UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

June 2, 2020

EPA-SAB-20-006

The Honorable Andrew Wheeler
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Science Advisory Board (SAB) Scientific and Technical Review of EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19

Dear Administrator Wheeler,

The EPA's Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) review the document entitled, "EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19." The SAB's review and recommendations are provided in the enclosed report.

In response to the EPA's request, the SAB assembled the SAB COVID-19 Review Panel with subject matter experts to provide rapid advice on opportunities for current and future EPA research activities that might enhance and inform EPA's current and any future responses to SARS-CoV-2. The SAB COVID-19 Review Panel met by teleconference on April 30, 2020, to deliberate on the charge questions. Written public comments were considered throughout the advisory process. This report conveys the consensus advice of the SAB.

Overall, the SAB commends the Agency on its development of a compendium summarizing current understanding and capabilities related to SARS-CoV-2. The SAB largely agrees with the current and future EPA research ideas and includes several recommendations within this report, including the following highlights.

Paramount to EPA's research efforts is the identification of an infectious dose of SARS-CoV-2. Although the SAB acknowledges that this may fall outside the EPA's purview, the identification of an infectious dose and proper sampling and analysis techniques are pivotal to EPA's research objectives and the SAB's recommendations. Also, the development of techniques to sample and analyze virus viability on various matrixes and settings should be an Agency priority. The SAB's additional research recommendations include: the formulation of

a conceptual model; the characterization of the long-term disinfection properties of various agents (e.g., nano-silver or nano-copper products); the characterization of the environmental persistence of the viable virus in air, water, and on surfaces (e.g., aerosols, particulate matter, surface/wastewaters, plastics, metals, fabrics, among others); the investigation of factors to reduce virus viability in indoor and outdoor environments (e.g., heat, humidity, ultraviolet/sunlight, among others); the mitigation of indoor aerosol exposure (e.g., air exchanges, filtration, stand-alone air cleaners); the characterization of personal protective equipment effectiveness, disinfection, and re-use; and any potential health effects from increased use of disinfectants. Based on our present understanding of SARS-CoV-2, the SAB suggests that the EPA prioritize efforts on: 1) characterization and mitigation of risks from aerosolized droplets from infectious people, and 2) characterization, mitigation, and communication of risks from increased disinfectant use.

The SAB encourages that the EPA take these recommendations, if they fall under the EPA's purview, into consideration as the Agency finalizes its research plan. We also encourage the EPA to seek partnerships with other research organizations, as appropriate, to address these research questions effectively, efficiently, and to avoid unnecessary duplication of efforts. The SAB appreciates this opportunity to review EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19.

Sincerely,

/s/

Dr. Michael Honeycutt, Chair
Science Advisory Board

Enclosure

NOTICE

This report has been written as part of the activities of the EPA Science Advisory Board, a public advisory committee providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use. Reports of the EPA Science Advisory Board are posted on the EPA website at: http://www.epa.gov/sab.

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ACRONYMS AND ABBREVIATIONS

ACS	American Chemical Society
ATSDR	Agency for Toxic Substances and Disease Registry
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWWA	American Water Works Association
BSL	Biological Safety Level
CDC	Centers for Disease Control and Prevention
CSO	Combined Sewer Overflows
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPR	Direct Potable Reuse Treatment
HEPA	High-efficiency Particulate Air
HID	Human Infectious Dose
HVAC	Heating, Ventilation and Air Conditioning
IOS	Isopropyl Alcohol/Organofunctional Silane Solution
KWR	KWR Institute
MERV	Minimum Efficiency Reporting Value
NAS	National Academy of Sciences, Engineering and Medicine
NBACC	National Biodefense Analysis and Countermeasures Center
NCIRD	National Center for Immunization and Respiratory Diseases
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institute of Health
NIOSH	National Institute for Occupational Safety and Health
NSF	National Sanitation Foundation International
NSF	National Science Foundation
OSHA	Occupational Safety and Health Administration
ORD	Office of Research and Development
PM	Particulate Matter
PPE	Personal Protective Equipment
RNA	Ribonucleic Acid
RT-PCR	Reverse Transcription Polymerase Chain Reaction
RV-PCR	Rapid Viability Polymerase Chain Reaction
SAB	Science Advisory Board
SES	Socio-economic Status
U.S. AMRIID	U.S. Army Medical Research Institute for Infectious Diseases
U.S. DOD	U.S. Department of Defense
USDA	U.S. Department of Agriculture
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Service
USFWS	U.S. Fish and Wildlife Service
UV	Ultraviolet
WEF	Water Environment Federation
WRF	Water Research Foundation

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) review EPA's *Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19*. The EPA has a role to help the Nation respond to disasters and emergencies, including threats from biological origins, to ensure the protection of human health and the environment. The EPA's ORD assessed its research portfolio and has identified research areas where there are opportunities to advance the Agency's capabilities to refine and improve on the current understanding of SARS-CoV-2.

In response to this request, the SAB Staff Office convened a panel of experts drawn from the Chartered SAB, the SAB Chemical Assessment Advisory Committee (CAAC), and the SAB Drinking Water Committee (DWC) to provide rapid advice on scientific and technical issues related to the COVID-19 pandemic. The COVID-19 Review Panel, formed under the auspices of the SAB, consists of subject matter experts selected to provide advice on opportunities for current and future EPA research activities that might enhance and inform EPA's current and any future responses to SARS-CoV-2. Dr. Michael Honeycutt was asked to be the Chair of the COVID-19 Review Panel. Sixteen other distinguished scientists accompanied Dr. Honeycutt for this review which began with a teleconference on April 30, 2020.

The SAB anticipates that the scope and scale of the COVID-19 pandemic will lead EPA Program Offices to request additional advice on an array of scientific and technical issues. The SAB thinks that rapid advice from nationally recognized scientists and public health experts will assist the Agency in developing and implementing timely and scientifically appropriate responses to the COVID-19 pandemic.

The COVID-19 Review Panel was given a compendium summarizing current understanding and capabilities related to SARS-CoV-2. The document identified short-term and long-term research needs that could build on and extend EPA's understanding of SARS-CoV-2 in different research categories along with a list of four charge questions all of which may be found posted on the SAB website (U.S. EPA SAB, 2020). Written public comments were considered throughout the advisory process.

The remainder of this report is organized by charge questions within each research category. Each section includes a summary followed by the SAB's responses and recommendations. All materials related to the public teleconference and this report are available at: https://yosemite.epa.gov/sab/sabproduct.nsf//MeetingCalBOARD/AFBB297A2E1C38258525854C005AD300?OpenDocument.

2. RESPONSE TO CHARGE QUESTIONS

2.1. Environmental Disinfection

The SAB addressed each charge question. We also provide specific recommendations in the corresponding sections below. The SAB also notes that there are additional research questions important for the EPA to address. These suggested questions are included in the responses to the charge questions.

2.1.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

All short-term and long-term research questions provided by EPA for this research category are clearly described and well-suited to EPA's mission and capabilities. The EPA is already the lead federal agency on disinfection approaches and has well-developed protocols to address these questions. The research questions listed are potentially impactful in responding to the SARS-CoV-2 pandemic.

The public and other partners would benefit from EPA's experience with decontamination issues. The consumer application of the research could benefit from collaborating with the Consumer Product Safety Commission (https://www.cpsc.gov/). Given the urgency of some of the research areas, we recommend that the EPA consider engaging additional research partners (private sector, academia).

2.1.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several recommendations with respect to other research questions that should be considered by the EPA. The research questions are listed in Section 2.1.4.

2.1.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term environmental disinfection research questions and efforts.

> • Can basic cleaning techniques (e.g., using soap/water) be effective for disinfecting surfaces to reduce environmental exposure to SARS-CoV-2?

This is an important question, as prior work has found that surgical scrub (containing iodine) was more effective for virus inactivation than just antimicrobial soap. The SAB acknowledges that there are questions on exactly which types of cleaning techniques result in SARS-CoV-2 inactivation and this is an area that requires further research.

> • How effective are devices such as ultraviolet (UV), ozone generators or steam devices at reducing or eliminating exposure to SARS-CoV-2 from surfaces or objects?

There are ample studies showing that UV, ozone, and heat (steam) are effective for virus inactivation at well-described doses (e.g., temperatures). The SAB finds that this question is a low research priority. Although compatibility with surface materials could be an issue with these technologies, which is a concern for almost all disinfectants, the SAB recommends that the EPA compile available information on the disinfection properties of UV, ozone, and heat (steam) into a rapid communication for the public.

> • What available disinfection methods can be effective for complex and difficult to disinfect areas/surfaces (such as porous materials, soft surfaces, and heating, ventilation and air conditioning (HVAC) units)? What are alternative disinfection methods, if such methods are not readily available or efficacious for an area?

Over 400 products are already available on EPA List N - Disinfectants for Use Against SARS-CoV-2. This list reflects products available to address disinfection on hard surfaces, porous surfaces, and to deliver the products as liquids, fogs, mists, vapors, or gases. Therefore, a high priority for EPA is to focus on complex and difficult to disinfect areas/surfaces and to develop methods to demonstrate prolonged disinfection. The SAB recommends research on nano-silver or nano-copper disinfectants or other modifications for fabric and high-contact surfaces. The research could involve the use of surface analytical techniques (e.g. X-Ray Photoelectron Spectroscopy or Secondary Ion Mass Spectrometry) to determine the surface composition of the materials treated or infused with nanoparticles to understand the effectiveness of the anti-viral activity (Montes, 2017). Further, release profiles of nanoparticles should be researched to characterize the fate and transport of the nanoparticles in the environment (Kwok, 2016; Montes, 2017). Similarly, titanium dioxide-coated-photocatalytic surfaces (e.g., glass) have potential to address disinfection. This work could have great impact against SARS-CoV-2 and should be given high priority. The SAB also suggests that the EPA conduct studies on hard surfaces (e.g., different types of plastic) and encourages the Agency to include studies that address normal wear and fouling. The accumulation of organic matter and debris in scratches and abrasions on hard surfaces can create environments that can shield viruses from effective contact with the disinfectant.

Thermal disinfection at moderate temperatures has been demonstrated to be highly effective for coronavirus and have potential merit for disinfection of complex areas and surfaces. The rapid development of guidelines and methods to assess disinfection and the impact on surface materials also merits attention (Gallandat, 2017).

• What are readily available alternative disinfectants (not currently on EPA List N) for large-scale or special situation use and by what methods can these disinfectants be applied effectively?

The SAB found no products using nano-silver, nano-copper or other modifications on the EPA List N. These products and/or similar products may have particular benefit as long lasting disinfectants. The SAB notes that the effectiveness of surface coatings impregnated with antimicrobials or other antimicrobial surfaces (e.g., silver, copper) could also have high potential in reducing or eliminating exposure to SARS-CoV-2. The SAB regards the evaluation of these products' effectiveness, when used alone or in combination, as a high priority area to investigate. Advanced techniques for surface analysis and determination of metal fate and transport should be considered. Thermal disinfection techniques and guidance development also warrant investigation.

• Do methods of application of List N products via fogging and/or electrostatic spraying provide the necessary contact time on surfaces to be efficacious against SARS-CoV-2?

The EPA has protocols for application methods of disinfectants. The SAB notes that manufacturers may be able to use EPA protocols and/or their own protocols to demonstrate disinfection efficacy. The SAB notes that fogging and/or electrostatic spraying are two inherently different methods of application. Electrostatic spraying is a relatively new area of application and the Agency should work with manufacturers to address it.

• How effective are products that claim to offer residual/long-term (e.g., hours to months) ability to reduce potential exposure risk to SARS-CoV-2?

The SAB considers this is a high impact/priority question that the EPA should devote major efforts towards. The ability to demonstrate prolonged virus inactivation would be a significant development for SARS-CoV-2 management. Studies of isopropyl alcohol/organofunctional silane solution (IOS) have shown benefits for bacterial control, but virus inactivation data are sparse. Nano-silver and nano-copper products should be investigated to determine their capacity to reduce potential exposure risk to SARS-CoV-2.

• What disinfection methods (including using List N products) are suitable for residential and business-owner conducted disinfection?

Many disinfectants and cleaners are targeted towards residential and commercial business applications. As EPA mentioned, the stringency of the registration process provides a high degree of confidence in the effectiveness of these products when used according to the product label (https://www.epa.gov/pesticide-registration/efficacy-requirements-antimicrobial-pesticides). Therefore, the SAB regards this question as a low research priority. The SAB recommends that the EPA promote labeling that conveys adequate and understandable instructions and precautions, including but not limited to, labeling instructions available in multiple languages (see also Section 2.1.4).

• How susceptible to disinfectants are each of the human coronavirus isolates used for antimicrobial product registration, SARS-CoV and SARS-CoV-2? This comparative research may lead to the use of a safer-to-handle surrogate virus for future regulatory and research purposes, thus facilitating additional product and technology development.

Examining various strains of SARS-CoV and SARS-CoV-2 and other coronaviruses could yield interesting variations in resistance. However, differences impacting the selection of a disinfectant dose are less likely. To date, studies of disinfectants on MERS, SARS-CoV, and SARS-CoV-2 have found high efficacy without any evidence of resistant strains. While this line of research is interesting in that it will help with the basic understanding of disinfection for these viruses, it is more likely a long-term than a short-term need.

Long-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's long-term environmental disinfection research questions and efforts.

> • Are there situations where environmental disinfection of surfaces or objects may not be effective to reduce or eliminate potential exposure to SARS-CoV-2?

Disinfection efficacy can be influenced by the presence of organic matter, dirt, biofilm, and other debris that can block the action of the disinfectant. In these cases, evidence is clear that cleaning of the surface, followed by disinfection is effective. The SAB recommends that the EPA investigate conditions that prompt the use of multiple procedures to result in SARS-CoV-2 inactivation.

> • In situations where the frequency of recontamination is high, how often is disinfection needed to effectively reduce or eliminate potential exposure to SARS-CoV-2?

This question is based on the frequency of recontamination, rather than the efficacy of disinfection. This question is more appropriate for long-term disinfectants and factors that impair the long-term efficacy.

> • If SARS-CoV-2 is airborne and continues to settle onto surfaces (e.g., after surface disinfection), does disinfection of surfaces alone effectively reduce potential exposure to SARS-CoV-2?

This question is focused on understanding the route of infection (i.e., aerosols versus exposure contact), rather than how to disinfect the virus. The SAB recommends removing this question from this list and consider it under the Environmental Exposure research category. It is more relevant when multiple avenues of disinfection (e.g., air, surfaces, hands, etc.) are considered to minimize risk.

> • How effective are surface coatings impregnated with antimicrobials or other antimicrobial surfaces (e.g. copper) in reducing or eliminating exposure to SARS-CoV-2 and how should disinfectants be used in combination with these treated surfaces?

This is an important research question. The SAB recommends this question to be addressed as a short-term research objective (see specific recommendations outlined above). Examination of nano-silver, nano-copper, or other modifications is highly recommended. Isopropyl alcohol/organofunctional silane solution (IOS) have shown benefits for bacterial control, but virus inactivation data are sparse. The use of combinations of disinfectants and cleaning procedures is also recommended. Research into the fate and transport of the nanoparticles in the environment is also recommended, as noted above (Kwok, 2016; Montes, 2017).

2.1.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The research questions posed by EPA largely focus on specific disinfectants, surfaces, or delivery methods. The SAB recommends that the EPA consider a more holistic approach to SARS-CoV-2 disinfection based on a systems level. The SAB has a few questions about parameters and input data that could be strengthened going forward.

- What guidance can EPA provide for disinfection at a building level (surfaces or vacant rooms), for vehicles, or public transportation (e.g., cars, subways, trains, busses, airplanes, etc.)? Could overnight, moderate-temperature thermal disinfection provide effective disinfection for businesses and public settings? The SAB recommends that the EPA partner with other federal agencies in the development of cleaning guidance as related to the Agency's role (e.g., Guidance on Cleaning and Disinfection for Non-emergency Transport Vehicles) (NCIRD, 2020).
- Could UV disinfection within HVAC systems (along with high-efficiency particulate air (HEPA) or electrostatic filters, in vacant rooms or at night) be effective systems control?

The safety of disinfection methods and products, particularly when used in combinations or when deployed as fogs, mists, vapors, or gases needs to be more fully understood. Specific examples include the risks related to re-volatilization after application, and risks related to childcare settings where oral exposure to disinfectant residuals is highly possible. The formation of disinfectant by-products could pose a potential hazard to the public and both for dermal and inhalation exposures, and hence should be considered.

2.2. Environmental Sample Collection Methods

The SAB acknowledges that the research questions in this category assume that the transmission of SARS-CoV-2 is predominantly from emitted droplets from infected persons to surfaces for pickup and transfer to others, rather than infection via direct inhalation of expelled aerosol from infected subjects. The SAB provides a discussion about why direct infection via inhalation of expelled aerosol from infected subjects is likely to be a significant pathway of disease transmission for this virus (see Section 2.5). Acknowledging that the inhalation of expelled aerosol is a significant route of exposure and infection, opens a new series of methodical questions for environmental sample collection. Environmental sample collection of respirable aerosols should fit directly into this category and should be investigated as a potential pathway.

The SAB notes that there are additional research questions important for the EPA to address. These suggested research questions are included in the responses below to the specific charge questions. We also provide specific recommendations in corresponding sections below.

2.2.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The SAB finds that all research questions for this research category are clearly described and are well-suited to EPA's mission. The SAB notes that this research category is inextricably linked to the various research categories, including *Environmental Sample Analysis* (Section 2.3) and *Environmental Exposures* (Section 2.5), and encourages the EPA to regard the comments provided in this research category when considering those comments. The ability to accurately collect and process samples is critical to assess both risk of infection and mitigation efforts to manage the SARS-CoV-2 pandemic. The research questions related to environmental collection and monitoring are central to EPA's current activities. The SAB acknowledges that the Agency has deep expertise in these areas.

The SAB notes that the U.S. Geological Service (USGS) also has deep expertise in some of these areas and could be consulted to establish collaborations. Recently, the National Academy of Science (NAS) provided expert consultation on a variety of topics related to COVID-19 (NAS, 2020). The SAB suggests that the EPA work with other research partners to identify key research issues where collaboration is appropriate to leverage resources and expertise. Additional comments aimed at improving the clarity of specific research questions are given below.

2.2.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

Environmental Sample Collection of Inhalable Aerosols

As mentioned above, acknowledging that the inhalation of expelled aerosol is a significant route of exposure and infection opens a new series of methodical questions related to environmental sample collection. The collection of inhalable and respirable aerosols should fit directly into this category. For example, the National Institute for Occupational Safety and Health (NIOSH) has developed a methodology to detect infectious airborne influenza virus using the NIOSH bioaerosol sampler (Cao, 2011). Other samplers that collect bioaerosols may be reasonable choices (e.g., SKC BioSampler). Furthermore, a recent article presents a photographic/imaging technique from Japan that allows for a direct spatial visualization of person-emitted aerosol in the critical size range of 0.1 to 100 microns aerodynamic diameter (Broom, 2020). This technique could be used to evaluate the risk of exposure to potentially virus laden aerosol droplets in various indoor and outdoor environments.

Statistical sampling strategies (e.g., numbers, locations, frequency) are typically driven by the distance between the exposure that is measured or measurable versus a benchmark for "allowable" exposure. If there is a large separation or distance between these two values, then there is no need for a highly precise measurement of exposure. The number of samples required is also relatively small and the natural variation or error in the method can be relatively large. Non-detect values (i.e., values below the limits of detection) can be used if the limits of detection are low enough, relative to the benchmark for allowable exposure. A well-defined exposure limit or a reasonably defined distribution of effects over a range of exposures could render a reasonable exposure assessment (Jahn, 2015). A data point selected from that distribution can then be used to set a deterministic exposure limit (e.g., the 5^{th} percentile). The SAB notes that if the available sampling equipment/resources are not showing a prescribed level of conformance relevant to the selected exposure limit, then this is an area that needs to be researched.

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term environmental sample collection methods research questions and efforts.

- Under what situations does environmental contamination need to be assessed (e.g., when is it useful to enhance or enable decision-making)?

The need for environmental contamination assessments will be driven by the circumstances. Currently, there is a clear need to monitor high traffic areas (e.g., subways, buses, airplanes, office buildings, etc.) with the purpose of assessing and ultimately reducing exposure. See Sections 2.6 and 2.7 for additional recommendations.

- What methods (e.g., swabs, wipes, material types) are most appropriate for surface sample collection of SARS-CoV-2?

A variety of sampling techniques will be needed, including swabs, wipes, grab and composite sampling for a variety of environmental media (e.g., air, water, among others). The methods used for surface sample collection of SARS-CoV-2 should provide sufficient sensitivity for risk assessments. The EPA should focus research efforts on sampling techniques that inform at levels relevant for public health, which will be dependent on concurrent emerging research on the identification of an infectious dose and understanding how this dose may be different according to different populations of individuals.

- What are the detection limits and sample collection efficiencies specifically for SARS-CoV-2 for various environmental sample collection methods?

This is a key, high priority, research question. The SAB notes that the EPA can provide input on sampling techniques, analytical methods and their sensitivity. Evaluating sample collection methodology and protocols should be part of any environmental sampling program. The EPA is in a strong position to establish protocols that could be used by different agencies throughout the country. Conducting the sampling using standardized methods will allow the data from each agency to be pooled confidently for informing public policy. Lastly, the EPA should replace "surface sample collection methods" with "environmental sample collection methods" in this research question to be more consistent with the previous question. As mentioned above, other media such as "air" or "water" are addressed later in this document.

- What environmental sampling strategy(ies) (including number of samples, sample locations, frequency of sampling, and timing of sampling) will provide the most effective characterization of the presence/absence of SARS-CoV-2 on both non-porous and porous surfaces?

The SAB notes that many of the issues in the charge question can be answered using a publication developed by the EPA, entitled: "Biological Field and Laboratory Methods" (U.S. EPA, 1973). While this EPA publication could be updated, many of the statistical approaches to address the charge question remain relevant today. More recent references (Gilbert, 1987; Keith, 1996) could be consulted to update or modify statistical methods outline in the EPA publication, as needed.

Monitoring programs conducted by the USGS related to storm events can be used as models to address issues such as sample locations, frequency and timing of sampling (USGS, 2001; USGS 2009). As pandemic events are considered "episodic" like storm events, routine environmental sampling approaches (e.g., annual, semi-annual, or quarterly sampling) are not likely to provide the same degree of information. The work conducted on storm sampling by the USGS illustrates that environmental sampling needs to be based on the duration of the event to capture episodic situations. The SAB notes that there should be a robust basis for making these sampling determinations as they are highly dependent on other research questions being answered first. The SAB thinks that EPA's guidance and expertise would prove valuable in this research category to ensure that proper sampling designs are considered.

2.2.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

As mentioned above, setting criteria for adequate detection limits and sampling design (e.g., number of samples, replicates, frequency) are among the highest priorities in this research category. While all the suggested research questions in this category are valuable, questions that are more attainable and can be completed quickly could have a great impact on the characterization of the presence/absence of SARS-CoV-2.

2.2.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

All the research categories overlap with one another. The SAB recommends that the EPA organize the research categories using basic risk assessment elements (U.S. EPA, 2014). Generally, an evaluation of potential exposure pathways using an infectious SARS-CoV-2 dose at relevant levels to inform public health, can help identify populations and critical subpopulations potentially at highest risk in the context of exposure type, intensity, frequency, and duration. Potential risks and subsequent risk reductions can then be estimated using various mitigation techniques to help prioritize research efforts, taking into account the associated uncertainties. Sections 2.5, 2.7 and 2.8. provide additional recommendations that could help the EPA organize the research questions to reflect what is known about the cause-effect pathways and what is not known about SARS-CoV-2.

2.3. Environmental Sample Analysis

The SAB notes that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.3.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

All research questions provided by EPA are appropriate and well-suited to EPA's mission, and will be central to EPA's role in responding to the COVID-19 pandemic. Having accurate, sensitive, and specific analytical methods will be important for making correct determinations regarding risk and mitigation. The SAB notes that this research category is inextricably linked to the *Environmental Sample Collection Methods* (Section 2.2) research category and encourages that the EPA regard the comments provided in this research category when considering those comments.

Furthermore, analytical methods for determination of SARS-CoV-2 are being pursued by several universities, research agencies, and commercial laboratories (e.g., the Water Research Foundation, the KWR Institute in the Netherlands, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia). It will be important for EPA to coordinate with these agencies or organizations to avoid duplication. As a federal agency, EPA is in a unique position to establish critical parameters related to detection limits for virus assays. The Agency should work with associations like the American Society for Microbiologists to formulate and establish protocols that can be followed so these critical parameters can be determined whenever the need arises.

The SAB recommends that the EPA work with other organizations such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Water Works Association (AWWA), the Water Environment Federation (WEF), the National Sanitation Foundation (NSF) International, and the American Chemical Society (ACS) to ensure that EPA's research can also be used to inform the needs of these organizations. Many of these organizations provide guidance to their constituents in public health protection areas that are not directly under EPA's purview. In the absence of EPA's regulatory authority, these partners play an important role in protecting public health and providing guidance to their constituents in implementing best management practices.

2.3.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The rapid viability polymerase chain reaction (RV-PCR) work being conducted by the EPA is critical and should be completed as expeditiously as possible. It will also need to be examined and validated by other laboratories. This has been a major research need, and if the method is independently validated, it would be a significant contribution to science. If successful, this research could aid other EPA programs by reducing sample completion times and reducing the cost of virus analysis (e.g., improving sample collection efficiency as it is still a barrier to improving detection capability). The SAB suggests that a less expensive and more rapid response time would improve EPA's understanding of the fate of the virus in the environment.

2.3.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB has several recommendations and provides areas for consideration with respect to long-term environmental sample analysis research questions and efforts. Comments regarding prioritization are embedded in the discussion below.

- What are the SARS-CoV-2 sample analysis objectives (adequate specificity, limits of detection, viability assessment, turnaround time) and which methods are most suitable or can be developed to meet those objectives?

The specificity, accuracy, and precision of the data derived from proper environmental sampling techniques and of validated SARS-CoV-2 assays could be used to predict the human exposure risks and inform public policy. As analytical capabilities continue to improve, this will be an ongoing task for the EPA. The SAB suggests that this research question is both a short-term and long-term task for the Agency.

Furthermore, it is critical to develop clear performance objectives for the analytical methods, particularly as they can inform EPA's risk management actions. For example, the fact that PCR methods do not measure infectivity is not critical if the objective of analysis is to show the elimination of viral ribonucleic acid (RNA) by cleaning or disinfection procedures. However, an assessment of SARS-CoV-2 infectivity could also be important when assessing risk (Mosites, 2020; Belser, 2020). Given that many disinfection techniques can create nucleic acid lesions preventing the application of inactivated virions, the SAB notes that the use of long read primers (McLellan, 2016), long range amplicons (Wolf, 2009) and viability dyes (Randazzo, 2016) have shown some promise for molecular analyses.

- What are the most appropriate sample custody, preservation, transport, and storage conditions to maintain sample viability prior to analysis for SARS-CoV-2?

It is important that protocols for sample custody, preservation, transport, and storage conditions are developed to maintain sample stability prior to analysis for SARS-CoV-2, as loss of the virus during sampling and analysis could result in an underestimation of risk. In terms of maintaining sample viability, this question would only pertain to methods that seek to determine the infectivity of the virus. Since most current monitoring efforts would be based on the detection of the virus (typically by reverse transcription-polymerase chain reaction (RT-PCR) or immuno-detection), the need to address viability

in the sampling protocols is a low research priority. As methods are developed to assess virus infectivity, loss of virus infectivity during sampling, transport, and analysis becomes critical and is a high research priority.

- What is the current laboratory capability and capacity for molecular and viability analysis for SARS-CoV-2 and what method improvements can be made to increase capability/capacity? How does this reflect on the required environmental sample analysis needs?

The SAB recommends that the EPA initiate or assist in a national monitoring program for water/wastewater, air, and building decontamination, as well as support the critical aspects of availability, capacity, training, and coordination of molecular and viability analysis for SARS-CoV-2. Proficiency tests, controls, and inter-laboratory comparisons will need to be performed to obtain accurate analyses. Currently, there is a research gap in the ability of environmental laboratories to perform these analyses. The SAB thinks that the EPA should identify this issue as a key research need. The SAB also recommends that the EPA coordinate with other federal and non-federal laboratories to assist with scaling up testing and enhance laboratory capacity.

2.3.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2, already mentioned in the charge questions above.

2.4. Environmental Stability/Persistence on Surfaces

The SAB notes that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.4.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

Overall, the SAB finds that the research questions for this category are clearly described, well within the capabilities of the EPA, and well-suited to the EPA's mission. Nonetheless, the SAB notes that the EPA should consider if other government or academic laboratories are addressing similar research questions, and whether collaborations or partnerships with other research institutions could enable synergies or advance research beyond what would occur with parallel independent efforts. For example, the National Institute of Health (NIH), the National Biodefense Analysis and Countermeasures Center (NBACC) and Rocky Mountain Laboratories are studying effects of temperature and humidity on SARS-CoV-2 survival. The NBACC is also planning to test effects of solar radiation on SARS-CoV-2 survival.

2.4.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB acknowledges that some of the recommendations listed below are inextricably linked to other research categories and encourages the EPA to regard the comments provided in this research category when considering comments in the *Environmental Exposure* (Section 2.5) and *Air* (Section 2.7) research categories. Given the importance of virus in aerosol expelled by individuals infected with SARS-CoV-2, supplementary questions could be generated around the stability of the virus in aerosol or other fomites in air.

The SAB has several recommendations and provides areas for consideration with respect to EPA's environmental stability research questions and efforts.

- How long does SARS-CoV-2 remain viable on nano-coated surfaces? If such surfaces reduce viability, temporary or removable nano-enabled coatings, could they be applied to frequently contacted surfaces (e.g., railings or door handles)? Could they augment, or potentially reduce the use of disinfectants?

- How do heat, humidity, and UV or sunlight interact with respect to viral persistence and infectivity, both indoors and outdoors? See Section 2.7 for additional recommendations.

- Are the effects of heat and humidity on SARS-CoV-2 viability similar across types of surfaces, or are there heat/humidity-surface interactions, with surface-dependent effects (e.g., hard vs. porous surfaces)? See Section 2.1 for additional recommendations.

- How long does SARS-CoV-2 remain viable on groceries or other purchased goods, and consequently, what is the probability that there are viable levels of SARS-CoV-2 on purchased items when they arrive at the home?

- How long does SARS-CoV-2 remain viable on PPE, such as masks, gloves? See Section 2.9 for additional recommendations?

- How long does SARS-CoV-2 remain viable on surfaces typically found in children's indoor and outdoor microenvironments (e.g., playgrounds, beaches, school lockers, sport facilities, gyms, among others), and does viability of SARS-CoV-2 on such surfaces depend on ambient conditions such as sunlight or cloud cover? This question could inform whether children's microenvironments could be safely used (while maintaining appropriate social distance). See Sections 2.7 and 2.8 for additional recommendations.

- In addition to glass and stainless steel, how long does SARS-CoV-2 remain viable on hard plastic surfaces, among others, that have some degree of surface damage or which may have a waxy grime that could extend the viable life of the virus?

2.4.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

While all the suggested research questions in this category are valuable, the SAB finds the following areas to have the greatest impact and suggests given them higher priority:

- How long does SARS-CoV-2 remain viable on surfaces in outdoor conditions such as direct sunlight and various levels of relative humidity, temperature, wind, and precipitation?

- How long can SARS-CoV-2 remain viable on fomites (e.g., dust)?

- How long can SARS-CoV-2 remain viable on libraries, books, computers, mail or clothing, and does it pose a take-home, including school-to-home risk?

The SAB notes that it is not clear how the question "How does temperature and humidity impact persistence indoors" differs from the question "Can alternate environmental conditions (heat and humidity) be used to effectively reduce or eliminate the presence of SARS-CoV-2 on environmental surfaces?" Nonetheless, once effects of heat, humidity and UV/sunlight are known, consideration can be given to define conditions that would promote virus inactivation (e.g., Could installation of UV lights in

HVAC systems and areas of air exchange facilitate virus inactivation?). See Sections 2.1 and 2.7 for additional recommendations.

With respect to how long SARS-CoV-2 remains active on frequently touched surfaces, there are two potential measures: 1) the amount of viral nucleic acids; and 2) the viral infectivity or titer. Whereas the first measure is relatively straightforward and could be more readily addressed in the short-term, viral infectivity is more relevant, and hence, considered the gold standard.

2.4.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

2.5. Environmental Exposure

Overall, the SAB finds that the EPA document is a good start in defining the environmental exposure research needs to assess SARS-CoV-2. The SAB thinks that this research category could be enhanced with the consideration of the inhalation exposure route as a critical element of the environmental exposure research to be conducted by the Agency. There is evidence that inhalation of expelled aerosol from infected individuals is potentially a significant pathway in the spread of SARS-CoV-2 (Alford, 1966; Douglas, 1975; Little, 1979; Tellier, 2006). The SAB presented some of this evidence as part of the public teleconference on April 30, 2020 (Jayjock, 2020). A continuum of particle sizes ranging from less than 1 micron to over 1,400 microns is emitted when people cough, sneeze, speak or exhale (Nicas, 2005; Chao, 2009; Lindsley, 2010; Milton, 2013; Bourouiba, 2014; Skaria, 2014; MacIntyre, 2016; Bourouiba, 2020). These particles can deposit into the deepest part of the lung, the alveoli (Milton, 2013; Lindsley, 2010). The SAB finds that it will be useful for the EPA to research: 1) how long these relatively small, virus-laden particles remain in the air, and 2) the path and distance traveled by particles from expelled air using fluid mechanics and visual analysis. This information could inform how likely expelled aerosols may cause human exposure to SARS-CoV-2 when determining the risk of COVID-19 (Bourouiba, 2014; Bourouiba, 2020).

The SAB notes that there are good animal models available for studying the infectious dose via both nasal installation and aerosol challenge. These models could also be used to assess the risk of human exposure to SARS-COV-2 from both deposited droplets and aerosol, when appropriate.

The SAB thinks that there are additional research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.5.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The SAB thinks that all research questions are within the EPA's mission. We believe that the questions presented above about aerosol exposure could lead to the development and implementation of mitigation measures that will have the most impact to society. The SAB thinks that such work will protect public health and help government with reopening society.

The SAB also finds that partnering and collaborating with other research groups is necessary and these research efforts could potentially be more productive by leveraging resources, reducing redundancy, and increasing EPA's research capacity. Potential partnering agencies include but are not limited to: Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Fish and Wildlife Service (USFWS), National Institute of Health (NIH) and U.S.

Department of Agriculture (USDA) as well as state health and environmental departments, and other international research organizations. The private sector and academia could also be effective partners.

2.5.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several recommendations and provides areas for consideration with respect to EPA's environmental exposure research questions. It is vital to identify the key potential sources and pathways of exposure as well as the routes of exposure, as together they will inform where preventive measures and/or mitigation are needed. The SAB acknowledges that some of the recommendations listed below are inextricably linked to other research categories and encourages that the EPA regard the comments provided in this research category when considering those comments.

Exposure Sampling

The SAB recommends that EPA conduct a study to measure viable SARS-CoV-2 levels in air in buildings and other microenvironments, to help characterize exposure in specific type of buildings, and which conditions likely lead to higher levels of exposure (see Section 2.7 for more recommendations). Research should include multiple locations within the building to determine how exposure varies as individuals move through common areas (e.g., the lobby; elevators due to individuals passing through; bathrooms; individual floors; food service areas; among others). The use of devices to conduct surveillance and assess the mobility of individuals is a new area of research that could inform the exposure of individuals inside buildings (Thakuriah, 2013; Sapiezynski, 2015; Ferretti, 2020). The SAB notes that the levels of CO_2 could simultaneously be measured to determine the relative number of people versus air exchange rates. Small and medium commercial buildings should be included to inform knowledge about how building size affects exposure (see Section 2.7 for more recommendations about research conditions).

Furthermore, the SAB recommends that fixed areas that are part of public transit be included in research (e.g., indoor and outdoor stations, number of cars, and buses, among others). The SAB notes that research should include other potential factors so that this work can provide guidance on what types of scenarios and possible mitigation strategies would be effective. Additional research activities should be completed to develop or refine personal monitors and/or monitoring equipment for SARS-CoV-2. The EPA should prioritize exposure assessments to identify how exposure varies among individuals on transit-related work activities (e.g., mail carrier, delivery personnel, cab drivers, medical personnel). The SAB notes that research into the accuracy and utility of personal monitors is critical to implementing research on the effectiveness of personal protective equipment and in the development of exposure assessments (see Sections 2.8 and 2.9 for additional recommendations).

Characterization of the potential for exposure in outdoor settings, such as beaches and sporting events, is also an area for consideration. How or do social distancing requirements change with respect to wind conditions and crowd density at outdoor events?

Exposure Mitigation

Studies have shown that there are insufficient levels of air exchange in indoor spaces. Furthermore, the National Academy of Sciences Rapid Expert Consultations on the COVID-19 (NAS, 2020) identified several studies showing that survival of the virus is reduced by higher temperatures and humidity. The EPA should prioritize research that evaluates building environment and characteristics for limiting risk in schools and other buildings. This research should assess exposure differences depending on window ventilation, HVAC system types (e.g. Minimum Efficiency Reporting Value (MERV)) and operating controls. This research should include additional impacts of changing air exchange rates, such as the potential change in energy costs associated with operating buildings.

The SAB notes that there has been considerable messaging in terms of public education regarding hand washing and face touching. These activities will be important when individuals transition between settings (e.g., from home to school, to the workplace or public areas). The SAB recommends that the EPA pursue research with public health partners to assess the effectiveness of different types of messaging.

The SAB recognizes that there are a variety of masks, face shields, and stationary shields being used to protect the general public and workers (see Section 2.9 for additional recommendations). The use and care of personal protective equipment (PPE) is important for their effectiveness. Previous work has demonstrated the strengths and weaknesses of the different types and combinations of PPE. The report from NAS Rapid Expert Consultation on the Effectiveness of Fabric Masks for the COVID-19 Pandemic (April 8, 2020) states that the available information on the effectiveness of homemade cloth masks is inconclusive. The NAS report provides information about the limited research available related to how the behavior of the individuals wearing masks plays a role in their effectiveness. The SAB thinks that this is an area of research that could be accomplished and include the use of face shields (as a stand-alone PPE) and/or in combination with masks.

2.5.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB recommends that the EPA focus on measures to characterize, prevent, and mitigate environmental exposures. Although research should be conducted on all potential exposures, EPA's research priorities should be focused on the pathways with the greatest potential exposure. The SAB recognizes that multiple research questions would need to be answered to accomplish this endeavor and advises that the EPA focus on research questions that could inform mitigation strategies. Additionally, the SAB recommends that the EPA investigate and evaluate mitigative measures that are feasible and easily implemented by the general public (e.g., measures and/or activities using household appliances or the use of sunlight or heat to disinfect items). If effective, these measures should be rapidly communicated to the public.

2.5.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate: 1) the potential for wildlife and/or domestic animals to be carriers (reservoir) of the SARS-CoV-2 virus, and 2) the interaction between wildlife and/or domestic animals with humans as a potential source of exposure. The SARS-CoV-2 virus is thought to have a zoonotic origin and come from bats (Yuan, 2020). The World Organization for Animal Health (2020) provides a summary of reports of various species of animals that have tested positive and they recommend that humans who test positive minimize their interaction with pets and farm animals. Additional evaluation on whether interspecies transfer of viable virus and the potential existence of animal reservoirs is needed. The SAB encourages the EPA to work with others to determine whether this is a potential short-term or long-term research effort as relates to EPA's role.

The SAB recommends that the EPA evaluate the following research question: what is the distance an infectious dose of SARS-CoV-2 aerosol can travel from an expelling source or source(s) indoors and outdoors (e.g. at a beach)?

Lastly, the SAB notes that the research recommendations provided in this document are important in the evaluation of the highest potential exposures associated with reopening our society. Even when an effective vaccine is developed for COVID-19, the research questions and categories identified by EPA, including the depth of information capture here, will be useful for future pandemics.

2.6. Water/Wastewater

Overall, the SAB finds that the research questions posed by EPA in this research category are well-considered, relevant, and clear. The research questions addressed EPA's mission of protecting public health and the environment. The SAB recommends that the EPA take this opportunity to clarify the nexus between the stated research questions and the Agency's regulatory activities. The SAB recommends that the EPA determine whether compliance with existing regulations provides protection against COVID-19 (i.e., whether exposure to pollutants within or below current regulatory limits leads to higher transmission rates, exacerbates morbidity or mortality, or increases susceptibility in the context of SARS-CoV-2). These findings could provide reassurance to the public that compliance with existing environmental regulations is sufficient, beneficial, and important.

The SAB notes that there are additional research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.6.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

The SAB notes that the bullets included in the "Current State of Knowledge" column for "Water/Wastewater," reflect current understanding regarding the threat posed by the virus. As stated in EPA's document, the bullets identified several research opportunities. The bullets are:

- Based on existing CDC information there is no indication that water or wastewater exposures pose a significant risk to human health.
- There is limited research to suggest that the virus might be transmitted via the fecal-oral route.

While the SAB thinks that the issue of direct fecal-oral transmission is outside of the scope of this research category, there are important questions that remain regarding waterborne transmission of the SARS-CoV-2 virus. Research assessing the efficacy of treatment unit processes on removing or inactivating the SARS-CoV-2 virus is needed to assure the general public that the current drinking water and wastewater treatment regulatory frameworks provide adequate public health protection from SARS-CoV-2.

In environmental settings where waterborne transmission is possible (e.g., swimming pools, hot tubs, beaches, combined sewer overflows, etc.), the SAB agrees that research should be conducted to ensure the risk of waterborne transmission is minimized. However, the EPA should recognize that the public may not be protected from direct fecal discharges in these settings. Some specific areas of research include, but should not be limited to:

- The need for information on the SARS-CoV-2 viral load in urine of infected individuals (as especially young children often urinate directly in pools).

- The kinetics of SARS- CoV-2 inactivation in various water matrices (e.g., saltwater pools - often with lower disinfectant dosing; freshwater pools; lake water; among others).

- The disinfection efficacy and kinetics of a suite of secondary disinfectants.

- The direct monitoring of SARS-CoV-2 levels in pools, hot tubs, and recreational waters.

The SAB agrees that disinfection chemistry is complex. When chlorine is used as a disinfectant in freshwater pools, chlorine can react with ammonia and amines (often from urine in the pool) to form a host of secondary oxidants. Specifically, breakpoint chlorination chemistry describes the formation of monochloramine, dichloramine, trichloramine, nitrogen gas with little oxidant residual, and free chlorine after the breakpoint. Furthermore, in saltwater, bromide above 1 mg/L in the water allows conversion of free chlorine to free bromine (and chloramines to bromamines) leading to bromamine formation. The SAB notes that the disinfection efficacy for SARS-CoV-2 will likely vary in swimming pools and hot tubs depending on chlorine or other disinfectant dosing approach and the water quality parameters (e.g., pH, total dissolved solids, etc). The SAB recommends that the EPA partner with public health officials as there is a need for the public to understand the level of risk associated with these water bodies.

The SAB thinks that the EPA is well-suited to summarize and evaluate the effectiveness of disinfectants on SARS-CoV-2 virus. However, the SAB notes that the citation (27) used as a reference regarding disinfectants, covers best practices for environmental cleaning in a healthcare facility and does not reflect the extensive background the Agency has on the disinfection of water and/or wastewater. The SAB recommends that the EPA use the following references: 1) the Surface Water Treatment Rule; 2) the Total Coliform Rule; 3) the National Pollutant Discharge Elimination System (NPDES) disinfection; and 4) the Recreational Waters guidance materials. These references would better reflect the breadth of knowledge and experience the Agency has with disinfection, as it applies to the production of drinking water and treatment of wastewater. The SAB thinks that this knowledge is not reflected adequately in the "Current State of Knowledge" column under the "Water/Wastewater" heading.

The EPA should consider initiating a parallel research study to identify a surrogate if SARS-CoV-2 proves to be difficult to analyze (Lin, 2017). Depending on the intended use, the surrogate should have characteristics and properties similar to SARS-CoV-2. The SAB suggests that the EPA review the report entitled "The Search for a Surrogate," as it provides key principles and guidance about how a surrogate should be identified and selected (AWWARF, 1988).

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The EPA has identified monitoring of wastewater as an important area of research to assess the rate of infection within a community. While the SAB thinks this is a laudable objective, it is not clear how the EPA's proposed approach improves the current disease reporting system used by the CDC. By making COVID-19 a reportable disease in the CDC reporting system, the health testing results would be used to establish infection rates in a community. Given the current state of knowledge, the SAB thinks that it would be more advantageous to use CDC's existing system, rather than establishing a community infection rate using environmental samples. The monitoring of wastewater would need to be adjusted

based on: 1) travel time in the sewer, which is highly variable depending on location of discharge to the sewer; 2) attenuation of the virus during travel to the point of sampling, shedding rate (which may be variable due to stage of disease in person); and 3) limitations of the analytical method (e.g., limit of detection). Each of these variables could create and/or add uncertainty to an infection rate calculated from a raw wastewater sample.

The SAB notes that other programs, such as monitoring over the counter medications sales, could be useful in monitoring the health of a community because new monitoring approaches can be developed using artificial intelligence and existing systems. Such systems could also be formated to send warnings when the sales of a certain types of over-the-counter medications exceed baseline levels.

However, the SAB recognizes that in communities, particularly smaller communities, where limited or no personal testing is available, wastewater testing could potentially be useful as part of an early warning system of infection and/or a measure of the extent of the infection. The lack of personal monitoring supplies or tests in a small community might preclude early warning through the CDC disease reporting system. Similarly, individuals who are asymptomatic might not choose personal (direct) testing, even if such testing were available. The EPA should consider using areas of high infectivity (e.g., areas with a high rate of COVID-19 cases) to test the efficacy of this proposed community monitoring program.

The SAB suggests that the EPA take into consideration the following factors for the wastewater testing efforts to be successful.

- The SARS-CoV-2 analytical test needs to be validated for wastewater matrices (including sample and storage).
- The survival and persistence of the virus needs to be established.
- The impact of travel times to the sample collection point needs to be established.
- The minimum infection rate needs to be established to begin observing viruses in the raw wastewater samples.

When conducting sampling for episodic events, the SAB recommends that the EPA consider partnering with the USGS, state agencies, the Water Research Foundation (WRF), NAS, NSF and/or other research organizations that may have expertise in this area. USGS's extensive experience with sampling of episodic events (i.e., storm events) will aid the Agency with the logistics needed to adequately sample an episodic event, such as an outbreak, to ensure adequate data are collected to characterize the event. Also, the SAB suggests that the EPA review the bibliographic resources of other organizations (e.g., the WRF, NAS, NSF, among others) before the details of any monitoring program are established (Bibby, 2017).

2.6.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB agrees that inhalation of the virus is a potentially significant route of human exposure, which is a research area that could combine air and wastewater mediums (i.e., the aerosolization of wastewater during treatment or activated sludge). The SAB recommends that the EPA work with the Occupational Safety and Health Administration (OSHA) to ascertain the likelihood or prevalence of infection in wastewater treatment plant operators. Wastewater treatment plant operators have a high potential for exposure. A study of their health status could be a venue to gain information on whether the aerosolization processes used at these plants or any other aspect of the wastewater treatment process is of concern. Research on the antibody levels in wastewater treatment plant workers exists but it is historical (several decades old) and does not cover SARS-CoV-2. Data from this research could also be useful in the development of public education materials regarding aerosolized transmission among workers. The SAB provides two references for EPA's consideration (Mulloy, 2001; Thorn, 2001).

2.6.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term water/wastewater research questions and efforts. The uncertainties are known and have been identified as part of this review. The SAB recommends that the EPA research the following data gaps or areas:

- What uncertainties exist and what refinements are necessary to more accurately quantifying SARS-CoV-2 in the various water types (i.e., drinking water, wastewater, surface water, and groundwater)?

- How much infectious virus is excreted by an infected person and survives in water? Does the answer to this change based on how sick the person is or whether the excretion is saliva, urine or feces or any other measurable factor (age, immune status, nutritional status, etc.)?

- What is the survival of the virus deposited by human waste (saliva, urine or feces) in different waters (e.g., disinfected recreational waters, flowing natural waters, raw sewage, treated wastewater, and combined sewer overflows (CSOs))?

- What is the impact of wastewater flows and point of sample collection on ability to detect virus?

- Are there special concerns for Direct Potable Reuse (DPR) treatments? Is there evidence whether existing treatment for enveloped viruses is sufficient for removal or inactivation of SARS-CoV-2?

- What is SARS CoV-2 persistence in untreated water (i.e., sewage or wastewater before final disinfection, surface water, and groundwater)?

As EPA mentioned during their presentation on April 30, 2020, the Agency plans to evaluate the efficiency in which unit processes remove or inactivate the SARS-CoV-2 virus. The SAB thinks that such data collection is critical to ensuring the treatment of drinking water and wastewater adequately protect public health. These data are needed immediately, and although the analytical methods for SARS-COVID-19 may be under development, the SAB recommends that the EPA work on developing a sampling program that can start immediately. The research should include a range of water quality conditions to ensure temporary changes do not impact the overall efficiency of the unit process. The SAB notes that this research is an appropriate and important use of the Agency's resources.

2.6.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate potential exposures from surface waters that might be contaminated from wastewater treatment plant discharges and/or other human activities. For example, beaches are closed every year due to contamination associated with human activities and EPA should assess whether current regulatory activities are protective in the context of SARS-CoV-2. The SAB notes that discharges from combined sewer overflows during heavy precipitation events should be evaluated. Although not directly intuitive, the SAB notes that the EPA should also reflect on some of the recommendations provided above as they relate to personal protective equipment, disinfection and transmission.

2.7. Air

Overall, the SAB recognizes that this is a critical research category in EPA's SARS-CoV-2 research program. The SAB acknowledges that, although the Agency provided a high-level briefing and members have vast experience in this field of knowledge, the lack of specifics in some of the air research questions made them difficult to evaluate.

The SAB notes that there is a lack of a clear definition of the subject of various research questions or potential studies. This is often called a metric and it is specific to the scope of the study. The SAB strongly recommends that the EPA define the metric (e.g., a virus particle, a water droplet or the residual genomic RNA, among others). The metric may also be different depending on the study and how the specific research question is going to be applied in the evaluation process. In addition, it is not clear where and/or how the research questions posed by the Agency fit into EPA's risk assessment process.

The SAB notes that this research category is inextricably linked to various research categories, including *Environmental Exposure* (Section 2.5) and the *Environmental and Human Health Factors affecting transmission and severity of COVID-19* (Section 2.8) research categories, and encourages the EPA to regard the comments provided in this research category when considering the comments in those sections.

In the fields of either human or ecological risk assessment, a key step is the formulation of a conceptual model that clearly describes the bounds of the research questions. Also, the cause-effect processes that cover the origin and transmission of the pathogen in the environment, how exposure occurs to the population, and the occurrence of the disease are important. The SAB recommends that the EPA develop a conceptual model that reflects what is known about the cause-effect pathways and what is not known about SARS-CoV-2. When using a conceptual model, uncertainties could be identified as well as each cause-effect pathway and the variability in the probability distributions of each event. Many of the research questions and categories identified by EPA can address these pathways. A conceptual model, accompanied with a sensitivity analysis, could help EPA ascertain what the key steps are in the overall cause-effect process for COVID-19. This basic framing tool could add a degree of certainty to the overall research analysis.

The SAB recommends that the EPA use a matrix approach to define the range of environmental conditions in which to determine the persistence and exposure SARS-CoV-2. The axes can include variables such as temperature, humidity, air velocity, particulates (including their type and size), the size of the water droplets, the presence of disinfectants, types of HVAC systems, and so on. This matrix approach will help frame in detail the research conditions and aid the building of a quantitative risk assessment.

In addition, the SAB notes that there are several questions regarding particulate size and the rate of infection of the virus that should be addressed. It is well known that there are particles in a wide variety of sizes that could be deposited in a wide range of materials (including plastics, metals, organics, clays), a variety of aspect ratios, surface to volume ratios, density factors, among others. All particulate sizes are potentially important, given the variety of respiratory system areas (e.g., nose, throat, bronchi, bronchioles, and alveoli) that can be infected.

Lastly, while spaces, rooms and the outdoors can be modeled, exposure can also be measured directly. The SAB notes that personal monitors could be used among vulnerable populations to get an accurate level of their viral exposure, if/when appropriate. In addition to ambient air background levels, the

personal cloud is critical in quantifying 'true' inhalation exposures. Also, activity log data could inform ventilation and/or inhalation rate estimates to attain exposure doses. The NIOSH is currently working on miniature sensors, which may open opportunities for personal sampling.

The SAB notes that there are additional research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.7.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

Overall, the research questions are relevant to the understanding of SARS-CoV-2. As mentioned above, a reasonable cause-effect model would be useful to be able to make specific recommendations. The SAB notes that, in some instances, it is not clear where and/or how the research questions posed by the Agency fit into its research program.

There are many potential partners, including the many components of the CDC, NIOSH, and others in the civilian governmental sector. Some of the potential partners have been identified previously in this document. As part of the U.S. Department of Defense (DOD), the U.S. Army Medical Research Institute of Infectious Diseases (U.S. AMRIID) at Ft. Detrick has had vast experience with infectious agents. Also, there is the U.S. Army Chemical Biological Center (U.S. CCDC) at Aberdeen Proving Ground, Maryland that has experience with a wide range of pathogens and biological materials. Lastly, a wide range of academic partners are also available from across the United States in schools of public health, engineering and environmental programs.

2.7.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

<u>Short-Term</u>

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term air research questions and efforts. All short-term research questions are important and should to be addressed.

- How long does the virus remain viable in ambient air (as a function of temperature, humidity, UV, precipitation)?

The SAB recommends that the EPA collect this important information in a wide range of conditions to be able to calculate a viability-condition surface using systematic approaches.

- Can air vented outside from contaminated indoor environments carry significant infectious viral load outdoors, particularly in dense urban environments, or in cases of re-entrainment of exhausted air back indoors?

The SAB notes that this research question may be dependent on the type of housing (e.g., row houses, duplexes, condos, single family homes, density, among others) as well as the receiving outdoor environment or atmosphere and encourages EPA to consider these variables.

- Are there potential indoor sources that can contaminate areas or lead directly to exposure, through aerosolization (e.g., drain traps, toilet flushing, vacuuming, dusting, wiping, re-aerosolization from surfaces)?

The SAB agrees that there are potential indoor sources that can contaminate areas or lead directly to exposure through aerosolization. However, the type of source and the activity will determine the amount of aerosolization and the persistence in the environment. The SAB recommends that the EPA collect and evaluate this information.

In terms of indoor ventilation, the SAB agrees that increasing the exchange rate with outdoor air (unless contraindicated), and indoor airflow rates and patterns are areas that should be considered. Increasing airflow through filtration systems could decrease air contamination levels, but high flows can increase local contamination areas. Computational fluid dynamic (CFD) models are appropriate to visualize the airflow for a given room (e.g., a surgical room, emergency room, intensive care or recovery room, among others). However, other locations such as community centers, stadiums, gyms, sport facilities, theaters, therapy areas, convalescent homes, aircraft, buses, schools, churches, among others, could also benefit from such modeling approaches. The SAB suggests that this type of research begin in the near term improve on the current understanding of SARS-CoV-2, with the realization that this research area could continue long-term as an important area of study.

- Does SARS-CoV-2 remain viable after traveling through an HVAC system? How does the answer vary for different types of HVAC systems in different types of buildings or indoor environments (hospitals, large commercial buildings, residences, schools, airplanes, trains, buses)?

There are many types of HVAC systems for a variety of applications and it is difficult to generalize when a characterization of the various types of HVAC systems must be made. The SAB thinks that this research question is one of the important axes for this research category and urges the EPA to quantify this information using a matrix-based study design.

<u>Long-Term</u>

The SAB has several recommendations and provides areas for consideration with respect to EPA's long-term air research questions and efforts. The SAB thinks that some of the long-term air research efforts should begin in the very near term.

- If aerosol risks are excessive, how can aerosol exposure indoors be reduced?

The SAB notes that there are a variety of engineering and other tools that can be applied to reduce aerosol exposure indoors. The SAB recognizes that it is important to understand the factors (inputs) that could drive the results and produce unacceptable aerosol indoor risks. This information could be used to develop engineering alternatives or protocols to control those factors. The SAB recommends that the EPA set a clear goal using a risk assessment, informed by engineering equipment and/or behaviors, to achieve those goals.

- What precautions, if any, must be taken when cleaning or replacing different types of HVAC or portable air cleaner filters?

The SAB notes that precautions are needed when cleaning or replacing different types of HVAC or portable air cleaner filters. This research question should be informed by some of the short-term air research questions, as it is an extension of that work.

- Can airborne SARS-CoV-2 deposit in water bodies and lead to exposure via contaminated water?

The SAB recommends that the EPA begin researching this question now and continue the program long-term. Humans are exposed to water bodies thru a variety of activities, including walking through puddles on a sidewalk or playground. It is not clear what the persistence of the virus is in water bodies found in urban, suburban, industrial and rural areas. There are also a wide variety of aquatic environments with ranges of pH, nutrients, particulates, salinity, etc. SARS viruses can exist in a variety of species and different environments. The SAB urges the EPA to identify if this information is available for SARS-CoV-2. If not, then appropriate experiments should be designed.

- Does home vacuuming remove SARS-CoV-2 from the surface or cause it to aerosolize?

It is not clear if vacuuming removes or aerosolizes SARS-CoV-2. However, it is known that vacuuming can stir allergens and move them into local air (breathing zone), while it may also be removing some of the materials. This research question depends on the type of vacuuming system, how it is used, among other factors. The SAB recommends that the EPA include this question as part of the short-term research efforts with the long-term goal of controlling exposure.

2.7.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

As part of the short-term questions, the SAB agrees with the importance of this research and its inclusion into the Agency's timeline. As noted above, the SAB thinks that some of the long-term research efforts should begin in the very near term.

2.7.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the

current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As noted previously, the SAB thinks that there is a need for stronger and parameterized conceptual model(s) describing specifically how SARS-CoV-2 exists in the environment, spreads in indoor and outdoor environments, and the factors that cause its transmission. There are a few epidemiological models that provide general information on infection rates and mortality, but they are limited in terms of site-specification. Many of the research questions provided by EPA and discussed above do not appear to be site specific. The SAB recommends that the EPA use its expertise in modeling site specific exposures to further define the research questions. The SAB also notes that the National Institute of Environmental Health Sciences (NIEHS) has experience in this area. The EPA could then use those models to help rank in a quantitative method or through a careful expert elicitation process the various research questions and set priorities.

2.8. Environmental and Human Health Factors affecting transmission and severity of COVID-19

This section provides the SAB recommendations for two research categories related to the transmission and severity of COVID-19.

As mentioned previously, the SAB finds that a conceptual model that describes causation and provides probabilistic estimates of exposure and risk would be beneficial to evaluate the importance and interconnectivity of the research areas. We note that for most risk assessment models, there are a few key variables that dominate the calculations, the uncertainty, or the decisions that must be made. The SAB encourages the Agency to ensure that results will be pertinent to specific exposure-effects pathways, as well as, accompanied by probabilistic descriptions and a careful, consistent uncertainty and sensitivity assessment.

The SAB thinks that there are additional research questions important for EPA to address. Some of the general questions are:

- What cause-effect pathway model is EPA assuming?
- Where do the specified areas of investigation fit into the larger framework?
- How will the Agency use the information produced by this research?

Specific recommendations are included in the responses to the charge questions and corresponding sections below.

2.8.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The SAB finds that the research questions posed by EPA are well considered, relevant and clear. In improving this research category, the SAB thinks that there is an opportunity for the Agency to clarify the nexus between the stated research questions and EPA's regulatory activities related to this work.

Although there is an overlap with other agencies (e.g., NIOSH, CDC, NIEHS and others), the SAB recommends that the EPA lead the development of these research questions to the extent permitted by their mandate and expertise. Also, the SAB notes that academic institutions and federal agencies that have ongoing research and/or expertise in the area of environmental exposures related to behavioral/socio-economic characteristics will be important partners in this research category. The SAB recommends that the EPA work with these partners to identify: 1) how to gather various types of data (e.g., COVID-19 cases and death rates as they become available), and 2) how to evaluate the range of

potential factors affecting the transmission and severity of COVID-19. In addition, the SAB encourages EPA to identify if there a unique role in terms of occupational exposure (for healthcare workers, emergency responders, construction workers, fire fighters, police officers, among others) that should be addressed and to partner with NIOSH and/or OSHA.

In terms of exposures to air pollutants (e.g., Research Category 8, item #2 in the EPA document), the EPA can assess air pollution exposure concentrations from their monitoring networks in combination with air quality and land use models and remote sensing data. In turn, this information can be integrated with case numbers as they become available from the CDC, along with other pertinent variables. The SAB thinks that federal agencies should work together to determine who should conduct epidemiological analysis and how to bring all data streams together seamlessly. These efforts will ensure readiness to evaluate impacts prospectively (e.g., exposures from wildfires in the context SARS-CoV-2 in advance of the season).

Lastly, the EPA in partnership with NIEHS, can help identify the best models for evaluating the built environment, including incorporating factors related to green space, socio-economic characteristics, health care access, population density, and stress conditions (e.g., exposures to crime or criminal activities). National databases (many at a national-level or census-tract scale) are available, and many researchers have developed models for these inputs.

2.8.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several research questions and recommendations that have the potential to refine or improve EPA's understanding and further support its role with respect to the pandemic.

- How are exposure estimates expected to be impacted in specific states and cities? How do population density and the use of mass transit impact exposure?

- There is an opportunity for EPA to provide reassurance that compliance with existing regulations is sufficient and beneficial. Is the exposure to pollutants within or below current regulatory limits expected to increase SARS-CoV-2 transmission rates, exacerbate morbidity, or increase viral load susceptibility - as that would indicate a need to strengthen regulations?

- How are exposure factors related to living and working near construction sites, agricultural operations, and/or large operational manufacturing facilities which represent other sources of particulate in air, being considered in the context of SARS-CoV-2? To the extent that workers in these work settings, as well as those living close by, would face prolonged exposures to particulate in air, emissions, smoke and/or other lung irritants, do they also face a higher likelihood of contracting COVID-19, or evolve to be more severe cases?

- How should lifestyle factors such as smoking and vaping (which are expected to affect lung function and the context of infection) be incorporated in exposure and risk models?

- What impact is expected related to exposure differences by age, given the interaction between age and living space layouts that interact with exposure factors (e.g., retirement communities, senior living, the use of handrails and elevators by the elderly, among others)?

- Given that the "personal cloud" (airborne materials in the breathing zone) adds to environmental ambient exposure, how should the effects of individual behavior be incorporated into models assessing inhalation exposure to the virus? For example, activities during work, play, sports, social gatherings, and other typical routines can place a person in close proximity to potentially infected individuals. These activities frequently increase breathing rates, with the effect of intensifying exposures above the level expected from passive exposures at low levels of exertion. In addition, intense exercise with oral inhalation can increase the rate of air intake by a factor of ten, bypass nasal collection, and thus increase aerosol deposition rates in the bronchial and alveolar airways.

- What is the impact of human health risk factors related to socio-economic status (SES) and its interaction with built environments, on SARS-CoV-2 virus transmission and risk? It is well established that how people recreate is related to SES, common leisure activities, how individuals use water bodies, what kinds of playgrounds are commonly available (paved vs. grassed vs. gravel vs. sand), among others. Other potential risk factors that could increase susceptibility and are related to SES include nutrition, access to health care, stress, life stage and co-morbidities.

- Personal exposure monitoring and logging of coincident levels of exertion, are topics worthy of short-term research efforts, along with air quality monitors.

2.8.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB notes that all research questions related to these two research categories have been designated as long-term in the summary of EPA's current understanding and capabilities related to SARS-CoV-2. However, some research questions are better suited for short-term prioritization (Qu, 2020). Given that SARS-CoV-2 has been moving relatively quickly through susceptible populations, especially the elderly and those with pre-existing conditions (Petrilli, 2020), some of the long-term research questions posed by EPA could be useful in the short-term to provide critical information.

In addition, the SAB recognizes that cities, counties and states are currently struggling to identify sports and/or recreational activities that the general population can participate in without increasing risk of disease transmission. The SAB thinks that, taken as a whole, the eleven research categories described by EPA could provide useful insight to: 1) help jurisdictions make informed decisions about what activities to encourage versus discourage, and 2) ensure that SARS-CoV-2 transmission, morbidity and mortality are minimized.

2.8.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

2.9. Personal Protective Equipment (PPE)

Overall, the SAB finds that the short-term research questions and areas of focus identified by the Agency for personal protective equipment (PPE) are all important. Several points of clarification directly related to these questions have been provided in this document. The SAB thinks that there are additional short-term and long-term research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.9.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The SAB finds that all the research questions for this category are clearly described and are well-suited to EPA's mission. The research questions in this category are well within EPA's capabilities and would benefit from their experience with such issues. The use of PPE is imperative to community protection in varied settings that range from occupational to the general community. Some tangible partners likely include: the CDC, NIH and NIOSH. The agency may also consider partners in the private sector, in particular those in the manufacturing industry of PPE. There are many researchers in academia with expertise in nanotechnology and the social sciences that could be instrumental in the development of more efficient PPE and implementation of training and compliance programs, respectively.

2.9.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB provides additional questions and/or recommendations to be considered in EPA's current and future research initiatives, as listed below.

- There is not a clear understanding about live virus release from PPE over time, especially during PPE re-use, and during other high-risk exposure scenarios such as when individuals change out of contaminated protective clothing. The Agency should consider research into understanding whether infectious virus particles can be released from PPE after use. Such research would dictate how many times PPE can be used or re-used while performing effectively.
- There are many options for disinfection for PPE reuse, likely with a wide range of effectiveness. The SAB suggests that the EPA research the efficacy of thermal, chemical and physical (including radiological) disinfection methods on various types of PPE. This research

should also assess the impact of disinfection and reuse on the durability and function of PPE materials as some disinfectants will degrade materials more than others (e.g., higher concentrations of an oxidant for a shorter time, versus a dilute oxidant for a longer time). The EPA should prioritize thermal approaches as a fast track solution because it has been shown to be relatively non-destructive, easy to implement, and works well for most materials. The thermal disinfection curves (e.g., time and temp to achieve specific levels of inactivation) are well established for many common pathogens but need to be validated for SARS-CoV-2.

- The Agency should consider conducting research on how contemporary technology (such as coating or impregnating PPE with nanomaterials) can improve efficacy and durability.

- The SAB recommends that the EPA investigate how well PPE disinfection and re-use protocols are implemented in various target settings since this is a critical component of their efficacy.

- The EPA should consider research on the use of personal monitoring to document inhalation exposures combined with modeling air flow in indoor environments. This research could inform how to improve air flow patterns to decrease exposures from contaminated PPE.

- In most cases performing research on PPE, specifically for SARS-COV-2, requires specialized biological safety level approval (BSL3). The SAB recommends that the EPA determine whether initial studies could be conducted/validated with appropriate surrogate viruses (which surrogates should be carefully determined) followed by validation with SARS-CoV-2.

2.9.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

While all research areas are important, the SAB suggests the following areas for long-term studies:

- The EPA should perform research to develop new and improved PPE technology (e.g., nanomaterials);

- The Agency should incorporate behavior studies into the assessment of PPE effectiveness (e.g. compliance);

- An important area of research includes improving air flow patterns in high risk areas (e.g., changing areas/rooms for contaminated protective clothing or work clothes) through the use of computational fluid dynamics modeling.

2.9.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the

current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate the following research components as they relate to PPE disinfection, re-use and transmission of COVID-19:

- Assessment of how well the current PPE works during re-use in various settings;
- Development of improved PPE with the use of contemporary materials (e.g., nanomaterials);
- Modification of historical approaches to disinfection (e.g., heat, chemical);
- Considerations of PPE tailored to defined communities (e.g., heath care setting versus schools versus general community); and,
- Re-use protocols for communities to implement and maintain high compliance.

2.10. Human Health Risks of Exposure to Disinfectants

The SAB thinks that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.10.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The SAB finds that the research questions for this category are well-suited to EPA's mission. The research questions in this category are well within the capabilities of the EPA and would benefit from their experience with such issues.

2.10.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SARS-CoV-2 pandemic has led to an increase in the use of disinfectants, including more frequent use as well as increased use in what are generally atypical scenarios and/or by atypical methods. The SAB has several recommendations and provides additional research questions/areas for consideration with respect to EPA's research efforts related to human health risks of exposure to disinfectants.

Exposure-Related Questions

Does EPA's List N for approved SARS-CoV-2 disinfectants account for potential of increased use (including increased frequency of use) or use in different forms, and hence greater/different exposure? This includes consideration of exposure during application as well as exposure to residual levels of disinfectant post-application. See Section 2.1 for additional considerations.

Exposure During Application

- To what extent do workers applying disinfectants have more prolonged exposures to higher levels of disinfectants that may cause adverse health effects, including lung irritation? Also, may workers be in demographic groups with a higher likelihood of contracting COVID-19? Would underlying health conditions predispose individuals to more severe cases of COVID-19?

- Have exposures been evaluated that involve potentially confined spaces, such as during application of disinfectant to automobile interiors?

- The scenarios listed in the EPA's Standard Operating Procedures (SOP) for Residential Pesticide Exposure Assessment focus on post-application exposures. What are exposures to residents that could occur during or after application of disinfectants (e.g., exposures from aerosolization of disinfectants)?

- Electrostatic disinfection appears to be increasing in use and it is a service offered by many professional cleaning companies. The SAB suggests that the EPA determine if this process leads to increased exposures and if PPE should be suggested when using this technique.

Exposure Post-Application

- Are there scenarios under which increased application of disinfectants could result in unacceptable risks to children (e.g., use in daycare facilities, school buses)?

- Are there scenarios under which increased application of disinfectants could result in unacceptable risks to the elderly, especially residents of nursing homes where there is likely to be greater use of disinfectants?

- Have exposures in more atypical scenarios been evaluated, such as volatilization of disinfectant applied to automobile interiors, especially under conditions of elevated ambient temperature?

- Are disinfectants stable or do they breakdown into more toxic or less toxic products? Will disinfectants, or compounds in disinfectant formulations such as terpenes, interact with ozone to form secondary pollutants? See reference Coleman, 2008.

Health Endpoints

- It is known that cleaning products can trigger asthma and/or asthma symptoms (Jaakkola, 2006). The SAB suggests that the EPA explore the feasibility of using machine learning and/or high-throughput assays to identify disinfectants that are not likely to trigger asthma/asthma symptoms, recognizing that the latter may be a longer-term research effort. In the meantime, the SAB recommends that the EPA provide guidance to organizations doing considerable cleaning work for workers and/or individuals with asthma to take additional PPE precautions.

Safe Use Instructions

- Considering that there may be many new individuals using disinfectants, including in both residential settings and public spaces, what are effective educational or outreach strategies for instructing users on safe application of disinfectants (e.g., users should ensure that air exchange rates are maximized during applications, opening windows, etc.)? The SAB notes that this is an area where the EPA could partner with the CDC or other research organizations.

- As greater quantities of disinfectant are likely to be used by workers, and for longer periods of time, should additional PPE recommendations be made for workers? Specifically, should PPE

protect for exposures to both the virus and the disinfectant? See Section 2.9 for additional considerations.

2.10.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB finds that short-term research questions that could inform the extent of social distancing and ability to resume typical activities (e.g., such as going to work) should be prioritized both across and within categories. For questions identified as long-term, the SAB suggests that the EPA undertake a near term scoping exercise to define what is needed and whether there are aspects of the long-term efforts that can or should be undertaken in the nearer term. For example, the topic of exposure data for novel application techniques should be incorporated in the near term to identify what those techniques are. While it may be a long-term effort to obtain the desired data through EPA research, the SAB thinks that the identification of the need as well as communication with relevant stakeholders, may provide additional approaches to obtain data. Similarly, the SAB notes that identifying options for addressing risks related to respiratory sensitivity could determine whether efforts should be short-term versus long-term in nature.

2.10.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

REFERENCES

Alford R.H., J.A. Kasel, P.J. Gerone, V. Knight. 1966. Human influenza resulting from aerosol inhalation. *Proc Soc Exp Biol Med* 122:800–4. [Available at: https://doi.org/10.3181/00379727-122-31255]

AWWARF and KIWA. 1988. The Search for a Surrogate. American Water Works Association (AWWA) Research Foundation, Denver, CO.

Belser J.A. 2020. Assessment of SARS-CoV-2 replication in the context of other respiratory viruses. *The Lancet* (published online May 7, 2020) [Available at: https://www.thelancet.com/action/showPdf?pii=S2213-2600%2820%2930227-7]

Bibby K., N. Aquino de Carvalho, K. Wigginton. 2017. Research Needs for Wastewater Handling in Virus Outbreak Response. *Environ Sci Technol*. 51(5):2534-2535. [Available at: https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b06492]

Bourouiba L., E. Dehandschoewercker, J. Bush. 2014. Violent expiratory events: On coughing and sneezing. *Journal of Fluid Mechanics* 745:537-563. [Available at: https://doi.org/10.1017/jfm.2014.88]

Bourouiba L. 2020. Turbulent Gas Clouds and Respiratory Pathogen Emissions: Potential Implications for Reducing Transmission of COVID-19. *JAMA*. [Available at: https://jamanetwork.com/journals/jama/fullarticle/2763852]

Broom D. Article: Japanese experiment shows how easily coronavirus can spread – and what you can do about it. World Economic Forum COVID Action Platform (Assessed on May 12, 2020). [Available at: https://www.weforum.org/agenda/2020/04/coronavirus-microdroplets-talking-breathing-spread-covid-19/]

Cao G., J.D. Noti, F.M. Blachere, W.G. Lindsley, D.H. Beezhold. 2011. Development of an improved methodology to detect infectious airborne influenza virus using the NIOSH bioaerosol sampler. *J Environ Monit* 3(12): 3321–3328. [Available at: https://doi.org/10.1039/c1em10607d]

Chao C.Y.H., M.P. Wan, L. Morawska, G.R. Johnson, Z.D. Ristovski, M. Hargreaves, K. Mengersen, S. Corbett, Y. Li, X. Xie, D. Katoshevski. 2009. Characterization of expiration air jets and droplet size distributions immediately at the mouth opening. *J Aerosol Science* 40:122-133. [Available at: https://www.sciencedirect.com/science/article/pii/S0021850208001882]

Coleman B.K., M.M. Lunden, H. Destaillats, W.W. Nazaroff. 2008. Secondary organic aerosol from ozone-initiated reactions with terpene-rich household products. *Atmos Environ* 42(35):8234-8245. [Available at: https://www.sciencedirect.com/science/article/pii/S1352231008006766]

Douglas R.G. 1975. Influenza in man. In: Kilbourne ED, editor. The influenza viruses and influenza. New York: Academic Press, pages 375–447.

Ferretti L., C. Wymant, M. Kendall, L. Zhao, A. Nurtay, L. Abeler-Dörner, M. Parker, D. Bonsall, C. Frase. 2020. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. *Science* 368 (6491). [Available at: https://science.sciencemag.org/content/sci/368/6491/eabb6936.full.pdf]

Gallandat K., M.K. Wolfe, D. Lantagne. 2017. Surface Cleaning and Disinfection: Efficacy Assessment of Four Chlorine Types Using Escherichia coli and the Ebola Surrogate Phi6. *Environ Sci Technol*. 51(8):4624-4631. [Available at: https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b06014]

Gilbert R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Co. LTD, New York.

Jaakkola, JJ and MS Jaakkola. 2006. Professional cleaning and asthma. *Curr Opin Allergy Clin Immunol* 6(2):85-90. [Available at: https://doi.org/10.1097/01.all.0000216849.64828.55]

Jahn S.D., W.H. Bullock, J.S. Ignacio. 2015. A Strategy for Assessing and Managing Occupational Exposures, 4th edition Paperback, AIHA Press, Fairfax, VA.

Jayjock M. 2020. Inhalation as a Probable Important (perhaps Predominant) Source of COVID-19 Infection. Presented at EPA SAB COVID-19 Review Panel Public Teleconference, April 30, 2020. [Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/E8F268B28A0EC5558525855A0056626A/$File/COVID-19+Review+Panel_+Slide+Deck_April+30+Teleconference.pdf]

Keith, L.H. 1996. Principles of Environmental Sampling. American Chemical Society, 2nd Edition.

Kwok, K.W.H., W. Dong, S.M. Marinakos, J. Liu, A. Chilkoti, M.R. Wiesner, M. Chernick, D.E. Hinton. 2016. Silver nanoparticle toxicity is related to coating materials and disruption of sodium concentration regulation. *Nanotoxicology* 10(9):1306-1317. [Available at: https://www.tandfonline.com/doi/pdf/10.1080/17435390.2016.1206150?needAccess=true]

Lin K. and L.C. Marr. 2017. Aerosolization of Ebola Virus Surrogates in Wastewater Systems. *Environmental Science & Technology* 51(5):2669-2675. [Available at: https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b04846]

Little J.W., R.G. Douglas Jr, W.J. Hall, F.K. Roth. 1979. Attenuated influenza produced by experimental intranasal inoculation. *J Med Virol* 3:177–88. [Available at: https://doi.org/10.1002/jmv.1890030303]

Lindsley W.G., F.M. Blachere, R.E. Thewlis, A. Vishnu, K.A. Davis, G. Cao, J.E. Palmer, K.E. Clark, M.A. Fisher, R. Khakoo, D.H. Beezhold. 2010. Measurements of Airborne Influenza Virus in Aerosol Particles from Human Coughs. *PLoS ONE* 5(11). [Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2994911/]

MacIntyre C.R., Y. Zhang, A.A. Chughtai, H. Seale, D. Zhang, Y. Chu, H. Zhang, B. Rahman, Q. Wang. 2016. Cluster randomised controlled trial to examine medical mask use as source control for people with respiratory illness. *BMJ Open* 6(12). [Available at: http://dx.doi.org/10.1136/bmjopen-2016-012330]

McLellan N.L., H. Lee, M.B. Habash. 2016. Evaluation of propidium monoazide and long-amplicon qPCR as an infectivity assay for coliphage. *Journal of Virological Methods* 238:48-55. [Available at: https://www.sciencedirect.com/science/article/abs/pii/S0166093416300866?via%3Dihub]

Milton D.K., M.P. Fabian, B.J. Cowling, M.L. Grantham, J.J. McDevitt. 2013. Influenza Virus Aerosols in Human Exhaled Breath. *PLoS Pathogens* 9(3). [Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3591312/]

Montes A., M.A. Bisson, J.A. Gardella, D.S. Aga. 2017. Uptake and transformations of engineered nanomaterials: Critical responses observed in terrestrial plants and the model plant Arabidopsis thaliana (Review). *Science of the Total Environment* 607–608:1497–1516. [Available at: https://doi.org/10.1016/j.scitotenv.2017.06.190]

Mosites E., E.M. Parker, K.E. Clarke, J.M. Gaeta, T.P. Baggett, E. Imbert, M. Sankaran, A. Scarborough, K. Huster, M. Hanson, E. Gonzales, J. Rauch, L. Page, T.M. McMichael, R. Keating, G.E. Marx, T. Andrews, K. Schmit, S.B. Morris, N.F. Dowling, G. Peacock. 2020. Assessment of SARS-CoV-2 Infection Prevalence in Homeless Shelters — Four U.S. Cities. *MMWR Morb Mortal Wkly* 69:521–522. [Available at: https://www.cdc.gov/mmwr/volumes/69/wr/pdfs/mm6917e1-H.pdf]

Mulloy K.B. 2001. Sewage workers: toxic hazards and health effects. *Occup Med* 16(1):23-38. [Available at: https://www.ncbi.nlm.nih.gov/pubmed/11107222]

NAS (National Academies of Sciences, Engineering, and Medicine). 2020. Rapid Expert Consultations on the COVID-19 Pandemic: March 14, 2020-April 8, 2020. Washington, DC: The National Academies Press. [Available at: https://doi.org/10.17226/25784]

NCIRD (National Center for Immunization and Respiratory Diseases). 2020. Interim Recommendations for U.S. Non-emergency Transport Vehicles that May Have Transported Passengers with Suspected/Confirmed Coronavirus Disease 2019 (COVID-19). [Available at: https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/disinfecting-transport-vehicles.html (Accessed May 26, 2020)]

Nicas M, W.W. Nazaroff, A. Hubbard. 2005. Toward Understanding the Risk of Secondary Airborne Infection: Emission of Respirable Pathogens. Journal of Occupational and Environmental Hygiene 2:143–154. [Available at: https://doi.org/10.1080/15459620590918466]

Petrilli C.M., S.A. Jones, J. Yang, H. Rajagopalan, L. O'Donnell, Y. Chernyak, K.A. Tobin, R.J. Cerfolio, F. Francois, L.I. Horwitz. 2020. Factors associated with hospital admission and critical illness among 5279 people with coronavirus disease 2019 in New York City: prospective cohort study. *Brit Med J* 369. [Available at: https://www.bmj.com/content/369/bmj.m1966]

Qu, G., X. Li, L. Hu, G. Jiang. 2020. An Imperative Need for Research on the Role of Environmental Factors in Transmission of Novel Coronavirus (COVID-19). *Environ. Sci. Technol*. 54:3730−3732. [Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7099677/pdf/es0c01102.pdf]

Randazzo W., F. López-Gálvez, A. Allende, R. Aznar, G. Sánchez. 2016. Evaluation of viability PCR performance for assessing norovirus infectivity in fresh-cut vegetables and irrigation water.

International Journal of Food Microbiology 229:1-6. [Available at: https://doi.org/10.1016/j.ijfoodmicro.2016.04.010]

Sapiezynski P, A. Stopczynski, R. Gatej, S. Lehmann S. 2015. Tracking Human Mobility Using WiFi Signals. *PLoS ONE* 10(7). [Available at: https://doi.org/10.1371/journal.pone.0130824]

Skaria S.D. and G.C. Smaldone. 2014. Respiratory Source Control Using Surgical Masks with Nanofiber Media. *Annals of Occupational Hygiene* 58(6):771-781. [Available at: https://doi.org/10.1093/annhyg/meu023]

Tellier R. 2006. Review of aerosol transmission of influenza A virus. *Emerg Infect Dis* 12(11):1657–1662. [Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3372341/]

Thakuriah P. and D.G. Geers. 2013. Transportation and Information: Trends in Technology and Policy. Springer, New York.

Thorn J., and E. Kerekes. 2001. Health effects among employees in sewage treatment plants: A literature survey. *Am J Ind Med* 40(2):170-179. [Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.1085]

U.S. EPA. 1973. Biological Field and Laboratory Methods Biological for Measuring the Quality of Surface Waters and Effluents. EPA-670/4-73-001. National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH. [Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=2000JIC8.PDF]

U.S. EPA. 2014. *Framework for Human Health Risk Assessment to Inform Decision Making*. EPA/100/R-14/001. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, D.C. [Available at: https://www.epa.gov/sites/production/files/2014-12/documents/hhra-framework-final-2014.pdf]

USGS. 2001. Effects of Storm-Sampling Frequency on Estimation of Water-Quality Loads and Trends in Two Tributaries to Chesapeake Bay in Virginia. U.S. Geological Survey, Richmond, Virginia. [Available at: https://va.water.usgs.gov/online_pubs/WRIR/01-4136.pdf]

USGS. 2009. Scientific Framework for Stormwater Monitoring by the Washington State Department of Transportation. U.S. Geological Survey, Reston, Virginia. [Available at: https://pubs.usgs.gov/of/2009/1236/pdf/ofr20091236.pdf]

Wolf S., M. Rivera-Aban, and G.E. Greening. 2009. Long-Range Reverse Transcription as a Useful Tool to Assess the Genomic Integrity of Norovirus. *Food Environ Virol* 1:129. [Available at: https://doi.org/10.1007/s12560-009-9016-7]

World Organization for Animal Health (OIE). Questions and Answers on the 2019 Coronavirus Disease (COVID-19) (Accessed on May 10, 2020). [Available at: https://oie.int/en/scientific-expertise/specific-information-and-recommendations/questions-and-answers-on- 2019novel-corornavirus/]

Yuan J., L. Yonglong, C. Xianghui, and C. Haotian. 2020. Regulating wildlife conservation ad food safety to prevent human exposure to novel virus. *Ecosystem Health and Sustainability* 6:1. [Available at: https://www.tandfonline.com/doi/full/10.1080/20964129.2020.1741325]

APPENDIX A. CHARGE AND RESEARCH QUESTIONS

Extracted from: EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19" Document

Background on EPA Science/Research Questions

As the SARS-CoV-2 pandemic unfolds, understanding of the virus and its impacts is evolving. EPA has a role to play to help the Nation respond to disasters and emergencies. Activities span across the Agency, to ensure the protection of human health and the environment and to take the lead on safely and effectively cleaning the environment following an incident. A responsibility of EPA's Office of Research and Development (ORD) is to ensure its research portfolio advances the capabilities of the Agency, as well as other federal, state, and tribal partners, to address threats to human health and the environment, including from biological origins.

Agency subject matter experts, in the table below, have identified research areas where there are opportunities to refine and improve on the current understanding of SARS-CoV-2. This activity was conducted with a goal of enhancing capabilities, capacity, and expanding the knowledge base to further support decision-making within the Agency and across the Nation. Maintaining a focus on the Agency's mission, the specific research categories identified include:

- Environmental Disinfection
- Environmental Sample Collection Methods
- Environmental Sample Analysis
- Environmental Stability/Persistence on Surfaces
- Environmental Exposure
- Water/Wastewater
- Air
- Environmental Factors affecting transmission and severity of COVID-19
- Human Health Risk Factors affecting transmission and severity of COVID-19
- Personal Protective Equipment (PPE)
- Human Health Risks of Exposure to Disinfectants

In the column titled "Current State of Knowledge and Capabilities," subject matter experts identified key points in our understanding of the SARS-CoV-2 pandemic as it relates to each research category, and what capabilities EPA already has at hand to address current needs. From that foundation, subject matter experts proceeded to identify additional research areas that could benefit EPA (column titled "Research Questions that Can Enhance Knowledge and Capabilities"). In several instances, the Agency has already identified research questions on which to initiate work (see highlighted questions in the table below).

Within these research categories, short-term and long-term research needs were broadly identified. "Short-term" activities are those efforts that could be aimed at helping with the current response to the SARS-CoV-2 pandemic, results likely to be available within several weeks or months. "Long-term" research means studies that would take longer to complete, 1-2 years, and may not impact the immediate response to the SARS-CoV-2 pandemic but would add to our long-term understanding. It is also likely

that longer term efforts would evolve and adjust based on results from short-term research efforts. No prioritization was developed.

Charge Questions

Referring to the attached table, EPA seeks input from the SAB members in the following general areas:

1. Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,
    a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?
    b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?
2. Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.
3. Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?
4. Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

U.S. EPA COVID-19 Science/Research Question List (April 20, 2020)
(**Note**: Yellow highlighting indicates where EPA research efforts are already initiated within ORD.)

Research Category	Current State of Knowledge and Capabilities	Research Questions that Can Enhance Knowledge and Capabilities*
Environmental Disinfection	• EPA List N - Disinfectants for Use Against SARS-CoV-2 – lists many disinfectants as effective for use against SARS-CoV-2 on pre-cleaned, hard, non-porous environmental surfaces. ▪ Narrower list of products for porous materials. ▪ Narrower list of products for use as fogs, mists, vapors, or gases for volumetric disinfection. • The stringency of the registration process provides a high degree of confidence in the effectiveness of these products when used according to the product label (https://www.epa.gov/pesticide-registration/efficacy-requirements-antimicrobial-pesticides) • EPA uses standard laboratory methods (e.g., ASTM E1053-20 and ASTM E2197-17) to quantitatively evaluate the performance of disinfectants against viruses, and which are currently considered suitable for evaluating SARS-CoV-2 claims. • Registered disinfectants do not require confirmatory sampling (post-application to ensure disinfection is achieved). (https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf) • Enveloped viruses (such as SARS-CoV-2, the virus that causes COVID-19)) are generally more susceptible to disinfection than non-enveloped viruses, vegetative bacteria, and bacterial spores.[i,ii,iii] • According to technical support requests that EPA has been involved with, the availability of disinfectants may be limited in supply in some areas. Alternative disinfection methods and products are being sought in these instances.	Short-Term • Can basic cleaning techniques (e.g., using soap/water) alone be effective for surfaces to reduce environmental exposure to SARS-CoV-2? • How effective are devices such as UV, ozone generators or steam devices at reducing or eliminating exposure to SARS-CoV-2 from surfaces or objects? • What available disinfection methods can be effective for complex and difficult to disinfect areas/surfaces (such as porous materials, soft surfaces, and HVACs)? What are alternative disinfection methods, if such methods are not readily available or efficacious for an area? • What are readily available alternative disinfectants (not currently on EPA List N) for large-scale or special situation use and by what methods can these disinfectants be applied effectively? • Do methods of application of List N products via fogging and/or electrostatic spraying provide the necessary contact time on surfaces to be efficacious against SARS-CoV-2? • How effective are products that claim to offer residual/long-term (e.g., hours to months) ability to reduce potential exposure risk to SARS-CoV-2? • What disinfection methods (including using List N products) are suitable for residential and business-owner conducted disinfection? • How susceptible to disinfectants are each of the human coronavirus isolates used for antimicrobial product registration, SARS-CoV and SARS-CoV-2? This comparative research may lead to the use of a safer-to-handle surrogate virus for future regulatory and research purposes, thus facilitating additional product and technology development.

Research Category	Current State of Knowledge and Capabilities	Research Questions that Can Enhance Knowledge and Capabilities*

		<u>Long-Term</u>
		• Are there situations where environmental disinfection of surfaces or objects may not be effective to reduce or eliminate potential exposure to SARS-CoV-2?
		  ○ In situations where the frequency of recontamination is high, how often is disinfection needed to effectively reduce or eliminate potential exposure to SARS-CoV-2?
		  ○ If SARS-CoV-2 is airborne and continues to settle onto surfaces (e.g., after surface disinfection), does disinfection of surfaces alone effectively reduce potential exposure to SARS-CoV-2?
		• How effective are surface coatings impregnated with antimicrobials or other antimicrobial surfaces (e.g. copper) in reducing or eliminating exposure to SARS-CoV-2 and how should disinfectants be used in combination with these treated surfaces?

Environmental Sample Collection Methods	• Studies have reported detection of coronavirus RNA on surfaces by environmental sampling.[iv,v,vi,vii,viii,ix] • The detection of coronavirus RNA does not equate to an exposure risk. RNA detection does not confirm that infectious virus is present. • Infectious dose combined with exposure is used to estimate public health risk. Environmental sampling may inform potential exposure.[x] • Researchers believe that the infectious dose for SARS-CoV-2 is less than that for SARS (estimated for SARS as an average of 240 viral particles).[xi,xii] • The efficiency of environmental sampling (e.g., of surfaces) for viruses is typically very low; detection limits are generally higher than infectious dose and thus higher than required to adequately assess potential risk.[xiii] • Due to the sampling inefficiencies for viruses on environmental surfaces, sampling would not be effective at confirming the efficacy of a registered disinfectant or at determining potential exposure risk prior to disinfection.	<u>Short-Term</u> • Under what situations does environmental contamination need to be assessed? (e.g., when is it useful to enhance or enable decision making.) • What methods (e.g., swabs, wipes, material types) are most appropriate for surface sample collection for SARS-CoV-2? • What are the detection limits and sample collection efficiencies specifically for SARS-CoV-2 for various environmental sample collection methods? • What environmental sampling strategy(ies) (including number of samples, sample locations, frequency of sampling, and timing of sampling) will provide the most effective characterization of the presence/absence of SAR-CoV-2 on both non-porous and porous surfaces?

Research Category	Current State of Knowledge and Capabilities	Research Questions that Can Enhance Knowledge and Capabilities*
	• Negative sampling results cannot be equated with the absence of viable virus.[10] • Registered disinfectants are routinely and appropriately used without confirmatory sampling (post-application to ensure disinfection is achieved) (https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf)	
Environmental Sample Analysis[xiv]	• Molecular methods (e.g., reverse transcription polymerase chain reaction, RT-PCR) are rapid (less than a day), available and provide specific detection of the virus; however, do not indicate viability or infectivity.[xv] • As noted by the National Academies of Sciences, "Studies that rely on PCR to detect the presence of viral RNA may not represent viable virus in sufficient amounts to produce infection."[xvi] • After disinfection with an EPA List N product per the label's instructions, it is possible that inactive viral remnants will remain on the surface. • Viral remnants detected from environmental sampling via molecular analysis methods do not indicate the presence of infectious virus (i.e., false positives). • The tissue culture-based method provides information on the viability of the virus; however, this method is not specific for SARS-CoV-2. Confirming viability and infectivity requires running a 4-7 day, tissue-based culture method.	Short-Term • What are the SARS-CoV-2 sample analysis objectives (adequate specificity, limits of detection, viability assessment, turnaround time) and which methods are most suitable or can be developed to meet those objectives? • What are the most appropriate sample custody, preservation, transport, and storage conditions to maintain sample viability prior to analysis for SARS-CoV-2? • What is the current laboratory capability and capacity for molecular and viability analysis for SARS-CoV-2 and what method improvements can be made to increase capability/capacity? How does this reflect on the required environmental sample analysis needs?
Environmental Stability/Persistence on Surfaces	• Viable SARS-CoV-2 can persist on plastic and stainless-steel surfaces for up to 3 days (at 21-23°C, 40% RH), with a half-life of 13-16 hours.[xvii] • Experience with other coronaviruses suggests that viable SARS-CoV-2 may persist on other surfaces up to several days, suggesting surfaces may be potential sources of exposure.[xviii,xix,xx] • Lower temperature (4-6℃) and moderate humidity (~50% RH) promote longer virus survival on	Short-Term • How long does SARS-CoV-2 remain active on frequently touched surfaces (e.g., escalator & subway hand holds, railings, door handles, etc.) as a function of environmental conditions? ○ How does temperature and humidity impact persistence indoors? ○ How long does SARS CoV-2 remain viable on surfaces and ambient air in outdoor conditions such as direct

Research Category	Current State of Knowledge and Capabilities	Research Questions that Can Enhance Knowledge and Capabilities*
	surfaces.[21] • SARS decay rates increase as temperature increases. Low (<30%) and high (>80%) humidity also increase decay rates.[xxi] • Testing with SARS and other enveloped viruses suggests that heat can accelerate virus decay on surfaces and in liquids.[xxii] • Presence of viral RNA or viable virus on surfaces does not necessarily imply exposure risk to the individual.[xxiii]	sunlight? ○ How long can SARS-CoV-2 remain viable on fomites (e.g., dust)? ○ How long can SARS-CoV-2 remain viable on mail or clothing, and does it pose a take-home risk? • Can alternate environmental conditions (heat and humidity) be used to effectively reduce or eliminate the presence of SARS-CoV-2 on environmental surfaces?
Environmental Exposure	• Contact transmission and inhalation and/or oral exposure to respiratory droplets produced when an infected person coughs or sneezes are thought to be the primary routes of transmission.[xxiv,xxv,xxvi] • There is a potential for exposure through touching contaminated surfaces and then touching of the mouth, nose or eyes, however this is not considered a primary route of exposure.[24,25,26] • Surfaces and objects frequently touched by multiple people, including but not limited to doorknobs, handrails, light switches, gas pumps, etc. have a higher potential as a source for surface exposure. Walls, ceilings, mirrors, and floors are considered lower touch (and lower exposure potential) surfaces.[xxvii]	<u>Short-Term</u> • How effective are sampling and analysis methods for assessing potential risk from environmental exposure? What improvements are necessary? • What measures can be used to mitigate environmental exposure to SARS-CoV-2? • Which exposure scenarios pose the highest potential risk for individuals self-isolated at home (e.g., shopping, handling mail, outdoor exercise, etc.)? <u>Long-Term</u> • If SARS-CoV-2 settle on carpets, clothing, or other objects, does it present a hand-to-mouth hazard? • Considering infectious dose and transmissibility, what amount of SARS-CoV-2 on widely prevalent surfaces poses a risk to public health?
Water/ Wastewater	• Based on existing CDC information there is no indication that water or wastewater exposures pose a significant risk to human health.[xxviii] • 53% of stool specimens from infected patients test positive for the virus, however, it has not been confirmed to be viable/infectious virus. • There is limited research to suggest that the virus might be transmitted via the fecal-oral route.[xxix,xxx] • SARS-CoV-2 can be inactivated using sodium hypochlorite and other disinfectants recommended by EPA.[27]	<u>Short-Term</u> • What uncertainties exist and what refinements are necessary to more accurately quantifying SARS-CoV-2 in the various water types (i.e., drinking water, wastewater, surface water, and groundwater)? <u>Long-Term</u> • What is SARS CoV-2 persistence in untreated water (i.e., sewage or wastewater before final disinfection, surface water, and groundwater)? • Do commonly used POTW biosolids stabilization methods effectively deactivate SARS-CoV-2?
Air	• Respiratory droplets produced when an infected person	<u>Short-Term (non-healthcare setting)</u>

Research Category	Current State of Knowledge and Capabilities	Research Questions that Can Enhance Knowledge and Capabilities*
	coughs or sneezes are thought to be a primary route of transmission.[xxxi,xxxii] • Recent reports indicate that SARS-CoV-2 can remain viable in aerosols for up to three hours.[xxxiii] • Research indicates that aerosols from a sneeze or cough could take an hour to settle and possibly longer for smaller aerosols.[xxxiv]	• How long does the virus remain viable in ambient air (as a function of temperature, humidity, UV, precipitation)? • Can air vented outside from contaminated indoor environments carry significant infectious viral load outdoors, particularly in dense urban environments, or in cases of re-entrainment of exhausted air back indoors? • Are there potential indoor sources that can contaminate areas or lead directly to exposure, through aerosolization? (e.g., drain traps, toilet flushing, vacuuming, dusting, wiping, re-aerosolization from surfaces) • Does SARS-CoV-2 remain viable after traveling through an HVAC system? How does the answer vary for different types of HVAC systems in different types of buildings or indoor environments (hospitals, large commercial buildings, residences, schools, airplanes, trains, buses)? <u>Long-Term (non-healthcare setting)</u> • If aerosol risks are excessive, how can aerosol exposure indoors be reduced? • What precautions, if any, must be taken when cleaning or replacing different types of HVAC or portable air cleaner filters? • Can airborne SARS-CoV-2 deposit in water bodies and lead to exposure via contaminated water? • Does home vacuuming remove SARS-CoV-2 from the surface or cause it to aerosolize?
Environmental Factors affecting transmission and severity of COVID-19	• We know that certain types and levels of air pollution exposure increase hospital admissions for respiratory infections including influenza.	<u>Long-Term</u> • Can particulate matter in the atmosphere serve as a vehicle for the transmission of SARS-CoV-2? • Does exposure to air pollutants, including wildland fire smoke or other air pollutants (e.g. ozone, particulate matter, diesel exhaust, pollen) increase the susceptibility to respiratory viruses like SARS-CoV-2? Or exacerbate existing COVID-19 infection? • Does ambient or indoor temperature or humidity affect the transmission of SARS-CoV-2 and severity of the COVID-19 illness?
Human Health	The CDC maintains the COVID-19 website to provide the	<u>Long-Term</u>

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Risk Factors affecting transmission and severity of COVID-19	latest information on what is known about the disease, its transmission, impacts, and what individuals can do to protect themselves and to help stop the spread. https://www.cdc.gov/coronavirus/2019-ncov/index.html	• Are there particular health risk factors (aside from pre-existing conditions) that make certain individuals or subpopulations more sensitive or vulnerable to COVID-19, e.g. characteristics of the built environment, seasonal allergies, chronic exposure to aerosolized pollutants, demographic conditions, etc.? • Do factors, such as socioeconomic status, gender, race, stress, and characteristics of the built environment affect transmission of SARS-CoV-2 and severity of the COVID-19 illness?
Personal Protective Equipment (PPE)	Appropriate PPE decontamination procedures are necessary. Guidance for PPE can be found on OSHA and CDC websites: https://www.osha.gov/SLTC/covid-19/standards.html https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/businesses-employers.html https://www.cdc.gov/coronavirus/2019-ncov/hcp/healthcare-supply-ppe-index.html https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/index.html	Short-Term • What are recommended procedures for disinfecting PPE for the purposes of reuse? • How many times can it be disinfected before it must be disposed? • Does hand sanitizer work on disposable gloves so they could be reused? This would include suits, N95s, gloves, and booties.
Human Health Risks of Exposure to Disinfectants	• Exposure to disinfectants can pose risks to children and sensitive subpopulations, including those with respiratory sensitivity. • The CDC has specific guidance for communities, schools, workplaces, and events (https://www.cdc.gov/coronavirus/2019-ncov/community/index.html). For example, information on childcare facilities that remain open during the COVID-19 pandemic is available (https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/guidance-for-childcare.html) • EPA's Office of Pesticide Programs conducts human	Long-Term • Some additional research would allow for more refined estimates of exposure for post application exposures. For example, measurements on residue transfer for disinfectants applied to toys and floor surfaces, amount of mopping solution used and volatilization of disinfectants into indoor air would provide useful information for assessing the risk of children and other susceptible populations. Is there other exposure information that would be informative? • The EPA has exposure data for trigger pump spray and hand-held spray wants (hand-held mechanical application). Are there any novel SARS-CoV-2 control application techniques (e.g., electrostatic sprayer) that would not be

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	health risk assessments for disinfectants using well-established, peer reviewed and science-based methodologies (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/standard-operating-procedures-residential-pesticide). • Disinfectants are currently undergoing registration review, the 15-year review cycle to determine whether they continue to meet the FIFRA standard for registration.	represented by the currently available exposure data? • With regard to assessing risk to people with respiratory sensitivity, are there laboratory animal models or non-animal methods (e.g., *in vitro* or computational approaches) that would be useful?

* Yellow highlighting indicates where EPA research efforts are already initiated within ORD.

[i] Block, S. S. (2001). Disinfection, sterilization, and preservation Philadelphia, PA, Lippincott Williams and Wilkins.

[ii] Spaulding, E. H. and E. K. Emmons (1958). "Chemical Disinfection." The American Journal of Nursing 58(9): 1238-1242.

[iii] McDonnell, Gerald E. 2017. Antisepsis, Disinfection, and Sterilization: Types, Action, and Resistance, second edition. ASM Press.

[iv] Yanfang Jiang, Haifeng Wang, Yukun Chen, Jiaxue He, Liguo Chen, Yong Liu, Xinyuan Hu, Ang Li, Siwen Liu, Peng Zhang, Hongyan Zou, Shucheng Hua (2020). Clinical Data on Hospital Environmental Hygiene Monitoring and Medical Staff Protection during the Coronavirus Disease 2019 Outbreak. medRxiv: 2020.2002.2025.20028043.

[v] World Health Organization. Surface sampling of coronavirus disease (COVID-19): A practical "how to" protocol for health care and public health professionals. 18Feb2020

[vi] World Health Organization. Disease Outbreak News: Pneumonia of unknown cause – China https://www.who.int/csr/don/05-january-2020-pneumonia-of-unkown-causechina/ en/?fbclid=IwAR2v89e9lp70O6GTra13FIPHCLw4WJ8kL20Uylx5zZNtWAYvbR0sEATr_rg

[vii] Bin SY, Heo JY, Song MS, Lee J, Kim EH, Park SJ et al. (2016) Environmental Contamination and Viral Shedding in MERS Patients During MERS-CoV Outbreak in South Korea. Clin Infect Dis. 62(6): 755-60.

[viii] Kim SH, Chang SY, Sung M, Park JH, Bin Kim H, Lee H, et al. (2016) Extensive Viable Middle East Respiratory Syndrome (MERS) Coronavirus Contamination in Air and Surrounding Environment in MERS Isolation Wards. Clin Infect Dis. 63(3): 363-9.

[ix] van Doremalen N, Bushmaker T, Munster VJ. Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions. Euro Surveill. 2013 Sep 19;18(38).

[x] U.S. Department of Agriculture/Food Safety and Inspection Service (USDA/FSIS) and U.S. Environmental Protection Agency (EPA) (2012). Microbial Risk Assessment Guideline: Pathogenic Organisms with Focus on Food and Water. FSIS Publication No. USDA/FSIS/2012-001; EPA Publication No. EPA/100/J12/001.

[xi] De Albuquerque, N.; Baig, E.; Ma, X.; Zhang, J.; He, W.; Rowe, A.; Habal, M.; Liu, M.; Shalev, I.; Downey, G. P.; Gorczynski, R.; Butany, J.; Leibowitz, J.; Weiss, S. R.; McGilvray, I. D.; Phillips, M. J.; Fish, E. N.; Levy, G. A., Murine hepatitis virus strain 1 produces a clinically relevant model of severe acute respiratory syndrome in A/J mice. J Virol 2006, 80 (21), 10382-94.

[xii] Dediego, M. L.; Pewe, L.; Alvarez, E.; Rejas, M. T.; Perlman, S.; Enjuanes, L., Pathogenicity of severe acute respiratory coronavirus deletion mutants in hACE-2 transgenic mice. Virology 2008, 376 (2), 379-389.

[xiii] U.S. Department of Agriculture/Food Safety and Inspection Service (USDA/FSIS) and U.S. Environmental Protection Agency (EPA) (2012). Microbial Risk Assessment Guideline: Pathogenic Organisms with Focus on Food and Water. FSIS Publication No. USDA/FSIS/2012-001; EPA Publication No. EPA/100/J12/001.

[xiv] Sean Wei Xiang Ong, Yian Kim Tan, Po Ying Chia, et al. Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a Symptomatic Patient. JAMA, March 2020. https://jamanetwork.com/journals/jama/fullarticle/2762692

[xv] Roberto A. Rodríguez, Ian L. Pepper, and Charles P. Gerba. Application of PCR-Based Methods To Assess the Infectivity of Enteric Viruses in Environmental Samples. Appl. Env. Microbiol., 75, 297–307, 2009. https://aem.asm.org/content/aem/75/2/297.full.pdf

[xvi] National Academies of Sciences, Engineering, and Medicine 2020. Rapid Expert Consultation Update on SARS-CoV-2 Surface Stability and Incubation for the COVID-19 Pandemic (March 27, 2020). Washington, DC: The National Academies Press. https://doi.org/10.17226/25763.

[xvii] van Doremalen, N.; Bushmaker, T.; Morris, D.; Holbrook, M.; Gamble, A.; Williamson, B.; Tamin, A.; Harcourt, J.; Thornburg, N.; Gerber, S.; Lloyd-Smith, J.; de Wit, E.; Munster, V., Aerosol and surface stability of HCoV-19 (SARS-CoV-2) compared to SARS-CoV-1. medRxiv 2020, 2020.03.09.20033217.

[xviii] Duan SM, Zhao XS,Wen RF, Huang JJ, Pi GH, Zhang SX, Han J, Bi SL, Ruan L, Dong XP; SARS Research Team (2003) Stability of SARS coronavirus in human specimens and environment and its sensitivity to heating and UV irradiation. Biomed Environ Sci 16: 246–255

[xix] Casanova, L. M.; Jeon, S.; Rutala, W. A.; Weber, D. J.; Sobsey, M. D., Effects of air temperature and relative humidity on coronavirus survival on surfaces. Applied and environmental microbiology 2010, 76 (9), 2712-2717.

[xx] The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. Adv Virol 2011, 2011, 734690.

[xxi] Ijaz MK, Brunner AH, Sattar SA, Nair RC, Johnson-Lussenburg CM (1985) Survival characteristics of airborne human coronavirus 229E. J Gen Virol 66: 2743–2748.

[xxii] Darnell, M. E. R., et al. (2004). "Inactivation of the coronavirus that induces severe acute respiratory syndrome, SARS-CoV." Journal of Virological Methods 121(1): 85-91.

[xxiii] DHS Master Question List for COVID-19, March 18, 2020.

[xxiv] CDC. 2020. How Coronavirus Spreads. Coronavirus Disease 2019 (COVID-19). Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/prepare/transmission.html

[xxv] OSHA. 2020. Guidance on Preparing Workplaces for COVID-19. Occupational Safety and Health Administration. OSHA 3990-03 2020. https://www.osha.gov/Publications/OSHA3990.pdf

[xxvi] Semple, S.; Cherrie, J.W. 2020. Covid-19: Protecting Worker Health. Editorial. Annals of Work Exposures and Health, 1–4 doi: 10.1093/annweh/wxaa033

[xxvii] CDC. 2019. Best Practices for Environmental Cleaning in Healthcare Facilities in Resource-Limited Settings. Centers for Disease Control and Prevention. https://www.cdc.gov/hai/pdfs/resource-limited/environmental-cleaning-508.pdf

[xxviii] https://www.osha.gov/SLTC/covid-19/controlprevention.html#solidwaste

[xxix] Gu, J. ; Han, B.; Wang, J. COVID-19: Gastrointestinal manifestations and potential fecal-oral transmission. Gastroenterology. 2020; Mar 3: pii: S0016-5085(20)30281-X. Epub ahead of print]

[xxx] Zhang, Y.; Chen, C.; Zhu, S.; Wang, D.; Song, J.; Song, Y.; Zhen, W.; Feng, W.; Wu, G.; Xu, J.; Xu, W. 2020. Notes from the Field: Isolation of 2019-nCoV from a Stool Specimen of a Laboratory-Confirmed Case of Coronavirus Disease 2019 (COVID-19). China CDC Weekly 2(8):123-124.

[xxxi] Tellier, R. Review of aerosol transmission of influenza virus. Emerging Infectious Diseases, 12, (11), 2006.

[xxxii] McKinney KR1, Gong YY, Lewis TG. Environmental transmission of SARS at Amoy Gardens. J Environ Health. 2006 May;68(9):26-30.

[xxxiii] Holbrook et al. Aerosol and surface stability of SARS-CoV-2 as compared to SARS-CoV-1. New England J Med [letter], March 17, 2020.

[xxxiv] Marr et al Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence. J R Soc Interface. 16 2018