meetings with other sub-groups and civil servants around planning or preparing evidence papers.

5.10. In addition to the paragraph above, I also worked with my co-chairs to determine the overall strategy for EMG, ensure effective governance of EMG and to review our progress and effectiveness. Together with my co-chairs we took responsibility for signing off EMG led papers and addressing any requests for amendment by SAGE.

5.11. On forming EMG, we received a large number of commissions in a very short time period, both to address gaps in knowledge and to provide information quickly to support emergence from the first lockdown in spring/summer 2020. EMG contributed to 18 separate commissions (13 as lead) in the first 3 months of its existence, as well as contributing to a huge number of wider discussions with multiple government departments and others around the practicality of real-world mitigation. All papers I was involved with were bespoke (i.e. we were not reporting the results of similar analysis each time) and turnaround time typically varied from around 7 days to 1 month depending on the complexity of the paper and the urgency of the request.

5.12. At the outset there were also a lack of immediate tools for modelling and risk assessment, as focus on the environmental aspect of transmission was not significantly included in pre-pandemic planning (in contrast to for example epidemic modelling where there was a maintained capability and models on “stand by”). As a

result, in late April 2020 we agreed to structure EMG into four working groups to be able to manage a substantial number of requests and consider future needs:

(1) Risk assessment and transmission

(2) Design and Behaviour

(3) Engineered systems

(4) Hospital Environments

5.13. Membership of these groups is indicated in Annex A hereto {CN/06 – INQ000192050}. Between 28 April 2020 and 9 June 2020, the main EMG was a subset of the whole group, with the leads of the four working groups, EMG co-chairs and a small number of other participants. EMG met weekly and working groups at least once per week, with increased frequency when preparing papers.

5.14. The working groups operated relatively informally sometimes with simple action points but no formal minutes. Their remit was on preparing evidence papers based on commissioned questions, scoping longer term activities for EMG (e.g., developing risk frameworks, modelling of risk, systematic reviews) and identifying where there were research needs that went beyond the capacity of EMG. Decisions around consensus views were taken in the main EMG meetings and hence these were minuted {CN/09 – INQ000192054, CN/10 – INQ000192055, CN/11 – INQ000192066, CN/12 – INQ000192074, CN/13 – INQ000192085, CN/14 – INQ000192086 & CN/15 – INQ000192087}.

5.15. From June 2020, the immediate urgency of EMG requests became slightly lower and at the EMG meeting on 9th June 2020 we moved to fortnightly meetings with the working group structure disbanded and all participants invited to EMG meetings {CN/15 – INQ000192087}. Broad activities around risk assessment, transmission, behaviour, design and engineered systems remained a core focus across the breadth of EMG activities. Hospital environments were not explicitly considered in future commissions except for the joint paper with the Hospital Onset COVID-19 Working Group (HOCI) in March 2021 (see section 7), but healthcare estates representation from NHS Scotland and NHS England remained on EMG together with the chair of HOCI.

5.16. Following this change, task and finish groups were convened as required to work on particular commissions from the SAGE secretariat. These task and finish groups were established based on the focus area of the questions, the expertise needed and the availability of EMG participants. In each case there was a nominated lead and a small

group from EMG who wrote the paper. Often the lead was one of the co-chairs, but on some occasions other members of EMG took the lead on a paper that was particularly related to their area. Where appropriate, participants from other SAGE sub-groups sometimes joined a T&F group to bring particular expertise.

5.17. In July 2020, a working group focusing on risk assessment and visualisation was established and met over a sustained period of time to lead a more in-depth body of work around understanding risk. This group was established because of the recognition of the complexity of transmission and how this is expressed and translated into quantifying/visualising risk. The group met informally without minutes and activities focused more on carrying out research rather than rapid review of the existing evidence base. Membership is in the Annex A hereto {CN/06 – INQ000192050}, and detailed work of this group is discussed in below (see paragraph 9.21).

5.18. On 9th November 2020 Professor Harry Rutter became a third co-chair of EMG. This was implemented as a means of more effectively distributing and managing workload as the routine demands of our day jobs returned alongside the continued commitment to EMG and SAGE.

5.19. In January 2022 the secretariat for EMG moved from HSE to GO-Science, who supported EMG through to a final wrap up meeting in May 2022. The former HSE secretariat continued to provide ad-hoc support where needed to provide continuity. The importance of the secretariat teams for the effective functioning of SAGE, EMG and all of the sub-groups cannot be overstated. The people within these teams worked incredibly hard behind the scenes and there are many people who deserve a considerable amount of recognition for their dedication and support to enabling the vast and rapid scientific response.

Diversity of expertise

5.20. The Inquiry has asked me to comment on the diversity of discipline areas in EMG and international perspectives. My view is that the diversity of participants within EMG was good with regards to discipline areas, particularly given that we were able to readily draw across other expertise within SAGE sub-groups and also seek views from other external experts where we needed different knowledge. Having co-opted members facilitated this, and over time collaboration between sub-groups grew, with many papers involving participation from people within other sub-groups. There was a need to balance numbers of people and expertise within EMG, as a very large group where

expertise was duplicated too much in particular areas would have been more challenging to manage.

5.21. Specific sub-groups of EMG focusing on the outdoor environment (TWEG) and epidemiological studies (TSG) were both established to address specific needs which emerged. The rational for creating these groups and their operation is discussed in section 6.

5.22. For a small number of EMG papers we invited a broader range of external expert participants to support the development of the paper. These external experts joined task and finish groups for the period of developing the paper only. Participants were asked to contribute because they had particular expertise and/or had recently carried out research that was needed for the paper. Where appropriate these participants completed declarations of interest and were aware of the confidentiality of the activity but did not attend EMG meetings. These participants are listed in Annex A {CN/06 – INQ000192050}.

5.23. With regard to protected characteristics, there was not as great a diversity as I would have liked. The rapid timescale for initiating EMG (less than one week) meant that it was not possible to go through the open recruitment process that would normally happen with a scientific advisory committee and therefore identifying people with whom we were less familiar with was challenging. In addition, the number of people who had expertise in research relating to transmission of infection and the environment was very small and there were a limited number of people with sufficient expertise to draw from.

5.24. EMG did not have a remit for international members as part of its core membership. However, we used our own international networks, the international round up provided by GO-Science and relevant connections through scientific advisers in government departments to ensure that we were appropriately aware of key international developments and new knowledge that was relevant to the work of EMG. I was directly involved with WHO work around ventilation through the Engineering Control Expert Advisory Panel (ECAP) (see section 7) and the Group-36 (see paragraph 10.6). Other members of EMG were linked into relevant international networks through their expertise areas. Our formal and informal networks meant that we were aware of studies being carried out around the world and new results being achieved.

5.25. On a number of occasions, we directly interacted with scientific advisors in other countries by email or via online meetings to share knowledge. This included specific conversations with advisors in New Zealand and Australia around their experience of

understanding transmission through data from quarantine hotels; email exchange with advisors in Belgium who had experience of applying carbon dioxide (CO_2) monitoring in public buildings; and discussion with advisors from the Ireland equivalent to EMG. Many of the EMG papers were cited by others around the world, particularly in Ireland, and therefore we had a reasonable degree of confidence that we were as aware of the emerging evidence around transmission as we could be.

5.26. I feel that the EMG group overall had a good knowledge of research expertise that related to environmental transmission and I and other participants were aware, through our research and wider activities, of ongoing research relating to COVID-19 in the UK and internationally. While we were never going to be able to keep on top of all of the vast body of research, we were fairly confident that we were aware of the vast majority of relevant work.

Commissioning of papers

5.27. Over the whole period of its existence EMG was involved in 59 papers, 44 were led by EMG or by the Transmission sub-group, and 15 were cross-group papers led by another sub-group. A full list of all the SAGE papers that I was involved together with an indication of my level of involvement is given in Annex B {CN/16 – INQ000192088}.

5.28. Requests received through SAGE secretariat were usually managed well and they, together with the EMG secretariat, provided an invaluable function in ensuring that commissions from different departments were appropriate and relevant. Not all questions directed to sub-groups were appropriate, usually because the questions were too specific to one government department, the scientific evidence had already been provided in previous papers, or the ask was too large a scope for a sub-group to answer in an appropriate timescale.

5.29. Some commissions were derived through discussions within SAGE or sub-groups where participants themselves or the GCSA / the Chief Scientific Officer (Sir Chris Witty (CMO)) identified that there was a knowledge gap that needed addressing. In these circumstances a process of agreeing the scope of a commission was carried out between the sub-group chairs, sub-group secretariat, SAGE secretariat and relevant departments to ensure that the paper would focus on aspects of evidence that were policy relevant. While there was rightly sometimes push back on these "self-commissions" due to their policy relevance or concerns over workload, some of the most highly cited papers that were produced by EMG, including papers on ventilation

and air cleaning, came about through this process {CN/17 – INQ000192089 & CN/18 – INQ000192090}.

5.30. Some requests came directly from government departments, most notably Cabinet Office, and these were usually to EMG co-chairs only to comment on documents they had produced based on SAGE evidence rather than develop an evidence paper. Some of these came with almost impossible timescales, for example requests to comment on papers from Covid-O officials' meetings with a four-hour turn around for comments {CN/19 – INQ000192091}. While these were clearly being driven by the need for officials to have information to share with ministers/senior civil servants at Covid-O, these were incredibly hard to deliver.

5.31. On occasion I had emails directly from government officials, usually in the Prime Ministers Office (No. 10) or Cabinet Office asking for advice. In many cases these were appropriate as they focused on clarification of information that we had provided in papers, often to ensure it was being interpreted correctly for use in guidance, or a quick question around technology approaches that had been suggested and officials were looking to gauge whether it was worth pursuing further {CN/20 – INQ000192094}.

5.32. Some emails were a distraction though, with questions coming from No. 10 advisors that would have been better directed properly to EMG via the SAGE commissioning process. For example, on one occasion a question about application of triethylene glycol as a method of mitigating airborne transmission in theatres and concert venues included stakeholders external to government/SAGE in the email chain. Such external stakeholders subsequently pushed for their approach to get greater consideration and suggested that EMG could sign an NDA (Non-disclosure Agreement) to get access to test data {CN/21 – INQ000192096}. As a scientific advisory group we were not able or willing to sign NDAs and we based our evidence upon advice that had been peer reviewed (or was in pre-print), or was from trusted academic and national laboratories. The approach of using triethylene glycol was always unlikely to be suitable, however the request meant that EMG had to spend time examining the evidence in detail and included substantial content on the potential application of glycol-based sprays in the EMG paper on air cleaning technologies {CN/18 – INQ000192090}, which was followed by a further policy paper led by BEIS {CN/22 – INQ000192097}.

5.33. I also had informal discussions with Cabinet Office officials and No. 10 special advisors on a small number of occasions around improving understanding of transmission and implementing better mitigations, and I was invited to occasionally attend meetings led by Cabinet Office, such as Covid-O officials, to provide technical expertise to support

discussion on policy options. I do not have a record of all of these meetings or discussions. To the best of my recollection, I only once spoke directly with a minister outside of formal evidence sessions such as a select committee or All-Party Parliamentary Groups (APPGs). This was in January 2021 when I spoke one-to-one with Scotland's Deputy First Minister, John Swinney MSP, about safety measures in schools {CN/23 – INQ000192098}.

5.34. The Inquiry has asked me to comment on an observation of an EMG associate bought to my attention that some requests to EMG *"were a bit vague or repetitive…it wasn't clear how the group could use its expertise to suggest issues that hadn't been commissioned 'from above'"* {CN/24 – INQ000056488/3}. There were occasions where government departments needed to give advice around specific aspects and would at times default to EMG to ask questions rather than use their own expertise. Often the relevant scientific evidence had already been shared, and there was no explicit evidence that related to the very specific ask. There were also a few occasions where we had been given advanced warning that a particular commission may be forthcoming, and therefore discussed it in advance in a meeting, but then the commission either didn't materialise or the focus was quite different. The science coordination group led by the GCSA was a valuable route to suggesting issues that needed to be explored, but unless there could be a clear "policy owner" then it was difficult to justify spending time on these questions even when they may be important.

5.35. A gap was around dealing with the slowly changing evidence base. Studies that produce a step change in evidence are quite rare, and the scientific knowledge evolves as a process of refinement rather than a wholescale shift around thinking. The process for being able to articulate this steady adjustment was quite limited. For example, officials may have asked for evidence relating to particular mitigation measures, such as physical distancing, masks, survival of the virus etc. Having received this once, it was quite rare that these questions were asked again. While the key principles of mitigations didn't change, there were small refinements, for example better understanding of survival of the virus in the real world compared to in a laboratory, or better understanding of how respiratory droplets and aerosols behaved. This meant guidance or the actions taken by organisations could sometimes be based on out-of-date evidence which potentially put insufficient emphasis on certain things or left in mitigations that were unnecessary.

5.36. Where it was possible and feasible to do so, and certainly where there were more significant new studies that changed the advice, we articulated this, either via an EMG

paper or sometimes by just drawing attention to specific studies in SAGE meetings or by email to senior advisors. The emergence of a new variant was often a useful moment to provide a general update on evidence. However, having a simpler mechanism involving a periodic check question of "has anything changed" would have been useful.

Governance of EMG papers

5.37. As a co-chair of EMG, I recognised that it was important that we had an appropriate level of governance with all papers. I worked with the secretariat and my co-chairs to ensure that, as far as timescales allowed, there was opportunity for input from all EMG participants. This was usually through the opportunity for open discussion and feedback from participants in a meeting and/or feedback from participants by email. The final paper was reviewed and signed off by co-chairs before submission for presentation at SAGE. We paid particular attention to papers which potentially had a greater impact on policy changes, or where there was likely to be greater public and media scrutiny.

5.38. Following discussion of a paper at a SAGE meeting, there were often small amendments requested before finalisation. In the majority of cases these were small points of clarification that didn't require additional EMG participant input and could be signed off by co-chairs. However, if there were more involved questions an updated version would be circulated to EMG participants. On one occasion, after a paper had been released publicly, an NHS Scotland led review group raised some concern about an inaccuracy in the paper. In this case I worked with co-chairs and the secretariat to clarify the text of the paper and released an updated version online. To my knowledge this is the only time that a correction was made to a paper post publication, and the change related to interpretation of a particular scientific study within the body of the paper and had no impact on the overall conclusions.

5.39. Being a participant in SAGE was a learning curve, and this included learning how to produce papers that gave clear and concise summaries with an appropriate level of supporting evidence, including confidence in that evidence. I recognised that papers could be used inappropriately if there was any ambiguity in the wording and took as much care as possible to limit this happening. By way of an example, following my oral evidence to the Science & Technology committee on 22 May 2020, a sentence was "cherry picked" out of context from one of the EMG papers to support a call for the reduction of the 2 metres distancing in a letter from Greg Clark MP (chair of the Science

and Technology Committee) to the Prime Minister, Boris Johnson (PM) on 29 May 2020 {CN/25 – INQ000192099}. At the time of this oral hearing and the EMG paper from 28 April 2020 {CN/26 – INQ000192100} there was limited evidence for aerosol transmission (beyond 2 metres) although by the time of the next EMG paper on transmission on 4 June 2020 {CN/27 – INQ000192101}) which followed this committee session, it was starting to emerge with a stronger focus. Following this experience, in subsequent papers we took as much care as we could to limit that someone could easily take a single sentence from the executive summary out of context, and routinely included confidence statements in papers.

Resources and Sustainability of EMG

5.40. Timescales and resources were a challenge throughout, but to a large extent this was inevitable given the circumstances. When I joined SAGE in mid-April 2020, there had previously been limited consideration of the role of the environment (although transmission modes had been discussed in NERVTAG meetings) and there were only a small number of prior papers that considered the application of environmental and behavioural NPIs.

5.41. Timescales and limited resources meant that we had limited capacity to undertake more in-depth systematic reviews of published literature and had to rely on expertise and awareness within sub-groups to be aware of the current evidence. Within EMG we drew on a number of resources. In some cases, participants could draw on some resource from people in their wider team in their organisation, with postdoctoral researchers and PhD students supporting literature review or modelling for some papers. PHE published a weekly digest of papers and pre-prints that were relevant which was a very valuable resource for keeping abreast of the most recent research. We were also able to get a small amount of resource to commission two systematic reviews via the Design and Behaviour working group. In the later stages (2021 onwards) there was also more opportunity to draw on analysis from PHE / the Joint Biosecurity Centre (JBC) as well as research studies which could provide information from outbreak investigations, case control and cohort studies, transmission modelling and laboratory experiments. However, particularly in the first 6-9 months of EMG, the vast majority of evidence gathering and evaluation was carried out directly by the EMG participants. At this stage we were predominantly relying on early-stage investigation reports, initial lab data and pre-pandemic understanding of respiratory transmission and mitigation (drawing on SARS, MERS, influenza, TB and other pathogens).

Research was commissioned via UKRI, with EMG feeding into research priorities, but timescales were far too long for the majority of questions.

5.42. Working remotely across multiple organisations brought a number of practical challenges with working collaboratively, particularly around IT. When EMG was created, the HSE secretariat did not have the IT infrastructure within their organisation to either host meetings or provide a shared directory (Microsoft SharePoint / OneDrive) to be able to work together on documents. With the urgency of the task, meetings were organised through University of Leeds Zoom, and documents shared via my University OneDrive. This enabled a sufficiently secure set up for participants to work on papers together, although some participants could not access documents and therefore for most versions of papers were also shared by email. IT provision improved as all organisations adapted to online working, although even towards 2022 we were unable to provide shared documents through a coordinated government-based site.

5.43. Although EMG operated for almost two years, the most intensive work was over the first 9 months, with 39/59 EMG papers produced between April 2020 and December 2020. As the requests for scientific advice became less frequent, there was considerable uncertainty for large periods of time over the future of EMG. Unlike several of the other groups (SPI-M, NERVTAG, SPI-B), EMG did not exist prior to the pandemic, and therefore had no remit outside of the pandemic and no "ownership" through a government department. We went through a number of discussions around future strategy and where EMG would fit into the evidence portfolio and felt that we were in limbo for long periods of time during 2021. This prevented us from considering aspects like identifying new members, as it was not feasible to invite someone to join a group that may be disbanded at any moment.

5.44. EMG gave advice throughout the pandemic until SAGE stopped meeting in February 2022 and restrictions were lifted in April 2022. EMG had a final wrap up meeting in May 2022 where the significant contribution was recognised, and members recommended that maintaining the capability in EMG would be important for future pandemic risk. Since May 2022, I have still been involved in giving advice to government departments, but on an ad-hoc basis via research projects (including the PROTECT study and studies relating to mitigations in schools) and one-off requests to me personally. This includes requests from the Department of Health & Social Care (DHSC), UKHSA, Department of Education (DfE), DfT, DCMS and the Ministry of Justice (MoJ) around ventilation in GP surgeries, care homes, schools, transport, sports facilities and prisons. These continued requests suggests that there is still

limited capacity within government to provide the expertise that was established in EMG, however to my knowledge there are not yet any plans to maintain this capability in any formal capacity.

6: Sub-groups aligned to EMG:

Transmission in the Wider Environment Task and Finish Group (TWEG)

6.1. TWEG was established in early May 2020 to address questions relating to transmission that were beyond the core remit of EMG. These focused on the potential for transmission associated with outdoor air, outdoor surfaces, water and wastewater and food. The need for this focus was identified by Defra CSA Professor Gideon Henderson in late April 2020 {CN/28 – INQ000192102}. Following discussion over the next few days, we agreed that Professor Gideon Henderson would establish a separate group of experts who could address these particular questions. There was overlap with EMG membership with Professor Gideon Henderson, Allan Bennett and I attending both. TWEG had a separate secretariat supported by Defra, who liaised with the EMG secretariat and SAGE secretariat to ensure that activities and commissions were appropriately coordinated.

6.2. The group first met on 13th May 2020 where terms of reference were agreed and a plan to produce a paper on outdoor environmental transmission was discussed. This group operated as a task and finish group, convening when there were relevant questions. Professor Henderson's regular attendance at EMG meetings ensured a constant connection to identify key areas of focus. TWEG produced two advisory papers in June 2020 and December 2020 {CN/29 – INQ000192103 & CN/30 – INQ000192104}.

6.3. I attended 8 out of 9 TWEG meetings, providing input on environmental transmission and mitigation, contributed to discussion and to the content of both papers, provided strategic connection to SAGE-EMG and support to sign off of papers.

Transmission sub-group (TSG)

6.4. In the early days of the pandemic, data was uncertain around where transmission happened. Although it was quickly apparent that indoor spaces were higher risk than outdoors and that there were particular risks in hospitals, reliable epidemiological studies to understand settings where transmission was more or less likely were limited

(see section 9). As the test and trace data and the Office for National Statistics (ONS) survey data became more substantial, and a number of larger epidemiological studies were conducted (e.g. the VirusWatch study led by University College London), the ability for epidemiological input to understanding transmission became more feasible, which led to the formation of the Transmission Sub-Group (TSG).

6.5. TSG was initially convened by UKHSA (PHE at the time) following an action in SAGE 62 {CN/31 – INQ000061570}. An initial terms of reference and suggested membership was drawn up in mid-October and the first meeting happened on 3rd November 2020. The membership of TSG was quite broad and drew people from across EMG, SPI-B, SPI-M, NERVTAG and also epidemiology and data expertise from UKHSA, HSE, ONS and others as needed for particular commissions. I do not have a list of members and would assume that GO-Science could provide this.

6.6. The group was initially tasked with addressing questions around "where is transmission happening". This is a complex question, and it was important to consider where there was relevant evidence for transmission in particular settings but at the same time consider the appropriate contextual information so as not to make assumptions or stigmatise settings. This is discussed in more detail in sections 9 and 10.

6.7. In December 2020 it was agreed that rather than TSG being a UKHSA convened group, it would become a sub-group of EMG as it fell within its remit of understanding transmission. The first meeting of this newly reconstituted group was on 15th January 2021{CN/32 – INQ000192105 & CN/33 – INQ000192106}. The formal connection to EMG also enabled an effective coordination between related activities in the two groups. Once TSG became an EMG sub-group it was co-chaired by Professor Paul Monks, CSA for BEIS and Dr Isabel Oliver, CSA for UKHSA with a secretariat provided via GO Science. Informal chairs catch up meetings across EMG and TSG were used to coordinate priorities on commissions, and a standing item was included on both TSG and EMG agendas for cross over reporting between the two groups.

6.8. To the best of my recollection, I attended 16 out of 18 of the TSG meetings from January 2021, a meeting between TSG and the Social Care Working Group, plus earlier meetings when it was led by PHE (I don't have a record of these). I provided input on environmental transmission and mitigation, contributed to discussion and to the content of majority of papers, provided strategic connection to EMG and support to sign off of papers.

7: Participation in other sub-groups:

HOCWG

7.1. I was a participant at HOCWG (also known as nosocomial working group) meetings during my early days as a SAGE participant. I attended 3 HOCWG meetings on 16 April 2020, 23 April 2020 and 7 May 2020. I may also have attended a meeting on 18 June 2020, however I do not recall and do not have a copy of the minutes. In these meetings I provided an update from EMG in meetings and input to discussion in the meeting relevant to transmission and mitigation strategies.

7.2. I also contributed to two joint papers between HOCWG and EMG on "Possible additional interventions to address hospital transmission risks of SARS-CoV-2" (12 May 2020) {CN/34 – INQ000192107}, and "SARS-CoV-2 in the hospital environment and risk of COVID-19 nosocomial transmission" (31 May 2020) {CN/35 – INQ000192108}. These papers were both led by Mark Wilcox (member of HOCWG and EMG) and had significant input from the EMG hospital environments working group detailed above (see paragraphs 5.12 – 5.14). Both papers consider practical mitigation actions. The paper from 31st May 2020 probably led to the introduction of universal face masks in healthcare settings. Informal discussion with Mark Wilcox together with the timing of the introduction of universal face masks in healthcare settings which happened in early June 2020, suggests that the paper from 31st May 2020 may have been influential in supporting the introduction of this new mitigation approach.

7.3. HOCWG was restructured at the end of June 2020 and became known as HOCI, and I no longer attended their meetings or remained on the mailing list for the group. Professor Mark Wilcox took over chair of HOCI and he also remained a participant in EMG, so there was still a potential route for EMG outputs to support understanding of risks in hospitals.

7.4. A third joint paper between HOCI and EMG was prepared in March 2021 on "Masks for healthcare workers to mitigate airborne transmission of SARS-CoV-2" {CN/36 – INQ000192109}. This paper was led by HOCI and was requested by the GCSA following concerns raised by myself and an EMG colleague around the continuing high rates of nosocomial transmission in hospitals.

Participation in Social Care Working Group (SCWG)

7.5. I was a participant in the Social Care Working Group (SCWG) from 8 May 2020 – 21 January 2022. I don't have good records of my meeting attendance, but I believe that I attended around 15 meetings. My role was to provide a connection to EMG for advice around transmission routes and the physical environment in care homes. I found attendance at meetings difficult due to multiple other commitments, so an EMG colleague (Dr Gormley) attended some meetings in my stead. I contributed to discussion and to the best of my recollection contributed to the content of two papers on 12th May 2020 (SCWG: Care homes analysis) and 26th May 2021 (SCWG: What are the appropriate mitigations to deploy in care homes in the context of the post vaccination risk landscape?) {CN/37 – INQ000192110 & CN/38 – INQ000192111}.

Participation in Children, Schools and Education Task and Finish group (CFT)

7.6. I was a participant in the Children, Schools and Education Task and Finish Working Group (CTF), which convened on a number of occasions between 23 April 2020 – February 2022. I was not involved in every meeting, but joined the group when commissions required input around the physical school environment, routes of transmission and approaches to mitigation. I do not have a record of which meetings I attended or the minutes of such meetings, however I provided input on environmental transmission and mitigation and contributed to discussion.

7.7. I led a connected pair of papers focused on transmission risks and mitigations in higher and further education on 3rd September 2020 (Principles for managing SARS-CoV-2 transmission associated with further education, Principles for managing SARS-CoV-2 transmission associated with higher education) {CN/39 – INQ000192112 & CN/40 – INQ000192113}, and contributed to papers on 8th July 2020 (TFC: Risks associated with the reopening of education settings) and 10th February 2021 (TFC: COVID-19 in higher education settings) {CN/41 – INQ000192114 & CN/42 – INQ000192115}.

Participation in Enduring Transmission Task and Finish Group

7.8. I was a participant in the Enduring Transmission Task and Finish Group between 30 March 2021 and April 2022. This group drew participants from across SAGE sub-groups and considered the complex reasons why transmission remained higher in some areas of England. I attended the majority of meetings, but I do not have a record of the meetings that I attended. I provided input on environmental transmission and

mitigation, contributed to wider discussion, and contributed to the content of a paper in April 2021 (Cross organisation study: Risk factors associated with places of enduring prevalence and potential approaches to monitor changes in this local prevalence) {CN/43 – INQ000192116}.

Participation in SPI-B meetings

7.9. I attended two SPI-B meetings (9th March 2021 and 8th February 2022) during the preparation of joint papers that were led by SPI-B where EMG contributed. These papers were 30 April 2021 (SPI-B: Sustaining behaviours to reduce SARS-CoV-2 transmission) and 10 February 2022 (SPI-B: Social and behavioural impacts for lifting remaining restrictions) {CN/44 – INQ000192117 & CN/45 – INQ000192118}. In these cases, I attended only for discussion of the joint paper rather than the whole of the SPI-B meeting. My purpose for attending the meeting was to hear the views of SPI-B members on the topic of the paper and to explain the evidence for transmission and mitigation from a physical/microbiological perspective. This was to ensure that when I was working on the draft of the paper that I understood the overarching behavioural context for the paper alongside the EMG focus on transmission.

7.10. There were several other papers that were collaborative between EMG and SPI-B, sometimes with other sub-groups involved too. For these papers, there was a short duration task and finish group drawn together from across relevant sub-groups who worked together specifically for the duration of preparing that particular paper. These would have sign off from EMG, SPI-B and other sub-groups and would have secretariat support from one or more groups as appropriate. These joint papers are all within the list included in Annex B {CN/16 – INQ000192088}, but I don't recall exactly the process that was followed for each paper.

Participation in Science coordination group (SCG) and GO-Science meetings

7.11. From early May 2020 I joined a weekly meeting for chairs of SAGE sub-groups. This was a brief 30 min meeting chaired by either the GCSA or a senior official in the SAGE secretariat and had the purpose of coordinating activity between the sub-groups and determining the timeline for what papers were coming to SAGE and when. The meetings could also be used to flag any new evidence that may be emerging or key areas of concern. Minutes of the discussion were not recorded, but key actions were

circulated. These meetings were usually attended by one co-chair from each sub-group together with the sub-group secretariat.

7.12. From, I believe, October 2020 this regular check-in meeting became the SCG, though I stand to be corrected. This group operated in a similar way with the purpose of enabling informal discussion between SAGE participants, including sub-group chairs, outside of the formal structure of SAGE meetings. The participants numbers were larger than in the sub-group chairs meeting and included all of the academic and CSA participants in SAGE. Meetings started as weekly then over time moved to fortnightly and eventually monthly. I don't have a record of these meetings but assume that GO Science will have details as the SAGE secretariat.

7.13. The SCG meetings were used for SAGE participants and sub-group chairs to enable situational awareness. They were used to provide an update on commissions sub-groups were working on, new evidence that may be emerging or key areas of concern. This was a valuable group for informal feedback and the ability to more effectively coordinate activities, identifying where there were crossovers in work, where we could support other sub-group activities and highlighting when particular analysis or evidence could be expected.

7.14. The SCG and other informal meetings led by GO-Science also provided a place to support the wellbeing of SAGE participants. There were times during the response where SAGE participants were under considerable pressure, either from the demands of the workload or associated with the political and/or media response to the pandemic. This on occasion included some quite vitriolic pieces in the media directed at SAGE participants. These informal meetings were a valuable place to discuss some of these pressures and provide a certain amount of peer support to each other. This was also supplemented by formal mechanisms for support and security briefings for SAGE participants.

Relationships between sub-groups

7.15. Sub-groups and task and finish groups provided the working space for collating, reviewing and agreeing a consensus around the scientific evidence prior to presentation and discussion at full SAGE meetings. This included whole sub-group meetings which were typically used to discuss the early stages of a commission, to review draft papers and to identify any key evidence or challenges on the horizon. When papers were developed, typically a small working group met to draft papers

based on the initial thoughts from the wider group. These would be brought to whole sub-group meetings for discussion and agreement before final sign off.

7.16. In all the sub-groups and task & finish groups I have participated in, people interacted with respect, courtesy and genuine commitment. There was always very clear respect and open discussion across different disciplines, and there was an atmosphere of "there are no stupid questions" across all groups that I interacted with. This approach made for very easy and open discussion, and I think helped people who had particular expertise develop their thinking by understanding better how something could be misinterpreted. While there were a range of views within all the groups that I interacted with, particularly around the strength of evidence, there was rarely significant disagreement between participants, and we were always able to reach a consensus.

7.17. The relationship between SAGE and its sub-groups, and between sub-groups, was excellent and grew over the course of the response. From my first interaction with SAGE and request to set up EMG, I felt supported by other sub-group chairs. Mechanisms for interactions included managed routes such as the regular science coordination groups discussed above, interactions between secretariats and direct communications between members. As already described EMG was set up specifically with co-opted members from other sub-groups to always ensure a link was maintained.

7.18. The work of sub-groups was almost always incorporated into the advice given by SAGE. Work within sub-groups usually led to papers that were then taken to SAGE. Sometimes these papers reinforced existing advice and therefore came as information rather than new evidence. Where papers presented a new consensus, this was discussed at SAGE, approved (sometimes subject to amendments) and then incorporated into advice. I am not aware of exactly how the advice was given, but I believe that key points were incorporated into SAGE minutes and were in the verbal advice that the GCSA, the CMO and other senior officials gave to ministers. The sub-group papers approved by SAGE were also circulated directly to Cabinet Office and relevant government departments to provide details to civil servants who needed evidence for their response. This normally happened immediately and before papers were released to the public. More details on the relationships between SAGE advice and the government response is in sections 11 and 14.

8: Role in other advisory groups:

WHO led groups

8.1. I was initially involved in communications with WHO as a result of a petition sent by the Group-36 international scientists in early April 2020 and subsequent papers and letters relating to airborne transmission of COVID-19 (see paragraph 10.6). However, I didn't have direct interaction with WHO during this period, such communications rather being led by Professor Lidia Morawska at the University of Queensland.

8.2. In August 2020 I was asked to join the WHO Environment and Engineering Control Expert Advisory Panel (ECAP) for COVID-19. This group brought together experts from the built environment such as engineers and architects as well as public health, epidemiology and IPC experts with the objective of supporting the development of guidance. As a member of this group I contributed to the development of a Ventilation Roadmap that set out recommendations for ventilation rates and approaches in different settings. This was published in early March 2021 {CN/46 – INQ000192119}. Through ECAP I also attended a small number of WHO meetings about COVID-19 transmission where I contributed to discussions on transmission and mitigation.

8.3. In December 2021 I was invited to join the WHO Europe High-Level Expert Group on COVID-19. In this group I provided expertise on transmission and mitigation of COVID-19, particularly focusing on advice relating to measures such as ventilation, air cleaning and masks. This advice was encompassed in regular reports (initially monthly but now lower frequency) to the WHO Europe Director Hans Kluge. This group also considered the response to Mpox, and it continues to meet at the time of writing this statement considering surveillance and long-term response to COVID-19.

8.4. The Inquiry have asked me to comment on the response to Mpox in comparison to COVID-19. I do not have enough knowledge to give a comprehensive view on this, however my impression from being in WHO meetings and through informal conversations with public health colleagues in the UK is that the experience of COVID-19 likely led to a more rapid and effective response to Mpox. The Mpox outbreak occurred while COVID-19 surveillance and research activities were highly active, and therefore my impression is that there were sufficient staff and resources to rapidly respond in terms of data analysis, environmental sampling, evaluation of transmission routes, surveillance and public health messaging. Scientists were also well connected and working together between different institutions and different disciplines, and therefore the environment for identifying and addressing the challenges of a new outbreak were already in place.

Institution of Mechanical Engineers (IMechE)

8.5. In spring 2020 I was involved in initial discussions with a number of members from the IMechE around the engineering response to COVID-19, and in summer/early autumn 2020 I attended a small number of meetings of the IMechE COVID-19 Task Force. I stepped back from the group for personal reasons but worked with a small number of IMechE members on an informal basis to support the development of a practical manual and to make the case for training for engineers to improve infection control in the built environment, particularly through ventilation and air cleaning methods.

8.6. In February 2021 the group was reformed under new leadership and became the Pandemic Infection Control Solutions Task Force (PICS). I have participated in the IMechE PICS group since, focusing on practical implementation of scientific evidence around mitigating transmission and enabling safer workplace environments. Within the group I have contributed to a number of initiatives including: developing an online manual on mitigating COVID-19 in workplaces, developing and delivering a CPD course on mitigating transmission; presenting at IMechE seminars including for international participants; presenting at a parliamentary event on the importance of ventilation; supporting modelling studies on airflow and the role of air cleaning devices in healthcare and schools; working with NHS England to develop guidance on using air cleaning devices in hospital environments.

8.7. Most of the work by IMechE PICS focused on practical guidance for the engineering community and acted as a route to disseminating evidence-based guidance rather than directly influencing policy makers. IMechE work around air cleaners has had a policy impact in the NHS which has led to the preparation of new guidance on HEPA filter and UV based portable air cleaners in hospitals which was published in May 2023. I cannot comment on whether any other advice from this IMechE group had a direct influence on political decision making.

Royal Society

8.8. From mid-April 2020 I was a member of the steering group for the Royal Society's Rapid Assistance in Modelling the Pandemic (RAMP) Initiative. In the early stages of this group I worked with the chair to recommend researchers who could lead work focusing on modelling transmission. This led to quite a large initiative within RAMP with a number of sub-groups exploring different aspects around the physical process of

exposure to respiratory aerosols and droplets, the role of ventilation and transmission via surfaces. I was not directly involved in modelling, but acted as a conduit to SAGE via the steering group to indicate where there were high priority questions where analysis by these sub-groups could be of assistance. As a member of the steering group, I was also involved in the general strategic direction of RAMP including, in the later stages, in planning dissemination events and recognition for early career researchers.

8.9. I also had some interactions with the Royal Society Science in Emergencies Tasking – COVID initiative (SET-C). This included reviewing some of their papers and a small number of meetings and email exchanges to discuss priority questions for their rapid evidence review work.

8.10. I believe that work led by the Royal Society did have a policy impact, with modelling carried out by RAMP and reviews carried out by SET-C (and the Data Evaluation and Learning for Viral Epidemics group (DELVE)) all supporting the advice given to government. Connections to SAGE via myself, members of SPI-M and the president of the Royal Society's participation in SAGE in 2020 enabled a route for the advice to be shared with SAGE and where appropriate on to policy makers. As the evidence from Royal Society groups came through SAGE, it meant that advice was joined up with other SAGE evidence and therefore ensured that policy makers had information largely through a coordinated route rather than ad-hoc through other approaches.

Academy of Medical Sciences

8.11. In late May 2020 I was asked to join an expert group convened by the Academy of Medical Sciences to carry out a rapid piece of work to advise UK government on what a challenging winter (2020/2021) may look like from a COVID-19 perspective. The primary focus of this work was on the impact on the NHS, however it also considered wider societal aspects that would impact on the NHS. As part of the expert group, I contributed to discussions around the structure and content of the report and was involved in drafting and reviewing certain sections. This report was published on 14 July 2020 {CN/47 – INQ000192120}.

8.12. In April 2021 I was asked to join the expert group again to revisit the work and produce a new report focusing on challenges for winter 2021/22. My role was similar in contributing to discussions and drafting and reviewing the report. This report was published in July 2021 {CN/48 – INQ000192121}.

8.13. Recommendations from both reports were shared with policy makers directly and via SAGE. I believe that the work had an impact on decision making in DHSC and the NHS, as well as more widely in government, however I am uncertain as to specific actions that were taken as a result of the reports.

Royal Academy of Engineering (RAEng)

8.14. I have developed a strong relationship with RAEng throughout the pandemic. In early April 2020 (prior to joining SAGE) I was contacted by the RAEng and asked to provide input on a document for the GCSA on concerns around airborne infection control relating to the Nightingale hospitals that were being set up at that time. This was followed by a second request a few days later to feed into a report the RAEng was preparing on engineering strategies for control of infection in the widest sense. On forming SAGE EMG, I invited representation from RAEng to participate in meetings.

8.15. In summer 2020 I was awarded a Presidents Special Award for Pandemic Service and was photographed as part of an online exhibition to recognise the role of engineers during the early stages of the pandemic.

8.16. In March 2021 I was asked to join a working group for a substantial piece of work on Infection Resilient Environments (IRE). This work was carried out at the request of the GCSA to understand the immediate challenges needed in the built environment prior to winter 2021/2022 as well as long term opportunities to improve resilience in buildings and transport environments for future pandemics. This work had two phases: Phase 1 reported in July 2021 and focused on immediate challenges, and Phase 2 reported in July 2022 and focused on long term needs {CN/49 – INQ000192122 & CN/50 – INQ000192123}.

8.17. I had significant involvement with the IRE work. For phase 1 this included initial scoping of the work, participation in the steering group, participation in workshops, drafting and reviewing the report and media activity following the report. For phase 2 I was involved in scoping the work, providing specialist advice and review for commissioned research studies on cost-benefit modelling and research capabilities, reviewing the report and supporting dissemination including presentation at conferences and media engagement.

8.18. The IRE work highlighted the potential for confusion in guidance and the need for clarity and practical advice particularly around implementing mitigations such as ventilation measures in buildings. The second phase of the work made a number of

longer-term policy recommendations relating to design, operation and maintenance of buildings, including focus on standards and regulations, compliance and enforcement, linking work around infection resilience to wider challenges around air quality and net-zero, and the need for joined up approaches. Cost-benefit analysis in this second phase provided evidence that ventilation measures in commercial and public buildings were likely to be a cost-effective long-term intervention to reduce the burden of respiratory infections.

8.19. I feel that the first phase of the IRE work had a rapid and significant policy impact, with BEIS, HSE and other government departments simplifying guidance and creating new practical explainers to support individuals and organisations to implement changes. The policy impact from the second phase of the work is longer term and is not directly relevant to the COVID-19 response between 2020 and February 2022. I am not aware of any direct impacts on political decision making during the pandemic from the second phase. However, I am hopeful that it will support long term change as part of the lessons learned from the pandemic. The IRE work has continued beyond summer 2022 and is currently still part of the strategic work of RAEng. This includes development of an online interactive graphic on ventilation that was released in March 2023 {CN/51 – INQ000192124}.

UKHSA / PHE led task and finish groups

8.20. I was part of task and finish groups led by UKHSA / PHE to look at specific questions. In summer 2020 a group was convened to look at evidence for potential for higher transmission risk when people were singing or playing wind instruments. This group reviewed published evidence and early results from scientific studies carried out by scientists at PHE and by a consortium led by Bristol University. As part of the group, I was involved in discussion of the evidence and drafting and agreeing a consensus statement {CN/52 – INQ000192125}. I also supported the presentation of this paper at SAGE via EMG.

8.21. In February 2021 I was asked to participate in a respiratory evidence group, which was looking at key evidence around aerosol transmission to inform mitigations, particularly face coverings and face masks. This group initially met three times and produced a first review on face coverings which was published in October 2021 {CN/53 – INQ000192126}. The group was reconvened in 2022 to look at evidence on face masks in healthcare. The panel met in July 2022 and published an evidence review in

March 2023 {CN/54 – INQ000192127}. In both cases this group discussed the findings from a rapid systematic review to come up with consensus statements.

9: Scientific evidence on transmission including the work of EMG:

9.1. In this section I have summarised the activities of EMG over the two-year period of its existence and outlined my views on how evidence changed through the pandemic, the complexity and uncertainty of this evidence, and how EMG took this into consideration. This is inevitably a summary seen through my viewpoint and it is not feasible to explain every piece of evidence.

9.2. I have focused on key areas and to the best of my recollection how the evidence led to scientific advice and how this aligned to different needs through the pandemic. I have referred to the majority of relevant papers that I was involved in as co-chair of EMG and through my involvement with other sub-groups, with some explained in greater detail than others. A full list of papers that I was involved in with a brief summary of each is included in Annex B {CN/16 – INQ000192088}. Section 10 follows this by focusing in more detail on the specific evidence worldwide for different modes of transmission and implications for mitigation of SARS-CoV-2.

Context through the pandemic

9.3. Questions posed to EMG throughout the whole period of its existence focused on understanding of how the virus transmits between people, the most appropriate mitigation strategies, how these mitigations apply independently and together in different settings, and the barriers and challenges with implementing mitigations.

9.4. At the time EMG was created in April 2020 we were in the first lockdown with very limited data on the virus, no vaccines and limited options for treatment. Therefore, throughout the spring and summer of 2020 there was a great deal of caution around the virus spreading, and a significant focus on building fundamental understanding of transmission to identify the best approaches for how to enable easing of restrictions and safe reopening of different sectors. EMG drew on its own expertise, the published research literature and evidence emerging from around the world and, over a longer period of time as research was carried out, new modelling, laboratory and epidemiological studies to inform the advice papers that were prepared.

9.5. As the evidence base grew, EMG considered evidence for specific mitigation approaches in more detail and worked more closely with colleagues across other sub-groups to consider the risk factors for transmission in different sectors and settings, and the benefits and challenges of implementing mitigation strategies. EMG also reconsidered evidence when new variants of concern emerged or at key points in the pandemic such as easing or tightening of restrictions, which provided an opportunity for a review of the wider evidence.

9.6. EMG focused on environmental and behavioural interventions, often called Non-Pharmaceutical Interventions (NPIs) rather than vaccines or clinical treatment. However, we considered interventions in the context of pharmaceutical strategies like the vaccine roll out particularly where there were impacts on transmission. Mitigation approaches within context were around hand and surface hygiene, physical distancing, masks and face coverings, ventilation and air cleaning, environmental conditions such as temperature and humidity, duration of exposure, design and use of spaces. Larger scale restrictions such as school closures, work from home or bubbles were typically within the remit of SPI-M as their epidemic models enabled these to be evaluated at a population scale. However, EMG worked collaboratively with SPI-M and SPI-B on number of papers where we were considering options for a range of measures in different settings {CN/39 – INQ000192112, CN/40 – INQ000192113, CN/41 – INQ000192114, CN/42 – INQ000192115, CN/43 – INQ000192116, CN/75 – INQ000075003, CN/79 – INQ000074992, CN/85 – INQ000138010, CN/89 – INQ000074989 & CN/93 – INQ000120651}. EMG also worked jointly on a number of papers with SPI-B around the behavioural implications of different mitigations {CN/44 – INQ000192117, CN/45 – INQ000192118, CN/66 – INQ000192139, CN/76 – INQ000188929, CN/77 – INQ000192150, CN78 – INQ000075014, CN/84 – INQ000063145, CN/90 – **INQ000075006** & CN/94 – INQ000075010}, and NERVTAG on the virology and epidemiological evidence for transmission and mitigation {CN/59 – INQ000192132, CN/60 – INQ000192133, CN/67 – INQ000120541, CN/80 – INQ000075016, CN/81 – INQ000074947, CN/82 – INQ000074945 & CN/92 – INQ000075005}.

9.7. Transmission of a communicable disease such as the SARS-CoV-2 virus is complex and uncertain, and despite more than three years of evidence and a considerable worldwide scientific effort which has led to a vast body of new publications, there remain many gaps in knowledge. It is highly likely that some of these gaps will remain uncertain for many years. The approach to understanding transmission involves identifying possible routes and evaluating the evidence base for whether a route is

likely, possible or very unlikely. This uncertainty poses a policy challenge. It is human nature to want to simplify something to a set of "rules" such as "wash your hands for 20 seconds" or "stay 2 metres apart", and yet the real world of transmission is a complex interaction between the virus, the environment and human behaviour, where none of these simple rules are absolute. Even understanding the relative importance of different measures is a challenge, and evidence through the pandemic suggests that the relative importance of, for example, masks or ventilation may depend on the particular setting and interactions between people.

9.8. As a disease that was strongly suspected from the early days to be predominantly transmitted through respiratory routes, a significant focus of collecting evidence throughout the whole pandemic was on the aerosols and droplets emitted from the nose and mouth of infected people. This evidence focused on understanding the mechanisms by which the virus was likely to be carried in these respiratory particles, how it could be transferred from these emissions by an infected person to the respiratory tract and mucous membranes of other susceptible people and how interventions "broke" this chain of transmission. Transmission via blood and urine was considered possible but unlikely, however transmission through faeces was recognised relatively early on as a possible route as patients were shown to shed large amounts of viral Ribonucleic acid (RNA). It was important within EMG to always be open to new evidence and to consider the possibility for transmission routes and mitigation measures that were outside our prior experience.

Evolving evidence base and types of evidence

9.9. In the first few months of 2020, data on transmission was extremely limited. A small number of research studies had been made available as early pre-print academic journal articles which included aspects such as initial sampling for the virus in air and on surfaces in hospitals as well as very early epidemiological data as well as anecdotal data around where transmission appeared to be happening. While these studies gave some important clues, it was important to treat evidence with a degree of caution. We were acutely aware that studies were carried out opportunistically and therefore may not be representative of all risks. This was particularly the case for data collected during lockdown periods where some sectors may have appeared to have a low risk, simply because they were closed or heavily restricted and so no data was available. We were also aware that aspects such as laboratory detection of the virus in sampling

were in early development and that absence of detection or inability to culture the virus may be either a genuine result or could result from limitations in lab methodologies.

9.10. Much of the early advice given by EMG around transmission and mitigation had to draw on pre-pandemic data around basic physical and microbiological principles as well as epidemiological data from other diseases including other coronaviruses (SARS, MERS, other human coronaviruses that cause mild respiratory disease), other respiratory viruses such as influenza, and airborne bacterial infections such as TB. This pre-pandemic evidence base was also relatively limited, particularly in terms of epidemiological studies, and we were aware that not all of the evidence could be directly translated to COVID-19.

9.11. Over the course of the pandemic, substantial research was carried out worldwide across all aspects on transmission and mitigation (alongside all other aspects of the virus and how it impacted on health and society). Some of this research was led by established teams who had a long track record in measuring and modelling transmission of communicable diseases, while some was from new teams who applied their knowledge and expertise to an area that was new to them. A large number of teams also produced review papers summarising evidence, but often with the objective of supporting or arguing against a particular opinion rather than presenting an unbiased overview. Over time seemingly more robust systematic reviews emerged, however even these could still at times be biased or limited in their usefulness by the question asked. For example, if a question only focuses on a particular timeframe for publications, particular types of studies or a very narrow question, they can often report that there is little or no evidence, whereas in fact there may be relevant evidence from sources outside of the defined search strategy.

9.12. EMG and other SAGE sub-groups played a role in identifying gaps in scientific evidence. In May 2020 we shared recommendations on research gaps with GO Science to share with key research funders such as UKRI and NIHR to help inform how they prioritised rapid research funding {CN/55 – INQ000192128}.

9.13. A significant challenge for EMG was in sifting the huge body of publications to identify evidence that was new, robust and important, and to identify where evidence from different studies aligned or was conflicting. As far as possible EMG drew on scientific advice that had been peer reviewed and published in a reliable academic journal or was from trusted academic and national laboratories who had a reliable track record in research in relevant fields. Some evidence from research papers that were in pre-print was used, particularly in the early days when evidence was very limited, however

this was always treated with a degree of caution. Information reported by the media could be useful to highlight potential new evidence, particularly as outbreaks could often be reported by media outlets before scientific information was available. However, this was always treated with care, recognising that the information may be incomplete or incorrect.

9.14. Across all advice, we were careful to not only draw on one source of knowledge. Within health fields, the use of epidemiological data collected via randomised control trials (RCT) and meta-analysis is seen by some as a "gold standard" of evidence to demonstrate causality or measure the efficacy of an intervention such as the response to a drug or medical treatment. However, such approaches are very challenging to apply to NPI measures such as environmental or behavioural mitigations in a pandemic. Some NPIs such as ventilation or air cleaning are applied to settings (buildings) rather than individuals and yet are affected by the behaviour of individuals. Those that are applied by individuals (e.g. masks, hand hygiene, 2 metres distancing) have impacts both on the person applying the intervention and other people who interact with that person. With a drug trial, the effect is on the individual who is taking the treatment, while in a pandemic a study needs to be able to measure whether there is a change in population (setting, local or national) scale transmission rates. All such intervention studies are subject to cofounding and bias, and in a rapidly moving pandemic, setting up research studies to be carried out without significant cofounders is almost impossible. Much of the data is collected opportunistically and, particularly in 2020, was also impacted by restrictions imposed on researchers and their laboratories. Data from RCTs represented a small proportion of evidence that EMG used because few of these studies existed and those which did were either pre-pandemic or emerged too late in the timeline to be of substantial use in informing advice.

9.15. As test and tracing data in the UK and worldwide became more substantial with the scale up of national testing systems and the introduction of measures such as contract tracing apps, EMG and particularly the Transmission Sub-Group (TSG) was able to draw more on epidemiological data on who was infected and where transmission was likely to be happening. These studies could draw on large data sets to identify associations with particular sectors, settings and activities and through associated surveys and cohort studies could identify risk factors that were likely to be important for transmission as well as suggest the relative benefit of some mitigation measures. Testing data was also able to provide insights into the range of viral load among different people infected with the SARS-CoV-2 virus, and how this changed depending on the variant of the virus, symptoms and day of illness. Such information could be

used within transmission models to explore the likely range of risks. While these epidemiological studies were very useful for identifying risk factors, they were not able to identify the specific modes of transmission that happened between individuals.

9.16. Evidence from specific outbreaks was a valuable source of information, particularly where an outbreak investigation included information on the environment, mitigation measures applied and the interactions between people. Several early outbreaks reported first in the media and then subsequently in scientific papers suggested the importance of both "superspreading" and airborne transmission as important for the dynamics of the pandemic. These studies enabled likely risk factors such as higher levels of activity (such as singing or exercise), long duration of exposure, crowded spaces, and poor ventilation to be identified. Outbreaks, particularly large ones, gave an insight into the extremes of the virus transmission, but care had to be taken not to over interpret the data as these were clearly not representative of the lower rates of transmission seen in most cases. Outbreak data from countries with very low COVID-19 rates, such as New Zealand, also proved very valuable as findings around how transmission happened could often be interpreted with greater confidence than in countries with high rates of transmission where there may be other explanations for who was infected and where.

9.17. Evidence from both laboratory studies and mathematical modelling studies was used quite extensively to understand some of the detailed mechanisms that may explain transmission. This included laboratory data on survival of the SARS-CoV-2 virus on surfaces and in air, measurement data from human volunteers on both the range of respiratory particles emitted and eventually a small number of studies on the amount of virus shed in these particles, data from animal models on transmission mechanisms and the infectiousness of different variants, data from environmental sampling studies on the presence of viral RNA in different environments, computational fluid dynamics models (see the PROTECT study in section 13) and associated aerosol measurements and visualisations that showed the complex behaviour of droplets and aerosols in air and how factors such as distance and ventilation could affect risks, quantitative microbial risk assessment models that modelled the influence of measures such as ventilation, masks and air cleaning. All of these approaches could provide insight into mechanisms, however again these studies had to be treated with care. Data on the behaviour of a virus in a controlled laboratory setting is not always reflective of what happens in the real world, computational models and proxy aerosol studies are idealised and can miss out key behaviours that happen in the real world, and a large

number of modelling studies made simple modelling assumptions based only on physics without considering the microbiological aspects of exposure.

9.18. Evaluation of evidence by EMG emphasised that transmission risk is continuous across all settings where people interact. There was a desire by many, including researchers and within government, to come up with simple rules that ranked different types of settings according to risk so for example people could quantify the risk in say a restaurant, compared to a bus, a shop, an office etc. This led to attempts by several organisations and researchers to produce personal risk tools and apps. However, this was never straightforward to do and even now I am not convinced that such a ranking has been successfully developed.

9.19. There are features of some settings that increase or decrease risk. For example, public transport settings are inherently environments where people are close together, hospitals are settings where there are higher numbers of vulnerable people, gyms involve higher activity levels. That being said, it is not just a particular setting/workplace that creates a risk, it is the interactions that go with it too. As an example, a number of outbreaks in meat processing plants led to a focus on whether it was poor ventilation in these settings that was causing the risk. Although this is very likely to be a contributor to risk it is not the only factor and other aspects such as shared transport to work and low paid workers living in shared accommodation were also shown to be significant risk factors. Settings can also not be assumed to be uniform across a sector. For example, when looking at risk associated with restaurants, these vary from spacious and well-ventilated settings with relatively low occupancy through to cramped, busy spaces with no ventilation. The exposure risks for customers may be different to staff depending on the size, design and interactions in both the restaurant area and the kitchens.

9.20. I have given just a few examples here to illustrate complexity, and to highlight that the scientific evidence never allowed for blanket judgements to be made. Throughout we took care to highlight this complexity and to indicate that it was important to have frameworks to support the right decision making to ensure that appropriate adaptions were made in different settings. While this sounds simple in theory, it was evident that this was challenging in the real-world with both a changing evidence base and a very wide range of understanding among the public and employers. I have commented further on this in section 12 where I talk about my experience with communications.

9.21. During winter/spring 2021 continuing uncertainty around modes of transmission led to a substantial piece of research led by the “risk and visualisation group” within EMG to

explore evidence and understanding for different modes of transmission. As there was not international consensus on the importance of different modes of transmission, the group carried out an expert elicitation exercise with international scientists using a detailed set of questions around the different elements that could result in aerosol, droplet or fomite transmission. This was a semi-quantitative exercise that asked for estimates around the proportion of transmission that could happen by different routes, as well as reasoning why and any supporting evidence. This work led to two connected publications, an article in BMJ Open that described the detail of the exercise and the findings {CN/56 – INQ000192129}, and a summary article with interactive infographic {CN/57 – INQ000192130} that was published in the BMJ. This exercise illustrated the uncertainty in transmission as well as the differing interpretation of evidence by different scientists around the world. Although there was broad consensus around many aspects, there were clear differences in opinion. The outcome of the exercise was shared with SAGE, and the resulting infographic was widely shared in the media.

9.22. The role of the media was important in how research studies were interpreted. The pandemic led to an unprecedented level of discussion of science in the media and I believe that there were some real benefits to public awareness and knowledge based on this. However, some research studies had levels of promotion that were perhaps greater than the significance of the study. This included significant attention around papers that were in pre-print, and some of these have never been fully published in a peer reviewed journal. Within EMG we always looked at relevant studies that had attracted a lot of attention. In some cases, these studies did provide new evidence that changed advice, but in the majority of cases these studies either just added further weight to an existing consensus or failed to provide anything noteworthy.

9.23. Throughout the work of EMG, and still even now, there has been considerable uncertainty around exactly how transmission happens and the relative importance of different modes of transmission and mitigation measures. While there is now greater consensus that can be drawn from a considerable body of evidence, there is no one study or approach that provides a definitive answer. Several knowledge gaps remain, and these are likely to remain so for many years to come.

EMG evidence during Spring/Summer 2020

9.24. During the early days of the pandemic, the advice given by the UK government and health authorities focused on washing hands thoroughly and then physical distancing (2 metres rule). I am not aware of the original evidence that was used to support these

recommendations, and I was not aware of any SAGE papers that had been considered prior to April 2020; to the best of my knowledge, I didn't see any SAGE papers from prior to 14th April 2020 until the papers were publicly released in May 2020.

9.25. In the first paper that I presented to SAGE on 14th April 2020 (Evidence of environmental dispersion of COVID-19 for different mechanisms) {CN/3 – INQ000192047}, we considered evidence from a range of sources including: pre-pandemic data on particles that are emitted from people (and environmental sources) and how they can carry virus; physics based studies on the dispersion and evaporation of respiratory particles in air; pre-pandemic evidence for how pathogens can transmit on surfaces and through air; evidence from early COVID-19 studies that had provided insights into where transmission may happen and real-world and laboratory measurements in air and on surfaces; evidence from pre-pandemic studies on mitigation approaches; and an indication of the approaches to measurement and modelling that could provide more insight into the mechanisms of transmission.

9.26. The first paper prepared by EMG and presented to SAGE on 28th April (Environmental influence on transmission of COVID-19) considered a number of questions relating to mitigation measures including duration of exposure, 2 metres distancing, surface cleaning and ventilation {CN/26 – INQ000192100}. Similar to above, this paper also drew on pre-pandemic studies with the small amount of early transmission data for the SARS-CoV-2 virus.

9.27. At this stage evidence for the routes of transmission for SARS-CoV-2 was uncertain. It was an appropriate assumption that as a virus that appeared to transmit through respiratory routes that it was important to consider the emission and fate of particles from human respiratory activities and the various mechanisms by which people could be exposed to virus carried in these particles, but that there was not clear evidence for the importance of particular routes. However even in early April 2020 there were some indicators that were important: most transmission appeared to be where people were in close proximity but there were reported outbreaks with large numbers of people infected in a short period of time which suggested super-spreading; there was minimal evidence of transmission of the virus in outdoor environments; laboratory evidence suggested that the virus was stable in air for several hours and could survive on some surfaces for up to 72 hours.

9.28. The EMG consensus from the early evidence suggested that close-range exposure to respiratory particles and via hands following contact with contaminated surfaces may be the most likely routes of transmission. However, emerging evidence suggested that

longer-range airborne transmission (greater than 2 metres distance) was a possibility and hence measures focusing on ventilation were recommended as important as a precautionary measure alongside hand/surface hygiene, reducing duration of exposure and 2 metres distancing. Updated evidence relating to these routes was shared in a paper on 4th June 2020, which highlighted the emerging but still weak evidence for airborne transmission {CN/27 – INQ000192101}. Papers over the period to support fundamental understanding for transmission routes included evidence around environmental survival, hand hygiene and airborne transmission {CN/58 – INQ000192131, CN/59 – INQ000192132 & CN/60 – INQ000192133}; these papers are discussed in more detail in the sections below on transmission modes.

9.29. During spring 2020 a significant contribution from EMG was around proposing risk assessment frameworks for supporting the identification and implementation of appropriate mitigation measures in different settings {CN/61 – INQ000192134 & CN/62 – INQ000192135}. This was based around an approach widely used in health and safety known as the hierarchy of control, which essentially classes different approaches according to how likely they are to be effective. The approach recognises that eliminating a hazard is the most effective approach, and that measures such as wearing personal protective equipment, while effective, rely on human behaviour and hence may be the least robust in practice.

9.30. Although the hierarchy of control is imperfect for managing transmission of a virus, it provided a useful and familiar risk assessment framework to consider mitigation measures that could be rapidly used to support recommendations. The approach recognised that the most effective measures were those that prevented people from interacting together (e.g. work from home/closure of settings), but that this was not always practical or desirable. Engineering controls such as ventilation and layouts of buildings, if implemented well, can provide effective baseline measures that require relatively little human intervention. In many settings it was essential to recommend a range of measures that considered both the routes of virus transmission and the engineering, administrative and personal approaches that could be applied to mitigate transmission.

9.31. Other questions considered by EMG (including their work with other sub-groups) over this initial period included specific risks and mitigations in healthcare settings, and care homes which was driven by concerns over risks for patients/residents and healthcare staff {CN/34 – INQ000192107, CN/35 – INQ000192108 & CN/37 – INQ000192110}; as well as public transport {CN/63 – INQ000192136 & CN/64 – INQ000192137};

theatres {CN/65 – INQ000192138}; schools {CN/41 – INQ000192114}; high contact occupations {CN/66 – INQ000192139}; and singing/music, which reflected the considerations for particular spaces and activities relating to easing of restrictions {CN/52 – INQ000192125 & CN/67 – INQ000120541}. Initial papers on air cleaning and disinfection technologies were also prepared to support questions around the potential for these approaches to mitigate risks {CN/68 – INQ000192141 & CN/69 – INQ000074995}.

9.32. In all of these cases, we applied understanding based on our understanding of transmission and approach to risk assessment alongside, where possible, sector or activity specific evidence. In some cases, there was emerging evidence that could be applied, or there was relevant pre-pandemic information either on the risk or on the environment and behaviours that may lead to risks.

9.33. Considerations around singing and playing of wind instruments was a particularly difficult challenge. This was prompted by evidence for a number of outbreaks worldwide that involved choirs, had high numbers of secondary cases and had some evidence that airborne transmission may play a role. This prompted the need for research activity and careful evaluation of the evidence, which was carried out through a NERVTAG/EMG paper {CN/67 – INQ000120541}, and then a more in-depth review led by UKHSA (PHE) {CN/52 – INQ000192125} (see paragraph 9.19). The consensus was that evidence suggested that singing could be a higher risk activity, as the act of continuous loud vocalisation could be more likely to generate higher numbers of virus carrying particles. However, in reviewing the evidence we were acutely aware of the importance of singing and other musical activities for society and for many people's health and wellbeing. Therefore, providing advice to support approaches for how these activities could be carried out as safely as possible was an important priority.

EMG Evidence during Autumn 2020

9.34. Evidence over this period continued to build for inhalation exposure prompting greater need for guidance around control measures for airborne transmission. EMG produced papers on ventilation and the role of air cleaning {CN/01 – INQ000192045, CN/17 – INQ000192089 & CN/18 – INQ000192090}, both of which had a significant influence on guidance provided by both government departments and external organisations such as the CIBSE. These two papers both drew on baseline understanding of ventilation and technologies from pre-pandemic studies as well as models and evidence during the pandemic. While there was good proxy evidence for both

ventilation and air cleaning technologies to suggest that they could reduce airborne transmission, there was very limited data from during the pandemic or pre-pandemic to indicate the likely extent of an effect on transmission rates. Analysis had to therefore draw more on modelling approaches to show the likely relative impact of ventilation and air cleaning measures on exposure to virus rather than absolute measured risk reductions.

9.35. The EMG ventilation paper included data from ventilation- airborne risk models and references to some of my own academic research publications which I had co-authored during the pandemic {CN/17 – INQ000192089}. These included: a study that developed a relative risk index to assess the likelihood of airborne exposure in different settings {CN/70 – INQ000192143}; an analysis of the potential role of ventilation in a choir outbreak {CN/71 – INQ000192144}; a study that showed how Carbon dioxide (CO_2) concentrations in spaces from exhaled breath could be related to a risk model {CN/72 – INQ000192145}; and a study that used measured data from schools to evaluate the likely differences in seasonal risk {CN/73 – INQ000192146}. These and other publications were used to illustrate how models could be used in different ways to compare relative risks. Models and analysis from my work and others worldwide were also used to make recommendations around CO_2 concentrations in indoor environments that were likely to be indicative of good ventilation and poor ventilation from a disease transmission perspective.

9.36. A key focus over Autumn 2020 was on supporting decision making and application of NPIs in different settings. This involved a greater level of bringing together advice from the perspective of several different sub-groups (including the newly formed TSG) to address a wider perspective on the complexity of factors that influence transmission, risks in different settings and practical challenges with applying different mitigation approaches {CN/74 – INQ000074996}.

9.37. Examples of cross-subgroup papers focusing on approaches to mitigating transmission during this period include a broad evaluation of NPIs including harms as well as effectiveness {CN/75 – INQ000075003}; papers on higher/further education which considered the reopening of these sectors in September 2020 {CN/39 – INQ000192112 & CN/40 – INQ000192113}; papers on the impacts of home environments {CN/76 – INQ000188929 & CN/77 – INQ000192150}; household social interactions {CN/78 – INQ000075014}; and celebrations and observances which were promoted by growing evidence that a large proportion of transmission happened in home environments and that during the autumn period people were more likely to

spend time indoors and get together for various religious festivals including Christmas {CN/79 – INQ000074992}. While these papers were prepared to support advice that could be given by policy makers, we were also aware that SAGE papers by this stage were widely disseminated by the media. Therefore, in providing evidence relating to practical advice that related to public interaction in homes we were mindful that this was very likely to be used directly by media outlets.

9.38. During Autumn 2020 EMG also worked with NERVTAG to provide an update on the complexity of transmission, the impact of seasonal conditions on transmission, and concerns over duration of wearing of face coverings {CN/80 – INQ000075016, CN/81 – INQ000074947 & CN/82 – INQ000074945}.

EMG Evidence during Winter 2021

9.39. The emergence of the alpha variant (B.1.1.7) in December 2020 prompted a review of evidence during early 2021 as it rapidly became apparent that the variant was more transmissible. This raised concerns that all routes of infection may be more likely to result in infection, and in particular that long range airborne transmission (across a room and potentially between rooms) could more readily occur. EMG presented updated evidence around distancing and face coverings, and worked with other sub-groups to consider broad mitigations, and reiterated advice on household transmission {CN/83 – INQ000074962, CN/84 – INQ000063145 & CN/85 – INQ000138010}.

9.40. The establishment of the Transmission sub-group (TSG) meant that a number of papers over the winter period looked at evidence for transmission and mitigation in specific sectors and settings based on a combination of analysis of large-scale epidemiological data, information from outbreaks and understanding of the environment and behavioural factors in settings. The majority of this analysis aligned with, and reinforced, evidence provided previously on transmission and mitigations, but provided a richer picture of the complexity of when and where transmission takes place and the real-world practical challenges and behavioural factors experienced in particular settings. Papers considered a broad comparison of workplaces, prisons, hospitality, retail and leisure, and cross group work on enduring prevalence {CN/86 – INQ000192159, CN/87 INQ000192160, CN/88 – INQ000192161 & CN/43 – INQ000192116}.

9.41. During winter 2021 EMG worked with HOCI to look at masks for healthcare workers {CN/36 – INQ000192109} (see paragraph 8.4). This was one of the more challenging

papers to write as it was addressing an issue where there was a great deal of controversy, an environment which at the time was experiencing the highest peak of the pandemic in terms of admissions and deaths and where there are a lot of complex interactions between staff and patients, and where data on transmission and mitigation was patchy and showed considerable variability between different hospital trusts. The paper drew on data from a number of sources as well as the most recent understanding of transmission in the light of the alpha variant. The consensus view was stronger recommendations on the use of respirator (FFP3) masks than had been applied to date, with better use of local risk assessment to inform usage.

EMG Evidence Spring 2021 – February 2022

9.42. Commissions in early spring 2021 focused on support to the roadmap for opening up after the winter 2021 lockdown. This included work across sub-groups to look at implementing long-term baseline NPIs to slow transmission and enable workplaces and public buildings to reopen in as safe a way as possible as more stringent restrictions were gradually removed {CN/89 – INQ000074989}. EMG also supported SPI-B in a paper around sustaining behaviours to continue to mitigate transmission as restrictions were eased {CN/44 – INQ000192117}.

9.43. Reflecting the changing understanding around transmission, ventilation measures to mitigate airborne transmission was focused more strongly in advice, with a lesser emphasis on transmission via surfaces. A large proportion of UK buildings are naturally ventilated and rely on occupants manually opening windows to provide ventilation. This clearly brings a substantial level of variability and leads to lower ventilation if there is inclement weather, or the external environment is noisy, polluted or unsafe. An EMG/SPI-B paper in May 202 considered the use of carbon dioxide (CO_2) monitoring as a mechanism for actively monitoring ventilation, and made recommendations for how and where monitors can be used and the practical and behavioural considerations to enable them to be applied successfully {CN/90 – INQ000075006}.

9.44. The government's desire to re-open hospitality venues and events through a programme of demonstration sites offered a valuable opportunity for research. SAGE participants from various sub-groups encouraged the collection of data from a scientific perspective during these demonstration events to understand the environments, the interactions and behaviours of people at the events, and where possible to measure cases of infection during/after the events. This would allow for a greater understanding of the risk factors associated with large events and the practical implications of

applying mitigation strategies in different venues. EMG worked with DCMS on a science framework to support the events research programme {CN/91 – INQ000147231}, and I was involved in recommending scientific groups to DCMS who could be involved in delivering parts of the study focused on evaluation of the built environment. While I was not directly involved in the studies, the CSAs from BEIS and DCMS gave regular updates to EMG, and I participated in regular informal meetings to give feedback on the studies.

9.45. The delta variant which emerged over summer/autumn 2021 was both more transmissible and vaccination or prior infection seemed to offer less immunity. This acted as a reminder that NPIs were still important in managing risk and promoted another review of evidence by EMG in collaboration with other sub-groups. A paper with NERVTAG highlighted that there was no evidence for a fundamental difference in modes of transmission, but that greater transmissibility meant that there may be increased risks particularly through aerosol exposure at short and long range {CN/92 – INQ000075005}. Work with SPI-B and SPI-M considered the effectiveness of a range of measures proposed as part of the plan B mitigations for Autumn 2021 {CN/93 – INQ000120651}.

9.46. The emergence of the Omicron variant in December 2021 again promoted a further review and advice around NPIs with SPI-B {CN/94 – INQ000075010}. Again, this was not fundamentally different to previous advice, but highlighted the need for greater rigour with a more transmissible variant. EMG also provided support to a SPI-B paper on the implications of lifting remaining restrictions in February 2022 which indicated the importance of mitigating harms to those who are most vulnerable {CN/45 – INQ000192118}.

10: Modes of transmission and implications for mitigation measures:

10.1. In this section I have summarised my views on what we understood about routes of transmission through the pandemic, how my involvement in different groups (including outside SAGE) improved understanding of transmission and influenced advice given to policy makers, and the implications for advice given to the public and businesses. This includes some comments on where there was debate about routes of transmission and/or issues or reluctance with the application of different mitigation measures.

The importance of airborne transmission

10.2. One of the key debates around the route of transmission was whether the SARS-CoV-2 virus is transmitted through very small aerosols which can remain suspended in the air for long periods of time or whether it was transmitted through larger respiratory droplets which deposit out of the air quickly, typically within 1-2 metres of the infected person who exhales them (or indeed whether both mechanisms are important). In healthcare, the term airborne is reserved specifically for transmission that occurs over several meters via the smallest aerosols, while diseases which normally transmit at close range are termed droplet. Textbook definitions state that droplets are greater than 5 micrometres in diameter and deposit out of the air in 1 metre, while airborne infections involve tiny aerosols less than 5 micrometres in diameter. Healthcare procedures termed "aerosol generating procedures" (AGPs) for a number of years pre-pandemic have been considered to have the potential to enhance the amount of small aerosols that an infected person produces, and thus turn a "droplet" disease into an "airborne" disease. These AGPs could include an intubation procedure, the use of nebulisers or other breathing support, or the use of a dental drill that may aerosolise saliva.

10.3. The delineation between airborne and droplet transmission are at the heart of decision making around infection control. In a hospital setting airborne diseases normally require isolation rooms with specialist negative pressure ventilation and use of fit-tested respirator (FFP3) masks as well as eye protection, while droplet precautions have always involved much simpler segregation without specialist ventilation and with much simpler personal protective equipment (simple fluid-resistant (FSRM) mask, eye protection).

10.4. However, the definitions are too simplistic, and in many respects, they are also fundamentally wrong. Knowledge of the physics of particle behaviour has grown over the pandemic, but even pre-pandemic it was known that defining a simple size cut off for a particle staying in the air or depositing is incorrect. Evidence for the routes of transmission for a range of respiratory diseases has been explored pre-pandemic, with studies (including some of my own research) over decades looking at the complexity around the size distribution of particles that infected people exhale, which particles contain virus or bacteria and how this varies for different diseases, how these particles evaporate and are transported in the air, and how they can subsequently expose people. The emergence of a new virus transmitted through respiratory routes that was impacting people worldwide moved many of these research studies into the

mainstream discussion (and prompted many more) and highlighted the already existing concerns that the evidence for transmission of respiratory viruses suggested far greater complexity and uncertainty than the simplistic definitions of either airborne or droplet.

10.5. The EMG consensus over spring 2020 aligned with those of many others around the world, that there was emerging evidence that airborne transmission was important. I and others were concerned from early April that this was being overlooked by the public health bodies who were focused almost exclusively on exposure to droplets when people were at close proximity and on the role of contaminated hands and surfaces.

10.6. Outside of my EMG activities I joined an informal international group of scientists in early April 2020 (known as Group-36) who had broad expertise in ventilation and airborne transmission of infection and who were raising concerns that not enough attention was being paid to the potential for airborne transmission of COVID-19. Together with others in this group I signed a petition that was sent to WHO on 2nd April 2020 asking them to take airborne transmission of the virus more seriously.

10.7. I worked together with others in the Group-36 of international scientists to raise concerns with WHO that airborne transmission was likely to be important and was not being properly considered. In spring 2020 (available online 27 May 2020) we published an academic paper "How can airborne transmission of COVID-19 indoors be minimised?" which set out the initial evidence (and uncertainty) for airborne transmission and highlighted a range of practical mitigation approaches {CN/95 – INQ000192168}. Following a number of communications with WHO that were not fruitful we eventually wrote a letter (It Is Time to Address Airborne Transmission of Coronavirus Disease 2019 (COVID-19)), signed by 239 scientists that was published in the journal Clinical Infectious Diseases on 6 July 2020 {CN/96 – INQ000192169}. I was one of the Group-36 who drafted the content of this letter which called for airborne transmission of COVID-19 to be recognised.

10.8. This letter led to worldwide media attention and started to shift opinion. The possibility of airborne transmission outside of AGPs in healthcare was acknowledged by WHO, although this was still fairly cautious. This, together with the media attention, led to more focus on airborne routes of transmission among the public.

10.9. In July 2020 EMG and NERVTAG prepared a joint paper for SAGE specifically on aerosol transmission (Role of Aerosol Transmission in COVID-19), which acknowledged the change in WHO stance and the growing body of evidence for

airborne transmission being important {CN/60 – INQ000192133}. The paper reemphasised the previous advice around airborne transmission and mitigation which had been given by SAGE and highlighted the importance of ventilation measures and face coverings. Airborne transmission mitigations featured in almost all EMG papers throughout the whole of the SAGE advice period, with a growing focus over time on ventilation and air cleaning as the evidence base built for the importance of airborne transmission.

10.10. Despite a growing evidence base there was global reluctance to properly acknowledge airborne transmission. A number of news articles, including a piece in Al Jeezera which I contributed too, published two years after the Group-36 letter, comment on the time it has taken to acknowledge airborne transmission and the apparent global reluctance to do so {CN/97 – INQ000192170}. Group-36 also published a paper in February 2023 which explains the rationale for why the group had acted to raise awareness of the importance of airborne transmission {CN/98 – INQ000192171}. The supplementary information for this paper includes details of email exchanges with WHO.

10.11. The Inquiry have asked that I comment on the reasons for the reluctance to acknowledge airborne transmission. I believe that these are complex, and I can't be certain of which issues were of the greatest importance to policy makers. However, some of the reasons that I believe may have played into this were:

(1) Challenging embedded/accepted views: The categorisation in healthcare that respiratory virus transmission is traditionally defined as droplet or airborne is long embedded. Although evidence pre-pandemic was already showing that they were too simplistic, they persist as that is what has been taught for years and runs through all of infection prevention and control guidance. Changing a very established view can understandably be difficult both from the personal perspective of accepting a new approach and the practical implications. I am aware that there was pushback from some internationally in that the challenge to the established approach was coming from aerosol scientists and engineers who were considered outsiders rather than the medical experts. I never experienced this discipline bias myself in the UK, but I can't speak for others.

(2) Implications for hospital infection control: If a disease is declared airborne, it is assumed to default to higher levels of protective equipment and environmental control which has very significant resource and operational implications. From an international (WHO) perspective this also brings challenges around inequalities as many developing countries would not be able to provide this

level of mitigation. At the outset airborne controls were only applied in healthcare settings where so called AGPs took place (including COVID-19 intensive care), but droplet precautions were the norm in other parts of hospitals and communities.

(3) Fear of public reaction: The term airborne is potentially fear inspiring and invokes some of the catastrophic risks seen in movies. In the early days I think there may have been concern that declaring a disease to be airborne could lead to significant public concern, particularly if people thought that it meant it could travel very long distances (say outdoors).

(4) Resourcing and ownership for mitigation: Transmission through the air needs ventilation or air cleaning measures to mitigate it. This both has a resource implication (cost and equipment) and also transfers responsibility for the mitigation from the individual to the owner/operator of a building.

(5) Complexity of mitigations: Airflows in buildings are complex and invisible so can be hard to understand. People's motivation for ventilating a building is more than just the role it plays in infection transmission, with aspects around energy costs for heating, thermal comfort, external air pollution, noise and security coming into play. The solution for one building is not necessarily the same as another. In terms of public messaging, improving ventilation is much harder to encourage than personal measures such as wash your hands.

10.12. Because airborne transmission is not an accepted "default" unless there are AGPs taking place there appears to have been a requirement for a much higher burden of evidence to underpin action around mitigation measures throughout the pandemic than for other modes of transmission. I feel that transmission via the air was not taken seriously enough, and the demand for more definitive evidence hampered mitigations being applied in a timely manner. The same level of scrutiny was not applied equally for all modes of transmission which in my view didn't lead to a balanced enough application of mitigation measures.

10.13. Evidence during the pandemic has shown the importance of the air, with the body of research demonstrating both mechanisms for transmission and the potential for mitigation approaches. However, there are still considerable research gaps around understanding the frequency with which airborne transmission happens and the extent of the role that it plays in the spread of an outbreak. Much of the understanding of airborne transmission comes from modelling and laboratory studies using proxies for airborne viruses, with a growing body of epidemiological evidence that the

transmission can only be explained by airborne routes in some cases. There is still a need to understand the details of airborne exposure and mitigation mechanisms and to properly couple mechanistic studies with epidemiological studies to understand the significance of airborne routes in different circumstances.

Transmission at close proximity

10.14. The risks of transmission when close to an infected person were a key part of early EMG focus primarily because this had a significant influence on guidance around physical distancing. Emerging evidence in spring 2020 suggested that risks were higher at close proximity, however this was difficult to corroborate as most early evidence was anecdotal rather than based on studies with sufficient epidemiological data to evaluate robustly.

10.15. As highlighted above, the conventional thinking in infection prevention is that transmission at close proximity is synonymous with exposure to large respiratory droplets that deposit out of the air quickly (see paragraph 10.2). However fundamental understanding of fluid dynamics and knowledge around the size of aerosol emissions produced by people indicates that this is not the sole explanation. Short-range exposure to small aerosols is as likely to lead to increased risks, simply because these aerosols are much more concentrated at the source. Although a virus is not the same, cigarette smoking can provide a useful analogy where smoke particles are densely grouped together close to the source, but then as they disperse in a room, they become diluted by the air and are less visible.

10.16. Alongside the activity of the Group-36 to raise awareness of long-range airborne transmission, members of this group also highlighted the importance of short-range exposure to aerosols through models and data that explained the physical processes involved. This activity led to WHO changing their statements on transmission on 23rd December 2021 to acknowledge that airborne transmission included both short-range and long-range exposure routes {CN/99 – INQ000192172}.

10.17. Judgements around the risks at close proximity were initially made in EMG papers based on evidence from modelling and laboratory studies which looked at the dispersion of aerosols and droplets in the exhaled breath of people. These studies recognised this short-range aerosol exposure as well as potential for exposure to larger respiratory droplets and highlighted that an exhalation, particularly a cough, singing or continuous talking produces a distinctive jet or a puff of exhaled breath that can carry

particles away from the infected person. Risk decreases with distance, and although 2 metres was used in guidance it is not the case that this is a fixed threshold whereby people are suddenly safe. In the absence of quantitative epidemiological data on distance, evidence from modelling studies were included in the EMG paper from 28th April 2020 to give some estimated differences in risk as distance increased {CN/26 – INQ000192100}. Based on the modelling data we indicated that the risk could be 10-30 times higher at 1 metre compared to 2 metres. This EMG paper also indicated that duration of exposure is an important factor, and highlighted that additional measures such as face coverings, enhanced ventilation, partitions and positioning of people could mitigate short range exposures to enable distancing below 2 metres.

10.18. Updated advice in the EMG paper on 4th June 2020 (Transmission of SARS-CoV-2 and Mitigating Measures EMG-SAGE) indicated further evidence for transmission at close proximity, and also drew on a newly published systematic review and meta-analysis around distancing and masks {CN/27 – INQ000192101}. While there was a lot of uncertainty in this meta-analysis and it almost exclusively drew on pre-pandemic infection data, it was the first attempt that we had seen to quantify the impact of distance on respiratory disease risks. An updated estimate of 2-10 times the risk at 1m compared to 2 metres was included in this EMG paper, based on both the new evidence and previous modelling and laboratory studies. It was highlighted that although a number of other countries recommended distancing less than 2 metres, almost all of them recommended additional measures, usually face coverings to mitigate close range exposures; at the time in the UK there were no other measures recommended to the public. This EMG paper also included summary tables for multiple mitigation approaches together with an evaluation of the confidence in the quality and quantity of evidence.

10.19. As well as distancing reducing direct exposure to the virus from face-to-face interactions, implementing a distancing requirement in some settings has the effect of reducing their occupancy. The importance of occupancy is relevant for all transmission routes, as the lower the occupancy the lower the probability of an infected person being present and the smaller the number of people who could be infected. Occupancy is highlighted in multiple EMG papers and also considered more widely in SAGE with respect to the concepts of “bubbles” or cohorting teams in workplace environments. Evidencing the effects of such approaches is challenging and largely outside of EMG activity, however it can be readily shown in models and indeed through basic logic that smaller groups of people are likely to result overall in lower risks.

10.20. Over time, data collected via the test and trace system on locations where people were infected and their recollection of behaviours, provided further evidence that exposure to the virus at close proximity was likely to be the most important route of transmission. This data is not able to explain the specific mechanism for transmission (large droplets, small aerosols or even direct contact), but provides further confidence that measures to mitigate exposure to aerosols and droplets at close proximity (distancing, face masks/face coverings) are important.

10.21. Media reports relating to a number of scientific studies have suggested that the 2 metres rule is an arbitrary distance or that the exposure could be as great at a larger distance when the air is well mixed throughout a room {CN/100 – INQ000192056 & CN/101 – INQ000192057}. Both of these studies use mathematical modelling techniques based on fluid dynamics to quantify risks, the former using computational fluid dynamics of a stationary person in an unventilated space to visualise the distance that particles travel, and the second to model exposure using the assumption that air in a room is well mixed and make the case for ventilation measures. Both are examples of studies that are in one sense correct and there is no "magic" distance which is safe, but the media focus their press release on a single aspect rather than considering the whole picture and complexity of transmission. Throughout EMG advice, although 2 metres has been used as a practical distance that reflects what we understand about face-to-face exposure with distance, it has always been acknowledged that it is not a fixed rule that determines safety, and that risk is a continuous range that depends on multiple factors including activity, distance, duration, and ventilation. It should also be noted that many of these studies were published in 2021 or later, long after the UK debate on 2 metres distancing in summer 2020.

10.22. The role of face masks and face coverings is particularly important for managing exposure to the virus at close proximity. A face mask or face covering worn by an infected person, known as source control, can substantially reduce the amount of virus emitted and therefore potentially reduces transmission by all routes of exposure. A face mask worn by a susceptible person can reduce the amount of virus that is inhaled. When people need to be at close proximity for any significant period of time (e.g. in personal care or health care settings) a mask is essentially the only practical mitigation measure to reduce transmission risks.

10.23. The effectiveness of how well a mask works as either source control or to provide personal protection depends on the quality of the mask itself, how well it fits the persons face, and whether they actually wear the mask regularly and correctly. Where

someone needs to be protected against aerosol exposure, including when at close proximity to an infected person, the most effective mask is one that is rated as FFP3 or N95, and is known as respiratory protective equipment (RPE).

10.24. Evidence for the effectiveness of masks comes from different sources. Laboratory studies, including using manikins and human volunteers confirm the effectiveness of the mask materials and can quantitatively show the relative impact of different types of masks particularly as source control. However, measuring the impacts of masks on transmission in the real-world is far more complex as their inherent ability to reduce transmission is compromised by the duration of wearing and how well they are worn. For example, a mask worn by an infected person for 10 minutes per day on a bus could comply with government mandates but would not impact on transmission that happens in that person's workplace, home or social settings. As a result, the impact of the mask on transmission at a population level may not be measurable.

10.25. EMG commissions in spring 2020 did not explicitly include requests to consider masks and face coverings, although these were increasingly included within the broad range of mitigation approaches. Masks and face coverings were considered explicitly in several papers where the evidence for both the mechanisms for how they worked and how they were worn were considered. This included papers on methods to enable re-use of PPE {CN/102 – INQ000075024}, the duration of wearing of face coverings {CN/82 – INQ000074945}, the role of face coverings and physical distancing in the context of mitigating the Alpha (B.1.1.7) variant {CN/83 – INQ000074962}, the joint paper with HOCI on masks for healthcare workers {CN/36 – INQ000192109}, and a consensus statement on face coverings contained within a wider paper on plan B measures {CN/93 – INQ000120651}.

10.26. Understanding how transmission happens when people are at close proximity is very challenging, as all transmission mechanisms may play a role, and transmission is likely to be very heavily influenced by human behaviour. There are very few studies that have attempted epidemiologically to quantify risk with distance, primarily because distancing is not an easy intervention to implement consistently as it relies on people complying with an instruction. Much of the evidence relating to risk with distance comes from modelling and laboratory studies, and there remains a need for future research to better measure transmission mechanisms using human data in realistic settings.

Transmission via fomites

10.27. Transmission of respiratory viruses via fomites refers to the role that surfaces and hands play in enabling exposure to the virus. Surfaces can become contaminated with virus via the deposition of exhaled droplets and aerosols from an infected person, and also by the infected person touching surfaces with their contaminated hands. A susceptible person could become infected if they touch the contaminated surface and transfer virus to their hands, and then they touch their mucous membranes (eyes, nose, mouth). For COVID-19 this route of transmission is feasible as there are receptor sites for the SARS-CoV-2 virus throughout the respiratory system including in the nose and the mouth.

10.28. At the outset of the pandemic, washing hands regularly and for twenty seconds was the primary advice for mitigating transmission. As indicated above, I am not aware of specific evidence to support this advice at the outset (see paragraph 9.24), but it is possible that this is either a default recommendation based on advice given for other respiratory viruses or was based on similar evidence to that which EMG reviewed in April 2020.

10.29. Early pandemic evidence of significant viral RNA on surfaces where infected people were present, and laboratory studies that showed long duration of virus survival on surfaces supported an evidence based for the EMG recommendations in spring 2020 to mitigate transmission through hand hygiene and cleaning surfaces. Evidence from an outbreak in Singapore and a study in China that found cleaning of surfaces to be beneficial also supported these recommendations.

10.30. NERVTAG and EMG considered transmission via hands in July 2020, including evidence from randomised controlled trials for hand hygiene interventions carried out pre-pandemic for other viruses {CN/59 – INQ000192132}. These suggested that good hand hygiene may reduce transmission of respiratory infections by around 16%, and that targeted hand washing in response to events was likely to be more effective than just regular washing.

10.31. Demonstrating transmission via hands and surfaces is a challenge, as in environments where people share surfaces, they also share the same air. For transmission to happen via fomites, it is necessary for enough virus to be transferred onto the surface, then transferred off the surface and successfully to the mucous membranes.

10.32. Mathematical models can help to analyse this risk, by characterising the probability of virus transfer at different steps in the process. A US Centers for Disease Control and

Prevention (CDC) evaluation of risks posed by surfaces which used such modelling estimated the risk could be as low as 1 in 10,000 for a single contact with a contaminated surface {CN/103 – INQ000192059}. Models of multiple surface contacts suggest there could be the potential for much higher risks of exposure in environments where there is a lot of shared surface contact {CN/104 – INQ000192060 & CN/105 – INQ000192061}.

10.33. As the pandemic progressed, the body of evidence for transmission via surfaces and hands did not grow at anywhere near the same rate as evidence for inhalation routes. A number of cases where fomite transmission was initially suggested in the outbreak investigation were dismissed following analysis of video evidence, additionally, epidemiological evidence from interventions was very limited. Evidence from animal models suggested that fomite transmission was possible but may be less efficient than via the air. This changing body of evidence meant that overtime, advice given by EMG (and by other bodies around the world) shifted from a strong focus on surfaces and hands and large droplets to a much greater emphasis on inhalation risks both at close proximity or via sharing the air in the same room/building.

10.34. Over the course of the pandemic there has been only a very small amount of epidemiological evidence that shows that a significant amount of COVID-19 is transmitted via surfaces, or that measures which focus on fomites (cleaning and hand hygiene) have been effective: yet these are recommended regardless and are considered a "default" measure. My own view is that we don't have evidence to dismiss fomite transmission, and based on modelling and laboratory studies transmission via surfaces and hands is possible and even though for COVID-19 it is almost certainly less important than inhalation, that mitigations still need to be in place. However, I also feel that we need further research studies to properly understand the importance of this mode of transmission, and that these studies have been overlooked both before and during the pandemic.

11: Relationship between evidence and actions taken by government:

Managing evidence vs policy interface

11.1. Throughout my SAGE activity I was careful to focus on scientific evidence and uncertainty and use this to highlight options and recommendations, but to recognise that decisions are taken by policy makers who have to balance information with a raft of other factors.

11.2. This was an important principle throughout preparing all papers I was involved in. EMG engaged with a very large number of departments. CSA's from HSE, BEIS, DCMS, DfT, Defra, DLUHC and representatives from NHS England and NHS Scotland all regularly attended meetings and actively participated in discussion, and I and other EMG participants spoke with multiple different Departments. This meant that EMG was able to be very responsive to direct concerns that were coming to those departments and scientific advice was able to more directly support guidance that was given to the public and businesses.

11.3. However, given the close relationship with CSAs, care was taken to ensure the challenges faced by departments were not used to influence scientific advice. We would look at evidence that related to challenges and reflect these challenges in papers, but EMG would not avoid saying something because it could lead to difficult policy choices. Where discussion in meetings inevitably strayed at times into aspects that were more operational, we used this to note potential challenges, barriers and trade-offs (including aspects beyond transmission of COVID-19). This was very beneficial for EMG participants as it provided an insight into the real-world complexity beyond some of the more theoretical or control scientific studies, but we were careful to reflect on these aspects appropriately in papers and to always identify the level of evidence to support statements in papers.

11.4. In some cases we would make direct recommendations, for example that specific guidance should be produced to support understanding for a particular mitigation. However, in many other cases it was recognised that any actions would be part of wider and more complex decision making and hence recommendations would be that the factors outlined in the paper should be used to inform strategy.

11.5. Expressing uncertainty in evidence has been an important consideration throughout all of the work we have carried out in EMG, other sub-groups and SAGE. In most of the documents that EMG produced the data did not lend itself to a quantitative description of uncertainty therefore we used appropriate wording based on the PHIA probability yardstick {CN/106 – INQ000192062}, and from June 2020 we routinely used confidence (low, medium, high) statements and to express uncertainty either in the evidence itself or in the extent of evidence available.

Government response to EMG guidance on transmission and mitigation

11.6. EMG evidence had a very clear and direct impact on the specific guidance that was issued to the public and to organisations around managing risks of transmission and the most appropriate mitigation measures that were implemented in homes, schools, workplaces, transport, and public buildings. Evidence from EMG papers influenced advice that was given around risk assessments, how and where to implement different mitigation measures and in the case of ventilation was the basis for specific values recommended for appropriate ventilation rates in buildings.

11.7. EMG evidence was generally reflected well in the guidance and "rules" that were set out by government. Scientific evidence from EMG and associated papers informed guidance provided by a wide number of departments including HSE, UKHSA, DfE, DfT, DCMS, BEIS and others. The direct relevance of the EMG advice was, I believe, what led to the attendance of so many CSAs at EMG meetings, as they needed the information to support their departments in writing sector appropriate guidance. Evidence from EMG was also acted upon by engineering professional bodies with the CIBSE, IMechE and RAEng all using EMG papers to underpin their advice and guidance.

11.8. I believe that the transfer of scientific advice into guidance and particularly the accuracy of this was facilitated by close relationships that developed between EMG, government departments and professional bodies. On multiple occasions I was asked to review guidance that had been prepared based on EMG advice. This did not change policy decisions but ensured that the information that was provided by government departments and agencies accurately reflected the scientific evidence to the best of our abilities.

11.9. We used "teach-in" presentations to policy makers in government on a number of occasions to explain the science behind the advice within papers in a more informal manner. These typically involved 3 speakers who would cover different aspects relating to evidence in a particular area, and always combined advice from EMG with relevant behavioural advice from SPI-B. This could allow us to better explain the complexity and uncertainty in an area which can be easier to do orally rather than written down. To the best of my knowledge, I spoke at five SAGE teach-in sessions and one teach-in for the RAEng IRE work. These are listed in Annex C of this statement {CN/107 – INQ000192063}. Based on high numbers of participants, and feedback from participants and the SAGE secretariat I believe that these were successful. They were all run as online seminars with the opportunity for participants to ask questions.

11.10. The practical relevance of EMG advice and the implications particularly for businesses meant that it came under scrutiny on a number of occasions, and as co-chair some of that scrutiny fell to me. For example, there was a substantial focus during spring 2020 around physical distancing and the 2 metres rule from a policy perspective, particularly driven by retail and hospitality business concerns that 2 metres distancing reduced occupancy to levels that were financially unsustainable. On 22nd May 2020 I was asked to give evidence to a Science and Technology select committee, where I discussed in detail the complexity of transmission and the evidence relating to physical distancing. A transcript of this evidence session is available {CN/108 – INQ000192064}. Letters from the chair of the committee Greg Clark to both the PM and the GCSA followed this session {CN/25 – INQ000192099 & CN/109 – INQ000062271}; one letter selectively used EMG advice (see paragraph 5.38). A distancing review published by Cabinet Office on 24th June 2020 drew on significant EMG evidence and was used to inform changes to guidance in summer 2020 {CN/110 – INQ000137229}.

11.11. The focus on 2 metres distancing extended to media reports with my select committee evidence and subsequent comments featuring in the media. In some media articles I am cited as "opposing" the reduction of the 2 metres rule {e.g. CN/111 – INQ000192068}. I urged caution because of my understanding of how virus can move in air and how distance relates to risk. In the advice that I gave through EMG, I recommended that where distances were reduced there should be additional mitigation measures implemented, such as face coverings or positioning people so they were not face to face, to mitigate the increased risk at shorter distances. This also reflected an EMG review of advice given in other countries; where distances less than 2 metres (or 6 feet) were recommended they either implemented additional measures or were in countries with very low rates of transmission {CN/27 – INQ000192101}. It is still my view that during 2020, with an unvaccinated population, that 2 metres was not over precautionary as it both reflected the understanding of how exhaled particles moved in air for people who were face to face, as well as acted to reduce occupant density in buildings.

11.12. While government departments were generally good at updating guidance as new evidence emerged, the dissemination of this guidance was not always as effective as it could be. In many cases legacy versions of guidance, particularly relating to risk assessments remained available online alongside new versions which created confusion for businesses. These were eventually replaced in June/July 2021 when there was a significant "tidy up" of the government websites. However, even following this, large numbers of businesses continued to display out of date risk assessments,

suggesting that they were either not aware that guidance had been updated or they had disengaged and were not interested in updating their approach. As a result, by late 2021, large numbers of businesses were not following approaches that were supported by evidence. Many were still implementing significant surface hygiene measures and utilising screens and barriers (both of which the evidence base now suggested to have very minimal benefit) but were not implementing ventilation measures which were likely to be more important.

11.13. There is clearly a challenge with ensuring that updated evidence is effectively disseminated to those who need to act on it, and explaining why the guidance has changed. There were substantial government communication campaigns that targeted the public (see paragraph 12.10). It appeared that there were less campaigns that were aimed at businesses, and some of the information was inconsistent as it came from a range of different and overlapping sources (e.g. HSE, BEIS, public health authorities, local and regional government bodies). Guidance was issued by multiple different government departments but could have some discrepancies. This may be a particular challenge where an organisation comes under a range of different departments. For example schools would be expected to follow DfE guidance but should also comply with HSE expectations and for performance spaces may also need to look at DCMS guidance. The focus groups in the RAEng IRE work (section 8) confirmed that there was confusion among organisations about the best approaches they should take.

11.14. The policy response to the emerging evidence around airborne transmission (see section 10) was not uniform across different sectors and was a source of frustration and concern for me. In some areas of government, the role of airborne transmission was recognised very quickly, and this was reflected in the public guidance. For example, although the mitigation measures were imperfect, when schools partially reopened in June 2020, they were recommended to keep their windows open. Similarly, there was a recognition in the guidance for public transport operators that ventilation was an important mitigation measure.

11.15. However, initially within UKHSA and even more so in the NHS, there appeared to be a reluctance to acknowledge the importance of airborne transmission beyond activities known as AGPs. While hospitals had taken steps early on to mitigate risks in their COVID-19 “red wards” there was less action on airborne transmission in other areas of hospitals or in pharmacies, GP surgeries or care homes. The advice given to the public on transmission was also led by UKHSA and therefore initially reflected the lack of awareness around airborne transmission. As detailed in sections 9 and 10 this

initially related to uncertainty of evidence, however the reluctance for health agencies worldwide to apply a precautionary principle around airborne transmission was likely due to multiple factors.

11.16. In September 2020 I raised concerns to senior advisors (Sir Patrick Vallance and Sir Chris Whitty) that the SAGE advice around transmission was not being reflected in the public guidance given by UKHSA and the NHS on their websites {CN/112 – INQ000192069}. Given that these were likely to be the main place people would visit for advice (particularly the NHS when looking for symptoms/testing), it was frustrating that these public information sources were not updated quickly to reflect the changing understanding around transmission. PHE (UKHSA) revised their information quickly in September 2020 {CN/113 – INQ000192070}, but it was not until June 2021 after further raising the issue at SAGE 91 on 3rd June 2021 that the NHS website was updated to recognise airborne transmission in their public guidance {CN/114 – INQ000061599 & CN/115 – INQ000192071}.

11.17. Actions within hospital and other care settings to mitigate transmission to protect both patients and staff could have better acknowledged airborne transmission. During the first wave, evidence was uncertain and although in hindsight greater action to mitigate airborne exposure would likely have reduced risks for staff and patients, making that judgement at the time was subject to uncertainty. Evidence reviews that EMG carried out in Spring 2020 together with HOCWG did have some positive impacts around use of masks in healthcare and other measures {CN/34 – INQ000192107 & CN/35 – INQ000192108}. In particular the widespread wearing of masks by staff, patients and visitors was recommended as a source control. However, as the pandemic has progressed and the evidence for airborne transmission strengthened, it would be hard to argue now that there is not a need to take precautions against asymptomatic transmission through aerosols. Yet even in April 2023 there were very high rates of nosocomial transmission with little action taken to combat it. Throughout the pandemic, the NHS/IPC cell have maintained their own rapid review service to provide an evidence base and appear to require a much higher burden of proof to accept airborne transmission or evidence for the better application of ventilation measures or use of respirator masks than other public and workplace settings across the UK.

Government response to wider SAGE guidance

11.18. The government response to SAGE advice appeared to vary quite a lot through the pandemic, with some advice acted on very well and other advice having a limited

impact. This is of course in part due to the need to balance the response to the pandemic with multiple other factors including the social and health harms that lockdown or restrictions created, as well as the very substantial economic impact of the pandemic. The economic aspect was not within the remit of SAGE, and we believed that others in government were evaluating this impact. While detailed analysis of the wider social and health impacts was also not strictly in our core remit, they very much featured in discussions and we drew on published evidence in multiple papers, with many SAGE participants acutely aware of the potential consequences of some actions.

11.19. In multiple papers that EMG was involved in we highlighted challenges with inequalities and that there were complex trade-offs around implementing and complying with guidance {CN/17 – INQ000192089, CN/18 – INQ000192090, CN/38 – INQ000192111, CN/39 – INQ000192112, CN40 – INQ000192113, CN/41 – INQ000192114, CN/42 – INQ000192115, CN/43 – INQ000192116, CN/44 – INQ000192117, CN/45 – INQ000192118, CN/61 – INQ000192134, CN/66 – INQ000192139, C/74 – INQ000074996, CN/75 – INQ000075003, CN/76 – INQ000188929, CN/77 – INQ000192150, CN/78 – INQ000075014, CN/79 – INQ000074992, CN/80 – INQ000075016, CN/83 – INQ000074962, CN/84 – INQ000063145, CN/85 – INQ000138010, CN/86 – INQ000192159, CN/87 – INQ000192160, CN/88 – INQ000192161, CN/89 – INQ000074989, CN/90 – INQ000075006, CN/93 – INQ000120651 & CN/94 – INQ000075010}. At an individual level we regularly highlighted aspects such as some people being in jobs where they were unable to work from home, the lack of sick pay for some who needed to isolate, and the variation in home environments with some people in cramped or poor-quality housing less able to apply mitigation measures. From a workplace or public building level we highlighted the challenges with outdated or poorly maintained infrastructure, as well as lack of knowledge, motivation or resource to implement changes. In some cases, we recommended that incentives (including financial) be considered to support structural and organisational actions to enable both individuals and businesses to comply with measures.

11.20. Although substantial support was put into test and trace, and some limited support was provided to enable people to isolate effectively, there was almost nothing implemented to enable organisations carry out significant mitigation actions around improving building ventilation to reduce exposure to the virus. This very likely had a negative effect on reducing inequalities, with those individuals and businesses with more

resources more likely to have the means to take more effective actions to reduce exposure.

11.21. The inquiry has asked me to comment on the view from the Institute for Government that *"in the initial months, ministers put too much weight on SAGE – relying on it to fill the gap in government strategy and decision-making that was not its role to fill".* This report particularly commented that ministers put too much weight on SAGE during the early months and that may have been a factor behind the timing of the first lockdown {CN/116 – INQ000063070}. As I was not a participant in SAGE until April 2020, I do not feel that I can make a judgement on the response to SAGE advice in the early months, including the events which led to the first lockdown. As a scientist with an understanding of disease transmission, it was clear from the exponential growth in cases and experiences in other countries prior to the first lockdown that the situation was going to get severe unless action was taken. However, this is my observation as an educated member of the public and I cannot comment on the relationship between scientific advice and decision making during this phase.

11.22. My first involvement in SAGE coincided with the spring 2020 lockdown and the considerations about how to best manage risks as restrictions were eased. Over summer and autumn 2020, there were a lot of different rules which appeared to change frequently but were largely attempting to manage transmission. Most were based to some extent on SAGE advice but were not always a sensible interpretation of it. For example, the "rule of 6" was likely based on advice that interaction in smaller groups could limit transmission, however the specific rule was defined by policy makers and was complex and cumbersome to apply particularly for larger families. Similarly, the tier system was based on understanding that a higher level of response in areas of higher prevalence could potentially reduce transmission, however the reality of the system led to considerable confusion as well as potentially compounding inequalities in areas where prevalence remained high.

11.23. The Inquiry has asked me to comment on the *"eat out to help out scheme".* This was an economic incentive for business rather than focused on managing the virus. To the best of my knowledge this scheme was not based on SAGE advice. From an EMG perspective focusing on environmental transmission, the fact that it only applied on certain days of the week was a concern as that could act to promote crowding through encouraging people to all visit venues on the same days. I am aware that analysis by the University of Warwick suggested that the scheme increased transmission; the detail of this analysis is outside of my expertise, but it is published in a reputable peer

reviewed journal, and I have no reason to doubt it {CN/117 – INQ000192072}. In early July 2020 SAGE participants indicated that there was a strong case for prioritising reopening schools over other settings, and that maintaining low transmission over the summer would be important for this to happen {CN/118 – INQ000061554}. There was a feeling that children had suffered more from the impacts of the lockdown and that keeping schools closed any longer would be highly detrimental to children's education and wellbeing. A scheme that prioritised pubs and restaurants over the summer seemed contrary to this priority.

11.24. Over the duration of my time as a SAGE participant, the period during autumn 2020 was probably the most frustrating. At this stage we were still dealing with the original variant in an unvaccinated population and therefore risks of severe illness and death remained high. Cases within the population were considerably lower than we are used to by 2023, but because the risk of severe illness was so great, there was considerable concern that cases would rise. Many restrictions had been eased, but there did not appear to be a good public or leadership commitment to many of the other measures such as face coverings and good ventilation. SAGE participants were concerned that cases were rising and that although in the early autumn the numbers were small, the patterns of earlier in the year looked set to be repeated. There was a desire to avoid a full-blown wave which would most likely result in further extensive lockdown, and hence limited duration restrictions or a "circuit breaker" together with closure of some settings were suggested as a way to reduce the size of the wave without creating such significant disruption.

11.25. This period was one of the few times where I expressed some public concern, including commenting in a Financial Times article that I didn't feel that measures such as a curfew and greater enforcement of the rule of 6 were likely to be effective when indoor hospitality venues were open {CN/119 – INQ000192073}. This was based on my understanding of transmission, including airborne transmission, and a view that if multiple groups of people were sharing a space for several hours, transmission could easily happen between groups and that shutting the venue early would make little difference.

11.26. The Inquiry asked me to comment on a cartoon that I shared on twitter in October 2020 {CN/120 – INQ000192075}. This cartoon subsequently featured in a story written in the Daily Mail about me, suggesting that I had criticised the government response {CN/121 – INQ000192076}. The cartoon commented on waiting for something to happen before taking action and indicated that by then it may be too late. I don't recall

my specific reasoning for sharing the cartoon; it was most likely related to concern over slow action in Autumn 2020, but it equally applied to many other things such as action on climate change. I do not know why the Daily Mail felt that this tweet was worth writing a story about. The experience made me realise that journalists were watching my twitter account and prompted further caution about sharing personal information.

12: Public Health Messaging and Communications:

Media engagement in a personal capacity

12.1. I have had significant media engagement in a personal capacity where I have been asked to comment in multiple articles in print, broadcast and online media. I have also been involved in some more significant media engagement both on how the virus is transmitted and on my own career. The most significant of these was the Royal Institution Christmas lectures in December 2021. Others included BBC radio productions (Life Scientific 19th Jan 2021, Inside Science 11th June 2020, Start the week 27th December 2021).

12.2. The vast majority of interviews and comments that I have given focus on explaining the science behind transmission and mitigation and highlight practical steps and the reasons why people can apply measures such as ventilation, air cleaning, masks, distancing etc. Throughout this media activity I have generally avoided commenting on either the work of SAGE or given a view on the UK response to the pandemic.

12.3. I am active on Twitter and have tweeted about the virus transmission and strategies to mitigate since February 2020. I have also posted on a small number of occasions on LinkedIn. As with print and broadcast media the majority of comments focus on explaining the science behind transmission and evidence rather than providing commentary on SAGE or a view on the UK response. In a small number of cases I have expressed some frustration on Twitter or in comments in the print media with government responses.

12.4. On occasion I have also provided some high-level explanation about how SAGE works or set right misunderstandings or commented on the benefits of working collaboratively with SAGE colleagues. As an independent academic participant in SAGE, I was not bound by any specific rules around talking to the media beyond my commitment to the Nolan principles. However, I always respected the confidentiality and sensitivity of SAGE activities and I have not commented on the discussions that happen in SAGE or its sub-groups or given a strong view on how well government has followed advice.

Support to government communications

12.5. In late August 2020 I was asked by the CMO'S Office in DHSC whether I would provide scientific support to a new public facing communications campaign including TV adverts around social distancing, washing hands and face coverings {CN/122 – INQ000192077}. This was the Hands Face Space (HFS) campaign. Initially they wanted someone from EMG to attend filming to be a "set consultant" with the idea of ensuring that the comms had a visual appeal but were scientifically realistic. The support was discussed between myself, CMO's office and the EMG secretariat and we also recommended that they involve someone from SPI-B to give advice from a behavioural side.

12.6. Through CMO's office I was introduced to others at DHSC and to people at Freuds who were producing the HFS campaign. I was not involved in the initial concept but was involved in a small number of meetings and email exchanges in planning the detail of the campaign in the few days running up to filming in early September 2020. These meetings all included members of the production team as well as colleagues from DHSC and the Government Communication Service (GCS).

12.7. The HFS campaign used a number of everyday interaction scenarios such as a supermarket, sitting on a park bench 2 metres apart as well as some visuals around contamination of hands and how droplets and aerosols dispersed from respiratory activity. The production team used video of people in staged sets (this was during restrictions so filming couldn't take place in real settings) which was then overlayed with a VFX technique to show the virus carrying particles. There was a particular concern around visualising how respiratory aerosols and droplets may move in the air, and the team producing the comms wanted this to be as realistic as possible whilst still being appropriately stylised for a media campaign.

12.8. I was not able to attend filming in person, however after some discussion I agreed to support remotely to check scenes and images via email and WhatsApp. This focused on commenting on positioning of people and objects on scene and the activities they did in order to best illustrate the transmission mechanisms and the impact of the protective measures. I was also involved in reviewing the script for the voice over to ensure that the right terminologies were used, in preparation of key messages for the press release (including quotes), and I gave a small number of interviews to the media that explained the science behind the videos. This first HFS campaign focused on personal actions, ventilation was not a core of the videos. However, although they did

not explicitly focus on ventilation, the script and the visuals were used to show the movement of respiratory particles in air, and ventilation was included in the key messages for the media. The campaign was released on 9th September 2020.

12.9. The Inquiry has asked me to comment on criticism by some scientists of the HFS campaign, who suggested that the order of the words placed emphasis on the wrong thing and suggesting that space was the most important {CN/123 – INQ000192078}. Our understanding of transmission would suggest that space or face are probably more important than hands, and as evidence has accumulated, that fresh air is also probably more important than hands. I was not involved in creating the initial "Hands, Face, Space" concept or strapline, and therefore I don't know why the words were placed in the order that they were. However, with respect to the actual campaign videos and materials there was no hierarchy in the actions, with distancing between people, face coverings and hand hygiene modelled throughout all of the scenarios in the campaign.

12.10. Following my involvement in these first HFS videos, I became involved more regularly in the development of comms. In all cases this included involvement in the initial discussion of new ideas as well as supporting the design, delivery and media promotion of several poster, social media and video campaigns relating to mitigating transmission. As best I can recall the specific campaigns I was involved in were: brief comments on a poster campaign in October 2020; a refresh of the HFS campaign in late November 2020 which included a specific focus on ventilation; the Every Action Counts "sliding doors" film in December 2020; a campaign focusing on parties in December 2020; the Hands Face Space Fresh Air campaign in March 2021 (coming out of lockdown); and Autumn behaviours (Stop COVID-19 hanging around) campaign in September to November 2021. In the majority of campaigns, I was quoted in the press release and often did media interviews. I was also filmed as part of an interview with media personality Katie Piper during February 2021 as part of the Stay at Home campaign during the winter lockdown. In the Autumn behaviours 2021 campaign I featured as an "expert" in a promotional piece in the print media, which was run across multiple national newspapers. I may have also been in a similar piece for another campaign, but I can't recall which one.

12.11. With respect to communications around the role of ventilation, it gradually featured more prominently over the course of the campaigns. In HFS September 2020, it featured in a minor way as indicated (see paragraph 12.8), but it featured more explicitly in the refresh campaign in November 2020 which actively showed ventilation behaviours like opening a window. In this case the words "fresh air" were preferred in

videos rather than ventilation as this was better supported by consumer research. Ventilation could be used as a word in the accompanying press notice and key messages as well as media broadcast. Estimates of the importance of ventilation based on a SAGE EMG paper were included in the key messages information for the press {CN/17 – INQ000192089}. Similarly in the two December 2020 campaigns, ventilation behaviours featured in the videos. In March 2021 the words "fresh air" were formally added to the HFS strapline and logos. I am not fully aware of the decision making behind it, however it is likely that it acknowledges the greater body of evidence around airborne transmission by this time, the potential that new variants of the virus could be more readily transmitted in air as well as an encouragement for people to meet outdoors or in very well ventilated spaces as restrictions were eased in Spring 2021.

12.12. I believe that many of these various campaigns had fairly extensive reach based on my own observation of seeing them on social media and broadcast media. The Hands, Face, Space strapline was quite extensively used, and it is still apparent sometimes, however my views may be biased as my role and involvement may mean that I am more likely to spot the use of particular campaigns. Different campaigns had different target audiences and were promoted on different channels. For example, I never saw the parties' campaign, however I am certain that this is because it was not promoted on the TV or social media sites that I use as I was not the target demographic. I am not aware of the full reach of any of the campaigns or any metrics of how successful they were; I assume that DHSC or the Cabinet Office has this evaluation.

12.13. Timing of communication tended to follow phases of the pandemic and restrictions that were in place. The initial HFS was post summer 2020 as schools and workplaces returned and cases were starting to rise, with the autumn refresh coinciding with higher rates of cases and a need to boost messaging. The third iteration of HFS + fresh air was in March 2021 to coincide with opening up after the winter lockdown period. The autumn behaviours campaigns in 2021 were a reminder as the weather turned colder so more people were indoors and there are generally higher rates of respiratory viruses circulating. Timing of campaigns was not always coordinated well with other announcements – unfortunately the first HFS campaign was released on the same day that the prime minister first announced a number of new restrictions including the "rule of 6", which I suspect distracted from the campaign message in the mainstream media.

12.14. My work in supporting communications arose out of my role in EMG and my knowledge of how respiratory particles disperse in rooms. As I had significant involvement in the

detail of the HFS video campaign and subsequent campaigns it is reasonable that I could be described as the main scientific consultant as detailed in an online article {CN/124 – INQ000192079}. I am aware of input from a colleague in SPI-B, and some of the campaigns I shared the key messages text with colleagues in EMG to ask for feedback, and I also involved colleagues from the PROTECT national core study in some of the discussions on particles in air, and also the ventilation and breathing videos for the 2021 Autumn behaviours campaign. However, I do not know whether there was further scientific advice given by others around the concepts for any of the campaigns. The campaigns focused on communicating scientific understanding rather than new scientific evidence and therefore did not involve EMG more widely. All the work I carried out to support communications was unpaid.

Consistency of communication

12.15. The Inquiry has asked me to comment on the channels of communication, whether changes in understanding were adequately communicated and the clarity, consistency and rationale of messaging over the pandemic. I have also been asked to comment on the observation from the Institute of Government that communication of risk was *"confusing…ministers have switched back and forth between alarm and reassurance, while failing to drive home key messages, such as the risk of gathering in indoor and poorly ventilated settings."* {CN/116 – INQ000063070}. While some aspects of communication worked well during the pandemic, at times I agree there was confusion. Over the course of the pandemic, there were many different rules, alert levels, tiers etc which varied across England, changed regularly and were not always consistent with the devolved nations. This was particularly the case through 2020 where there were a great number of changes and the government response felt very reactive rather than proactive. It felt like the communications in 2021 were more consistent, and at the same time, based on the requests to SAGE, there appeared to be greater levels of coordination and consistency in planning and response from government. For example, aspects of the staged approach out of the winter 2021 lockdown were discussed with SAGE, with scientific advice from across the sub-groups used to support actions at each step.

12.16. With respect to guidance around aspects relevant to EMG such as ventilation, distancing, face coverings etc, this was predominantly in written documents available online for businesses and in communications campaigns aimed at the public. While these measures were mentioned regularly in the government briefings, they were given

limited explanation. I think the podium speeches could have been an opportunity to explain in more detail why these measures were likely to work. I believe that people are more likely to comply with measures if they understand how the virus spreads and therefore why the actions they are being asked to do are likely to be effective. It was this need that was at the heart of my own interactions with the media where I felt it was important to help the public to understand scientific evidence around transmission. With respect to government, I felt that the teach-in sessions (see paragraph 11.9) were valuable in supporting this understanding for civil servants.

12.17. My experience in working with government communications campaigns was that the advice shared through these routes became more consistent as the pandemic progressed, and increasingly campaigns were related to particular events during the pandemic to encourage behaviours as restrictions were changed. The communications and actions from ministers and advisors did not always align to the guidance and expectations they had set for the public and I believe that this created some significant issues with trust. Occasions of high-profile figures breaching guidance and not complying well with social distancing or wearing face coverings may well have set a tone that influenced public behaviour.

12.18. The Inquiry has asked me to comment on whether uncertainties in the scientific evidence were successfully communicated to government and then to the public. As highlighted above, expressing the limitations and uncertainty in evidence was always included in SAGE papers and was therefore in the advice that went to policy makers (see paragraph 11.5). I do not have knowledge of how this was discussed verbally with senior policy makers or how policy makers interpreted it.

12.19. Uncertainty did not always seem to be well understood by the public, but it is hard to determine whether this was because of government communications or media interpretations. I believe that it is the case that some media outlets presented some SAGE outputs without appropriate levels of uncertainty, for example though presenting the worst-case scenarios in SPI-M model data as "predictions". With regard to aspects relevant to EMG there were some very good examples that explained the complexity of transmission and mitigations, and EMG participants including myself were often involved in supporting these media pieces (e.g. BBC's piece on ventilation and the Guardian's masks piece {CN/125 – INQ000192080 & CN/126 – INQ000192081}). However, there were also occasions where things were presented by the media in a deliberately provocative way. For example, face masks and face coverings have been

a contentious issue throughout the pandemic, and some media outlets worldwide have used uncertainty in evidence to dismiss face coverings as not worthwhile.

13: Aligned Research Projects:

13.1. Throughout the duration of and prior to the pandemic I have been involved in research relating to transmission of infection in indoor environments and the role of engineering control strategies. This includes two significant projects which received funding during the pandemic and the Inquiry have asked me to discuss, together with a number of other studies some of which were funded and others which were collaborations without specific funding.

PROTECT National Core Study

13.2. The PROTECT National Core Study on Transmission and the Environment was a £21 million programme that ran 2020-2023 led by Professor Andrew Curran at HSE involving, as far as I recall, 37 projects and over 200 researchers. The project was funded as one of six national core studies supported directly by HM government.

13.3. PROTECT was conceived in early summer 2020 after recognising the lack of robust data on transmission, particularly around where and how transmission was happening and the environmental factors that affect it. It was recognised that addressing these questions required a coordinated effort that considered the virus, environment and human behaviour together through an interdisciplinary approach.

13.4. The programme had six core themes which overlapped: Theme 1 focused on evaluating transmission in real work places predominately through outbreak investigations and analysis of national level data related to the work environment; Theme 2 focused understanding the physical mechanisms of transmission, modelling transmission and mitigations at a local scale (between people in the same location) and understanding ventilation mitigations in real work environments; Theme 3 focused on sector specific studies using deep dives and national level data to explore transmission and mitigation in a number of different sectors; Theme 4 focused on methods for measuring emission of virus and survival of virus in both laboratory and real-world settings; Theme 5 focused on experimental infection studies using animal models and human challenge data; Theme 6 was the overarching knowledge synthesis focusing around advice and practical tools.

13.5. I was asked by Professor Andrew Curran in summer 2020 to lead theme 2 of the programme, and in this role I was also part of the delivery management board (DMB) for the study. Theme 2 was, I believe, the largest theme in the programme encompassing at least 20 projects with 13 academic and Public Sector Research Establishments (PSREs) partners overall. The theme 2 budget was approximately £5 million distributed among partners according to the particular scale and duration of the various projects. This funded investigator and project management time, researcher salaries, consumables, travel and institutional overheads.

13.6. As part of the programme the University of Leeds had a total funding of £850,000 (2020-2023) to lead several projects on modelling transmission in air and on surfaces and exploring a new face mask design for sampling exhaled breath. This funding also supported my involvement in the management of the programme and my involvement in technical aspects of several other projects including risk modelling, ventilation studies, CFD modelling.

13.7. As a member of the DMB I was involved in the overall strategic vision for the programme, adapting this through the course of the funding, management of the programme, monitoring and reporting on progress, supporting the coordination of researcher networking events, identifying key findings that were particularly relevant to policy and practice, and dissemination activity.

13.8. As theme 2 lead I had responsibility for defining the overall strategic goals of the theme, working with individual project partners to define their particular programme of work and budget, forming connections between projects within the theme and across to other themes and other relevant research projects, monitoring and reporting on progress to the DMB and working with individual project leads to identify gaps in knowledge and new opportunities. I also had direct technical input into research activities in several areas through the specific project funding allocated to the University of Leeds.

13.9. The programme commenced in October 2020 with an initial group of projects including work on: outbreak investigations in workplaces led by HSE and PHE (theme 1), deep dives into industry sectors to understand their response (theme 3), initial modelling of transmission including computational fluid dynamics models (CFD), quantitative microbial risk models and agent based workplace transmission models (theme 2), methods for understanding of respiratory emissions (theme 4) and transmission via animal models (theme 5).

13.10. When funding was confirmed for year 2 (April 2021-March 2022) in early 2021, theme leads within the DMB developed strategic needs for the year and brought in a wider group of projects and partners to deliver research. Due to the short time period between funding being announced and commencing, most of these partners were already in the programme or invited based on their expertise through working on projects in related areas either during the pandemic or prior to the pandemic. However, this second financial year also included an open call for projects that brought in new partners, though again these were constrained in time by the funding model. The final year of the programme (April 2022-March 2023) had reduced funding, so focused on consolidation and application with a slightly reduced group of papers. Most of the research was completed by January 2023, with the programme ended on 31st March 2023.

13.11. A key part of theme 2 work was on developing and applying models for the transmission of COVID-19 and mitigation methods. Rather than the population scale epidemic models that were widely used to inform national level policies via SPI-M work, the modelling within PROTECT theme 2 focused on local scale transmission to look at person-to-person mechanisms in a single room, a series of connected rooms or a whole workplace. This meant that models were built on physics principles that considered aspects such as the emission, evaporation and dispersion of respiratory particles, the physical properties of the room(s) that people may be in, the presence of mitigation measures (masks, screens, ventilation etc) and how these worked from a physics perspective.

13.12. Data on human behaviour was incorporated into models, for example the duration of time that people spent at different distances from each other, the frequency with which people coughed, talked, touched surfaces, cleaned hands, touched their face etc. These physics-based models were coupled with microbial data on for example viral load/emissions from an infected person, survival of the virus in air or on surfaces, breathing rate for inhalation exposure, and in some cases how the virus interacted with the susceptible person to lead to infection.

13.13. Some risk models considered simplified approaches focusing on a particular aspect, which can be useful for making quick estimates about the relative importance of different parameters. Other models were complex and involved, with either a very detailed representation of the behaviour of aerosols and droplets using computational fluid dynamics (CFD) or stochastic (probabilistic) models that considered different routes of exposure to the virus known as Quantitative Microbial Risk Assessment

(QMRA). These more complex models are able to explore the variability due to different parameters, and the relative impact of different mitigation measures in quite complex scenarios.

13.14. It is essential to recognise that these models are an approximation of reality that include multiple assumptions and while some can be visually impressive, they are a representation rather than an exact representation. The level of detail depends on the complexity of the model, but all have to simplify a scenario and use parameters in the model that may be uncertain. These parameters can be determined through other studies with varying degrees of certainty including laboratory experiments, experiments with human volunteer, epidemiological data, real-world environment measurements.

13.15. Throughout the work in PROTECT, and in how the findings were interpreted and shared, we were always careful to highlight the limitations and uncertainty in the work. In some cases, we had a degree of experimental or real-world validation for models which could give a greater level of confidence in the findings. In other cases, some of the uncertainty could be expressed directly in the outputs from the models through showing ranges in a probabilistic model or showing the effects of changing parameters. The work within theme 2, and indeed the whole of PROTECT allowed an understanding of the relative importance of different factors and how that played out in reality. But as highlighted in section 9, no one study gives a definitive answer, and it is the combination of evidence from different sources that enables a more confident understanding of the most likely ways in which transmission happens.

13.16. Some projects within theme 2 ran over the whole duration of the programme and evolved depending on the priorities for research, while other projects were shorter, typically over a period of 9-18 months. Within theme 2 we grouped projects into three areas: 1) projects that focused on modelling the overall exposure/risk through different routes; 2) projects that focused on characterising one element of the process (e.g. aerosol and droplet dispersion, ventilation, virus emission rates, transfer efficiency for touching surfaces); and 3) projects that focused on human behaviour such as frequency of interaction in workplaces or frequency of face touching. Connectivity between projects allowed learning from one area (e.g. touch transfer efficiency) with other areas (e.g. modelling virus exposure via surfaces) to combine data in models and inform design of studies. Throughout, but particularly in the final year data from other PROTECT themes (e.g. outbreak sites, viral load from human challenge studies) was more widely used to inform models.

13.17. The Inquiry has asked me to comment on three specific projects within theme 2. These projects are examples which illustrate some of the studies undertaken, but represent only a small proportion of the activity within theme 2 and PROTECT as a whole:

(1) *Droplet Modelling: Understanding the Physics of Dispersal* used a simulation tool known as Computational Fluid Dynamics (CFD) to model how respiratory particles emitted from a person disperse over time and space. CFD is a well-established method for modelling the velocity, pressure and temperature of liquids and gases, and also modelling the movement of particles or gases within them. A programme which ran throughout the whole of PROTECT led by HSE and Dstl and in partnership with the University of Leeds developed and applied new models for particles emitted by a person when they cough or talk. These models incorporated aspects such as the angle of the exhalation, the temperature and humidity of the exhaled air, the size distribution of particles and how much virus they may carry, the evaporation of particles, and the movement of particles in air. Models were used to show how different sizes of particles may deposit out of the air or be carried by the airstream, what people's exposure to the virus may be at different distances from the infected person, and how factors such as ventilation, temperature and humidity in the room, and the use of screens could affect this. The initial model was validated against human respiratory bacteria emissions measured by UKHSA and published in an academic journal paper in February 2022 {CN/127 – INQ000192082}. Further modelling focused on the exposure with distance, temperature and humidity and illustrated that the exhaled air can carry particles further than expected. This model also showed that sometimes the higher levels of air movement experienced at higher ventilation rates can increase exposure for some people over short time durations. While the model is for a particular scenario it supports the guidance around 2 metres distancing as it suggests that for face-to-face interactions it is 2-3 metres when exposure starts to reduce more consistently. The work on temperature, humidity and distancing was published in an academic journal paper in November 2022 {CN/128 – INQ000192083}. The CFD model was also used to explore the impact of screens and added to evidence that screens could reduce exposure at close-proximity and for short periods of time, but that they do not mitigate aerosol exposure {CN/129 – INQ000192084}.

(2) *Agent-based Modelling of Workplace Transmission* developed an epidemic model for workplaces that could be used to explore the impact of different

mitigation measures on the likely transmission. This project was led by HSE, with input from across theme 2 and other themes within PROTECT to inform parameters used within the model. The project ran throughout the whole of PROTECT, with initial development during the first 6 months, refinement, verification and application in year two, and a focus on application to a particular workplace in the energy sector (with theme 3) in year three. The model represented individuals in the workplace (agents) and simulated the dynamics of infection over a time period of days to weeks based on a number of factors including their interactions with each other at close range and further proximity, whether they wore masks, whether they carried out testing, whether they were vaccinated, the ventilation in the workplace, and the density of occupancy (how many worked from home). The model was able to show the potential progression of an outbreak depending on a probabilistic model of how infectious people were and the interactions and mitigations present and could illustrate how some cases led to a significant outbreak, but other cases led to almost no transmission. The model could be used to show how different measures were likely to affect the progression of an outbreak and was compared with outbreak data from theme 1 analysis to verify the model.

(3) *Wear-It: Using Wearable Technologies to Characterise Physical Interactions in Workplaces* is an HSE led project that focuses on understanding whether it is feasible to use wearable devices using a combination of Bluetooth (BLE) and ultra-wideband (UWB) radio signals to measure interactions between people in workplaces. This data is important to understand how much time people spend at close proximity compared to greater distance in the same shared spaces in different types of work environments. Using wearable devices enables distance and duration of interactions to be estimated. Distance between wearables initially identified by BLE to be within a 5m range are then accurately estimated using UWB and Time of Flight measurements. Data from the study can be used in models, such as the agent-based model described above, to provide more realistic estimates of workplace interactions. This study was conceived during the second year of PROTECT (April 2021) and extended through into the third year of the programme. There was a relatively long lead time as the study needed ethical approval, identification, purchase and testing of the wearable technology, and then recruitment of workplaces into the study which commenced in November 2021. Data was collected from three initial workplace sites of different sizes (a science and technology organisation, a food

manufacturer, an engineering organisation) during the first quarter of 2022, and the devices were also deployed during a conference in May 2022. A further five sites were visited during the second half of 2022.

13.18. The types of transmission models developed in theme 2 of the PROTECT study (and supporting data collection) have also been developed and used throughout the pandemic by other researchers in the UK and around the world. Models had also been developed for other diseases pre-pandemic, and many of the models developed in PROTECT were based on this body of previous research from partners within PROTECT and from studies published by other groups in the world. Models (and associated experiments) are useful for exploring the factors that influence exposure to virus and how different mitigation measures may impact on this exposure.

13.19. Evidence from transmission models were regularly included within EMG papers. The majority of evidence included in EMG papers was from models published by others rather than the PROTECT study, primarily due to the timescale for PROTECT compared to when evidence was requested. This meant that models were largely for other diseases or were relatively simple models, as the more complex work took time to develop. The majority of EMG requests that would benefit from these models were in 2020 and early 2021, which was before PROTECT had developed and published work. However, the fact that PROTECT was actively working on these models meant that I and others involved in both EMG and PROTECT developed very good awareness on the strengths and weaknesses of different approaches which was very useful for judging the quality of evidence used within EMG papers. Findings from CFD modelling of screens was incorporated directly into an EMG paper {CN/129 – INQ000192084}. Much of the findings from PROTECT also corroborated advice given in the earlier stages of the pandemic when there was significant uncertainty over the importance of different factors for transmission.

13.20. Learning from PROTECT was shared through a number of routes including: publication in scientific papers; presentation at scientific and practice facing conferences; publication of reports, blogs, videos and public facing statements on the web and on social media; and direct advice to officials in relevant government departments. As HSE was the lead for the programme, they were able to readily incorporate learning from the project into advice given to workplaces during the pandemic. A number of the theme 2 projects involved close interaction with specific government departments including Department for Education and Ministry of Justice. Learning from theme 2

also fed into government communications and advice given to care homes (early 2023).

13.21. To the best of my knowledge, the PROTECT programme is unique worldwide in being a connected study that considers transmission and its mitigation through multiple different approaches. There are many other excellent studies worldwide, some of which have been able to look at a particular area with a greater depth than PROTECT. However, the ability to bring together learning from across such a wide range of different disciplines and approaches has enabled very significant cross-over learning and enriched all of the projects within the programme.

13.22. My view is that the PROTECT study had a very good impact in understanding the complexity in how the virus is transmitted and in how best to develop and deploy measures to mitigate transmission. This impact would have been greater if the PROTECT study was initiated sooner, or more likely if this learning had been present to a greater extent pre-pandemic. However, this is hindsight, and in reality, given the massive amount of activity that was underway and the demand on people's time, I believe that PROTECT was set up and delivered in the most realistic timescale that it could.

13.23. PROTECT has developed new capacity and capability within academia and PSREs to be able to measure and model transmission of respiratory infection, together with substantial networking and connections, which I hope will be beneficial for future pandemics and the management of endemic respiratory diseases. There are currently no firm plans to retain this capacity. The PROTECT team as at July 2023 are actively preparing proposals to bid for future funding, however this will most likely be through standard UK research funding routes rather than through any strategic investment to maintain this capability.

13.24. The major limitation with PROTECT was in the funding model, which was delivered in financial years. This was a significant barrier, particularly for academic partners, who were not able to offer attractive research contracts to postdoctoral researchers (a 9-12 month fixed term contract is not particularly desirable) or to have confidence that they could retain research staff from one year to the next. This has three impacts: (i) larger scale projects such as intervention trials were not possible as they typically take more than 12 months from concept through to results; (ii) PROTECT has built capability and knowledge among senior researchers but has had a more limited impact in developing the next generation of early career researchers. This is both in continuity of funding, and that short duration studies do not allow sufficient time for key career development

activities such as presenting at conferences; (iii) many of the researchers who have worked on PROTECT will have already moved onto other projects, and if further funding is secured new staff will have to be recruited and trained. This is a loss of knowledge.

Transport Risk Assessment for Covid Knowledge (TRACK)

13.25. TRACK is a £3.4 million project funded by the Engineering and Physical Sciences Research Council (EPSRC) through their COVID-19 response funding and the Department for Transport (DfT). It is a large multi-partner project led by the University of Leeds and involving the Universities of Manchester, Cambridge, Newcastle, Imperial College, and two PSREs, UKHSA and Dstl. The research is carried out in collaboration with DfT and multiple transport stakeholders. I am the overall lead for this project providing coordination across workstreams as well as technical input to risk modelling.

13.26. TRACK was initiated by the former DfT CSA Professor Phil Blythe in response to the significant unknown risks around transmission on public transport and how to mitigate it. Following an online workshop with a number of academic stakeholders in Spring 2020 to discuss gaps in knowledge and how we could respond, I agreed to lead the project. The project commenced in September 2020 and initial funding was for 18 months, with an extension to funding taking the project end to December 2023.

13.27. The initial phases of the project focused on understanding the potential mechanisms for transmission of the SARS-CoV-2 virus on public transport, how this varied by mode of transport, how passenger demographics and use of public transport influence risks, and the relative effectiveness of different mitigation approaches. Within the project, we use a number of approaches including: mathematical modelling of transmission risk and mitigations, measurement of environmental parameters such as CO_2 as proxy for ventilation, use of surveys and wearables to collect passenger usage and preferences, use of CCTV analysis to understand where people sit and which surfaces they touch, microbial sampling to understand the prevalence of SARS-CoV-2 RNA within trains and buses, laboratory studies to evaluate the efficacy of some approaches such as anti-viral coatings.

13.28. TRACK was not able to directly measure transmission on public transport and didn't set out to address this question. We focused on using a range of proxy measures to evaluate the likely factors that were most important in transmission risks.

13.29. The close interaction with DfT and transport operators meant that findings from TRACK could potentially inform actions taken in transport as well as indicate where there were concerns in both the long and short term. TRACK did not inform the early response to the pandemic, but initial results were shared in winter/spring 2021 which may have influenced the roadmap for reopening and the long-term living with COVID-19 strategies.

13.30. Information was shared through a number of mechanisms including short summary statements for policy makers on findings, presentations and discussion at project steering board meetings, early access to scientific papers that had been submitted for publication, and regular informal discussion with officials. A TRACK academic journal paper on modelling transmission on a subway was also shared with SAGE for information prior to publication {CN/104 – INQ000192060}.

13.31. Conversations with DfT suggest that the TRACK project has been useful to support the policy maker understanding of transmission and mitigation approaches on public transport and provided evidence to support their policies, but I do not know how has actually informed political decision making.

14: Lessons Learned:

SAGE as an advisory group

14.1. The Inquiry has asked me to comment on the observation by the Institute for Government that SAGE was never designed for a semi-permanent role in long running crisis {CN/116 – INQ000063070}. I would agree with this, however my experience is that SAGE and its sub-groups worked remarkably well together and found effective ways to interact and provide relevant and timely advice. The way SAGE worked appeared to evolve over time, which I suspect was a combination of improving the efficiency of processes (for example around commissioning), as well as its participants and those in sub-groups collectively learning and becoming more effective at working together.

14.2. Given the significance and the duration of the crisis it was important that SAGE participants and papers were placed into the public domain, and many on SAGE would have liked this to happen sooner. However, this then placed a new degree of scrutiny on SAGE, with participants targeted by the public and the media with everything from helpful (but often wacky) ideas through to hate mail and threats. I along with other SAGE participants regularly spoke to the media about the science of the pandemic, in

some cases to support communication of our understanding of the virus but sometimes simply to limit the chance that people with an incorrect understanding filled the vast media void and created misinformation. It is inevitable that in a crisis such as COVID-19 that the scientific advisors will have some public exposure, but it would be important to consider for future crises how to more effectively manage this from the outset.

14.3. We were supported to manage security and potential threats with regular briefings and responsive contacts in GO-Science where we could raise anything more worrying. Being in the public eye was a new experience and at times was difficult from a wellbeing perspective. Over the course of the pandemic, I have become used to the press attention, and I have also had a lot of positive engagement with the press with many science journalists wanting to understand the science behind transmission and mitigations. However, at the point when SAGE participants names were made public, I was particularly concerned about what the media reaction may be resulting in tightening up my own and my family's security.

14.4. An effective advisory approach needs to have an ability for advisors to provide scientific advice to policy makers in a trusted and confidential environment. This does not mean that all advice should remain secret, but there needs to be appropriate space for policy makers to reflect on advice, make plans, and ask questions before everything is publicly scrutinised. I believe that overall, SAGE managed this process well, and once papers were made public allowed an appropriate timescale for policy makers to review papers before they were released.

14.5. The Inquiry has asked me to comment on the view from another SAGE participant who suggested that the UK should look to the models of other countries for scientific advisory structures {CN/130 – INQ000056580/9}. I am not familiar with the structures of other countries, so I am not able to comment on this suggestion. However, I would comment that scientific research and advice from the UK during the pandemic has been widely used in other countries, and some of our analysis and surveillance approaches, particularly the ONS infection survey, have been regarded as world-leading.

14.6. The Inquiry has asked me to comment on whether the UK's science-policy advisory mechanisms should be re-evaluated and how scientists and policy makers can work more closely and collaboratively to ensure effective translation of science into policy. My experience of the interface between science and policy has been predominantly during the pandemic, with relatively little experience prior to the pandemic, and therefore I don't have a good benchmark for interactions under normal circumstances.

14.7. However, I have had some very good experiences both through SAGE and through my research of working collaboratively with policy makers. As with many things, it is important to have good structures but much of what facilitates a good and trusted relationship between science and policy making is the people involved. Mechanisms to facilitate conversations and connections between scientists and engineers, and policy makers are invaluable for building relationships and helping both to understand each other's language and motivations. My experience working with government departments, is that where there is a science team within a department, that relationship works more effectively, as there are civil servants with scientific knowledge or a remit for understanding science who help to bridge between researchers and those who make policy. These teams can provide a valuable interface between scientists and senior policy makers, as a route to working collaboratively to understand the questions that need to be asked, to determine the routes and timescales for filling knowledge gaps, and to provide evidence in a balanced way.

Practicalities of SAGE

14.8. Joining SAGE and starting a new sub-group was a very rapid and significant learning curve, especially at the outside. This was both learning the role of SAGE, how SAGE interacted with policy makers, the roles of the different subgroups, as well as learning how different government department's function and interact together. Although the SAGE secretariat, Professor Andrew Curran, the HSE secretariat and many others within SAGE sub-groups and government were hugely helpful and took time to explain things to me, it would have been helpful to have some form of more formal induction with information on structures, who's who, do's and don'ts etc.

14.9. IT and data sharing was a frustration throughout the pandemic, with many participants struggling to access and work on shared documents across different organisations or even within different government departments. Despite this, the use of online meetings transformed the ability for SAGE to bring together expertise from across the UK and even worldwide, as well as for scientists to collaborate effectively on critical studies.

14.10. Creating simple, secure and cost-effective common systems to enable rapid sharing and collaborative working on documents would be really beneficial. This is both something for government to consider with regard to alignment of systems across different departments, but also more widely for providers of systems to consider accessibility of these systems across different organisations with different IT

infrastructure. The most accessible shared services (e.g. google docs) are rarely considered secure enough for cross organisational working.

14.11. I am aware that access to data from test and trace, hospital admissions etc was a major challenge for some of the other sub-groups and is an important part of lessons learned. This was less of a challenge for EMG as we were not reliant on specific data streams to inform our consensus. However, in a future scenario, this may become more important as models developed through research activities could well be effective in future pandemics if they can draw on the right data.

14.12. The secretariat teams were invaluable and carried out an amazing job behind the scenes. Each sub-group had its own secretariat which were often from different government departments, and therefore the ways of working differed between groups. This brought some benefits in terms of diversity as there could be cross-learning between sub-groups with regard to how they were run. However, at times this also made things more complex as there was a need to deal with different organisations, and different IT systems.

Understanding of the role of SAGE

14.13. The Inquiry has asked that I comment on whether boundaries between scientific advice and decision making were adequately communicated to the public, and my view on the comment by the Institute for Government that *"ministers' insistence that they were 'following the science' was inaccurate and damaging"* {CN/117 – INQ000192072}. I do think that the phrase "following the science" was at times used as a "shield" by ministers to push some of the responsibilities for their actions onto others. In some cases government actions did closely follow scientific advice, however at many other times the actions of government combined information from science around the pandemic with multiple other factors to take decisions that appeared to not align to the scientific advice. This is inevitable as the role of policy makers is to balance across different aspects and consider impacts that are wider than COVID-19 alone. However, the boundaries and scope of SAGE was not made clear to the public.

14.14. The public, and at times MPs, have misunderstood the role of SAGE with various commentators suggesting that "scientists had too much power", not recognising the difference between scientific advice and policy making, or not knowing the terms by which SAGE participants were engaged. It would be very helpful to have

processes/documents that make this process clearer for the public and for MPs so that these misunderstandings could be more readily rebutted.

14.15. SAGE participants were not paid for the very substantial time that they dedicated to the response. After the first few months, for independent participants a scheme was set up whereby Universities were provided with some funding to "buy out" time. While this provided a recognition of SAGE participants time, it was nowhere close to the financial value of the time that experts put in; I and I suspect many others worked very long hours at times approaching double our contracted working week. I firmly believe that this was the right approach and that SAGE participants should not be either seconded as civil servants or be paid experts; both approaches would limit the ability for academic participants in SAGE to be independent. However, there is a lack of public understanding of that SAGE participants were not paid (in comparison to many other organisations who received very large contracts from government), and that the time and financial value of their input has not been properly acknowledged; even though this will not be paid, I would like to see it valued.

14.16. At times the lines between external participants on SAGE and what would be expected if I was a civil servant felt like they were blurred, in terms of the time input and number of requests. Alongside my role in SAGE and as co-chair of EMG, I was asked to participate in a huge number of discussions, meetings, working groups and give comment by email on documents. Some were directly related to the scientific advice that we had given via SAGE or were specific committees/groups with a very clear purpose or remit. Others, for example my input to communications and some of the requests for input to documents, started as a request because of my role in SAGE, but after a while I was asked to input on multiple occasions. As I stated in my initial disclosure document at times it felt like some in government forgot that external participants of SAGE had day jobs in a university alongside the advice they were giving around the pandemic response. Perhaps in my case this was because there appeared to be quite limited in-house expertise within government departments and agencies around some aspects of transmission and mitigation, particularly with regard to ventilation and air cleaning, and therefore I seemed to become the "go-to" person for multiple departments whenever there was a question in this area.

Capacity and capability relating to environmental transmission

14.17. EMG was a new sub-group which had not been considered necessary at the outset of the pandemic or beforehand yet became one of the most significant groups of SAGE

with regard to guidance given to the public and businesses. The group brought together expertise in engineering/physics/design knowledge with the more established areas of mathematical modelling of disease, behavioural science, microbiology and health sciences that regularly feed into health response.

14.18. EMG had a very small pool of expertise to draw on; pre-pandemic there were a very small number of people in the UK (and indeed worldwide) who specialise in the relationship between the built environment and transmission of infection. Unlike some of the more established sub-groups, EMG had no past history of working together as a group and very limited capability in terms of labs, models and people to draw upon. The pandemic sparked a huge interest in research in the area of environmental transmission from people across the world working across a range of engineering, aerosol science, fluid dynamics and related disciplines. These people have done some tremendous work but were starting from a very low baseline without established collaborations or expertise and were not available at the outset for EMG to draw on.

14.19. As highlighted above, the message that airborne transmission was important was slow to be heard worldwide and not acted on well in many settings, particularly in healthcare. This was most likely due to a higher demand for evidence for something that appeared to challenge an accepted paradigm. However, it is also reflective of the relatively limited prior recognition of the importance of cross-disciplinary scientific advice relating to environmental transmission.

14.20. Over the course of the pandemic EMG proved to be invaluable as the scientific advice it delivered had the closest match to the practical guidance (distancing, masks, ventilation, hygiene etc) that government departments needed to provide to businesses and the public. The limited research capacity in this area was recognised by UKRI and Royal Society both of which provided funding for projects driven by academia and industry in the area of environmental transmission and mitigations. This was also recognised during the formation of the national core studies, where NCS PROTECT was funded to bring together a large group of researchers to address key questions relating to transmission and the practical experience in the real world.

14.21. Despite the importance of EMG during the pandemic, there are currently no confirmed plans for sustaining this expertise under normal times or embedding environmental and engineering considerations into future pandemic risk planning. Funding to support the area was discussed by UKRI and other UK research funders, but with government interest waning in the pandemic this has not been sustained and researchers are now

largely back to relying on the same generic funding streams that were available pre-pandemic.

14.22. As a result, many researchers who developed capacity in this area will return back to their pre-pandemic interests. This feels like a risk and a missed opportunity to build capacity in what is an obvious gap. I have a concern that if there is another pandemic in 10, 20, 50 years' time, this area will be back close to square one rather than having developed in a coordinated way with a connection into policy makers.

Future pandemic policy

14.23. As highlighted above, there is a need to consider the routes for scientific advice relating to the environment and mitigations for future diseases. At the moment there is no standing committee that has a role similar to EMG. I feel that it is important that future plans include routes for external advisors to contribute, as this provides a route to engaging with the wider research community should a challenge need it. I would also recommend that this expertise more routinely includes engineers who are not often engaged in advice relating to health challenges.

14.24. The Inquiry has asked me to comment on whether the public should be more engaged in the development of pandemic policy and how the country can work in partnership with communities on the ground. Engaging individuals and communities in research studies is routine in the health disciplines and is growing across other research areas. By engaging with stakeholders with different perspectives, knowledge and motivations it can provide valuable insights to research studies to understand the practicalities of new ideas and innovations rather than the theory. Within my field there are numerous examples of where technology interventions in the built environment have not been as successful as they should because the user understanding, and behaviour was not properly considered. Better engagement with communities can build trust and in the case of a pandemic is likely to result in better communication of risks and mitigations as well as more rapid understanding of the barriers to success. These aspects were repeatedly highlighted by SAGE, including in multiple papers that EMG produced often in collaboration with SPI-B.

14.25. I am not an expert in behavioural science and therefore there will be others with more expertise than me, but it feels like it is important to consider how public and community engagement can consider a wide range of views and issues in a transparent and balanced way. During the pandemic there have been a very large number of pressure

groups created who have held views on multiple different aspects of the pandemic response, often highly conflicting. In some cases, these groups act locally and independently, while in other cases they have backing of significant resource from PR groups, MPs etc. Some of these groups have been driven by their own issues, others have been driven by wider political agendas with COVID-19 being a useful vehicle to push other issues. It is important that any public input to pandemic policy is developed in a way that is objective and equal and doesn't just listen to those who have the loudest voices. Using and expanding on already trusted research-community or public-patient-partnership mechanisms to enable greater public involvement may be a good route to engagement.

14.26. Equality has been a challenge throughout the pandemic with those who have the lowest incomes, least stable jobs and live in the most deprived areas being impacted the most, both in terms of their chance of catching the virus and severity of disease and living in places that were most impacted by restrictions. It is important that the combined effects of multiple factors, which often have a cumulative impact, are considered in developing future pandemic policy.

14.27. I believe that closure of schools was a major issue during the pandemic with the greatest impacts from an educational and health perspective in those who were already most disadvantaged. While closures in March 2020 may have been inevitable due to the very significant and uncertain risks at the time, there were other phases during the pandemic such as during summer and autumn 2020 where keeping hospitality venues open was given a higher priority than education. Although schools were supported in monitoring ventilation through CO_2 monitors and access to air cleaners, this was not until late autumn 2021. Putting a greater level of investment into mitigating environments which contribute so much to long term societal equality and long-term economic growth such as schools could be better prioritised.

14.28. Evidence throughout the pandemic has exposed that a large proportion of buildings including schools, healthcare settings, transport, care homes, hospitality venues, workplaces and homes are poorly ventilated, and a focus on the cost of energy and climate mitigation is making this worse. A programme to improve environments in buildings, alongside other public health system interventions, would likely improve resilience to future pandemic risks including reducing inequalities, as well as also bringing wider health benefits.

Closing words

14.29. Despite the seriousness and urgency of the COVID-19 pandemic, and the tremendous amount of work it entailed, it was a privilege to have been part of SAGE and its sub-groups. I have never before worked in an environment that was so collaborative, so cross-discipline, so welcoming and so open to discussion. I feel that the experience of being on SAGE has made me a better scientist and engineer with a much better understanding of how multiple different disciplines can work together, and the importance of considering a wide range of factors well beyond those in my own knowledge. I have learned a tremendous amount from other scientists and civil servants and have gained a much greater respect for the diversity of science and the need for many different types of expertise to solve large and complex problems. I very much enjoyed working with the many participants on SAGE and in the sub-groups, and some have since gone on to become collaborators in research projects and proposals.

14.30. As co-chair of EMG I am tremendously proud of the achievements and commitment from members of EMG and wider SAGE participants and feel honoured to have worked with such a collegiate group of people. I feel proud that we started from nothing and rapidly became an important part of the pandemic response with a reputation for giving effective and practical advice. I would also like to pay a huge tribute to the incredible support from the HSE, GO-Science and other departmental secretariat teams who supported EMG, SAGE and other sub-groups throughout everything providing valuable advice on processes and coordination between teams often with limited capacity, time or resources.

Statement of Truth

I believe that the facts stated in this witness statement are true. I understand that proceedings may be brought against anyone who makes, or causes to be made, a false statement in a document verified by a statement of truth without an honest belief of its truth.

Signed: Personal Data

Dated: 20th July 2023