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# Reusability of filtering facepiece respirators after decontamination through drying and germicidal UV irradiation

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## ABSTRACT

**Introduction** During pandemics, such as the SARS-CoV-2, filtering facepiece respirators plays an essential role in protecting healthcare personnel. The recycling of respirators is possible in case of critical shortage, but it raises the question of the effectiveness of decontamination as well as the performance of the reused respirators.

**Method** Disposable respirators were subjected to ultraviolet germicidal irradiation (UVGI) treatment at single or successive doses of 60 mJ/cm$^2$ after a short drying cycle (30 min, 70°C). The germicidal efficacy of this treatment was tested by spiking respirators with two staphylococcal bacteriophages (vB_HSa_2002 and P66 phages). The respirator performance was investigated by the following parameters: particle penetration (NaCl aerosol, 10–300 nm), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry and mechanical tensile tests.

**Results** No viable phage particles were recovered from any of the respirators after decontamination (log reduction in virus titre >3), and no reduction in chemical or physical properties (SEM, particle penetrations <5%–6%) were observed. Increasing the UVGI dose 10-fold led to chemical alterations of the respirator filtration media (FTIR) but did not affect the physical properties (particle penetration), which was unaltered even at 3000 mJ/cm$^2$ (50 cycles). When respirators had been used by healthcare workers and undergone decontamination, they had particle penetration significantly greater than never donned respirators.

**Conclusion** This decontamination procedure is an attractive method for respirators in case of shortages during a SARS pandemic. A successful implementation requires a careful design and particle penetration performance control tests over the successive reuse cycles.

### Key questions

**What is already known?**

- N95 or FFP2 disposable respirators are the most common respiratory protection devices used in healthcare settings to prevent contamination from airborne aerosols.
- The decontamination and recycling of respirators is an alternative in case of shortage, provided that the procedure is balanced to allow sufficient disinfection with the least possible impairment of the properties of the respirators.

**What are the new findings?**

- Decontamination through drying and a UV irradiation of 60 mJ/cm$^2$ was sufficient to ensure decontamination (>3 log reduction in virus titre) without mechanical or filtration performance impairment of the respirator.
- Wearing the respirators causes a greater decrease in penetration efficiency than the disinfection cycle.

**What do the new findings imply?**

- In case of shortage, respirators can be recycled using drying and germicidal UV, which is relatively simple and inexpensive procedure.
- The integrity and penetration efficiency of the respirators during disinfection-recycling cycles must be monitored.

## INTRODUCTION

The SARS-CoV-2 pandemic (COVID-19) that started at the end of 2019 led to a severe shortage of respirators such as the filtering facepiece respirators (FFRs) in Europe. This respirator shortage was caused by the tremendous need in protecting civilians and healthcare workers from airborne SARS-CoV-2. Infection control procedures call for disposable single-use FFR to avoid cross-contamination.

Respirators are rated according to percentage of penetration to aerosols, according to the labels FFP1-FFP2-FFP3 (EU Standard) and N95-N99-N100 (US standard).

The most common respiratory protection used in healthcare settings are disposable FFP2 and N95 respirators and are capable of capturing ≥94% and ≥95%, respectively, of aerosols in submicron range.[1 2] Contrastingly, surgical masks do not provide respiratory protection from small airborne particles due to their loose fit and low filtration capacity.[3 4] FFR are negative pressure air-purifying particulate respirators that differ from other respirators because the filtering media itself is the respirator. These disposable respirators are not recommended for reuse and should only be considered in a situation of critical shortage. One recommendation of respirator reuse during the COVID-19 pandemic is to provide one respirator per day for each healthcare worker who may be in direct contact with infected patients.[5] This recommendation is based on the persistence of SARS-CoV-2 up to 72 hours on different surfaces.[6] Decontamination of disposable FFR is the last resort. Appropriate methods need to be developed that inactivate viral particles, are harmless to the user and do not significantly compromise respirator filtering capacity.[7]

Several methods have been evaluated for their efficiency in decontaminating FFR such as autoclaving, steam generated by heat or microwaves, ethylene oxide, vaporised hydrogen peroxide and bleach. Moreover, a >4 log reductions in viable viral particles has been obtained after decontamination of H1N1 influenza-contaminated and H5N1 avian influenza-contaminated FFR via ultraviolet germicidal irradiation (UVGI) with a dose of 1440–1800 mJ/cm$^2$.[8 9] A similar log reduction has been observed with a dose of 1800 mJ/cm$^2$ on the MS2 coliphage,[10] but a 3-log reduction was already achieved with a 30 mJ/cm$^2$ UVGI dose.[11]

Advantages of UVGI systems are the setup flexibility, short treatment time, facility of dosage and the absence of residual disinfecting agent after treatment. The UVGI treatment is less aggressive than other disinfection methods used in the hospital sector (eg, autoclaving or bleach), thus limiting damage to disposable respirators.[12] Nevertheless, UVGI treatment is one of the germicidal procedures frequently used in the hospital and biological field. Other 'softer' disinfection methods, such as drying at medium temperature (typically between 70°C and 90°C), have been suggested to deactivate the SARS-CoV-2.[13–15] Arguably, drying and storing the respirators for a few days could be sufficient to deactivate the coronavirus, which cannot survive indefinitely outside the human body. However, the disadvantage of the latter methods when used alone is they do not necessarily eliminate other pathogens that may be present. Moreover, a recent review highlighted UVGI as one of the most promising decontamination methods for N95 FFRs.[16]

The effects of UVGI on respirator appearance, airflow resistance (breathability), particle filtration efficiency (penetration rate) and in one instance fit, have been studied in detail for multiple decontamination cycles. No significant effects were found for UVGI doses of 176–181 mJ/cm$^2$ after a 30 min irradiance (15 min each side)[17] as well as for UVGI doses of 1620 mJ/cm$^2$ (each side) in particular for particle penetration and airflow resistance of different models of FFR.[18] Only at extreme UVGI doses (120 000 to 950 000 mJ/cm$^2$) a slight effect on strength, particle penetration (1.25% increase) and airflow resistance (below 5%) of the material was observed.[19] However, no study has yet demonstrated simultaneously that a treatment was efficient in decontaminating FFRs while maintaining its physical integrity over multiple decontamination cycles.

By using a protocol similar to a reference protocol developed at the University of Nebraska, USA,[20] our aim was to test a decontamination procedure involving drying and germicidal UV ensuring germicidal efficacy while being low enough to avoid a physical or chemical alteration of the filter medium and allowing multiple recycling treatments.

## METHODS

The full description of the methods and the experimental setting used is in the online supplemental material. Our method is based on a procedure developed by the University of Nebraska.[20] Briefly, the decontamination procedure consisted of subjecting disposable FFP2 respirators (3M 6923 and 1862, 3M, Germany) to a drying cycle (oven temperature at 70°C for 30 min) and subsequently exposing them to germicidal treatment with UVC. The respirators were suspended in a rotating circulating rack and irradiated for 4 min at an irradiance of 0.25 mW/cm$^2$ corresponding to a dose of 60 mJ/cm$^2$ (UVC, 254 nm). The respirators were irradiated homogeneously by multidirectional irradiance set-up by the distribution of several UVC light sources (n=10) and the presence of reflective walls in the chamber.

The effectiveness of the decontamination procedure was tested using two *Staphylococcus aureus*' bacteriophages (vB_HSa_2002 and P66 phages), belonging to the family of double-stranded DNA viruses. A count of viable phage particles on contaminated respirators subjected to germicidal treatment was compared with controls (spiked respirators that were not treated). The effect on the integrity of the respirators after successive decontamination cycles was assessed by increasing the UV doses from 60 mJ up to 3000 mJ/cm$^2$ (corresponding to 50 cycles). Physical and chemical alterations were investigated through scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR) and a fine particle penetration test (NaCl aerosol, 10–300 nm range). Respirators were also visually inspected after the decontamination procedure for possible mechanical damage (deformation, seal integrity and strings). Tests were conducted on both unused and used respirators, the latter being collected from frontline units from the Center for Primary Care and Public Health (Unisanté).

## RESULTS

### Decontamination procedure efficiency and phage release from FFR

No viable phage particles were recovered from any of the FFR extract solutions (12 masks and n=2 per mask) obtained from decontaminated FFR (table 1).

**Table 1** Viable *Staphylococcus aureus* phage particles measured on FFR before and after the decontamination process

| | | vB_HSa_2002 | | p66 | |
|---|---|---|---|---|---|
| | | Phage titre (PFU/mL) | Total amount of PFU/FFR | Phage titre (PFU/mL) | Total amount of PFU/FFR |
| UVGI treated (n=12) | Mean | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | SD | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Untreated (n=8) | mean | 1.00E+05 | 2.00E+05 | 1.33E+04 | 2.66E+04 |
| | SD | 6.50E+04 | 1.16E+05 | 1.15E+04 | 2.02E+04 |

FFR, filtering facepiece respirators; PFU, plaque-forming units; UVGI, ultraviolet germicidal irradiation.

Similar fractions (approximately 1/2000, ie, $2\times10^5\pm1.16\text{x}10^5$ plaque-forming unit (PFU) and $2.66\times10^4\pm2.02\text{x}10^4$ PFU for phage vB_HSa_2002 and P66, respectively) of the total amounts of phage particles applied (ie, $4\times10^8$ PFU and $4\times10^7$ PFU for phage vB_HSa_2002 and P66, respectively) were released from untreated masks within the FFR extract solutions after 1 hour shaking (table 1). It should be noted that the brief heat-drying phase alone has a germicidal effect. No viable phage particles were recovered after preliminary heat-drying tests carried out on a reduced number of respirators (n=4) with the vB_HSa_2002 phage (see online supplemental material).

### Respirator integrity with increasing UVGI doses

While some structural changes were perceptible, the overall integrity and performance of the respirator was only moderately affected by UVGI dose. Penetration rates for fine particles (10–300 nm) were on average slightly higher in UVGI-treated compared with non-treated respirators (figure 1A). There was no clear trend between structural changes and UVGI doses. Particle penetration rates remained below 2% at UVGI doses up to 1200 and 3000 mJ/cm$^2$, corresponding to 20 and 50 treatment cycles. Note that penetration rates for respirators that have been worn once by healthcare professionals were

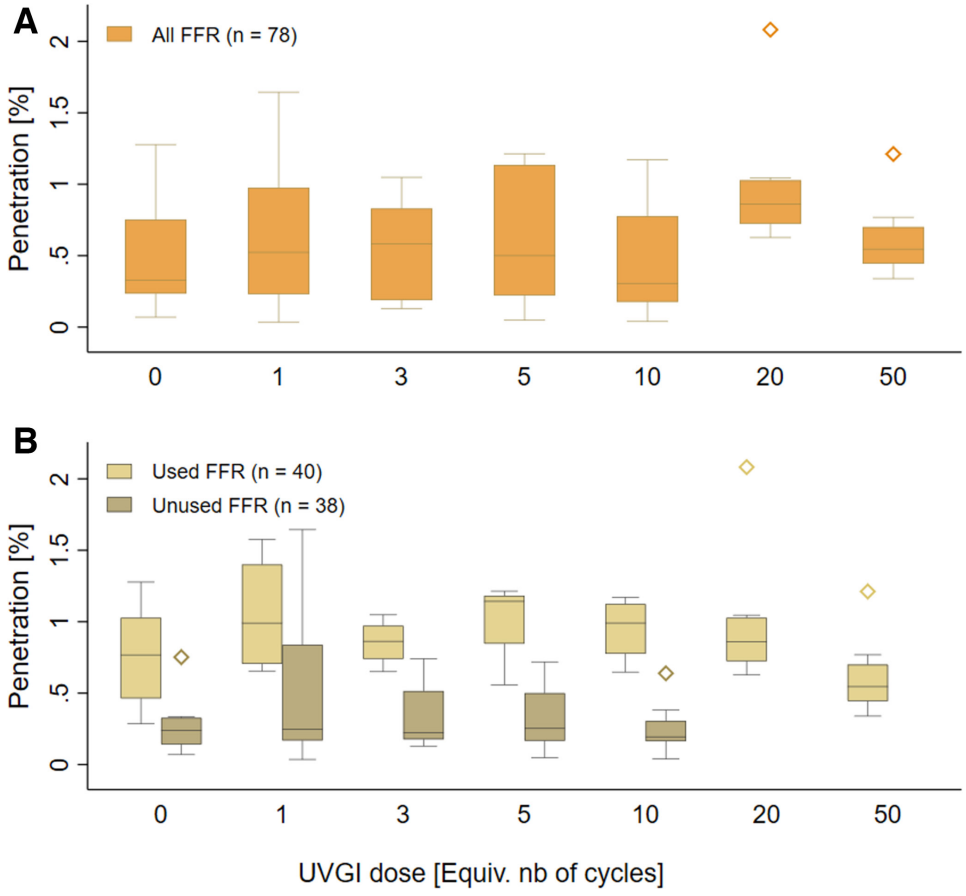


**Figure 1** Penetration of fine particles (10–300 nm) through the FFR filter media in % as a function of the UVGI treatment duration (in equivalent number of cycles): (A) all respirators together and (B) separating unused respirators and respirators used once. FFR, filtering facepiece respirator; UVGI, ultraviolet germicidal irradiation.

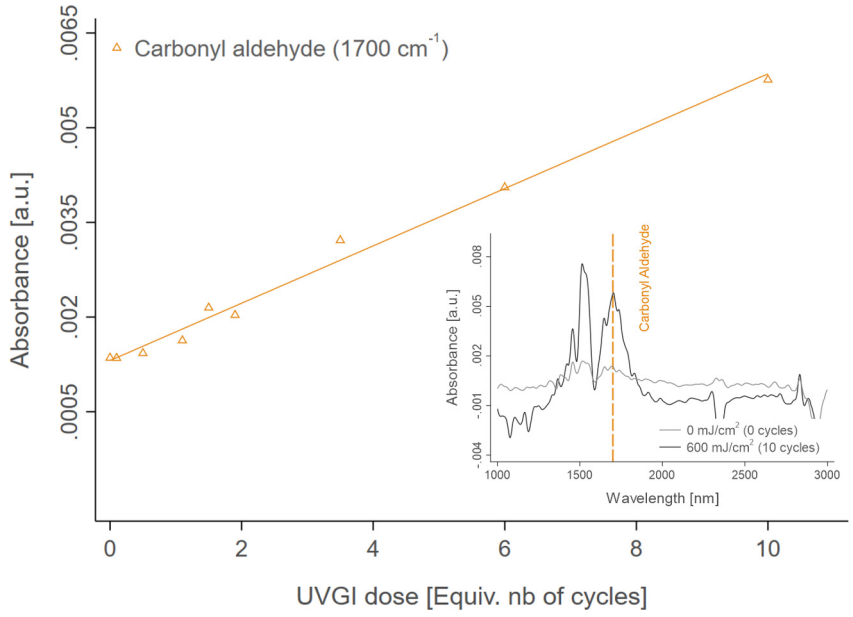


**Figure 2** Structural change in the FFR filtering media observed by Fourier-transform infrared spectroscopy as a function of the number of UVGI treatment cycles. In thumbnail, examples of IR absorbance spectrum of the media after 0 and 10 cycles. UVGI, ultraviolet germicidal irradiation.

significantly higher (mean penetration 0.9%) compared with unused respirators (mean penetration 0.3%) (analysis of variance, p<0.001) (figure 1B).

An increase of the germicidal UV dose up to 10 cycles (600 mJ/cm$^2$) did not lead to any visible damage (with the naked eye or by electron microscopy) (see online supplemental material). The stiffness and strain to failure was also not significantly altered, and the crystallinity and melting enthalpy of the respirator material remained identical (see online supplemental material). Structural alterations of the filter media surface were observed with increasing UV dose as increases in aromatic C–C bonds (1520 1/cm) and carbonyl functions (1700 1/cm)[21 22] in the FTIR chromatograms corresponding to the oxidation of polypropylene (figure 2). This change in respirator surface properties could affect particle–surface interception mechanisms, such as direct interception and interception due to Brownian motion.

A generation in reactive oxygen species (ROS) was measured during the UVGI cycle in the exposure chamber air. Ambient hydrogen peroxide ($H_2O_2$) levels were determined with photonic-based detection and increased from 35±31 (background) to 200±52 nmol/$L_{air}$. Interestingly, the consumption of ozone ($O_3$) was observed concomitantly, and $O_3$ concentration fell from 33 ppb for background to 17 ppb after germicidal UV treatment. According to the existing literature on advanced oxidation processes, UV irradiance at 254 nm triggers the photocatalytic dismutation of $O_3$ into hydroxyl radicals (HO·) that, in turn, can form more stable airborne $H_2O_2$ molecules.[23]

## DISCUSSION

Two phages were used as model systems to test the efficacy of our decontamination procedure (drying cycle+UVGI) on viral particles infectivity. Indeed, despite these phages being non-enveloped harmless virus models, it has been shown previously that the enveloped (H1N1 and HSV1) and the non-enveloped viruses (eg, DNA murine minute virus)—which are generally more resistant than enveloped viruses—were fully inactivated by a combination of heat and exposure to 17 mJ/cm$^2$ UVC.[24] Therefore, a procedure fully inactivating non-enveloped DNA phages would be very likely efficient in inactivating SARS-CoV-2. Our setting allowed recovery in solution of fractions of the applied viable viral particles well above the detection limit of our drop tests assay (ie, 2×10$^2$ PFU/mL). Our results demonstrated that after a single decontamination cycle, no viable phage particles were recovered from any of the 24 phage-contaminated FFR tested. The developed decontamination procedure successfully inactivated the phage particles and represents therefore a valuable strategy to decontaminate FFR contaminated with SARS-CoV-2. However, it is difficult to precisely quantify its germicidal efficacy due to the detection limit of the method, which is due in particular to the biological material loss during extraction from the respirator in this experiment.

The germicidal efficiency observed for the overall decontamination process is due to both UVGI and heat-drying treatments. As already shown in our preliminary tests and in previous studies,[14] heat treatment alone has a germicidal effect. However, the UVGI treatment alone is also an effective decontamination method in general and has the advantage of having a broad germicidal action spectrum. Nevertheless, a drying process is required to

achieve optimal and reproducible UVGI treatment in the depth of the material. By combining the two methods, we propose additional safety by overcoming some of the limitations of each treatment alone and bring convincing arguments for healthcare facilities, which are familiar UVGI treatment.

A drying of 70°C during 30 min and a UV dose of 60 $mJ/cm^2$ per recycling cycle ensured a germicidal effect without damaging the mechanical and protective properties of the respirator as have been previously published. Although chemical structure changes are measurable on the surface of the filter media at doses below 120 $mJ/cm^2$ (two cycles), respirator performance assessed as particle penetration across the filtering media was only moderately affected by UVGI treatment. Even after 10 cycles, fine particle penetration remained below the 5%–6% thresholds expected for FFP2 or N95 type FFRs.

Our results also show that the wear and tear caused by the use of the respirator affects the penetration performance more than the decontamination procedure itself. This is probably due to the condensation of the user's exhaled breath in the respirator, as high humidity levels have been previously associated with a deterioration of the electrostatic charge of the filtering media.[25] Tests for multiple reuse cycles were not conducted in this study since recycled respirators can only be used in case of effective shortage, which we did not encounter. These results suggest that respirator performance tests after recycling are necessary. It could be that the number of decontamination cycles are not the limiting factor but rather the number of times the respirator is used.

UVGI treatment and thermal drying are easy to install and relatively inexpensive. Consequently, the decontamination procedure is an interesting alternative in a situation where there is a shortage of disposable respirators. However, the implementation of the decontamination procedure requires some precautions that could limit its germicidal effectiveness such as shading due to the geometry of the respirator and the rapid attenuation of radiation in the filtering media. By using of multidirectional UV sources, controlling the effective radiation dose during treatment, and pretreating the respirator with heat (70°C), these undesirable effects are avoided. ROS and ozone measurements suggested the presence of $H_2O_2$ concomitantly with the UV treatment. $H_2O_2$ is a gaseous reactive species and can act as a biocidal agent in the depth of the filtering medium giving the UVGI treatment an additional desired effect.

Only one FFP2 respirator brand was used in this study. Similar findings are expected with other FFP2 respirators undergoing UVGI treatment because the filter media are typically polypropylene. There are, however, some caution needed in extrapolating these results to other FFP2 respirator brands, in particular during periods of respiratory supply shortage. Respirators that have not undergone testing and can be of lower quality will then likely appear on the market. For this reason, recycling should be limited to respirators with particularly low penetration rates, typically around 1%. This gives a larger margin of safety with respect to the minimum requirements of the FFP2 and N95 standards.

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**Contributors** DV, GS, AO, NBH, HN-H, NC-L and KB, conceived and designed the study. GS, JS, AO, NC-L, GR, VM, LD-P and NC acquired the data. DV, GS, AO, HN-H, GR and VM contributed to data interpretation and analysis. DV, GR, VM and GS wrote the first draft of the manuscript, and all authors were involved in critical revision of the article and approved the final version for publication.

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## Supplement material

### Decontamination setup

In an exposure chamber of 10 $m^3$, 10 UV-C light sources (TUV 36W SLV/6, Philips SA, Netherlands) exhibiting a narrow emission peak at 254 nm (Figure A1) were mounted vertically in concentric circles (Figure A1). The outer circle, of about 150 cm in diameter, was made of seven light sources facing inwards. The inner circle was made of three lights sources facing outwards. The intermediate circle, of 80 cm in diameter, was constituted of a rotating metal grid, on which about 100 respirators can be hung simultaneously during the decontamination procedure. The surface of the chamber was of stainless steel and aluminium foils. The geometry of the setting and the reflective nature of the chamber surface ensured a multidirectional and homogenous irradiance of the respirators. The respirator irradiance at the intermediate grid, measured with a dosimeter (X1-3 with XD-45-HUV-4 detector, Gigahertz-Optik, GmbH, Munich, Germany), was of 0.25 $mW/cm^2$. After a preliminary drying in a laboratory oven at 70°C for 30 min, the respirators were irradiated for 4 minutes for each cycle, corresponding to a dose of 60 $mJ/cm^2$. FFP2 respirators (3M 6923 and 1862 respirators, 3M, Germany), either unused or used once, were treated with the decontamination procedure. Discarded respirators were collected in the front-line units from the Center for Primary Care and Public Health (Unisanté). They were worn, usually for 4 hours, by nurses or doctors during consultations and nasopharyngeal swabs in patients with SARS-CoV-2 symptoms.

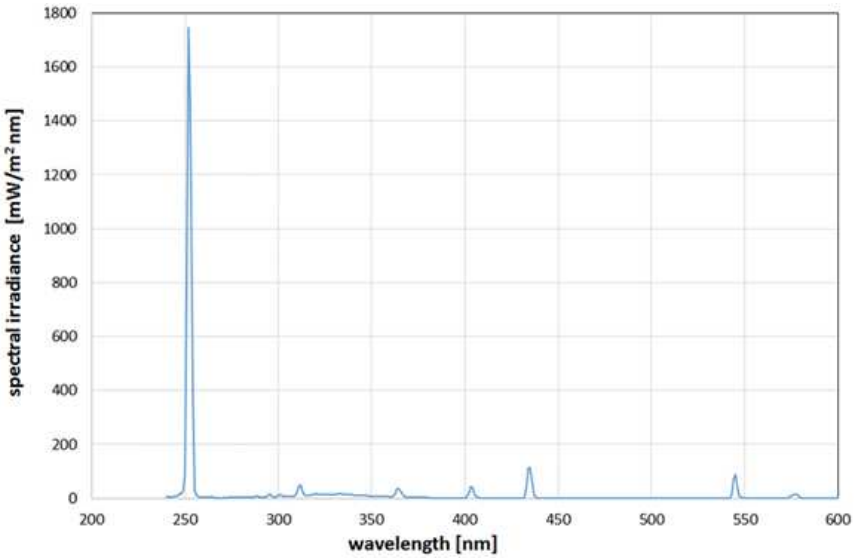


Figure A1. Emission spectrum of low pressure mercury UVGI lamp, reproduced courtesy of Schmid et al. (1)

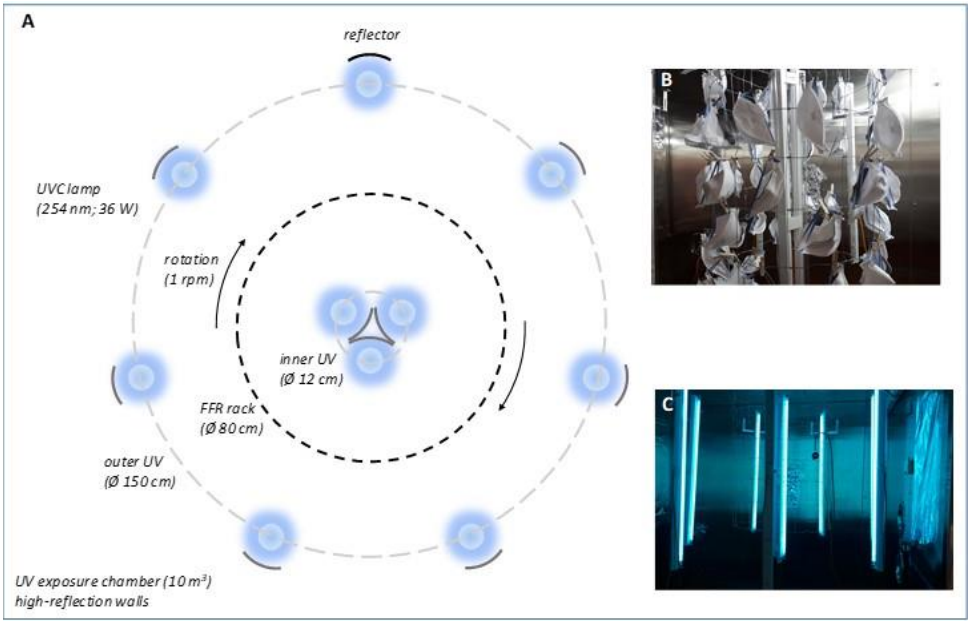


Figure A2. A) Top view schematic of the UV exposure chamber (not at scale); B) Photogram of used FFP2 respirators hung on the rotating rack prior to decontamination; C) Photogram of the treatment chamber during UV exposure.

**Germicidal efficiency testing**

**Bacteriophages.** The *S. aureus* lytic phage vB_HSa_2002 was isolated from sewage water collected at the Vidy wastewater treatment plant, Lausanne, Switzerland. It is a member of the Herelleviridae family of the Caudovirales order with a >140kb double-stranded genomic DNA.

The *S. aureus* lytic phage 66 (P66) has previously been kindly provided by Phagomed GmbH to G. Resch. This double-stranded DNA phage belongs to the Podoviridae family of the Caudovirales order and has a genome of >18kb in length (Genbank NC_007046).

For the purpose of the present study, both phages were amplified in batch cultures by mixing 1 mL of phage lysates with a 2L culture of the human *S. aureus* carriage strain Laus102 (i.e. production strain) previously collected at CHUV in the nasopharynx cavity of a healthy patient. After 3h incubation at 37°C and 200 rpm, the amplification mixtures were centrifuged twice at 4000g for 1h and supernatants filtered at 0.45µm after each centrifugation to remove remaining bacterial cells. The supernatants were further concentrated to 100mL and buffer exchanged against 2L of phosphate buffer saline (PBS) pH 7.4 using tangential flow filtration. The phage titers of the purified phage solutions were determined through classical diluted drop test assay at ca. $10^{10}$ PFU/mL and $10^{9}$ PFU/mL for phage vB_HSa_2002 and P66, respectively. The phage solutions were stored at 4°C until further use for FFP respirators contamination.

**Contamination of FFP respirators and phage particles recovery**

***Contamination*.** Twenty FFR were contaminated with eight 5µl droplets of either vB_HSa_2002 or P66 deposited within a 1.3 cm diameter circle on two different areas on the right and left side of a respirator. Thus, each area contained $4x10^{8}$ PFU or $4x10^{7}$ PFU when contaminated with vB_HSa_2002 or P66. FFR were dried at room temperature for 60 minutes.

***Decontamination*.** Twelve FFR were decontaminated using dry heat and UVGI and eight were not treated. After treatment, 1.3 cm diameter circular punches were collected separately in 2 ml of PBS

buffer pH 7.4 and agitated on a reciprocating shaker for 60 minutes. FFR extract solutions were stored at room temperature and processed within 2 h.

***Determination of phage titers in the FFP respirators extract solutions***. To evaluate the efficiency of the different decontamination treatment procedures, viable counts of vB_HSa_2002 and P66 in the FFR extract solutions were determined through diluted drop test assays. Briefly, 5µL of 10-times serially-diluted FFR extract solutions were deposited on the surface of solidified Tryptic Soy Broth (TSB) soft agar layers seeded with *S. aureus* indicator strain Laus102. After overnight incubation at 37°C, phage titers were determined by counting PFU on plates.

***Germicidal efficiency tests conducted for dry heating alone***

To evaluate the efficiency of the dry heating alone, seven respirators were contaminated with eight 5µl droplets vB_HSa_2002, applying the procedures already described for contamination and phage particle recovery and with an initial concentration of 3.80E +08. Four respirators were decontaminated by heating and seven were not treated. Results are summarized in Table A1.

| | | **vB_HSa_2002** | |
|---|---|---|---|
| | | **Phage titer [PFU/mL]** | **Total amount of PFU/FFR** |
| **Heat-treated (n=4)** | Mean | 0.00E+00 | 0.00E+00 |
| | SD | 0.00E+00 | 0.00E+00 |
| **Untreated (n=7)** | mean | 5.53E+06 | 1.11E+07 |
| | SD | 9.72E+06 | 1.94E+07 |

Table A1. Viable S. aureus phage particles measured on FFR with and without thermal drying

**Filter aerosol penetration.**

The penetration test is performed by measuring the differential number concentration of NaCl aerosol (11-307 nm) enabled to pass through the filter sample. Fine particle aerosol stream is generated from NaCl solution (0.6% w/v) using a Collison-type nebulizer (1-jet; flow rate: 1 L/min).

Aerosol dilution with dry air (1.5 L/min) ensures relative humidity control (45-50%). Each respirator sample is prepared (circular punch; 37 mm) and inserted in the filter cassette housing (Casella, UK) positioned on the aerosol line. Downstream, the particle number concentration is measured via scanning mobility particle sizer (SMPS; GRIMM Germany) in the size range 11 to 1082 nm. The penetration rate is calculated as the ratio between particle number concentration (average of three scans) measured alternatively through the respirator sample and the free-path, in the size range between 11 and 307 nm. For each tested respirator several samples are prepared and analysed (n≥3). Although the experimental setup does not strictly follow the method described in the standard EN 13273-7, in particular for air flow rates and filter sample dimensions, the final air velocity through the mask remains in the same order of magnitude (3,9 cm/s).

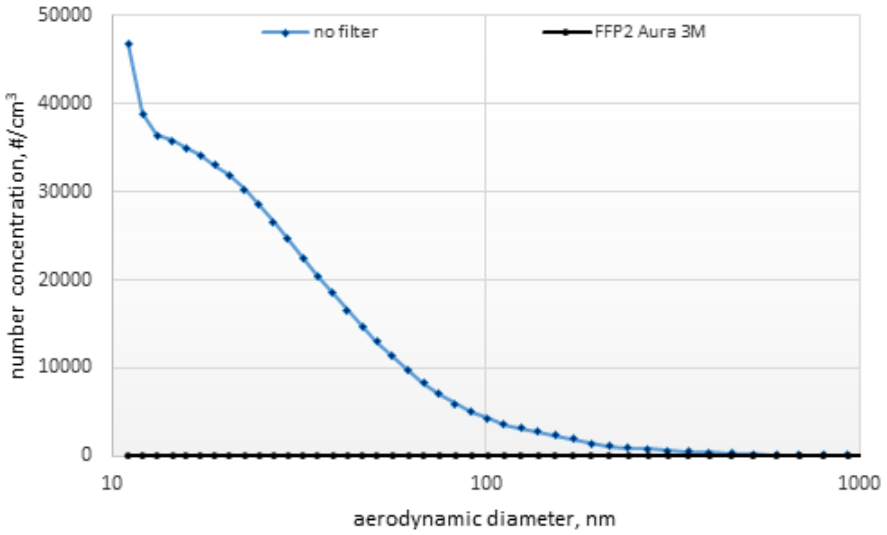


Figure A3, Size distribution of NaCl aerosol generated during filter particle penetration test and measured by Scanning Mobility Particle Sizer.

**Observational and SEM analysis.**

A 15mm circular punch was extracted from a disposable respirator (3M™ 06923+ Aura, FFP2). The core sample is composed of almost two layers including a hydrophobic layer on the outside and a fine fibers layer towards the face. Both layers, with and without treatment, were separately mounted on a carbon coated support and observed by scanning electron microscopy (SEM) with back-scattered detector at 15 kV and 600X magnification (Figure A4).

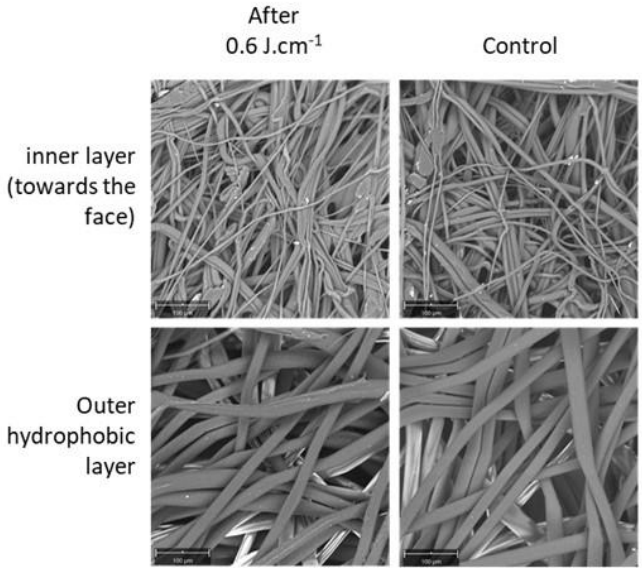


Figure A4. SEM-BSE of the two layers of the respirator, before and after UV-C exposure (image size: 450 x 450 µm).

**Polymer melting properties**

Melting behaviour was measured on 5-10mg samples extracted from the external layer of a disposable respirator (3M™ 06923+ Aura, FFP2) and subjected to a heating cycle of 10°C/minute in a DSC (TA Instruments DSC Q100) from 20 to 210°C. The melting behaviour exhibits two peaks which are characteristic of drawn PP filaments (2), and no significative difference is found between samples.

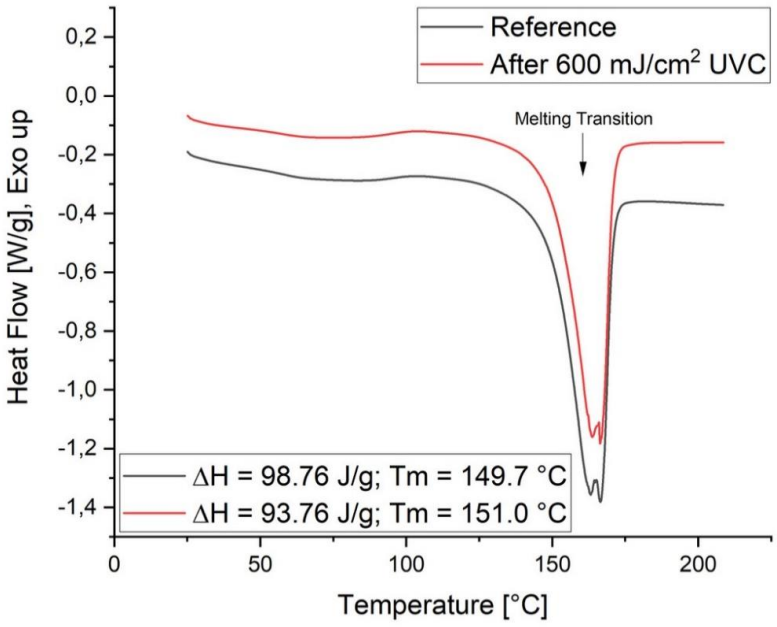


Figure A5: Heat flow behaviour of the external layer of the respirator, before and after 600 mJ/cm$^2$ UVC exposure.

**Measurement of mechanical properties**

Dog bone samples with a gauge length of 27mm and a width of 4mm were cut out of a disposable respirator (3M™ 06923+ Aura, FFP2), the layers were separated and each sample tested in a Zwick teachXpert-mobile testing machine with a 5kN load cell. For each sample the maximal force and the strain at failure were recorded. Due to the small quantity of samples (7 per condition) which was not sufficient to reach a statistical significance per layer and per position in the mask, the difference between the maximal force and the strain at break was calculated for all samples exposed at 600 $mJ/cm^2$ with respect to the reference samples, and averaged. Results exhibit a large scatter as expected for non-woven textiles and indicate a loss of 2%±18% in maximal force and 17%±27% in strain to failure, which represent a non-significant alteration of the layers mechanical performance.

**Measurement of gas-phase ROS**

Ambient ROS was collected using two impinging sets (5 mL milli-Q water; 0.5 L/min) placed on the mask rack prior and during one UV cycle. The quantitative analysis of air samples was achieved via the photonic detection system that combines multi-scattering absorbance enhancement and FOX assay (3). In brief, a fraction of the collection medium (300 µL) is inserted into the reaction vial containing FOX (700 µL) and positioned on the photonic instrument where the formation of coloured complexes in the presence of ROS is monitored (3 min; $\lambda$ = 580 nm). Raw data (formation rate, $s^{-1}$) are converted into equivalent of $[H_2O_2]$ per collected air volume and expressed in $nmol/L_{air}$. Replicates were performed for each analysed sample (n≥4). ROS quantitative determination was performed at the same cabin ventilation rate as used during mask UV-treatment process.

**Measurement of ozone**

Direct reading instrument based on electrochemical detection of ozone (Aeroqual 500, measurement range 0 - 150 ppb, Aeroqual Inc., Auckland, New Zealand) was placed on the mask rack in the UV treatment cabin. Ambient ozone level was monitored for 10 min in the closed cabin prior to UV treatment (background data; n=11) and continued during ten consecutive UV-cycles (40 min; n=43). Ozone monitoring experiments were performed at the same cabin ventilation rate as used during mask UV-treatment process.

**FTIR analysis**

A sample of the inner layer (toward the face) of the respirator was exposed to UV-C radiation and periodically measured by FTIR (IRAffinity-1S Shimadzu) in absorbance mode with 2 $cm^{-1}$ resolution (32 scans) with a control sample (not exposed to UVGI) as background scan. Nine levels of exposure were scanned with a cumulative UV-C dose from 0 to 0.6 $J.s^{-1}$. The carbonyl content variation was monitored using the peak height at 1700 $cm^{-1}$ (carbonyl stretching peak) taking the value at 1600 $cm^{-1}$ as a reference (figure 2).

**References**

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