

- 1                   **Assessment of N95 respirator decontamination and re-use for SARS-CoV-2**
- 2     Robert J. Fischer<sup>1</sup>, Dylan H. Morris<sup>2</sup>, Neeltje van Doremalen<sup>1</sup>, Shanda Sarchette<sup>1</sup>, M. Jeremiah Matson<sup>1</sup>
- 3             Trenton Bushmaker<sup>1</sup>, Claude Kwe Yinda<sup>1</sup>, Stephanie N. Seifert<sup>1</sup>, Amandine Gamble<sup>3</sup>, Brandi N.
- 4             Williamson<sup>1</sup>, Seth D. Judson<sup>4</sup>, Emmie de Wit<sup>1</sup>, James O. Lloyd-Smith<sup>3</sup>, Vincent J. Munster<sup>1</sup>
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- 6             1. National Institute of Allergy and Infectious Diseases, Hamilton, MT
- 7             2. Princeton University, Princeton, NJ
- 8             3. University of California, Los Angeles, Los Angeles, CA
- 9             4. University of Washington, Seattle, WA

10 The unprecedented pandemic of COVID-19 has created worldwide shortages of personal protective  
11 equipment, in particular respiratory protection such as N95 respirators<sup>1</sup>. SARS-CoV-2 transmission is  
12 frequently occurring in hospital settings, with numerous reported cases of nosocomial transmission  
13 highlighting the vulnerability of healthcare workers<sup>2-4</sup>. In general, N95 respirators are designed for single  
14 use prior to disposal. Several groups have addressed the potential for re-use of N95 respirators from a  
15 mechanical or from a decontamination perspective (for a full literature overview see Supplementary  
16 Appendix).

17  
18 Here, we analyzed four different decontamination methods – UV radiation (260 – 285 nm), 70°C heat,  
19 70% ethanol and vaporized hydrogen peroxide (VHP) – for their ability to reduce contamination with  
20 infectious SARS-CoV-2 and their effect on N95 respirator function. For each of the decontamination  
21 methods, we compared the inactivation rate of SARS-CoV-2 on N95 filter fabric to that on stainless steel,  
22 and we used quantitative fit testing to measure the filtration performance of the N95 respirators after each  
23 decontamination run and 2 hours of wear, for three consecutive decontamination and wear sessions (see  
24 Appendix). Vaporized hydrogen peroxide and ethanol yielded extremely rapid inactivation both on N95  
25 and on stainless steel (Figure 1A). UV inactivated SARS-CoV-2 rapidly from steel but more slowly on  
26 N95 fabric, likely due its porous nature. Heat caused more rapid inactivation on N95 than on steel;  
27 inactivation rates on N95 were comparable to UV.

28  
29 Quantitative fit tests showed that the filtration performance of the N95 respirator was not markedly  
30 reduced after a single decontamination for any of the four decontamination methods (Figure 1B).  
31 Subsequent rounds of decontamination caused sharp drops in filtration performance of the ethanol-treated  
32 masks, and to a slightly lesser degree, the heat-treated masks. The VHP- and UV-treated masks retained  
33 comparable filtration performance to the control group after two rounds of decontamination, and  
34 maintained acceptable performance after three rounds.

35

36 Taken together, our findings show that VHP treatment exhibits the best combination of rapid inactivation  
37 of SARS-CoV-2 and preservation of N95 respirator integrity, under the experimental conditions used here  
38 (Figure 1C). UV radiation kills the virus more slowly and preserves comparable respirator function. 70°C  
39 dry heat kills with similar speed and is likely to maintain acceptable fit scores for two rounds of  
40 decontamination. Ethanol decontamination is not recommended due to loss of N95 integrity, echoing  
41 earlier findings<sup>5</sup>.

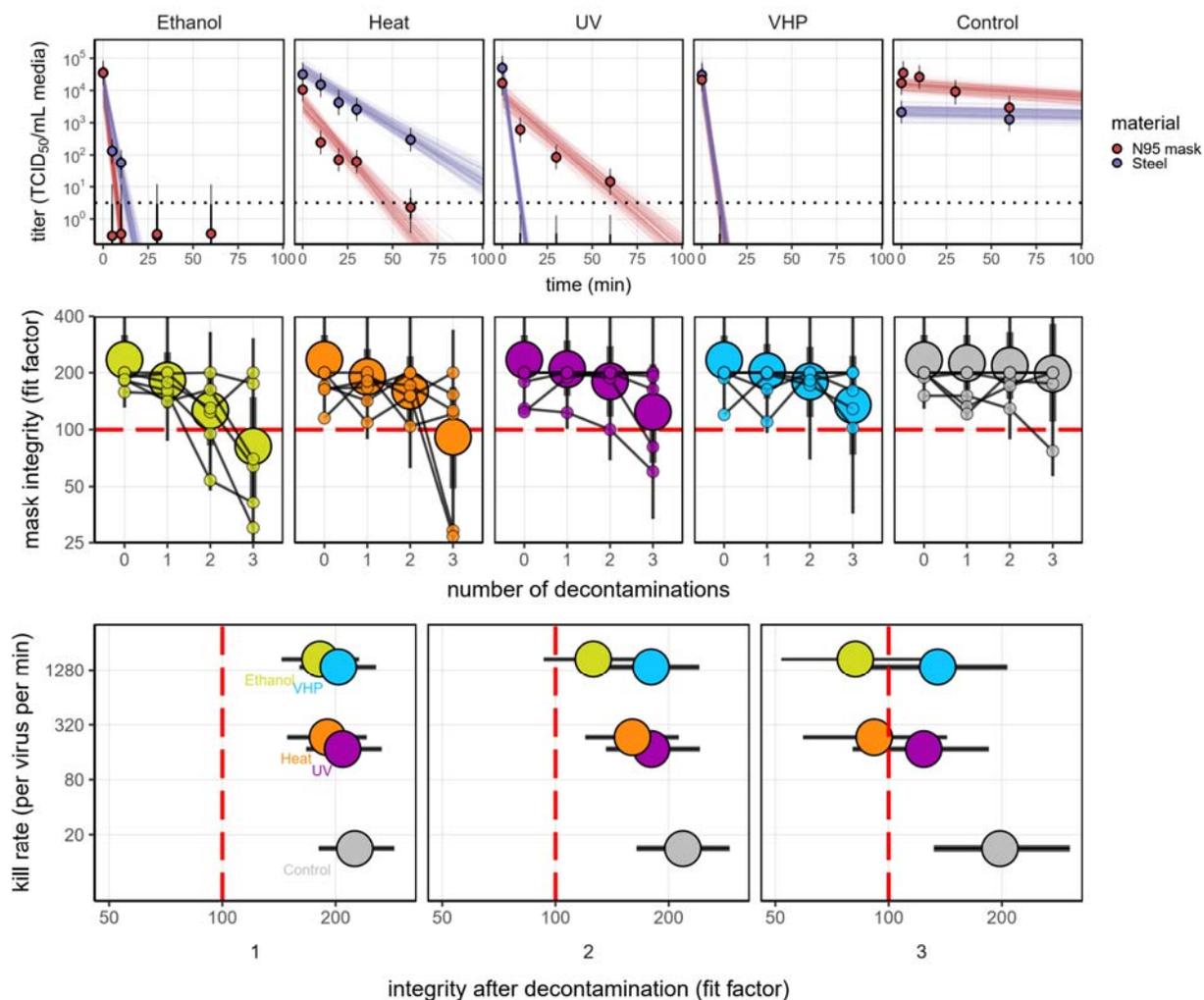
42

43 All treatments, particularly UV and dry heat, should be conducted for long enough to ensure that a  
44 sufficient reduction in virus concentration has been achieved. The degree of required reduction will  
45 depend upon the degree of initial virus contamination. Policymakers can use our estimated decay rates  
46 together with estimates of degree of real-world contamination to choose appropriate treatment durations  
47 (see Appendix).

48

49 Our results indicate that N95 respirators can be decontaminated and re-used in times of shortage for up to  
50 three times for UV and HPV, and up to two times for dry heat. However, utmost care should be given to  
51 ensure the proper functioning of the N95 respirator after each decontamination using readily available  
52 qualitative fit testing tools and to ensure that treatments are carried out for sufficient time to achieve  
53 desired risk-reduction.

54



55

56 **Figure 1.** Decontamination of SARS-CoV-2 by four different methods. **A)** SARS-CoV-2 on N95 fabric  
 57 and stainless steel surface was exposed to UV, 70 °C dry heat, 70% ethanol and vaporized hydrogen  
 58 peroxide (VHP). 50  $\mu$ l of 10<sup>5</sup> TCID<sub>50</sub>/mL of SARS-CoV was applied on N95 and stainless steel (SS).  
 59 Samples were collected at indicted timepoints post exposure to the decontamination method for UV, heat  
 60 and ethanol and after 10 minutes for VHP. Viable virus titer is shown in TCID<sub>50</sub>/mL media on a  
 61 logarithmic scale. All samples were quantified by end-point titration on Vero E6 cells. Plots show  
 62 estimated mean across three replicates (dots and bars show the posterior median estimate of this mean and  
 63 the posterior inter-quartile range, or IQR). Lines show predicted decay of virus titer over time (lines; 50  
 64 random draws per replicate from the joint posterior distribution of the exponential decay rate, i.e. negative

65 of the slope, and intercept, i.e. initial virus titer). Black dashed line shows maximum likelihood estimate  
66 titer at the Limit of Detection (LOD) of the assay:  $10^{0.5}$  TCID<sub>50</sub>/mL media. **B) Mask integrity.**  
67 Quantitative fit testing results for all the decontamination methods after decontamination and 2 hours of  
68 wear, for three consecutive runs. Data from six individual replicates (small dots) for each treatment are  
69 shown in addition to the predicted median and IQR (large dots and bars respectively) fit factor. Fit factors  
70 are a measure of filtration performance: the ratio of the concentration of particles outside the mask to the  
71 concentration inside. The measurement machine reports value up to 200. A minimal fit factor of 100 (red  
72 dashed line) is required for a mask to pass a fit test. **C) SARS-CoV-2 decontamination performance.** Kill  
73 rate (y-axis), versus mask integrity after decontamination (x-axis; bar length represents IQR). The three  
74 panels report mask integrity after one, two or three decontamination cycles.

75

## 76 **References**

- 77 1. Health C for D and R. N95 Respirators and Surgical Masks (Face Masks). FDA [Internet] 2020 [cited  
78 2020 Apr 10]; Available from: [https://www.fda.gov/medical-devices/personal-protective-equipment-](https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks)  
79 [infection-control/n95-respirators-and-surgical-masks-face-masks](https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks)
- 80 2. McMichael TM, Currie DW, Clark S, et al. Epidemiology of Covid-19 in a Long-Term Care Facility  
81 in King County, Washington. *New England Journal of Medicine* 2020; in press.
- 82 3. Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019  
83 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for  
84 Disease Control and Prevention. *JAMA* 2020;323(13):1239–42.
- 85 4. Livingston E, Bucher K. Coronavirus Disease 2019 (COVID-19) in Italy. *JAMA* [Internet] 2020  
86 [cited 2020 Apr 10]; Available from: <https://jamanetwork.com/journals/jama/fullarticle/2763401>
- 87 5. Liao L, Xiao W, Yu X, Wang H, Zhao M, Wang Q. Can N95 facial masks be used after disinfection?  
88 And for how many times? [Internet]. Stanford University and 4C Air, Inc; 2020 [cited 2020 Apr 10].  
89 Available from: <https://stanfordmedicine.app.box.com/v/covid19-PPE-1-2>

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## 101 **Supplemental methods**

### 102 Short literature review:

103 The COVID-19 pandemic has highlighted the necessity for large-scale decontamination procedures for  
104 PPE, in particular N95 respirator masks<sup>1</sup>. SARS-CoV-2 has frequently been detected on PPE of  
105 healthcare workers<sup>2</sup>. The environmental stability of SARS-CoV-2 underscores the need for rapid and  
106 effective decontamination methods<sup>3</sup>. Extensive literature is available for decontamination procedures for  
107 N95 respirators, using either bacterial spore inactivation tests, bacteria or respiratory viruses (e.g.  
108 influenza A virus)<sup>4-11</sup>. Effective inactivation methods for these pathogens and surrogates include UV,  
109 ethylene oxide, vaporized hydrogen peroxide, gamma irradiation, ozone and dry heat<sup>4,6,8,10-13</sup>. The  
110 filtration efficiency and N95 respirator fit has typically been less well explored, but suggest that both  
111 filtration efficiency and N95 respirator fit can be affected by the decontamination method used<sup>12,14</sup>. It will  
112 therefore be critical that FDA, CDC and OSHA guidelines with regards to fit testing, seal check and  
113 respirator re-use are followed<sup>4,15-18</sup>.

### 114 *Laboratory experiments*

#### 115 Viruses and titration

116 HCoV-19 nCoV-WA1-2020 (MN985325.1) was the SARS-CoV-2 strain used in our comparison<sup>19</sup>.  
117 Virus was quantified by end-point titration on Vero E6 cells as described previously<sup>20</sup>. Virus titrations  
118 were performed by end-point titration in Vero E6 cells. Cells were inoculated with 10-fold serial dilutions  
119 in four-fold of samples taken from N95 mask and stainless steel surfaces (see below). One hour after  
120 inoculation of cells, the inoculum was removed and replaced with 100  $\mu$ l (virus titration) DMEM (Sigma-  
121 Aldrich) supplemented with 2% fetal bovine serum, 1 mM L-glutamine, 50 U/ml penicillin and 50  $\mu$ g/ml  
122 streptomycin. Six days after inoculation, cytopathogenic effect was scored and the TCID<sub>50</sub> was calculated  
123 (see below). Wells presenting cytopathogenic effects due to media toxicity (e.g., due to the presence of  
124 ethanol or hydrogen peroxide) rather than viral infection were removed from the titer inference procedure.

#### 125 N95 and stainless steel surface

126 N95 material discs were made by punching 9/16" (15 mm) fabric discs from N95 respirators,  
127 AOSafety N9504C respirators (Aearo Company Southbridge, MA). The stainless steel 304 alloy discs  
128 were purchased from Metal Remnants (<https://metalremnants.com/>) as described previously. 50  $\mu$ L of  
129 SARS-CoV-2 was spotted onto each disc. A 0 time-point measurement was taken prior to exposing the  
130 discs to the disinfection treatment. At each sampling time-point, discs were rinsed 5 times by passing the  
131 medium over the stainless steel or through the N95 disc. The medium was transferred to a vial and frozen  
132 at -80°C until titration. All experimental conditions were performed in triplicate.

### 133 Decontamination methods

134 *Ultraviolet light.* Plates with fabric and steel discs were placed under an LED high power UV germicidal  
135 lamp (effective UV wavelength 260-285nm) without the titanium mesh plate (LEDi2, Houston, Tx) 50  
136 cm from the UV source. At 50 cm the UVAB power was measured at 5  $\mu$ W/cm<sup>2</sup> using a General UVAB  
137 digital light meter (General Tools and Instruments New York, NY). Plates were removed at 10, 30 and 60  
138 minutes and 1 mL of cell culture medium added.

139 *Heat treatment.* Plates with fabric and steel discs were placed in a 70°C oven. Plates were removed at 10,  
140 20, 30 and 60 minutes and 1 mL of cell culture medium added.

141 *70% ethanol.* Fabric and steel discs were placed into the wells of one 24 well plate per time-point and  
142 sprayed with 70% ethanol to saturation. The plate was tipped to near vertical and 5 passes of ethanol were  
143 sprayed onto the discs from approximately 10 cm. After 10 minutes,, 1 mL of cell culture medium was  
144 added.

145 *Vaporized hydrogen peroxide (VHP).* Plates with fabric and steel discs were placed into a Panasonic  
146 MCO-19AIC-PT (PHC Corp. of North America Wood Dale, IL) incubator with VHP generation  
147 capabilities and exposed to hydrogen peroxide (approximately 1000 ppm). The exposure to VHP was 10  
148 minutes, after the inactivation of the hydrogen peroxide, the plate was removed and 1 mL of cell culture  
149 medium was added.

150 *Control.* Plates with fabric and steel discs and steel plates were maintained at 21-23°C and 40% relative  
151 humidity for up to four days. After the designated time-points, 1 mL of cell culture medium was added.

152 N95 mask integrity testing

153 N95 Mask (3M™ Aura™ Particulate Respirator 9211+/37193) integrity testing after 2 hours of wear  
154 and decontamination, for three consecutive rounds, was performed for a total of 6 times for each  
155 decontamination condition and control condition. Masks were worn by subjects and integrity was  
156 quantitatively determined using the Portacount Respirator fit tester (TSI, 8038) with the N95 companion  
157 component, following the modified ambient aerosol condensation nuclei counter quantitative fit test  
158 protocol approved by the OSHA (Occupational Safety and Health Administration, 2012). Subjects were  
159 asked to bend over for 40 seconds, talk for 50 seconds, move head from side-to-side for 50 seconds, and  
160 move head up-and-down for 50 seconds whilst aerosols on inside and outside of mask were measured. By  
161 convention, this fit test is passed when the final score is  $\geq 100$ . For the N95 integrity testing, a Honeywell  
162 Mistmate humidifier (cat#HUL520B) was used for particle generation.

163 *Statistical analyses*

164 In the model notation that follows, the symbol  $\sim$  denotes that a random variable is distributed  
165 according to the given distribution. Normal distributions are parametrized as Normal(mean, standard  
166 deviation). Positive-constrained normal distributions (“Half-Normal”) are parametrized as Half-  
167 Normal(mode, standard deviation). Normal distributions truncated to the interval [0, 1] are parameterized  
168 as TruncNormal(mode, standard deviation).

169 We use  $\langle \text{Distribution Name} \rangle \text{CDF}(x \mid \text{parameters})$  and  $\langle \text{Distribution Name} \rangle \text{CCDF}$  to denote the  
170 cumulative distribution function and complementary cumulative distribution functions of a probability  
171 distribution, respectively. So for example  $\text{NormalCDF}(5 \mid 0, 1)$  is the value of the Normal(0, 1)  
172 cumulative distribution function at 5.

173 We use  $\text{logit}(x)$  and  $\text{invlogit}(x)$  to denote the logit and inverse logit functions, respectively:

174 
$$\text{logit}(x) = \ln \frac{x}{1-x} \quad (1)$$

175 
$$\text{invlogit}(x) = \frac{e^x}{1 + e^x} \quad (2)$$

176 Mean titer inference

177 We inferred mean titers across sets of replicates using a Bayesian model. The  $\log_{10}$  titers  $v_{ijk}$  (the titer  
178 for the sample from replicate  $k$  of timepoint  $j$  of experiment  $i$ ) were assumed to be normally distributed  
179 about a mean  $\mu_{ij}$  with a standard deviation  $\sigma$ . We placed a very weakly informative normal prior on  $\log_{10}$   
180 titers  $\mu_{ij}$ :

181 
$$\mu_{ij} \sim \text{Normal}(3, 3) \quad (3)$$

182 We placed a weakly informative normal prior on the standard deviation:

183 
$$\sigma \sim \text{Normal}(0, 0.5) \quad (4)$$

184 We then modeled individual positive and negative wells for sample  $ijk$  according to a Poisson single-  
185 hit model<sup>21</sup>. That is, the number of virions that successfully infect cells in a given well is Poisson  
186 distributed with mean:

187 
$$V = \ln(2) 10^v \quad (5)$$

188 where  $v$  is the  $\log_{10}$  virus titer in TCID<sub>50</sub>, where  $v$  is the  $\log_{10}$  virus titer in TCID<sub>50</sub>, and the well is infected  
189 if at least one virion successfully infects a cell. The value of the mean derives from the fact that our units  
190 are TCID<sub>50</sub>; the probability of infection at  $v = 0$ , i.e. 1 TCID<sub>50</sub>, is equal to  $1 - e^{-\ln(2) \times 1} = 0.5$ .

191 Let  $Y_{ijkdl}$  be a binary variable indicating whether the  $l^{\text{th}}$  well of dilution factor  $d$  (expressed as  $\log_{10}$   
192 dilution factor) of sample  $ijk$  was positive (so  $Y_{ijkdl} = 1$  if the well was positive and 0 otherwise), which  
193 will occur as long as at least one virion successfully infects a cell.

194 It follows from (5) that the conditional probability of observing  $Y_{ijkdl} = 1$  given a true underlying titer  
195  $\log_{10}$  titer  $v_{ijk}$  is given by:

196 
$$L(Y_{ijkdl} = 1 | v_{ijk}) = 1 - e^{-\ln(2) \times 10^x} \quad (6)$$

197 Where

198 
$$x = v_{ijk} - d \quad (7)$$

199 is the expected concentration, measured in  $\log_{10}$  TCID<sub>50</sub>, in the dilute sample. This is simply the  
200 probability that a Poisson random variable with mean  $(-\ln(2) \times 10^x)$  is greater than 0. Similarly, the  
201 conditional probability of observing  $Y_{ijkl} = 0$  given a true underlying titer  $\log_{10}$  titer  $v_{ijk}$  is given by:

$$202 \quad L(Y_{ijkl} = 0 | v_{ijk}) = e^{-\ln(2) \times 10^x} \quad (8)$$

203 which is the probability that the Poisson random variable is 0.

204 This gives us our likelihood function, assuming independence of outcomes across wells.

### 205 Virus inactivation regression

206 The durations of detectability depend on the decontamination treatment but also initial inoculum and  
207 sampling method, as expected. We therefore estimated the decay rates of viable virus titers using a  
208 Bayesian regression analogous to that used in van Doremalen et al., 2020<sup>3</sup>. This modeling approach  
209 allowed us to account for differences in initial inoculum levels across replicates as well as other sources  
210 of experimental noise. The model yields estimates of posterior distributions of viral decay rates and half-  
211 lives in the various experimental conditions – that is, estimates of the range of plausible values for these  
212 parameters given our data, with an estimate of the overall uncertainty<sup>22</sup>.

213 Our data consist of 10 experimental conditions: 2 materials (N95 masks and stainless steel) by 5  
214 treatments (no treatment, ethanol, heat, UV and VHP). Each has three replicates, and multiple time-points  
215 for each replicate. We analyze the two materials separately. For each, we denote by  $Y_{ijkl}$  the positive or  
216 negative status (see above) for well  $l$  which has dilution  $d$  for the titer  $v_{ijk}$  from experimental condition  $i$   
217 during replicate  $j$  at time-point  $k$ .

218 We model each replicate  $j$  for experimental condition  $i$  as starting with some true initial  $\log_{10}$  titer  
219  $v_{ij}(0) = v_{ij0}$ . We assume that viruses in experimental condition  $i$  decay exponentially at a rate  $\lambda_i$  over time  $t$ .  
220 It follows that:

$$221 \quad v_{ij}(t) = v_{ij0} - \lambda_i t \quad (9)$$

222 We use the direct-from-well data likelihood function described above, except that now instead of  
223 estimating titer distribution about a shared mean  $\mu_{ij}$  we estimate  $\lambda_i$  under the assumptions that our  
224 observed well data  $Y_{ijkl}$  reflect the titers  $v_{ij}(t)$ .

#### 225 *Regression prior distributions*

226 We place a weakly informative Normal prior distribution on the initial  $\log_{10}$  titers  $v_{ij0}$  to rule out  
227 implausibly large or small values (e.g. in this case undetectable  $\log_{10}$  titers or  $\log_{10}$  titers much higher than  
228 the deposited concentration), while allowing the data to determine estimates within plausible ranges:

$$229 \quad v_{ij0} \sim \text{Normal}(4.5, 2) \quad (10)$$

230 We placed a weakly informative Half-Normal prior on the exponential decay rates  $\lambda_i$ :

$$231 \quad \lambda_i \sim \text{Half-Normal}(0.5, 4) \quad (11)$$

232 Our plated samples were of volume 0.1 mL, so inferred titers were incremented by 1 to convert to  
233 units of  $\log_{10}$  TCID<sub>50</sub>/mL.

#### 234 Mask integrity estimation

235 To quantify the decay of mask integrity after repeated decontamination, we used a logit-linear spline  
236 Bayesian regression to estimate the rate of degradation of mask fit factors over time, accounting for the  
237 fact that fit factors are interval-censored ratios. Fit factors are defined as the ratio of exterior  
238 concentration to interior concentration of a test aerosol. They are reported to the nearest integer, up to a  
239 maximum readout of 200, but arbitrarily large true fit factors are possible as the mask performance  
240 approaches perfect filtration.

241 We had 6 replicate masks  $j$  for each of 5 treatments  $i$  (no decontamination, ethanol, heat, UV and  
242 VHP). Each mask  $j$  was assessed for fit factor at 4 time-points  $k$ : before decontamination, and then after 1,

243 2, and 3 decontamination cycles. We label the control treatment  $i = 0$ . So we denote by  $F_{ijk}$  the fit factor  
244 for the  $j^{\text{th}}$  mask from the  $i^{\text{th}}$  treatment after  $k$  decontaminations (with  $k = 0$  for the initial value).

245 We first converted fit factors  $F_{ijk}$  to the equivalent observed filtration rate  $Y_{ijk}$  by:

246 
$$Y = 1 - 1/F \quad (12)$$

247 *Observation model and likelihood function*

248 We modeled the censored observation process as follows.  $\text{logit}(Y_{ijk})$  values are observed with  
249 Gaussian error about the true filtration  $\text{logit}(p_{ijk})$ , with an unknown standard deviation  $\sigma_o$ , and then  
250 converted to fit factors, which are then censored:

$$251 \quad \text{logit}(Y_{ijk}) \sim \text{Normal}(\text{logit}(p_{ijk}), \sigma_o) \quad (13)$$

252 Because our reported fit factors are known to be within integer values and right-censored at 200, for  
253  $F_{ijk} \geq 200$  we have a conditional probability of observing the data given the parameters of

$$254 \quad L(F_{ijk} | p_{ijk}, \sigma_o) = \text{NormalCCDF}(\text{logit}(1 - 1/200) | \text{logit}(p_{ijk}) \sigma_o) \quad (14)$$

255 That is, we calculate the probability of observing a value of  $F$  greater than or equal to 200 (equivalent a  
256 value of  $Y$  greater than or equal to  $1 - 1/200$ ), given our parameters.

257 For  $1.5 \leq F_{ijk} < 200$ , we first calculate the upper and lower bounds of our observation  $Y^+_{ijk} = 1 - 1 /$   
258  $(F_{ijk} - 0.5)$  and  $Y^-_{ijk} = 1 - 1 / (F_{ijk} - 0.5)$ . Then:

$$259 \quad L(F_{ijk} | p_{ijk}, \sigma_o) = \text{NormalCDF}(\text{logit}(Y^+_{ijk}) | \text{logit}(p_{ijk}) \sigma_o) - \\ 260 \quad \text{NormalCDF}(\text{logit}(Y^-_{ijk}) | \text{logit}(p_{ijk}) \sigma_o) \quad (15)$$

261 That is, we calculate the probability of observing a value between  $Y^+_{ijk}$  and  $Y^-_{ijk}$ , given our parameters.

262 *Decay model*

263 We assumed that each mask had some true initial filtration rate  $p_{ij0}$ . We assumed that these were  
264 logit-normally distributed about some unknown mean mask initial filtration rate  $p_{avg}$  with a standard  
265 deviation  $\sigma_p$ , that is:

$$266 \quad \text{logit}(p_{ij0}) \sim \text{Normal}(\text{logit}(p_{avg}), \sigma_p) \quad (16)$$

267 We then assumed that the logit of the filtration rate,  $\text{logit}(p_{ijk})$ , decreased after each decontamination  
268 by a quantity  $d_{0k} + d_{ik}$ , where  $d_{0k}$  is natural degradation during the  $k^{\text{th}}$  trial in the absence of

269 decontamination (i.e. the degradation rate in the control treatment,  $i = 0$ ), and  $d_{ik}$  is the additional  
270 degrading effect of the  $k^{\text{th}}$  decontamination treatment of type  $i > 0$ ). So for  $k = 1, 2, 3$  and  $i > 0$ :

271 
$$\text{logit}(p_{ijk}) = \text{logit}(p_{ij(k-1)}) - (d_{0k} + d_{ik}) + \varepsilon_{ijk} \quad (17)$$

272 where  $\varepsilon_{ijk}$  is a normally-distributed error term with an inferred standard deviation  $\sigma_\varepsilon$ :

273 
$$\varepsilon_{ijk} \sim \text{Normal}(0, \sigma_\varepsilon) \quad (18)$$

274 And for the control  $i = 0$ :

275 
$$\text{logit}(p_{0jk}) = \text{logit}(p_{0j(k-1)}) - d_{0k} + \varepsilon_{0jk} \quad (19)$$

276 *Model prior distributions*

277 We placed a weakly informative Half-Normal prior on the control degradation rate  $d_0$ :

278 
$$d_0 \sim \text{Half-Normal}(0, 0.5) \quad (20)$$

279 We placed a weakly informative Half-Normal prior on the non-control degradation rates  $d_i$ ,  $i > 0$ :

280 
$$d_i \sim \text{Half-Normal}(0.25, 0.5) \quad (21)$$

281 reflecting the conservative assumption that decontamination should degrade the mask at least somewhat.

282 We placed a Truncated Normal prior on the mean initial filtration  $p_{avg}$ :

283 
$$p_{avg} \sim \text{TruncNormal}(0.995, 0.02) \quad (22)$$

284 The mode of 0.995 corresponds to the maximum measurable fit factor of 200. The standard deviation of  
285 0.02 leaves it plausible that some masks could start near or below the minimum acceptable threshold fit  
286 factor of 100, which corresponds to a  $p$  of 0.99.

287 We placed weakly informative Half-Normal priors on the logit-space standard deviations  $\sigma_p$ ,  $\sigma_e$ , and  
288  $\sigma_o$ .  $\sigma_p$  reflects variation in individual masks' initial filtration about  $p_{avg}$ .  $\sigma_e$  reflects variation in mask's true  
289 degree of degradation between decontaminations about the expected decay, and  $\sigma_o$  reflects noise in the  
290 observation process.

291 
$$\sigma_p, \sigma_e, \sigma_o \sim \text{Half-Normal}(0, 0.5) \quad (23)$$

292 We chose a standard deviation of 0.5 for the priors because a standard deviation of 1.5 (i.e.  $3\sigma$  in the  
293 prior) in logit space corresponds to probability values being uniformly distributed between 0 and 1; we  
294 therefore wish to tell our model not to use larger standard deviations, as these squash all  $p_{ijk}$  to one of two  
295 modes, one at 0 and one at 1<sup>23</sup>.

#### 296 Markov Chain Monte Carlo Methods

297 For all Bayesian models, we drew posterior samples using Stan (Stan Core Team 2018), which  
298 implements a No-U-Turn Sampler (a form of Markov Chain Monte Carlo), via its R interface RStan. We  
299 ran four replicate chains from random initial conditions for 2000 iterations, with the first 1000 iterations  
300 as a warmup/adaptation period. We saved the final 1000 iterations from each chain, giving us a total of  
301 4000 posterior samples. We assessed convergence by inspecting trace plots and examining  $R^2$  and  
302 effective sample size ( $n_{eff}$ ) statistics.

303

304

305

306

307 **Supplemental table**

308 Table S1. Effect of decontamination method on SARS-CoV-2 viability and N95 mask integrity.

Treatment	Material	half-life (min)			time to one thousandth (min)			time to one millionth (min)		
		median	2.5%	97.5%	median	2.5%	97.5%	median	2.5%	97.5%
Control	N95 mask	78	65.3	89.7	777	650	894	1.55e+03	1.3e+03	1.79e+03
	Steel	286	243	324	2.85e+03	2.42e+03	3.23e+03	5.7e+03	4.84e+03	6.45e+03
Ethanol	N95 mask	0.639	0.55	0.721	6.37	5.49	7.19	12.7	11	14.4
	Steel	1.06	0.888	1.23	10.6	8.85	12.2	21.2	17.7	24.5
Heat	N95 mask	4.64	3.87	5.41	46.3	38.5	53.9	92.6	77	108
	Steel	8.83	7.49	10.1	88	74.7	101	176	149	201
UV	N95 mask	6.26	5.31	7.15	62.4	52.9	71.2	125	106	142
	Steel	0.733	0.649	0.802	7.31	6.47	7.99	14.6	12.9	16
VHP	N95 mask	0.78	0.685	0.858	7.78	6.82	8.55	15.6	13.6	17.1
	Steel	0.765	0.669	0.843	7.63	6.67	8.4	15.3	13.3	16.8

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310 **Code and data availability**

311 Code and data to reproduce the Bayesian estimation results and produce corresponding figures are  
 312 archived online at OSF: and available on Github:

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## 325 Supplemental references

- 326 1. Ranney ML, Griffeth V, Jha AK. Critical Supply Shortages - The Need for Ventilators and  
327 Personal Protective Equipment during the Covid-19 Pandemic. *N Engl J Med* 2020.
- 328 2. Ong SWX, Tan YK, Chia PY, et al. Air, Surface Environmental, and Personal Protective  
329 Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a  
330 Symptomatic Patient. *JAMA* 2020.
- 331 3. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and Surface Stability of SARS-CoV-2  
332 as Compared with SARS-CoV-1. *N Engl J Med* 2020.
- 333 4. Decontamination and Reuse of Filtering Facepiece Respirators  
334 . 2020. (Accessed 4/5/2020, 2020, at [https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-  
335 strategy/decontamination-reuse-respirators.html](https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html).)
- 336 5. Final Report for the Bioquell Hydrogen Peroxide Vapor (HPV) Decontamination for Reuse of N95  
337 Respirators. 2016. at <https://www.fda.gov/media/136386/download>.)
- 338 6. Fisher EM, Shaffer RE. A method to determine the available UV-C dose for the decontamination  
339 of filtering facepiece respirators. *J Appl Microbiol* 2011;110:287-95.
- 340 7. Heimbuch BK, Kinney K, Lumley AE, Harnish DA, Bergman M, Wander JD. Cleaning of filtering  
341 facepiece respirators contaminated with mucin and *Staphylococcus aureus*. *Am J Infect Control*  
342 2014;42:265-70.
- 343 8. Heimbuch BK, Wallace WH, Kinney K, et al. A pandemic influenza preparedness study: use of  
344 energetic methods to decontaminate filtering facepiece respirators contaminated with H1N1 aerosols and  
345 droplets. *Am J Infect Control* 2011;39:e1-9.
- 346 9. Lin TH, Tang FC, Hung PC, Hua ZC, Lai CY. Relative survival of *Bacillus subtilis* spores loaded  
347 on filtering facepiece respirators after five decontamination methods. *Indoor Air* 2018.
- 348 10. Mills D, Harnish DA, Lawrence C, Sandoval-Powers M, Heimbuch BK. Ultraviolet germicidal  
349 irradiation of influenza-contaminated N95 filtering facepiece respirators. *Am J Infect Control* 2018;46:e49-  
350 e55.

- 351 11. Viscusi DJ, Bergman MS, Eimer BC, Shaffer RE. Evaluation of five decontamination methods for  
352 filtering facepiece respirators. *Ann Occup Hyg* 2009;53:815-27.
- 353 12. Avilash Cramer ET, Sherryl H Yu, Mitchell Galanek, Edward Lamere, Ju Li, Rajiv Gupta, Michael  
354 P Short. disposable N95 masks pass qualitative fit-test but have decreases filtration efficiency after  
355 cobalt-60 gamma irradiation. *MedRxiv*.
- 356 13. Chemical Disinfectants, Guideline for Disinfection and Sterilization in Healthcare Facilities. 2008.  
357 at [https://www.cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-](https://www.cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-methods/chemical.html#Hydrogen)  
358 [methods/chemical.html#Hydrogen.](https://www.cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-methods/chemical.html#Hydrogen))
- 359 14. Lin TH, Chen CC, Huang SH, Kuo CW, Lai CY, Lin WY. Filter quality of electret masks in filtering  
360 14.6-594 nm aerosol particles: Effects of five decontamination methods. *PLoS One* 2017;12:e0186217.
- 361 15. N95 Respirators and Surgical Masks (Face Masks). 2020. (Accessed 4/5/2020, 2020, at  
362 [https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-](https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks)  
363 [surgical-masks-face-masks.](https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks))
- 364 16. Temporary Enforcement Guidance - Healthcare Respiratory Protection Annual Fit-Testing for N95  
365 Filtering Facepieces During the COVID-19 Outbreak. 2020. at [https://www.osha.gov/memos/2020-03-](https://www.osha.gov/memos/2020-03-14/temporary-enforcement-guidance-healthcare-respiratory-protection-annual-fit)  
366 [14/temporary-enforcement-guidance-healthcare-respiratory-protection-annual-fit.](https://www.osha.gov/memos/2020-03-14/temporary-enforcement-guidance-healthcare-respiratory-protection-annual-fit))
- 367 17. User Seal Check Procedures (Mandatory). 2020. (Accessed April 11, 2020, at  
368 [https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134AppB1.](https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134AppB1))
- 369 18. Respirator Fit Testing [WWW Document]. U. S. Dep. Labo. 2012. at  
370 [https://www.osha.gov/video/respiratory\\_protection/fittesting\\_transcript.html](https://www.osha.gov/video/respiratory_protection/fittesting_transcript.html) (accessed 4.10.20.)
- 371 19. Holshue ML, DeBolt C, Lindquist S, et al. First Case of 2019 Novel Coronavirus in the United  
372 States. *N Engl J Med* 2020.
- 373 20. van Doremalen N, Bushmaker T, Munster VJ. Stability of Middle East respiratory syndrome  
374 coronavirus (MERS-CoV) under different environmental conditions. *Euro Surveill* 2013;18.
- 375 21. Brownie C, Statt J, Bauman P, et al. Estimating viral titres in solutions with low viral loads.  
376 *Biologicals* 2011;39:224-30.
- 377 22. Gelman A. Bayesian data analysis. Third edition. ed. Boca Raton: CRC Press; 2014.
- 378 23. Northrup JM, Gerber BD. A comment on priors for Bayesian occupancy models. *PLoS One*  
379 2018;13:e0192819.

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