

Evaluation of Decontamination Techniques for the Reuse of N95 Respirators

N95 Working Group Report

The COVID-19 Healthcare Coalition is a collaborative private-industry response to novel coronavirus. Our mission is to save lives by providing real-time learning to preserve healthcare delivery and protect populations. (<https://c19hcc.org>)

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Report from the N95/PPE Working Group, updated May 28, 2020

[Updated Requirements for Ultraviolet Germicidal Irradiation \(UVGI\) Treatment of N95 Respirators](#)

Following decontamination and inactivation studies performed by various research groups on the effectiveness of UVGI on filter efficiency and inactivation, the scientific community recommends a minimum dosage of 1 J/cm² of UV-C light (200 – 280 nm) to effectively decontaminate N95 respirators.¹ The CDC also provides the following caveats: “Not all UV lamps provide the same intensity thus treatment times would have to be adjusted accordingly. Moreover, UVGI is unlikely to kill all the viruses and bacteria on an FFR due to shadow effects produced by the multiple layers of the FFR’s construction.”²

Summary

A review of the best scientific results published to date points to selecting one of the following N95 respirator decontamination methods (see Table 1):

- Vaporized Hydrogen Peroxide (VHP)
- UVGI (or UV-C)
- Moist Heating (≥ 80% RH)
- Heat Inactivation (low RH)

The COVID-19 Healthcare Coalition (C19HCC) (<https://c19hcc.org>) has diligently researched and collated the current best methods for decontamination and reuse (i.e., recharging, recycling) of N95 respirators. We acknowledge that knowledge of COVID-19 and the

¹ Heimbuch, B.K. and D. Harnish. Research to Mitigate a Shortage of Respiratory Protection Devices During Public Health Emergencies. 2019; Available from: <https://www.ara.com/news/ara-research-mitigate-shortage-respiratory-protection-devices-during-public-health-emergencies>

² <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>

implications of recharging N95 respirators is evolving. This paper represents the best knowledge available in the scientific community at this time. Our goal is to make this information easily accessible to those who are on the front lines of this pandemic.

When investigating available methods, we considered three primary factors:

- 1) Evidence that the treatment denatured or destroyed similar enveloped ss-RNA viruses to SARS-CoV-2 (COVID-19)
- 2) Research demonstrating that the filter component maintains the gold standard: blocking >95% of 300nm particles and flow, as measured by pressure drop, post-treatment
- 3) Practicality of establishing methods, acknowledging that supplies (e.g., UV lights, hydrogen peroxide units, laboratory ovens, etc.) may be limited and set-up could be resource-intensive (if not already available)

Each decontamination method carries caveats, and users should consider these caveats before and during implementation of recharging treatments. We do not have data on the number of treatment iterations N95 respirators can undergo before impact on performance.

It is important to note that effectiveness of the listed decontamination techniques assumes proper fitting of the N95 filtering facepiece respirators (FFRs). A poorly fitted N95 FFR permits leakage of contaminants into the breathing zone by introducing gaps in the interface region between the face and the respirator seal. Therefore, it is imperative that users take into consideration proper fitting of the FFR prior to reuse, regardless of decontamination treatment.¹⁴

For healthcare providers and institutions that seek to recycle their N95 resources, Table 1 provides insight the top 4 decontamination techniques for N95 respirators.

If you have additional questions or concerns, please do not hesitate to write the COVID-19 Healthcare Coalition at c19hcc@mitre.org with “Attn: PPE/N95 working group” in the subject line.

We encourage feedback on experience with these or other methods. We will update this guidance as more data becomes available.

Table 1: Best Guidance in Current Literature on Top 4 N95 Respirator Decontamination Treatments

Method of Decontamination	Overview	Considerations
<i>Vaporized Hydrogen Peroxide (VHP)</i> ^{1,4,7,16, 18}	Respirators are strung across a sealed room and exposed to VHP for duration of decontamination cycle (15 min)	<ul style="list-style-type: none"> • VHP decontamination for a single warm cycle did not significantly affect FFR filter aerosol penetration or filter airflow resistance in study.

<p>Source: Duke Health System, Battelle, and Johns Hopkins Applied Physics Lab, CDC Decontamination Recommendations</p>	<p>dwel and 125 min clearance time). VHP has been shown to be sporicidal at temperatures ranging from 4 – 80°C, with sterilant concentrations ranging from 0.5 to <10 mg/L. FFR fit was shown to be unaffected for up to 20 VHP treatments cycles using a head form (straps began to degrade after 30 treatments)¹⁶</p>	<ul style="list-style-type: none"> • The only visible physical effect on the FFRs was a slight tarnishing of the metallic nosebands. • Respirators may absorb VHP (dependent on respirator type and material). • VHP processing is limited by the fact that cellulose-based products (e.g., cotton, which may be present in some head straps or some FFR layers) absorb hydrogen peroxide and can cause the VHP cycle to abort due to low hydrogen peroxide vapor concentration (successful with types N95-A, N95-B N95-C, SN95-D, SN95-E and SN95-F respirators).
<p><i>Ultraviolet Germicidal Irradiation (UVGI)</i>^{2,4,8, 18} Source: University of Nebraska Medical Center, Stanford Medicine, CDC Decontamination Recommendations</p>	<p><i>Option 1:</i> Respirators are illuminated with 254 nm UV light for a minimum required dosage of 60 mJ/cm². The UVGI technique is implemented as ss-RNA viruses, such as SARS-CoV-2, are typically inactivated by UVGI exposure of 2-5 mJ/cm². <i>Option 2:</i> 10 cycles of UV treatment (254 nm, 30 minutes, 8W bulb) also showed no change in filter properties.² 90–100% passing rate after 3 cycles depending on model per CDC guidance.</p>	<ul style="list-style-type: none"> • Personnel should ensure the respirators are not shadowed during light exposure. • UV-C is highly carcinogenic. Personnel should not come into direct contact with UVC (200 – 280 nm) light, as it may damage the eyes and skin. • Even illumination of the respirators on all sides should be considered. • Components within the respirators can absorb UV and reduce possible effectiveness. • UV treatments will primarily target the surface of the respirators, not necessarily deeper layers. • Healthcare professionals should not wear facial products containing sunblock as it may hamper UV decontamination if these materials are on the respirator.
<p><i>Moist Heat</i>^{1, 18} (~80% RH) Source: Bergman et al., CDC Decontamination Recommendations</p>	<p>Respirators are placed in a laboratory incubator at 60°C and 80% relative humidity (RH) for 30 minutes and air-dried for 30 minutes.¹</p>	<ul style="list-style-type: none"> • Some respirators experienced partial separation of inner foam nose cushion, compromising seal required for proper protection of respirator.
<p><i>Heat (60-75°C) Inactivation</i>^{1,2,3} (~30% RH) Source: Bergman et al., Stanford, Rabenau et al.</p>	<p><i>Option 1:</i> Respirators are placed in a laboratory oven at 60-75 °C for 30 minutes; this heating time will depend on the respirator materials and manufacturer processes. Measure respirator</p>	<ul style="list-style-type: none"> • Dry heating temperature refers to the respirator temperature rather than the oven air temperature. • Heat must be kept within the approved usage range of the N95 respirators (please refer to the N95 Material Safety Data Sheet (MSDS)).

	<p>temperature with an infrared (IR) thermometer to confirm respirator is sufficiently heated.</p> <p><i>Option 2:</i> Heat in a convection oven for 30 minutes at 75°C showed no change in pressure drop or 0.3 µm particle filtration efficiency after 15 cycles. After 20 cycles, the elasticity of the ear/face straps were not degraded and were still suitable for use.</p> <p>Incubation at 60°C for 30 min resulted in no infectious virus remaining, regardless of the presence of the protein additive.³</p>	<ul style="list-style-type: none"> • Slight filtration efficiency decreases were observed in the respirators in study after dry heating².
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References

- [1] Bergman, M. S., Viscusi, D. J., Heimbuch, B. K., Wander, J. D., Sambol, A. R., & Shaffer, R. E. (2010). Evaluation of Multiple (3-Cycle) Decontamination Processing for Filtering Facepiece Respirators. *Journal of Engineered Fibers and Fabrics*. <https://doi.org/10.1177/155892501000500405>.
- [2] Price, A. and Chu, L. (2020). Addressing COVID-19 Face Mask Shortages [v1.1]. Retrieved March 25, 2020, from: https://m.box.com/shared_item/https%3A%2F%2Fstanfordmedicine.box.com%2Fv%2Fcovid19-PPE-1-1
- [3] Rabenau, H.F., Cinatl, J., Morgenstern, B. et al. Stability and inactivation of SARS coronavirus. *Med Microbiol Immunol* 194, 1–6 (2005). <https://doi.org/10.1007/s00430-004-0219-0>
- [4] Dennis J. Viscusi, Michael S. Bergman, Benjamin C. Eimer, Ronald E. Shaffer. (2009). Evaluation of Five Decontamination Methods for Filtering Facepiece Respirators. *The Annals of Occupational Hygiene*. 53: 815-827. <https://doi.org/10.1093/annhyg/mep070>
- [5] <https://news.bloombergenvironment.com/environment-and-energy/sterigenics-closer-to-resuming-ethylene-oxide-use-in-georgia>
- [6] <https://www.epa.gov/hazardous-air-pollutants-ethylene-oxide/frequent-questions-health-information-about-ethylene-oxide#carcinogen>
- [7] <https://www.fda.gov/emergency-preparedness-and-response/mcm-regulatory-science/investigating-decontamination-and-reuse-respirators-public-health-emergencies>
- [8] <https://www.nebraskamed.com/sites/default/files/documents/covid-19/n-95-decon-process.pdf>
- [9] Zhou, Y. and Cheng, Y.S. (2016). Evaluation of N95 Filtering Facepiece Respirators Challenged with Engineered Nanoparticles. *Aerosol Air Qual. Res.* 16: 212-220. doi: 10.4209/aaqr.2015.06.0399.

- [10] Martin, S.B. and Moyer, E.S. (2000). Electrostatic Respirator Filter Media: Filter Efficiency and Most Penetrating Particle Size Effects. *Appl. Occup. Environ. Hyg.* 15: 60`17-617. doi: 10.1080/10473220050075617.
- [11] <https://home.howstuffworks.com/dry-cleaning.htm>
- [12] <https://www.calpaclab.com/polypropylene-chemical-compatibility-chart/>
- [13] <https://www.sciencedirect.com/science/article/pii/S019665530900827X?viewFullText=true>, Chun-Chieh Tseng & Chih-Shan Li (2006) Ozone for Inactivation of Aerosolized Bacteriophages, *Aerosol Science and Technology*, 40:9, 683-689, DOI: 10.1080/02786820600796590
- [14] Michael S. Bergman, Dennis J. Viscusi, Ziqing Zhuang, Andrew J. Palmiero, Jeffrey B. Powell, Ronald E. Shaffer (2012). Impact of multiple consecutive donnings on filtering facepiece respirator fit. *American Journal of Infection Control.* 40: 375-380, <https://doi.org/10.1016/j.ajic.2011.05.003>.
- [15] <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>.
- [16] Final Report for the Bioquell Hydrogen Peroxide Vapor (HPV) Decontamination for Reuse of N95 Respirators. Prepared by Battelle Columbus, Ohio. Prepared under Contract No. HHSF223201400098C. Study Number 3245. Prepared for the FDA. July 2016. Accessed, March 31, 2020 <https://www.fda.gov/media/136386/download>.
- [17] Fisher, E.M., J.L. Williams, and R.E. Shaffer, Evaluation of microwave steam bags for the decontamination of filtering facepiece respirators. *PLoS One*, 2011. 6(4). <https://doi.org/10.1371/journal.pone.0018585>.
- [18] CDC Decontamination Recommendations. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>

Appendix

Table 1: Decontamination Treatments Under Coalition Investigation and Review, Pending Additional Guidance from Literature

Method of Decontamination	Overview	Considerations
<i>Steam Heating</i> ¹⁷	Six FFR models were placed in microwave steam bags in a microwave oven for 90 seconds. Three FFRs were further evaluated for three cycles of steam exposure and demonstrated no change in filtration performance. Microwave steam bag treatment achieved 99.9% inactivation of MS2 bacteriophage. ¹⁷	<ul style="list-style-type: none"> It is unclear what effect on more than three treatment cycles has on filter efficiency and water absorption properties of the FFRs.¹⁷
<i>Liquid Hydrogen Peroxide</i> ¹	Respirators are submerged in 6% solution of hydrogen peroxide for 30 minutes and dried for a minimum of 16 hours.	<ul style="list-style-type: none"> Submersion in liquid reduces the electrostatic characteristics of the filter. Respirators in the study were required to dry and outgas for 16 hours. Respirator models containing metal staples were observed to oxidize to varying degrees.
<i>Ethylene Oxide (EtO)</i> ^{1,4,5}	Respirators are packed in sterilization pouches and placed in a sterilizer/aerator unit. The respirators are exposed to 100% EtO for 1 hour followed by a 4-12-hour aeration cycle. EtO decontamination did not affect the filter aerosol penetration, filter airflow resistance, or physical appearance of the FFRs used in the study.	<ul style="list-style-type: none"> Length of time required for sufficient off-gassing of EtO is 5 hours, which may be a limiting factor in the timely processing of large numbers of filtering facepiece respirators (FFRs). EtO is classified as a carcinogen by the EPA.⁶ There are upfront costs in acquiring EtO sterilizer/aerator units and necessary auxiliary equipment and consumables.

Table 2: Non-Recommended Decontamination Treatments

Method of Decontamination	Overview	Considerations
<i>Bleach</i> ^{1,4}	Respirators are submerged in 0.6% solution of sodium hypochlorite for 30 minutes, rinsed with deionized water, and dried for a minimum of 16 hours.	<ul style="list-style-type: none"> Chlorine gas residue persists even after rinsing with deionized water. Hypochlorite powder, solutions, and vapor can be irritating and corrosive to the eyes, skin, and respiratory tract. Submersion in liquid reduces the electrostatic characteristics of the filter. Respirator models containing metal staples were observed to oxidize to varying degrees.
<i>Isopropanol (IPA)</i> ^{9,10}	Respirators are dipped into liquid isopropanol for 1 minute and dried by evaporation for at least 24 hours in a hood at room temperature before use. Dipping the filter material in IPA removes the electrostatic charges, resulting in significant increase in penetration to a MPPS range of 200 – 400 nm, which is comparable to filters relying solely on mechanical collection mechanisms. ¹⁰	<ul style="list-style-type: none"> Submersion in liquid reduces the electrostatic characteristics of the filter. Respirators in the study were required to dry and outgas for at least 24 hours.
<i>Microwave Generated Steam (MGS) Heating</i> ¹	Two pipette tip boxes were filled with ~50mL tap water and placed on the revolving glass carousel of a microwave oven (1100 W manufacturer rated). Respirators were placed outer side down on top of the boxes and irradiated at 750 W/ft ³ for 1 minute on each side. The respirators were dried for 1 hour between exposure. ¹	<ul style="list-style-type: none"> This process melts the rubber components of the respirator. Some respirators in the study experienced slight melting of head straps during heating cycle. Respirators experienced partial separation of inner foam nose cushion (eliminating necessarily seal components).
<i>Hydrogen Peroxide Gas Plasma (HPGP)</i> ¹	Respirators are packaged in specialized sterilization pouches and placed in hydrogen peroxide gas plasma sterilizer units. The respirators are sterilized for approximately 55 minutes at 45-50°C.	<ul style="list-style-type: none"> Decreases structural integrity of respirator. There are upfront costs in acquiring HPGP sterilizer units and necessary auxiliary equipment and consumables.

Method of Decontamination	Overview	Considerations
<i>Ozone Inactivation</i> ¹³	Airborne viruses required ozone doses of 0.34 to 1.98 and 0.80 to 4.19 min-mg/m ³ for 90% and 99% inactivation, respectively.	<ul style="list-style-type: none"> • While inactivation of bacteriophages (unenveloped) using ozone has been investigated, there are no existing studies on the effect of ozone technique on the SARS-CoV-1 or 2 viruses, or the effects of ozone on N95 respirators and other personal protective equipment (PPE). • Ozone at concentrations <10 ppm showed a significant inactivation in 15 seconds. In general, higher inactivation levels were obtained for bacteriophages at 85% relative humidity (RH) compared with the levels at 50% RH. The effect of ozone was attributed to its interaction with capsid protein of the virus.¹³ • There are upfront costs in acquiring ozone generator and necessary auxiliary equipment and consumables. • There are personnel safety concerns with ozone use.
<i>Traditional Dry Cleaning</i> ^{11,12}	Respirators are loaded into a large drum machine and cleaned with a perchloroethylene (PCE). The respirators are gently agitated in the solution after which the solvent is drained, filtered, and recycled. Lastly, the respirators would be "rinsed" in a fresh PCE solution.	<ul style="list-style-type: none"> • Chemical incompatibility with traditional dry cleaning, PCE is incompatible with the polypropylene within the respirators. • Carbon dioxide (CO₂) cleaning has potential, but approach not currently used for textiles.