COVID-19: Potential Decontamination Strategies for N95 Respirators

This guidance is intended for medical officers and directors, and professionals working in infection prevention, infectious diseases, operations, emergency preparedness coordinators, materials management, and respiratory safety.

Purpose: To provide health care providers with data on various decontamination approaches for safe reuse of N95 respirators in times of severe resource limitations during the coronavirus disease 2019 (COVID-19).

When exposures to aerosols containing SARS-CoV-2 (the virus that causes COVID-19) are expected, N95 respirator masks (N95s) are necessary to protect health care workers (HCWs) from infection. Critical shortages in N95s and other personal protective equipment (PPE) have necessitated reuse of single-use items. However, virus deposited on the filter materials of the N95 may be transferred to the wearer, and repeatedly donning (putting on) and doffing (removing) already contaminated PPE can increase risk of exposure. This document summarizes strategies to conserve and reuse N95s, provides an overview of the available literature on disinfection and gives general considerations to extend use of N95s.

One strategy to conserve N95s is to wear either a face shield (preferred) or a face mask (surgical or procedural) over the N95.[1] This may lower viral load deposited on the respirator mask. However, N95s may still be contaminated after exposure, especially during aerosol-generating procedures. To reduce self-contamination when reuse is necessary, a strategy of rotating a small supply of used N95s can be considered (described below). Although studies evaluating the persistence on various surfaces is limited, one suggested that the virus can survive 72 hours on some surfaces [van Doremalen et al. (2020)], though data on survival in filter materials are sparse. A recently published study suggests that viable virus may be detected on the outer layer of a surgical mask at seven days (mask had been inoculated with viral culture), but with a >3 log reduction in viral load, and the same dataset shows no viral load detected on any surface at 14 days [Chin et al. (2020)]. Therefore, if viral contamination of the N95 is reduced by covering with a barrier (for example, a face shield or face mask), risk of re-exposure can be greatly reduced. Visit nyc.gov/health and search for **guidance on PPE reuse,** for more information.

Based on these findings, storage and reuse of N95 respirator masks is an actionable intervention to conserve PPE and reduce the risk of HCW exposure to COVID-19. This strategy takes advantage of natural viral reduction over time by issuing seven N95s (or equivalent filtering facepiece respirators or FFR) to each HCW who is caring for patients with confirmed or possible COVID-19 in higher-risk units where aerosol generation is likely (like intensive care units, emergency departments). The HCW would wear one N95 each day (labeled with their name on the strap), store it in a paper bag or other clean breathable container at the end of each shift and keep in a warm and dry location. The order of use would be repeated every seven days and each mask or paper bag could be labeled for each day (Monday, Tuesday, Wednesday and so on). HCWs should recognize that there is a theoretical risk that the N95 might still be contaminated, but at a significantly lower level than if recently worn. Shorter duration of storage could be considered, but could increase the risk of contamination and exposure. This approach also could be combined with more rigorous disinfection processes as they are available.

[1]The use of a surgical mask over an approved N95 respirator was not evaluated or approved by the National Institute for Occupational Safety and Health (NIOSH).

If supplies are more severely limited, N95 decontamination can be considered. The following table presents evidence on the efficacy of different decontamination techniques with a focus on viral inactivation and preservation of N95 structural integrity and filtration. The New York City Department of Health and Mental Hygiene does not endorse any specific methods for decontamination or commercial provider of these services.

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Ultraviolet Germicidal Irradiation (UVGI)					
Duan et al. (2003)	N	N/A	N	Used UV irradiation (260 nm-length UV) for 60 minutes on SARS-CoV-1 in a culture medium, resulting in undetectable levels of infectivity	Strong for viral inactivation (SARS-CoV-1)
Viscusi et al. (2009)	Y	Evaluated the UVGI method on lab performance and physical appearance of 9 NIOSH-certified respirators; exposure was with a 40-W UV-C light for 15 minutes on each side. Performance (airflow resistance, aerosol penetration) and appearance were not affected. Repeated UVGI cycles were not evaluated.	N	Not evaluated	Strong for mask integrity
Lore et al. (2012)	Y	There was no observed reduction in filtration performance.	N	Study examined effectiveness of UVGI method on deactivation of H5N1 virus on N95s and subsequent filter performance. After decontamination, N95s were examined by viral culture; UVGI reduced viral load by >4 log median tissue culture infective dose, and lower levels of detectable viral RNA than microwave-generated steam and moist heat.	Strong for viral inactivation (influenza virus) and mask integrity

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Lindsley et al. (2015)	Y	Exposed four N95s to UVGI doses (120-950 J/cm^2) and tested respirator integrity and filtration afterwards. UVGI exposure had little impact on flow resistance, a small increase in particle penetration and a larger effect on the strength of respirator materials, the magnitude of which varied based on model. Respirator straps were less impacted. UVGI may be a suitable method but the number of cycles will be impacted by the type of respirator and UVGI dose needed for viral inactivation.	N	Not evaluated	Moderate for mask integrity
4C Air/Liao et al. (2020)	Y	4C Air laboratory testing demonstrates that exposure to 30 min of UV light decontaminates N95s safely and without loss to filtration efficiency; Liao et al. found that exposure at 254 nm, 8W, for 30 minutes did not degrade performance after 10 cycles. Authors raise concern about depth of UV light penetration, and whether particles deep in the filter are inactivated, as well as importance of stacking respirators so that each gets adequate UV light coverage.	N	Not evaluated	Moderate for mask integrity (not yet peer-reviewed)

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Hydrogen Peroxide Vapor (HPV)					
Viscusi et al. (2009)	Y	Evaluated the HPV method on lab performance and physical appearance of nine NIOSH-certified respirators; exposure was 55-minute cycle in an HPV gas plasma sterilizer. Performance (airflow resistance, aerosol penetration) was not affected; metallic nosebands were slightly tarnished. Repeated HPV cycles were not evaluated.	N	Not evaluated, but it has been demonstrated that HPV is sporicidal at 4-80 degrees Celsius with concentrations between 0.5 - <10 mg 1^{-1}.	Strong for pathogen inactivation
Battelle Final FDA Report (2016)	Y	Study demonstrated complete deactivation of *Geobacillus stearothermophilus* spores (aerosol and liquid droplets) on an N95 and tested respirator integrity and performance after multiple cycles in the Bioquell Clarus C HPV generator. Total cycle duration, including aeration, is 8 hours. Airflow resistance and aerosol collection efficiency not affected at 50 cycles; elastic straps started to degrade after 30 cycles.	N	No; demonstrated a 6-log deactivation of *G. stearothermophilus* spores.	Strong for pathogen inactivation; FDA has granted an emergency use authorization (EUA) for Battelle's method as of March 29, 2020 (not peer-reviewed).

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Hydrogen Peroxide Vapor (HPV)					
Schwartz et al. (2020)	Y	This validation study expanded upon the FDA study to demonstrate that N95s met performance requirements following HPV decontamination over 30 times and passed standardized quantitative fit testing on human models.	N	No; demonstrated a 6-log deactivation of *G. stearothermophilus* spores.	Strong for pathogen inactivation (accepted for publication)
Wood et al. (2020)	N	N/A	N	No; evaluated the efficacy of HPV on two bacteriophages (one an accepted surrogate for Ebola Virus) inoculated onto six material types; 25 ppm (low concentration) was effective against both phages on all materials without blood at 2 hours. On samples with blood, >400 ppm for 24 to 32 hours resulted in a 2-6 log reduction.	Strong for pathogen inactivation
Moist Heat (Heat and Humidity)					
Bergman et al. (2010)	Y	Investigated three cycles of moist heat decontamination and other methods on six N95 respirator models (incubation at 60 degrees Celsius and 80% relative humidity in a laboratory incubator), followed by air-drying/fan drying; respirators had expected levels of filter airflow resistance and aerosol penetration (<5%). A partial separation of the inner foam nose cushion from the respirator was observed in two models (also observed in Bergman et al. 2011).	N	Not evaluated	Moderate for mask integrity

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Moist Heat					
Viscusi et al. (2011)	Y	Examined impact of moist heat incubation (MHI) and other methods on respirator fit, odor, comfort and donning ease for six N95 models. Two out of six models had a statistically significant reduction in fit post-decontamination using MHI, but mean fit factors were still >100.	N	Not evaluated	Strong for mask integrity
Heimbuch et al. (2011)	N	Not evaluated	N	Assessed effectiveness of warm moist heat (65 degrees Celsius +/- 5 degrees Celsius/85% +/- 5% RH for 30 min) to decontaminate N95s inoculated with H1N1 (aerosols and droplets). Using this method, a >4-log reduction of viable H1N1 virus was observed for all but one N95 model.	Strong for viral deactivation
Ethylene Oxide (EtO)					
Viscusi et al. (2007)	Y	Evaluated filtration performance of two FFR models post-decontamination. Respirators were exposed to EtO for 60 minutes followed by 4 hours for aeration. Post-EtO process, average penetration was slightly increased but not beyond NIOSH certification criteria, and straps for one model (P100) were slightly darkened.	N	Not evaluated	Strong for mask integrity
Viscusi et al. (2009)	Y	Evaluated the EtO method on lab performance and physical appearance of nine NIOSH-certified respirators; exposure was a single warm cycle for 1 hour, then 4	N	Not evaluated	Strong for mask integrity

		hours of aeration. Performance (airflow resistance, aerosol penetration) and appearance were not affected. Repeated EtO cycles were not evaluated. Aeration cycle believed to remove residual EtO gas.			
Source	**Structural integrity or performance of N95 evaluated? (Y/N)**	**Evidence on structural integrity or performance of respirator**	**Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)**	**Evidence on viral stability/inactivation**	**Strength of evidence**
Dry Heat (oven)					
Duan et al. (2003)	N	N/A	N	When SARS-CoV-1 was exposed to 56, 67 and 75 degrees Celsius for 90, 60 and 30 minutes, respectively, the virus was inactivated.	Strong for viral inactivation (SARS-CoV-1)
Viscusi et al. (2007)	Y	Study evaluated filtration performance of two FFR models post-decontamination. At 80 degrees Celsius for 60 minutes in a laboratory oven, no visible changes were observed, but a small increase in average penetration was observed. At 160 degrees Celsius, both respirators melted after 22 minutes.	N	Not evaluated	Weak for mask integrity at high temperatures
Stanford Med (2020) and Liao et al. (2020)	Y	Laboratory testing demonstrates that N95 respirator exposure at 75 degrees Celsius for 30 minutes over 20 cycles in an oven did not reduce filtration efficiency (remained at >95%) or cause mechanical deformation; ear straps were not degraded but retained appropriate elasticity.	N	Not evaluated	Strong for mask integrity (not yet peer-reviewed)

Source	Structural integrity or performance of N95 evaluated? (Y/N)	Evidence on structural integrity or performance of respirator	Stability or inactivation of SARS-CoV-2 evaluated? (Y/N)	Evidence on viral stability/inactivation	Strength of evidence
Steam (UNPROVEN)					
Stanford Med (2020)	Y	4C air lab testing found that exposing N95 to hot water vapor from boiling water for 10 minutes decontaminated it without loss to filtration efficiency.	N	No; E. Coli used for testing.	Weak (not yet peer-reviewed)
Liao et al. (2020)	Y	Expanded on above study; exposed N95 to hot water vapor from boiling water for 10 minutes over several cycles; for <3 treatments, filtration efficiency is >95%; after five cycles, it reduced to ~85%, and at 10 cycles, ~80%. Steam may not be ideal due to the polypropylene in the meltblown layer; saturation of the fiber may lessen its static charge and compromise filtration.	N	Not evaluated	Moderate – evidence does not support multiple cycles of this method (not yet peer-reviewed)
RIVM (2020)	Y	Study in The Netherlands found that some FFP2 respirators became deformed or failed fit tests after steam sterilization at 134 degrees Celsius.	N	Not evaluated	Evidence does not support this strategy

Summary of the evidence presented in the table

The strategies with the most robust available evidence for both deactivation of respiratory viruses and maintained respirator performance and fit after multiple cycles are UVGI, HPV and moist heat (65 to 80 degrees Celsius with 50-85% humidity for 30 minutes). Dry heat has also been shown to be effective, though at higher temperatures results in respirator degradation; limited and emerging evidence (Duan et al., 2003; Liao et al, 2020) suggests 75 degrees Celsius for 30 minutes does not degrade the respirator and inactivates viruses. EtO, a sterilant, may also be considered, though viral inactivation on N95s was not reported and recent Centers for Disease Control and Prevention (CDC) guidance on decontamination strategies noted concern over potential toxicity if not aerated sufficiently.

General Considerations When Evaluating Decontamination Methods

- Depending on facility need, some methods may be difficult to scale for large batch processing.
- Some strategies may be performed in the hospital setting, while others may require shipping to a decontamination system site (like Battelle).
- Consider how you will validate your onsite disinfection process for each cycle; if using a vendor, request information about their validation process.
- May need to think through logistics regarding returning masks to the same HCW post-decontamination, which is recommended by experts to assure good respirator fit over multiple uses. For the moist heat method, masks must be returned to original users because of the risk of cross-contamination of resistant bacterial and mold spores.
- If returning respirator to the same user, use a Sharpie to write on the outside of the mask or on the straps; do not use a ballpoint pen.
- Potential strategies take various lengths of time to complete a cycle (30 minutes at 75 degrees Celsius for dry heat versus several hours to complete HPV and Et0 cycles including aeration).
- Need to consider if the method of disinfection is appropriate based on model of respirator. For example, Battelle vaporous hydrogen peroxide (VHP) method cannot be used for N95s that contain cellulose-based materials. See Appendix A (adaptation of Table 4 from recent CDC guidance) to see what masks have been tested by method. To read guidance, visit cdc.gov and search for **FFR decontamination and reuse**.
- CDC has raised concerns about the potential harm of the EtO method to respirator wearers if there is not sufficient aeration for large numbers of N95s.

What NOT to Do

- Do NOT attempt to decontaminate your respirator in a home oven! The respirator should never come home with you due to risk of environmental contamination.
- Do NOT use a microwave oven to decontaminate your respirator. Some studies have shown that parts of the respirator can melt, making them deformed and less effective, and metal noses pieces can cause sparking.
- Do NOT use disinfectant wipes or hand sanitizer to wipe down your PPE. These methods may alter respirator performance by degrading filtration or losing electrostatic charge [CDC, 2020].
- Do NOT use bleach to decontaminate your mask! It will degrade filtration and leave an odor behind.
- The CDC indicates that cloth masks, such as scarves, be used only as a last resort by HCWs if surgical masks or respirators are not available due to severe PPE shortages [CDC, 2020]. Evidence on the use of cloth masks suggests that they are less protective than surgical masks and can even increase the risk of infection due to moisture, liquid diffusion and retention of the virus. Studies have shown significant penetration of particles into the mask (40% to 90%) and significantly higher viral illness among HCWs using cloth versus surgical masks [ECDC, 2020].

Helpful Resources:

1. CDC guidance on disinfection strategies (March, 2020)
    a. https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html.
2. N95 Decontamination Consortium (March, 2020)
    a. Fact Sheets, Technical Reports, and Bibliography for UVGI, Moist Heat, and HPV Methods
3. ACOEM Webinar on Protecting HCWs: Reuse and Decontamination of N95 Respirators (4/3/20)
    a. Recording and Slides
4. Dry heat, UVGI, and steam protocol
    a. Liao et al. (2020) – pre-print (not yet peer-reviewed) study: https://stanfordmedicine.app.box.com/v/covid19-PPE-1-2
5. UVGI protocol
    a. University of Nebraska Biocontainment Unit: https://www.nebraskamed.com/sites/default/files/documents/covid-19/n-95-decon-process.pdf
6. HPV protocols, factsheet and EUA
    a. Battelle's FDA Study: https://www.fda.gov/media/136386/download
    b. Duke Health System's HPV protocol: https://www.safety.duke.edu/sites/default/files/N-95_VHP-Decon-Re-Use.pdf.
    c. Battelle's EUA: https://www.fda.gov/media/136529/download
7. Stanford Medicine's "Addressing COVID-19 Face Mask Shortages" [v1.2: https://stanfordmedicine.app.box.com/v/covid19-PPE-1-1]
8. Announcement about Medline's EtO method to decontaminate N95s
    a. https://www.medicaldesignandoutsourcing.com/medline-to-reprocess-n95-respirators-to-fight-covid-19-spread/

Additional Reading

1. Tseng, C.C. & Li, C.S. (2007). Inactivation of Viruses on Surfaces by Ultraviolet Germicidal Irradiation. Journal of Occupational and Environmental Hygiene. 4;6(400-405).
2. Feldmann et al. (2019). Gamma irradiation as an effective method for inactivation of emerging viral pathogens. The American Journal of Tropical Medicine and Hygiene. 100(5):1275-7.
3. Fisher, E.M. & Shaffer, R.E. (2011). A method to determine the available UV-C dose for the decontamination of filtering facepiece respirators. Journal of Applied Microbiology. 110(1):287-295.
4. Heimbuch, B.K. & Harnish, D. (2019). Research to Mitigate a Shortage of Respiratory Protection Devices During Public Health Emergencies. Available from: https://www.ara.com/news/ara-research-mitigate-shortage-respiratory-protection-devices-during-public-health-emergencies
5. Heimbuch et al. (2014). Cleaning of filtering facepiece respirators contaminated with mucin and Staphylococcus aureus. American Journal of Infection Control. 42(3):265-270.
6. Kampf et al. (2020). Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. Journal of Hospital Infection. 104:246-251.
7. Kenney et al. (2020). Hydrogen Peroxide Vapor sterilization of N95 respirators for reuse. medRxiv.

8. Mills et al. (2018). Ultraviolet germicidal irradiation of influenza-contaminated N95 filtering facepiece respirators. American Journal of Infection Control. 46(7):49-55.

Appendix A (adapted from CDC's Decontamination and Reuse of Filtering Facepiece Respirators using Contingency and Crisis Capacity Strategies, 2020)

Decontamination methods evaluated for each FFR model

FFR Model	Respirator Type	HPV	UVGI	EtO	Steam	Moist heat
3M 1860	N95	X	X	X	X	X
3M 1870	N95	X	X	X	X	X
3M 8000	N95	X	X	X	X	X
3M 8210	N95	X	X	X	X	X
3M 9210	N95		X			
3M Vflex 1805	N95		X			
Alpha Pro Tech	N95		X			
Cardinal Health	N95				X	
Gerson 1730	N95		X			
Kimberly Clark PFR-95	N95	X	X	X	X	X
Moldex 1512	N95		X			
Moldex 1712	N95		X			
Moldex 2200	N95	X	X	X	X	X
Moldex 2201	N95	X	X	X	X	X
Precept 65-3395	N95		X			
Prestige Ameritech RP88020	N95		X			
Sperian HC-NB095	N95		X			
Sperian HC-NB295	N95		X			
U.S. Safety AD2N95A	N95		X			
U.S. Safety AD4N95A	N95		X			
3M 8293	P100	X	X	X		
Moldex 2360	P100	X	X			
North 8150	P100	X	X			