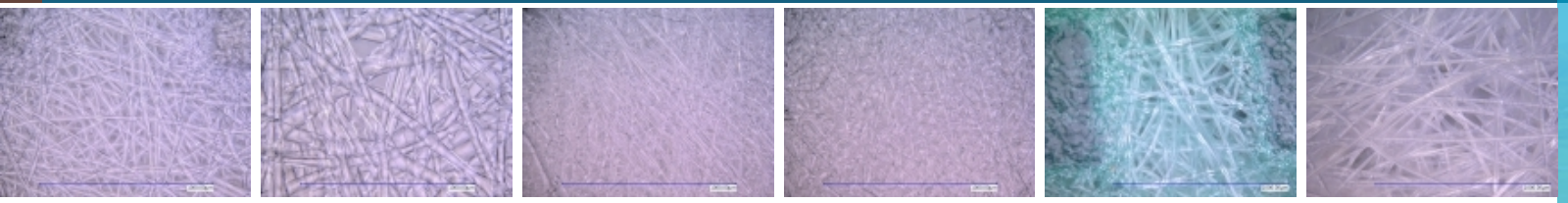
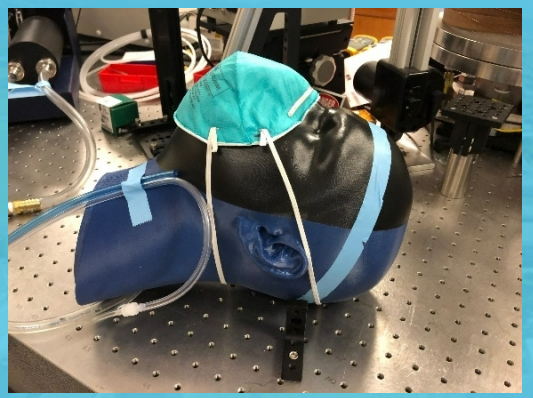
SAND2022-1497C

Performance and electret charge of N95 respirators after decontamination





PRESENTED BY

Anne M. Grillet

Engineering Sciences Division
Sandia National Laboratories

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What is an N95 Respirator?

N95 is a classification of the National Institute for Occupational Safety and Health (NIOSH)

- NIOSH 42 CFR 84 N95 requirements for a minimum 95% filtration efficiency against solid and liquid aerosols that do not contain oil.
- Maximum inhalation resistance 35mm Hg

KN95 and KF94 are Chinese and Korean filtration standards respectively

Food and Drug Administration approved surgical mask

- Demonstrate ability to resist penetration by fluids at a velocity consistent with the intended use
- Materials are biocompatible

Two main differences that contribute to protection

- Fit
- Electrostatic charge of the filtration layer (electret)

3M 8210 N95 respirator

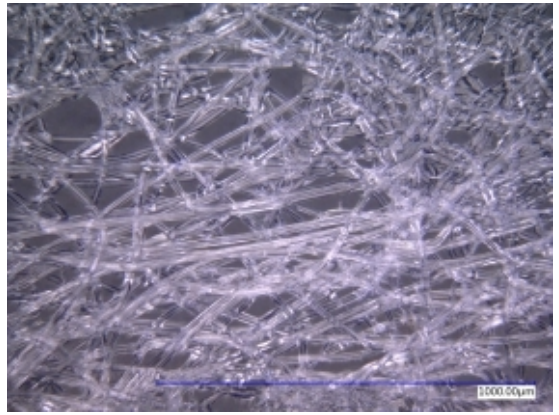
Surgical mask

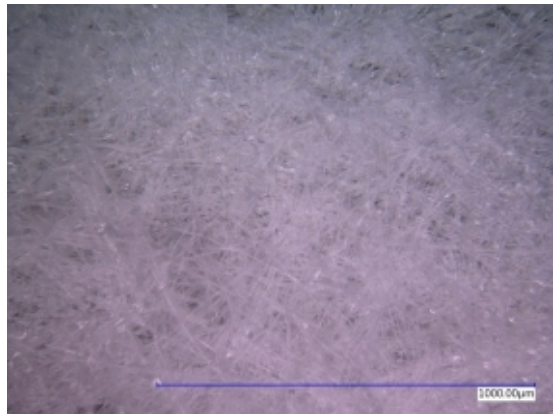
3M 1860 N95 surgical respirator

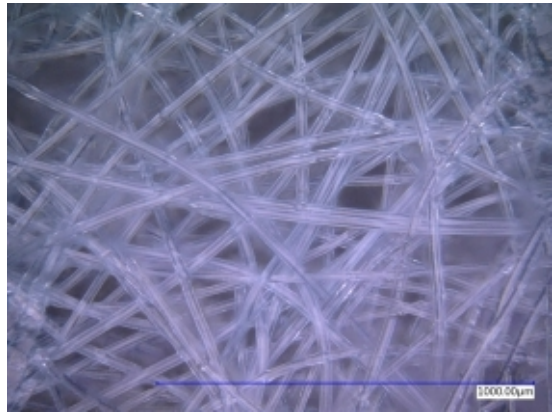
https://www.aerotechdesigns.com/surgical-face-mask-blue-disposable-3-ply.html

High Resolution Images of Surgical Mask and N95 Respirator Components

Surgical mask





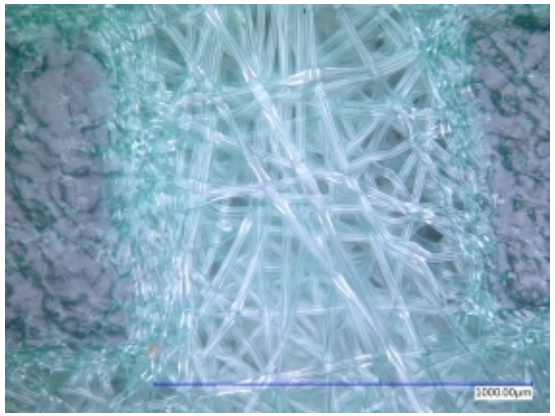


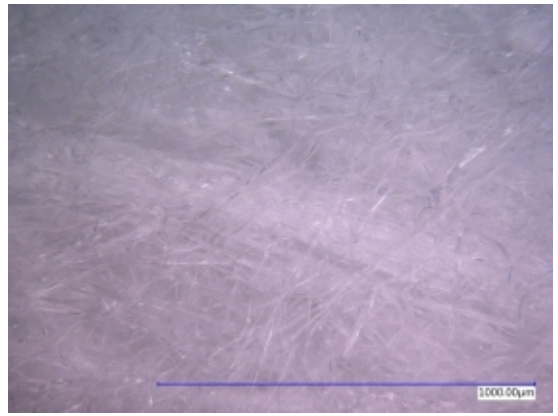
Melt-blown polypropylene cover and filter

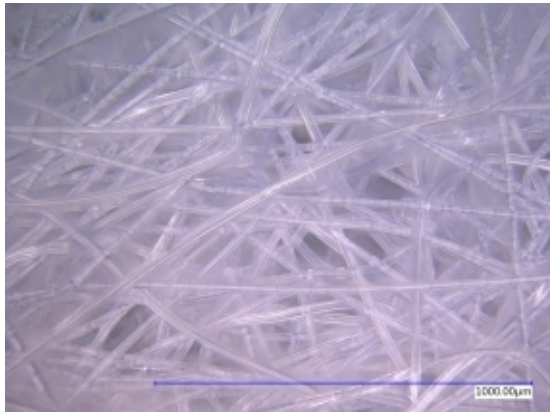
Polyester shell

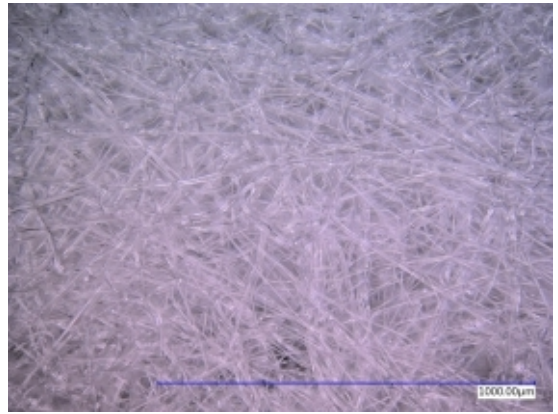
Surgical mask	Fiber (micron)
Outer 1	16-18
2	2.7-4
Inner 3	16-19

N95	Fiber (micron)
Outer 1	19.9 (0.9)
2	2.6 (1.2)
3	3.2 (1.8)
Inner 4	20.6 (2.3)





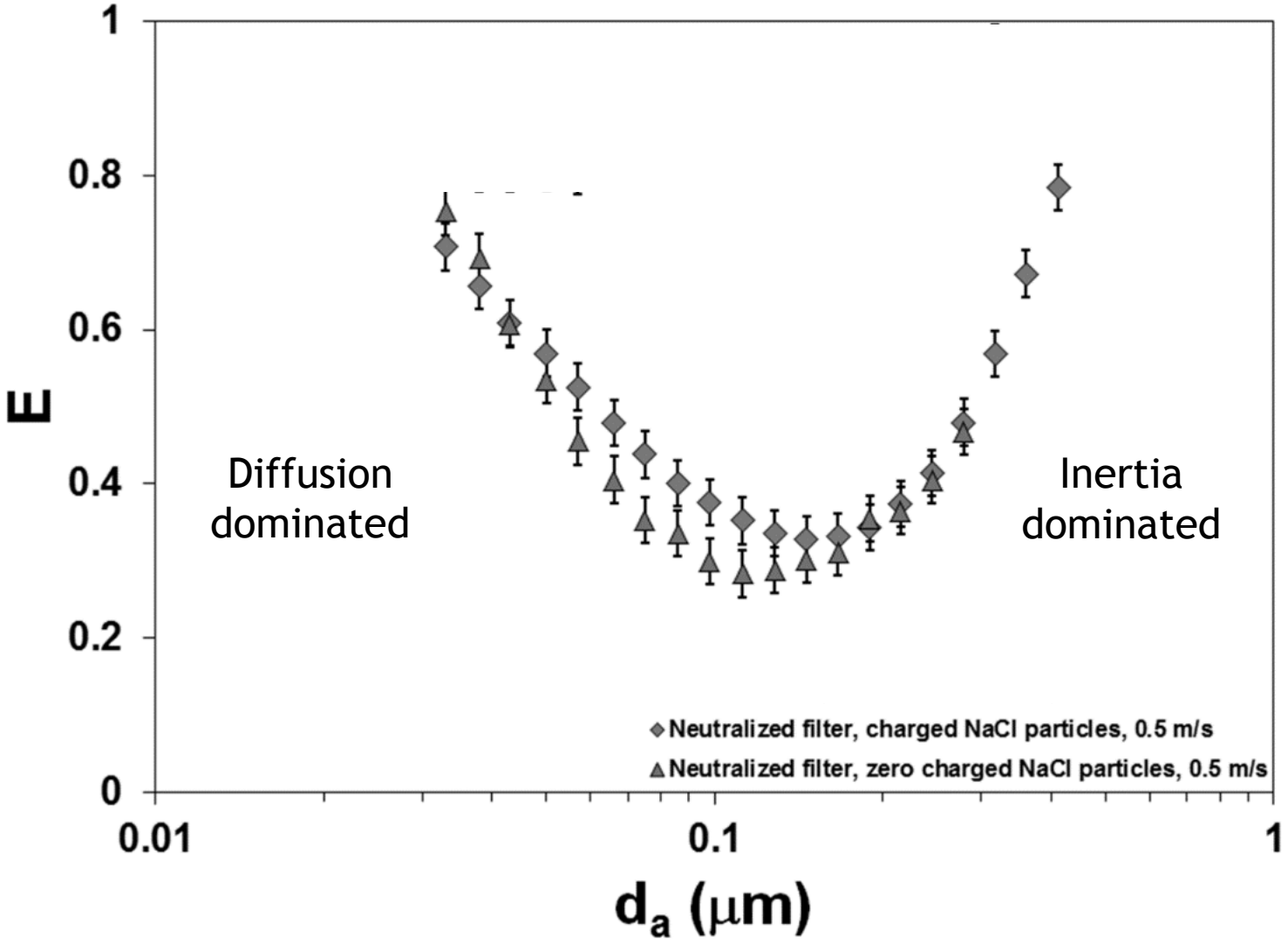




N95 Respirator

Electrostatic Charge Enhances Filtration Efficacy

Electrostatic surface potentials enable the efficient capture of sub-micron particles



Total filter efficiency (E) as a function of aerodynamic particle diameter (d_a) for a nominal filter face velocities of 0.5 m/s Sanchez et al. (2012)

Outline

- Introduction to N95 respirators
- Extended use and reuse recommendations
- Scoping experiments with surrogate materials
- N95 respirator studies with University of New Mexico Hospital
- Conclusions

CDC Response to N95 Respirator Shortages

Institute of Medicine predicted that a **42**-day outbreak of a respiratory virus would require more than **90 million N95 respirators**

Centers of Disease Control & Prevention strategies :

- Strategic reserve of N95 respirators
- Extended Use (not removing the N95)
  - Prior practice was to discard after a single patient
- Reuse (removing and redonning)
  - Single user to utilize an N95 for multiple donnings
- Decontamination Methods (4/3/2020)
  - **Recommended:**
    - Ultraviolet Germicidal Irradiation (UV)
    - Vaporous Hydrogen Peroxide (VPH)
    - Moist Heat (oven, microwave steam)
  - **Promising:** Steam treatment, Liquid Hydrogen peroxide
  - **Not recommended:** Autoclave, dry heat, isopropyl alcohol, soap, dry microwave irradiation and bleach

Institute of Medicine (2006)

RAPTR N95 developed at Sandia

Sandia team designed to meet the requirements for a medical-grade reusable N95 respirator

- Respirator can be completely disassembled for cleaning and is compatible with autoclave sterilization
- N95 filters are easily replaceable
- Resonator transmits the voice for unstifled communication

Winner of *two* 2021 R&D100 awards

- Analytical/Test Category
- Special Recognition: Corporate Responsibility – Silver Medal

Sandia engineer Todd Barrick demonstrating the mask he developed with a cross disciplinary team across Sandia Labs

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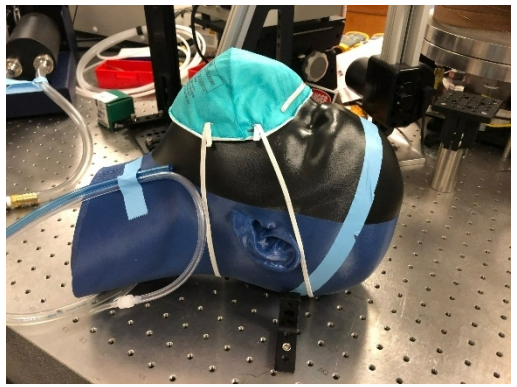
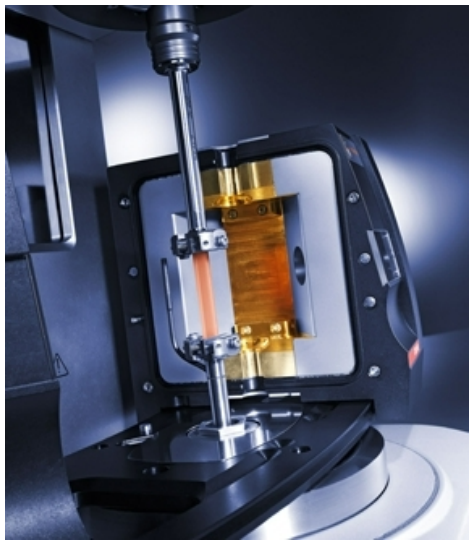
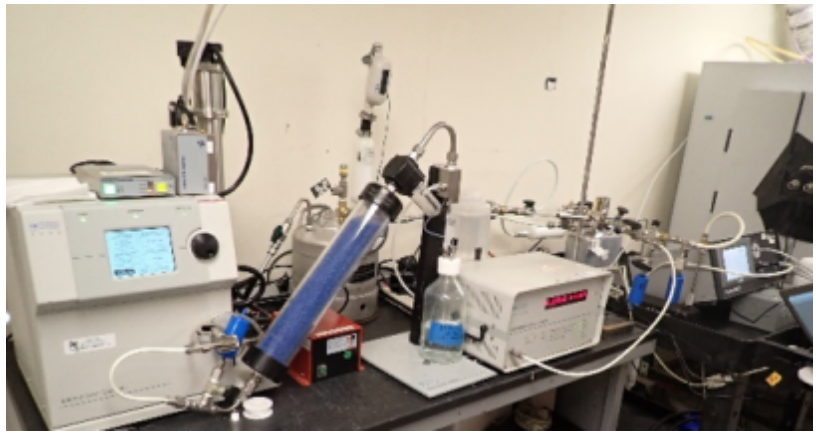
Do Conservation Strategies Effect the Performance of N95 Respirators?

Partner with University of New Mexico Hospital
- Dr. D.J. Perkins

Utilize four performance metrics
- Filtration performance
- Fit
- Electret charge
- Wear of mechanical straps







Initial Studies on Alternative Charged Materials

Decontamination Methods:

Vaporous Hydrogen Peroxide (VHP):
- BioQuell Clarus C system

Liquid hydrogen peroxide (6 wt%)

UV (254nm, ThermoForma Biosafety cabinet)

Moist heat (60C, 85% relative humidity)

Dry heat (75°C 30 minutes)

Bleach (10wt% bleach - 0.6wt% NaOCl 30 minutes)

Bleach + 3wt% hydrogen peroxide rinse

Ethanol (70wt%, 30 minutes)

Isopropyl alcohol (30 minutes)

Detergent (2wt% 30 min, DI water rinse 20 min)

Viscusi et al (2007), Perkins et al (2020), Grillet et al (2021)

Alternative materials

NP097 NanoNxt (distributed by Filti)
- polypropylene outer layer, nanofiber center layer and a polyester inner layer.
- The manufacturer claims a 95% filtration efficiency, though those results are not guaranteed to be representative of all Filti material

Swiffer dry cleaning wipes (Procter & Gamble)
- Unspecified composition
- Manufacturer claims charge properties help dust collection

Polyester filter fabric (McMaster Carr)
- 100% polyester (negative surface charge)
- Advertised to remove particles down to 50 micron

Filti Face Mask Material Data Sheet. 2020

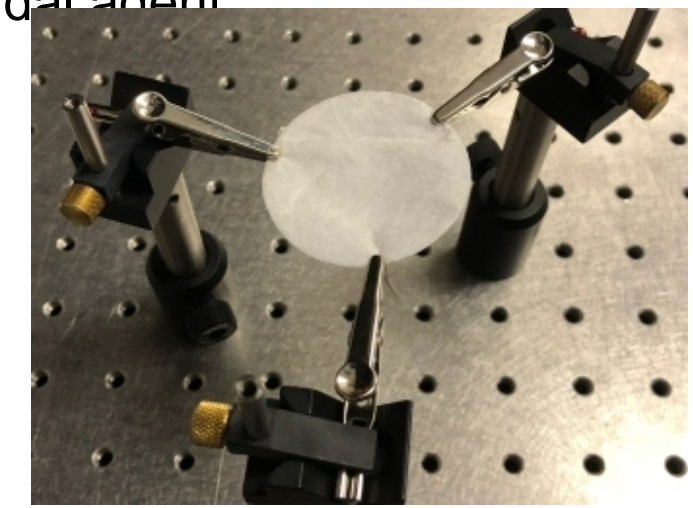
Down-Select of Decontamination Methods

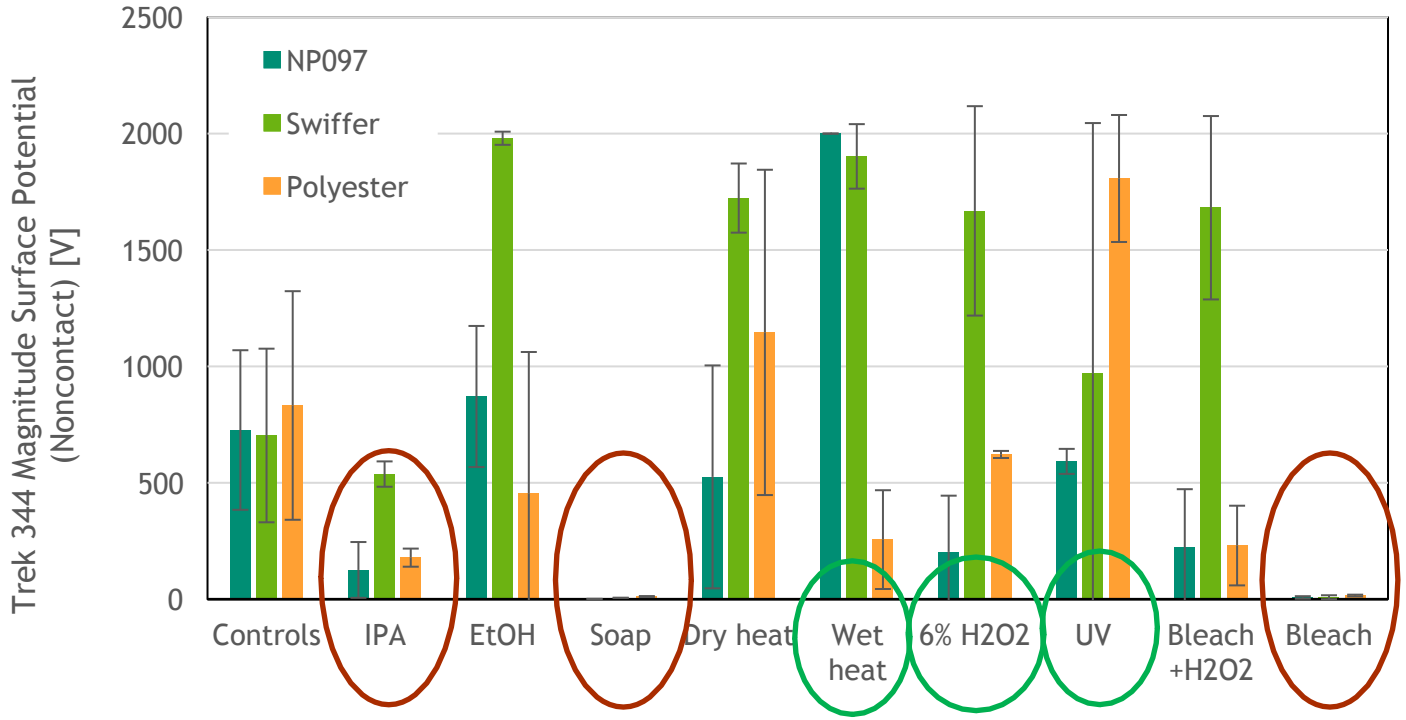
Recommended methods did not negatively impact charging

- Wet heat
- Hydrogen peroxide
- UV irradiation

Soap and bleach very effectively neutralized the charging of the non-woven fabrics

Isopropyl alcohol is a more effective germicidal agent





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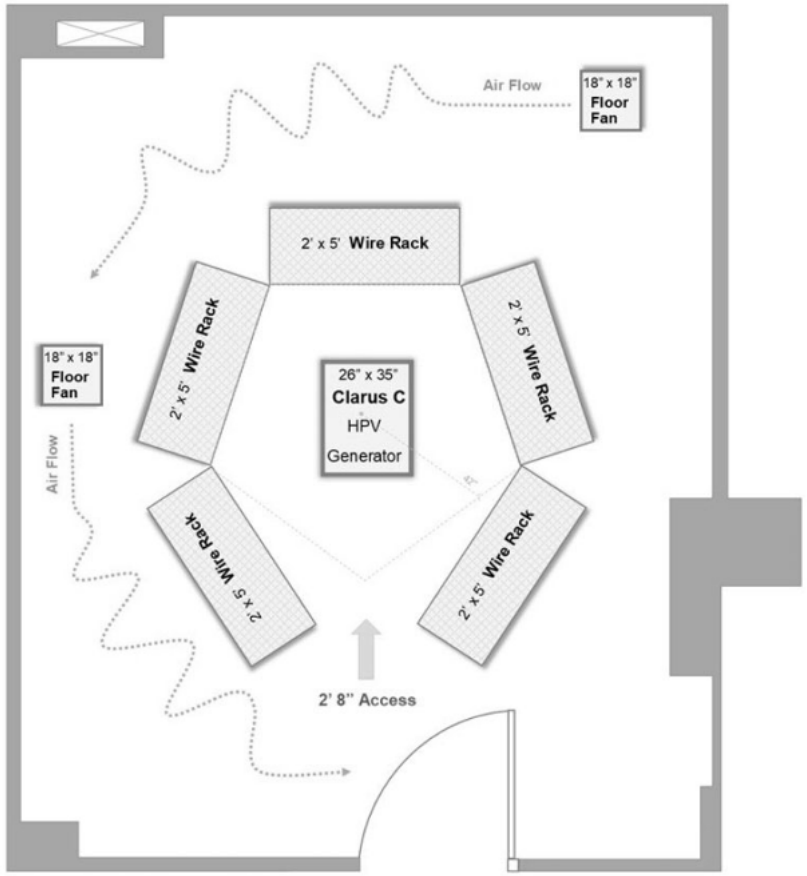
N95 respirators

N95 respirators were provided by University of New Mexico Hospital after reuse & extended use and decontamination using Vaporous Hydrogen Peroxide (VHP)

	# N95s (# HPV cycles)	
	3M™ 1870+ Aura™	3M™ 1860
Control	2 (0)	2 (0)
HPV	2 (1 & 2)	2 (1 & 2)
Wet heat	2 (1 & 2)	2 (2 & 2)
Bleach	2 (1 & 2)	2 (1 & 2)
UV	1 (1)	1 (0)
IPA	1 (2)	1 (0)
Soap	1 (2)	1 (0)

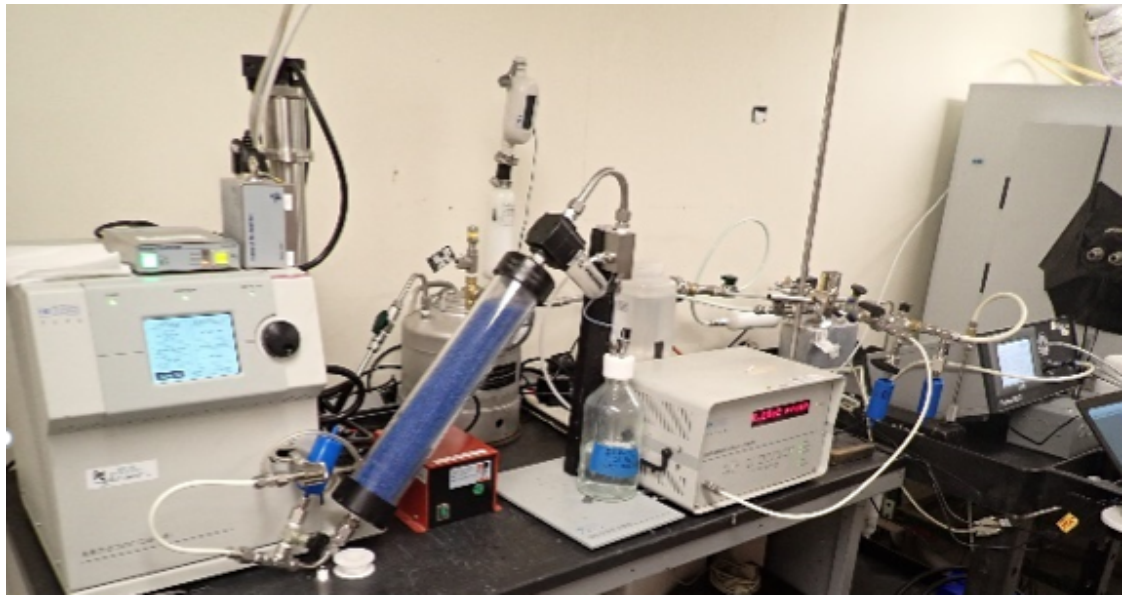


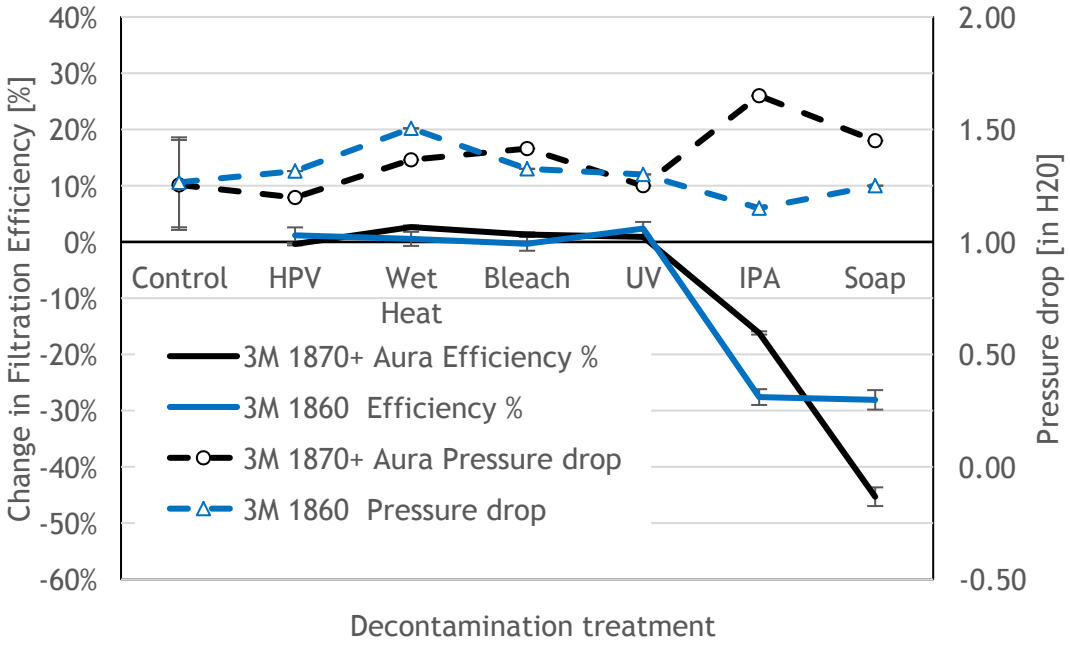
Perkins et al. (2020)

Filtration and Pressure Drop

N95 respirators treated with recommended decontamination and bleach retained their filtration efficiency

Isopropyl alcohol and detergent both substantially degraded filtration efficiency but pressure drop was not effected.





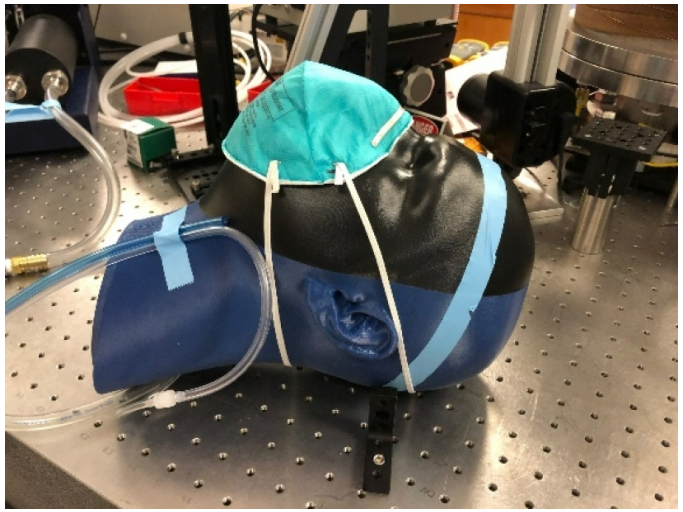
Quantitative Fit Testing

Decontamination respirators were tested using static headforms as recommended by the National Personal Protective Technology Laboratory (NPPTL)

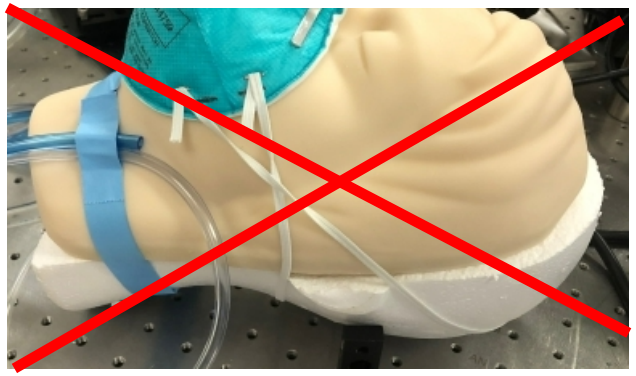
TSI PortaCount measures particle counts inside and outside of the respirator and take the ratio

TSI PortaCount 8038

simulated breathing



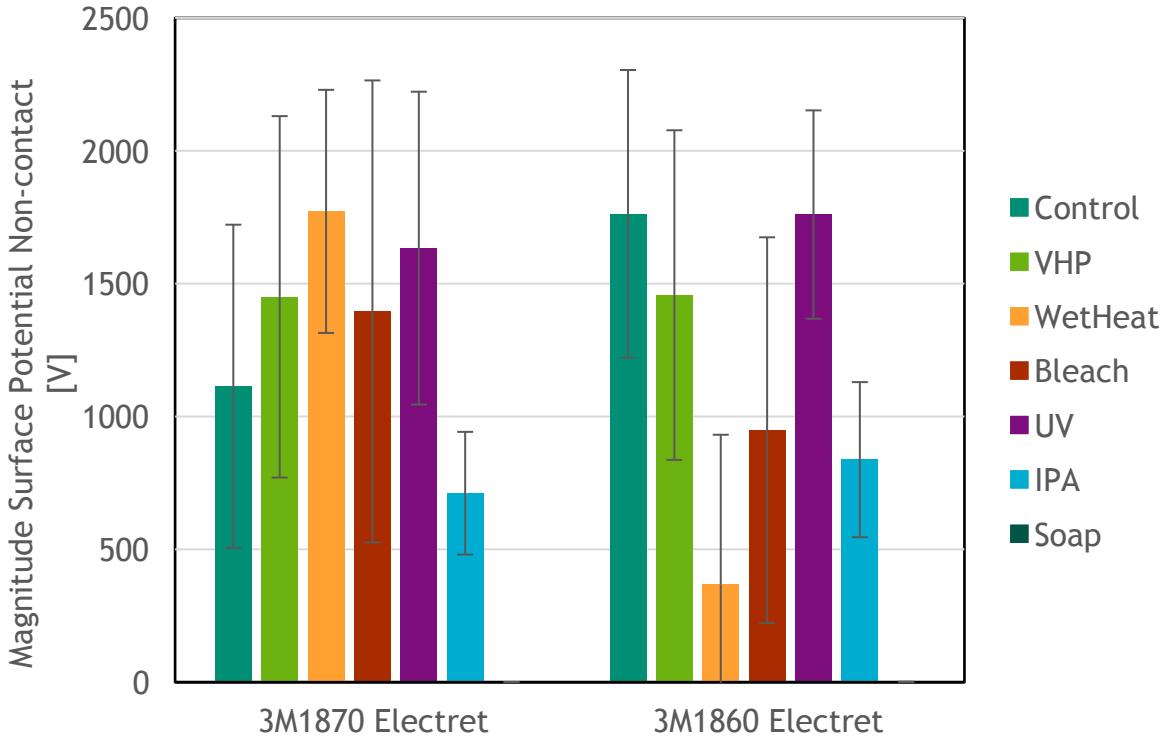
3M™ 1870 (# respirators)	Manikin Fit Factor
Control (2)	200+
VHP (4)	200+
Wet Heat + VHP (2)	150/200+
Bleach + VHP (2)	200+
UV + VHP (1)	200+
IPA + VHP (1)	39
Soap + VHP (1)	10

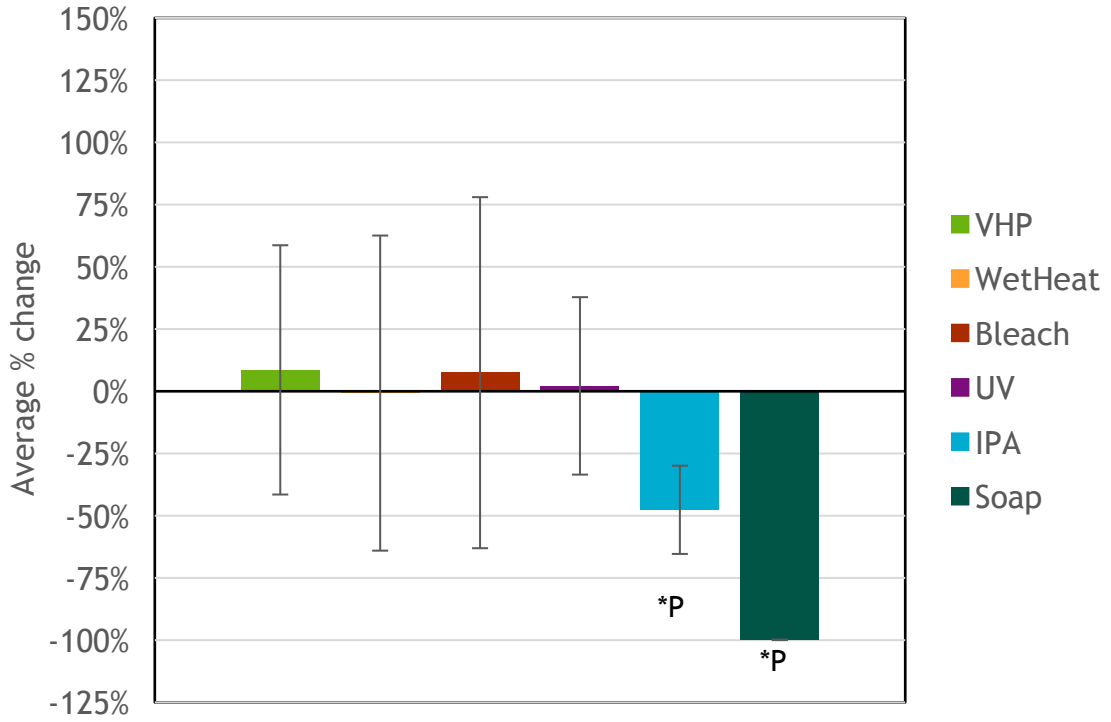


Incorrect strap placement - No passing fit scores!

Electret Filtration Layer Surface Potential

Despite the large uncertainty in the measurements, the results for both isopropyl alcohol showed statistically significant decreases in electrostatic surface potential, confirming for the first time that the decrease in filtration performance is directly correlated to loss of surface potential.

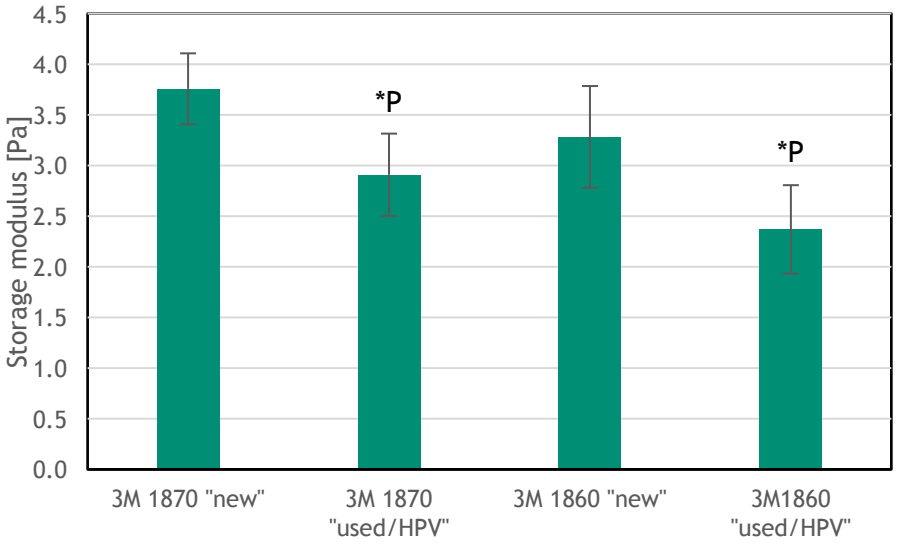


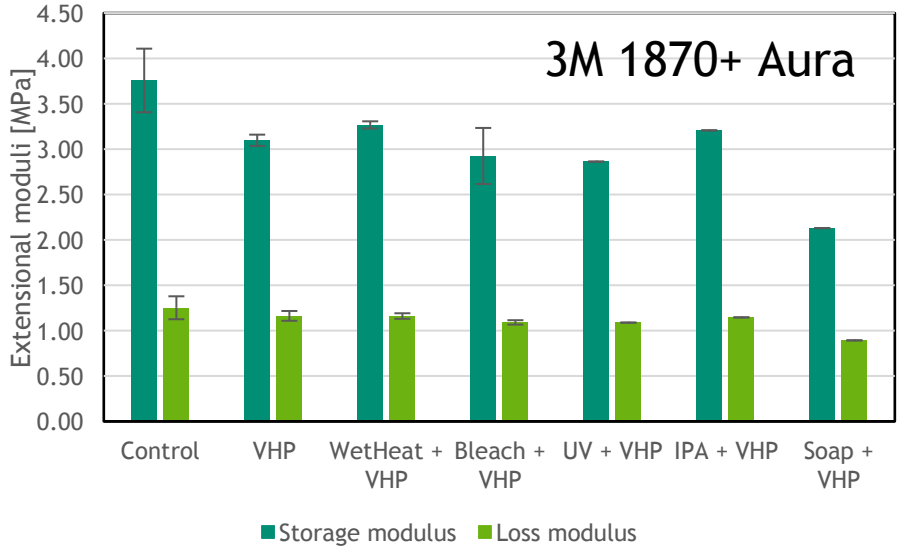


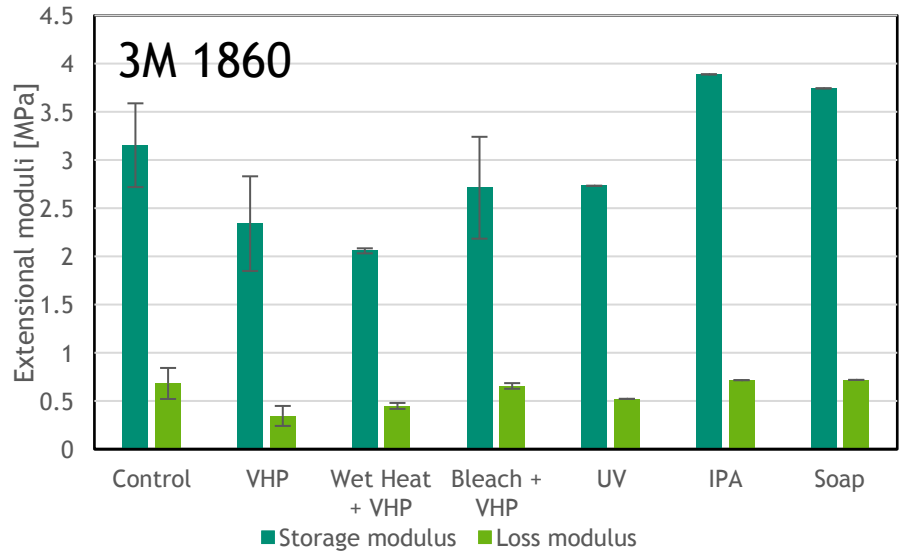
Mechanical Measurement of the Elastic Straps

Linear viscoelastic (small strain) oscillatory testing to measure storage and loss moduli of the elastic straps.

Analyzing the “new” versus “used” respirators showed a statistically significant difference in strap stiffness



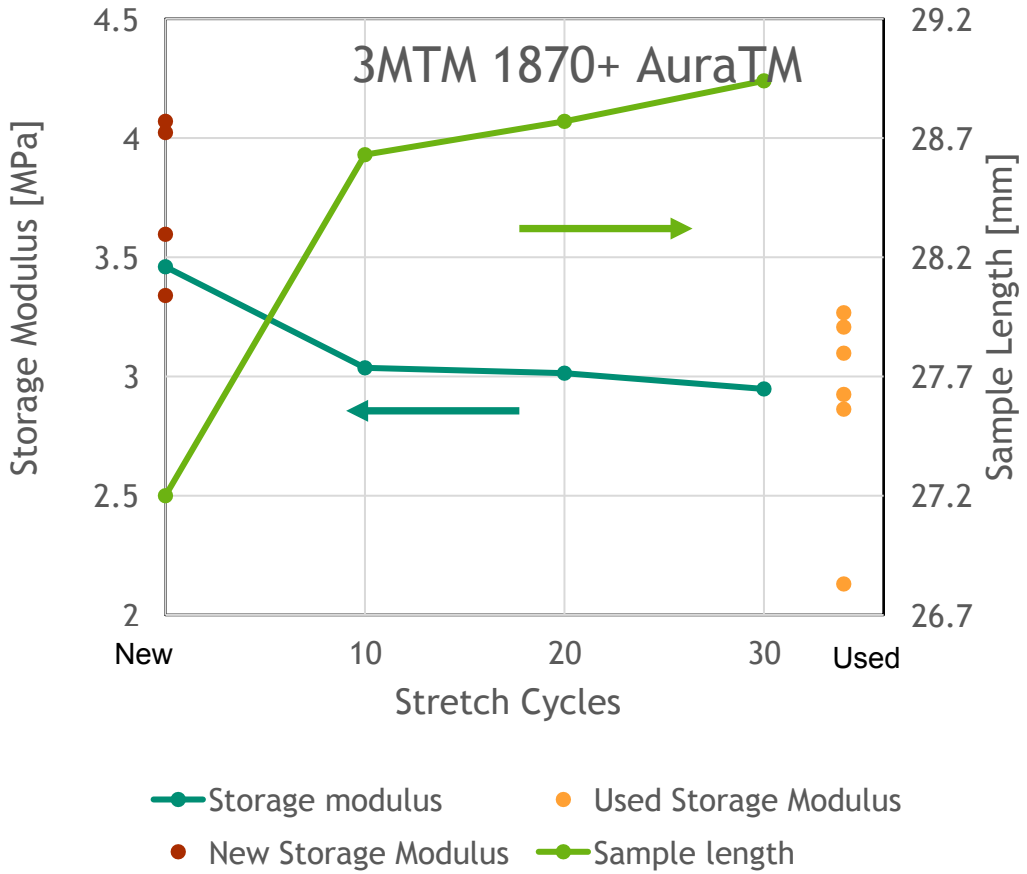


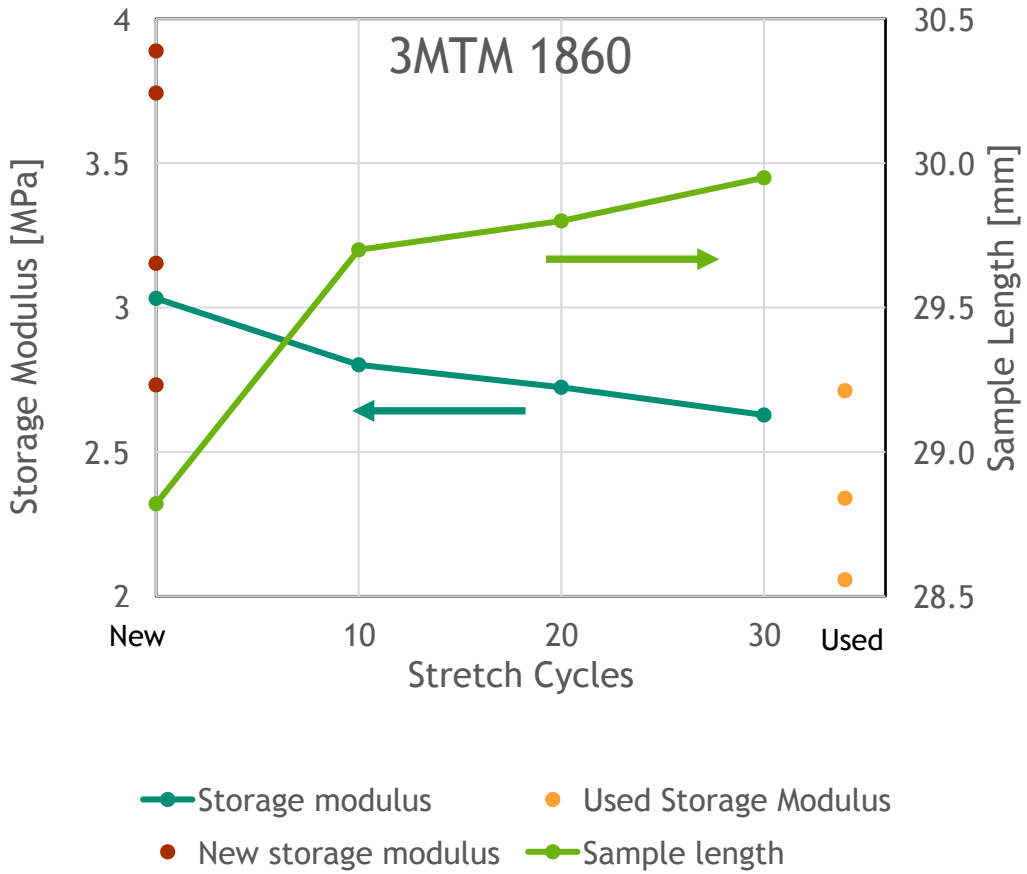


Mechanical Cycling of N95 Respirator Straps

Performed repeated cycling to 150% strain (approximate strain required to pass over the head when donned.

Degradation of mechanical properties could be due to repeated donning and doffing of the respirator during extended use.





Conclusions

Filtration, pressure drop and quantitative fit of N95 respirators were robust to several decontamination methods including

- Vaporous hydrogen peroxide,
- Wet heat,
- Bleach
- Ultraviolet light

Bleach may not have penetrated the hydrophobic outer layers of the N95 respirator

Isopropyl alcohol and detergent both severely degraded the electrostatic charge of the electret filtration layer

- First data in N95 respirators that he loss of filtration efficiency was directly correlated with loss of surface potential on the filtration layer
- The pressure drop was unchanged, so **loss of filtration efficacy would not be apparent during a user seal check**

Mechanical straps degrade with repeated mechanical cycling during extended use.

- Decontamination did not appear to degrade the elastic straps
- Significant loss of strap elasticity would be apparent during a user negative pressure seal check

Grillet et al. Experimental Biology and Medicine 2021; 246: 740–748

Team

Vaporous Hydrogen Peroxide Decontamination and epidemiology

- Dr. Douglas J Perkins & Ivy Hurwitz
  - Department of Internal Medicine, Center for Global Health, University of New Mexico Health Science Center, Albuquerque, NM 87131, USA;
  - University of New Mexico-Kenya Programs, Kisumu and Siaya, 40100, Kenya

Filtration Measurements

- Andres L. Sanchez and Steven Storch – WMD Treats and Aerosol Sciences, Sandia

Fit testing

- Edward S. Piekos and Jonathan Leonard – Engineering Sciences, Sandia

Surface Potential Testing

- Martin Nemer – Engineering Sciences, Sandia

UNM – Sandia COVID Working Group

- Dr. Thomas Byrd, University of New Mexico
- Martin Nemer – Engineering Sciences, Sandia

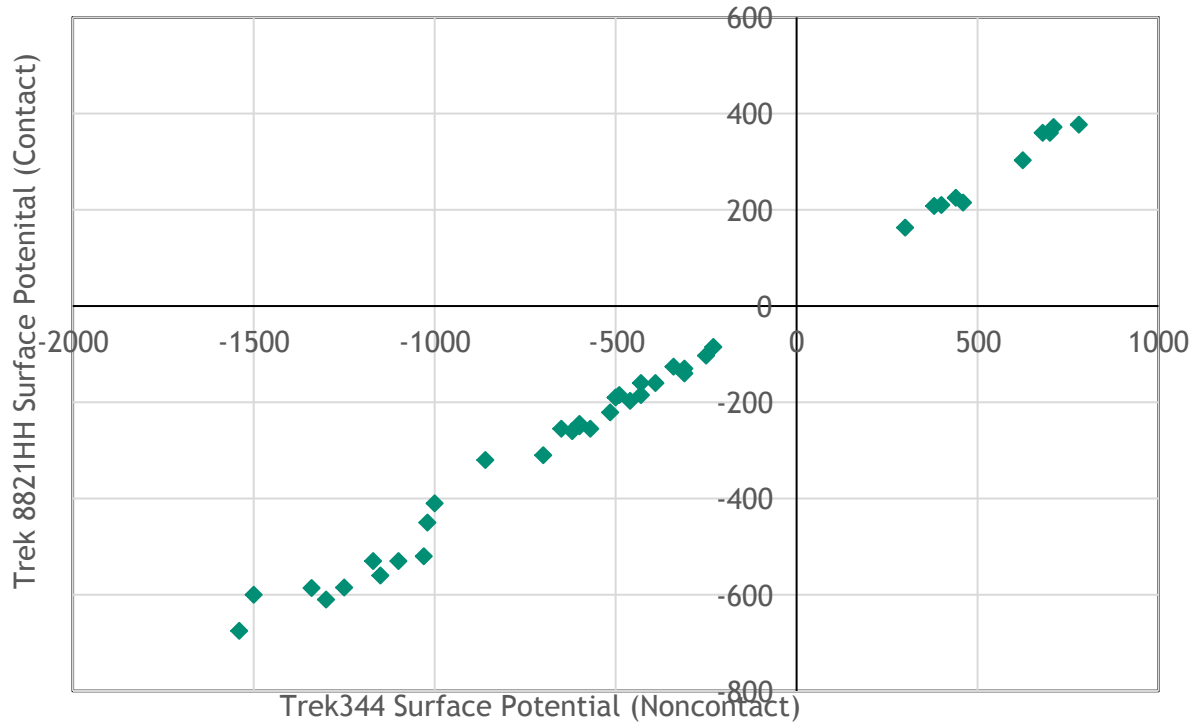
LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Backup slides

Contact vs Non-Contact Surface Potential Measurement

Trek 344 – noncontact surface potential

Trek 882 – contact surface potential



Correlation between surface potentials measured with contact and non-contact electrostatic voltmeters. 40 individual measurements taken on 4 control samples of Swiffer Dry

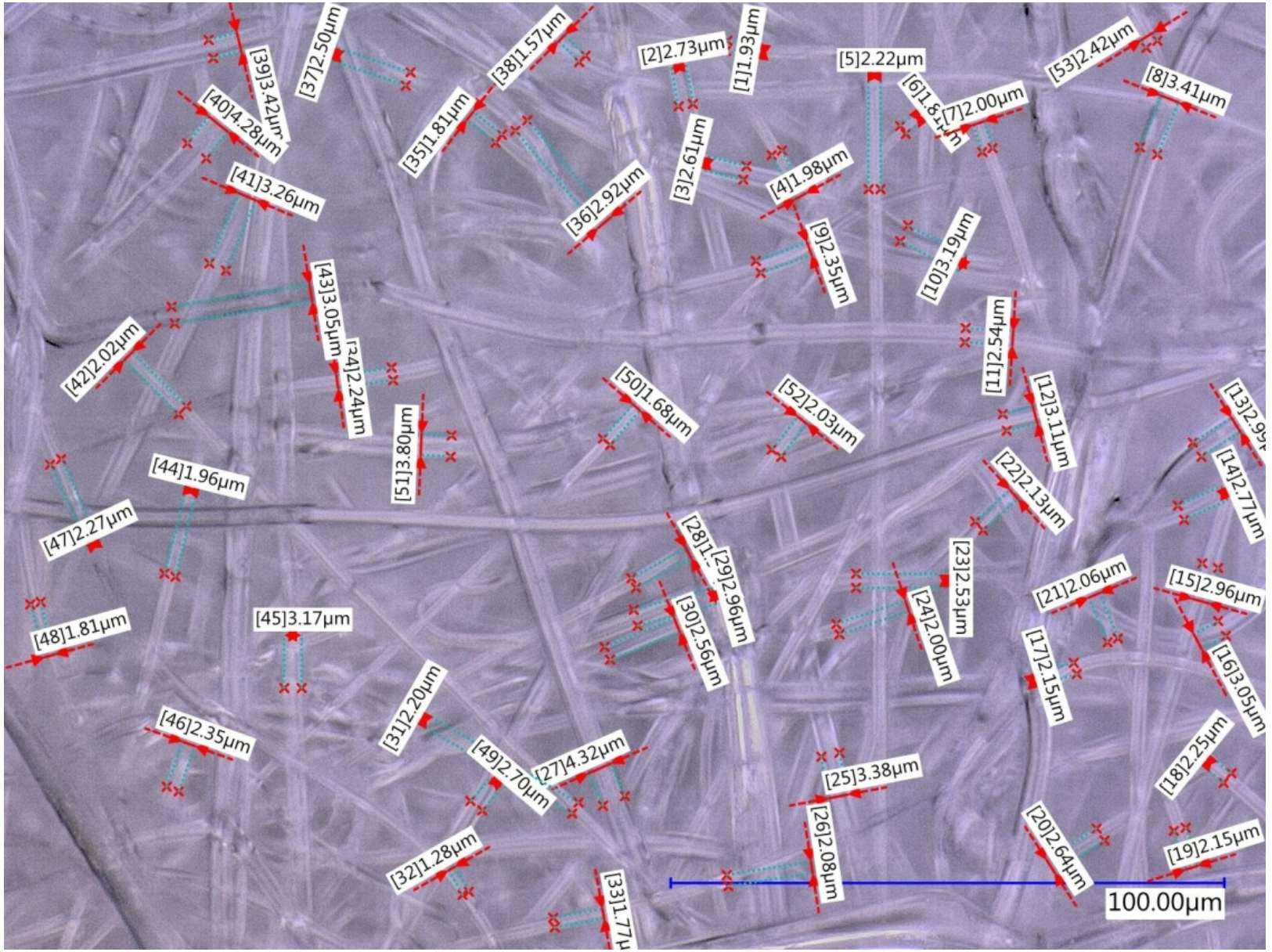
Round 2: Improved Fiber Size Measurement

Use of 3D image reconstruction allows more fibers to be in focus for measurement

HDR improves image resolution by combining image data from multiple exposures to generate the image.

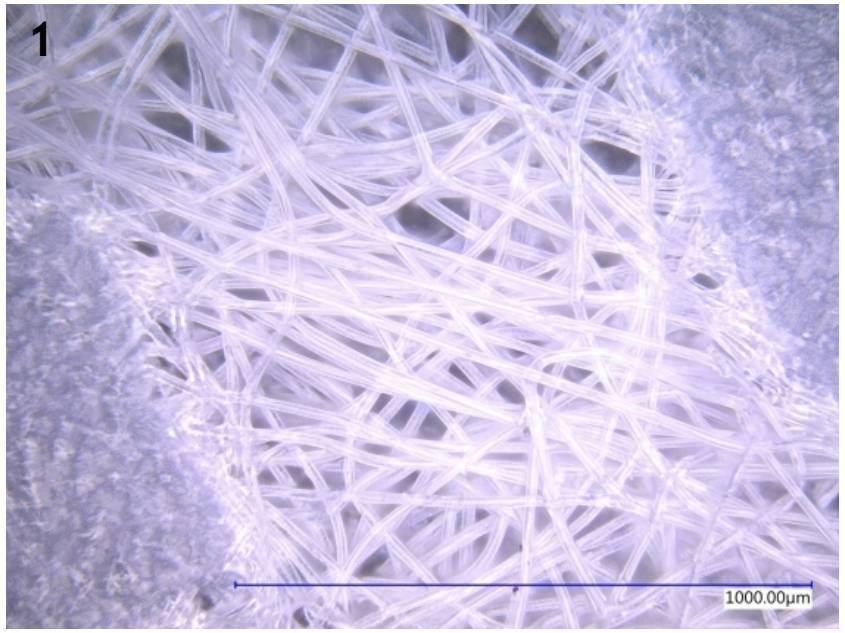
HDR also allowed images at higher magnification to be used for measurements which should improve accuracy

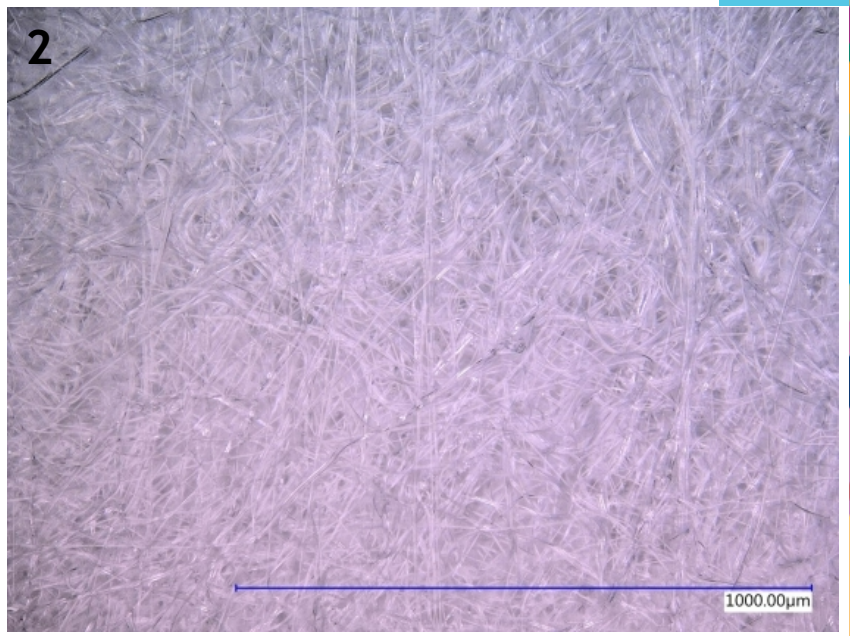
Here 1500x image of outer face of second layer in KC PRF95 N95 surgical mask with 0MRad dose

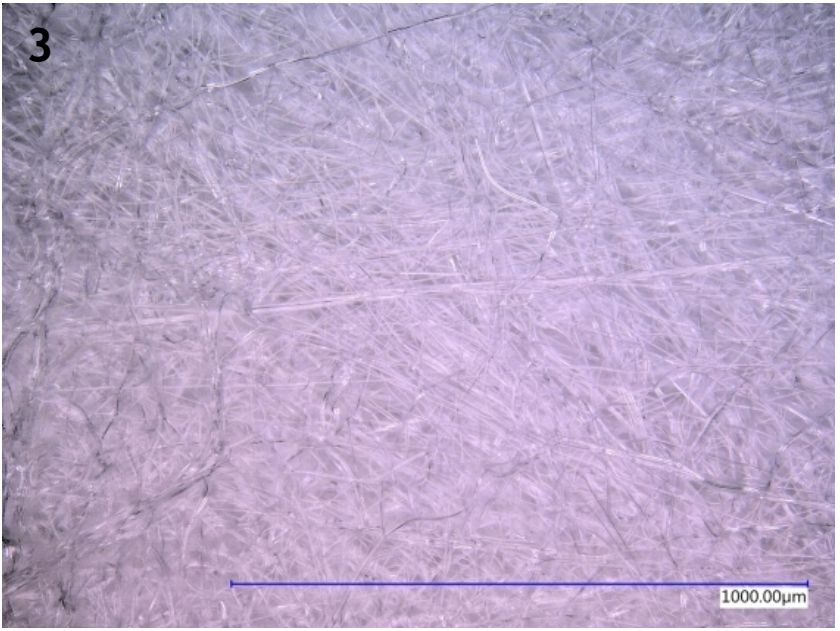


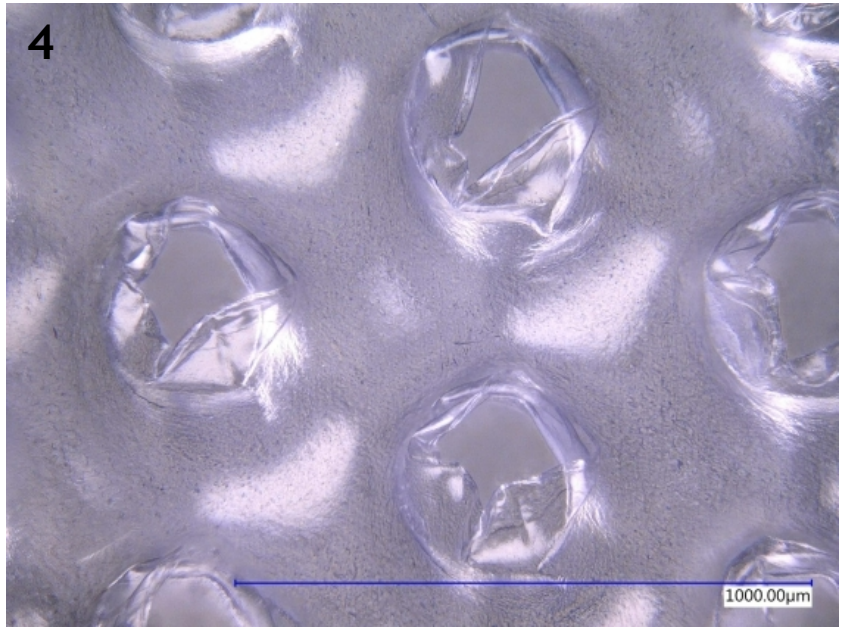
Kimberly Clark Mask Layers

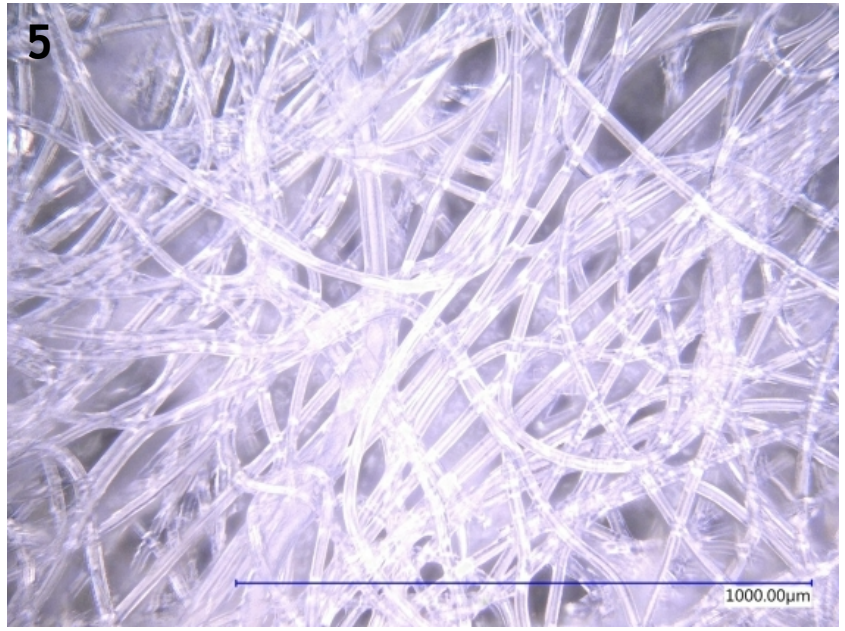
Outer face of each layer
at 250x & 0 Mrad





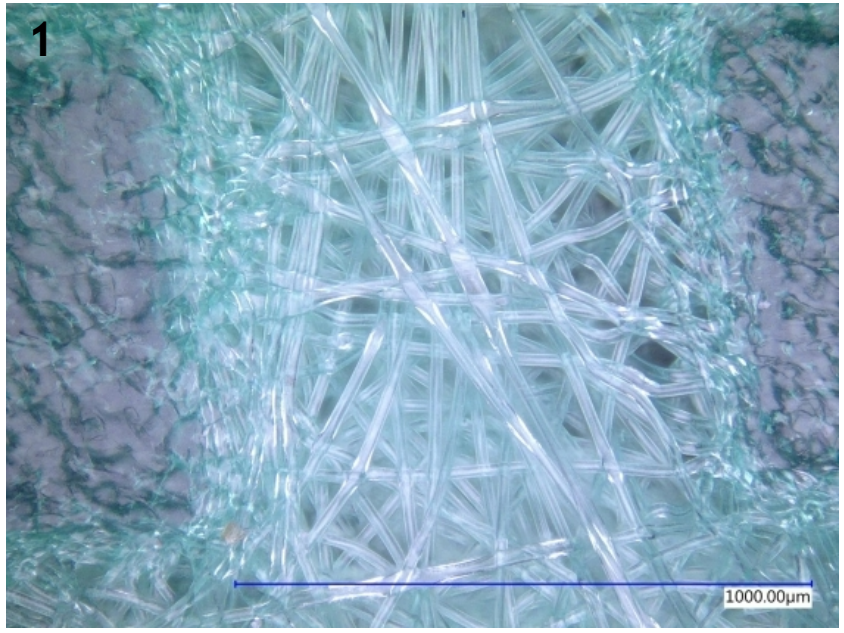


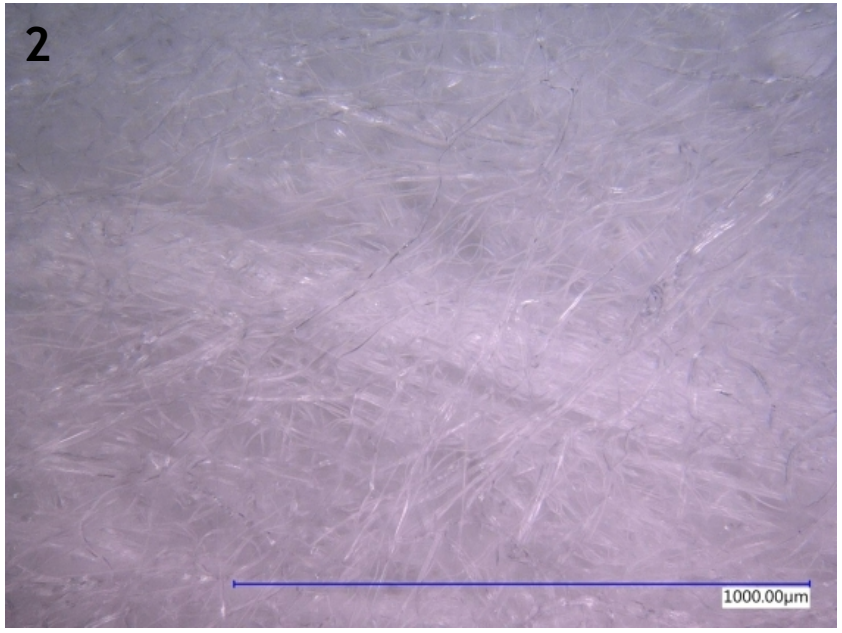


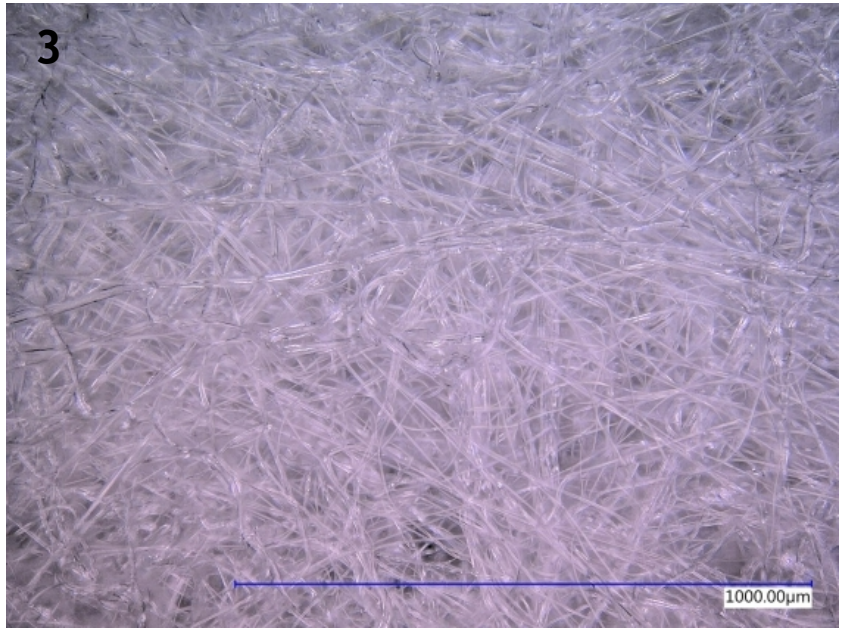


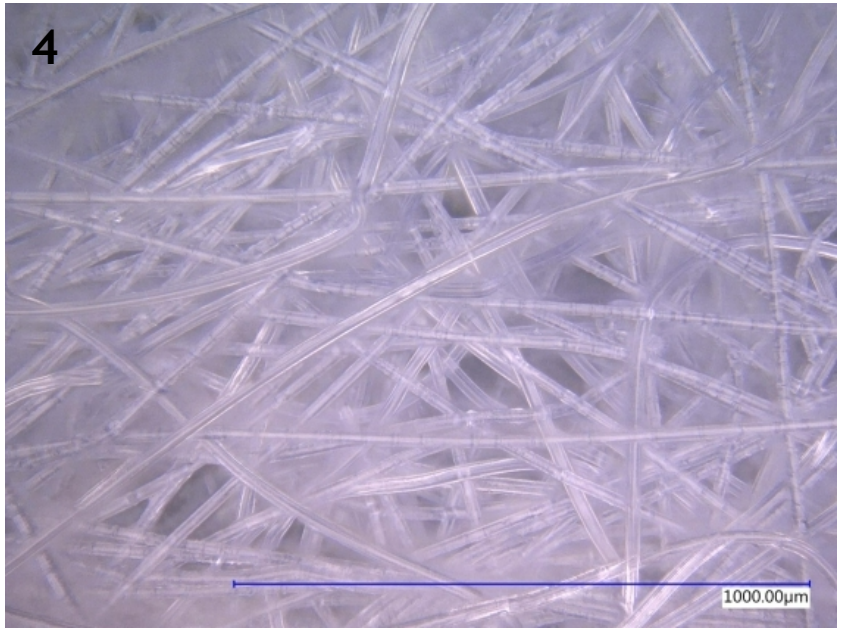
3M 1860 N95 Mask Layers

Outer face of each layer at 250x & 0 Mrad



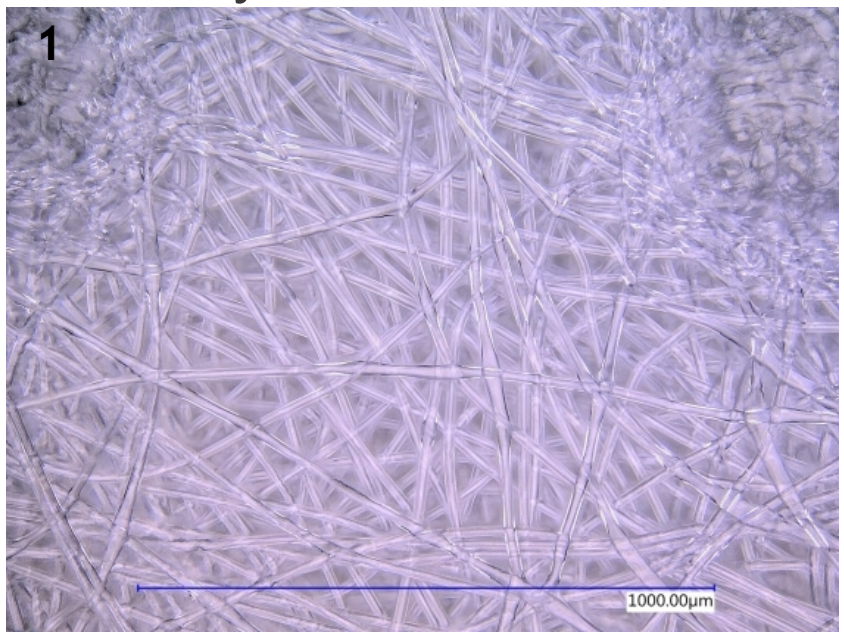


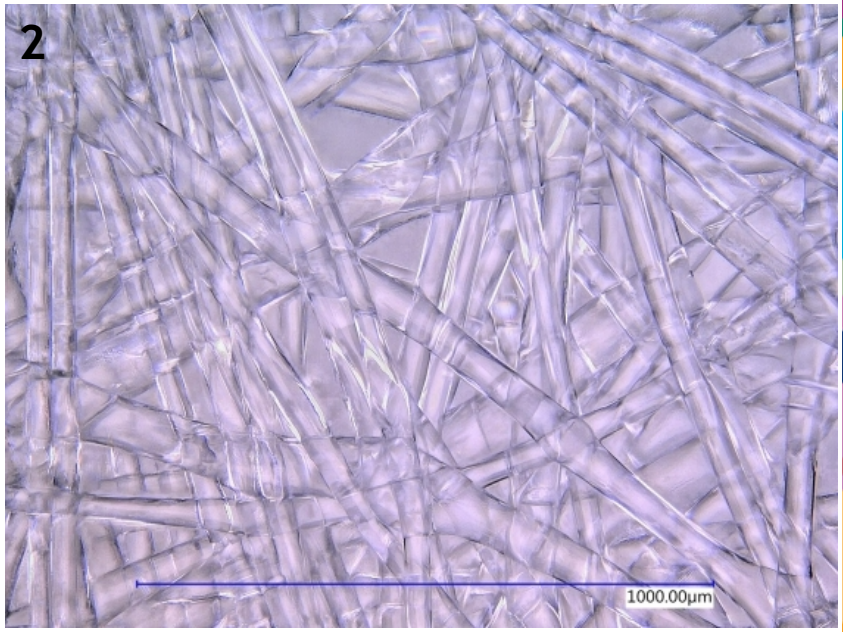


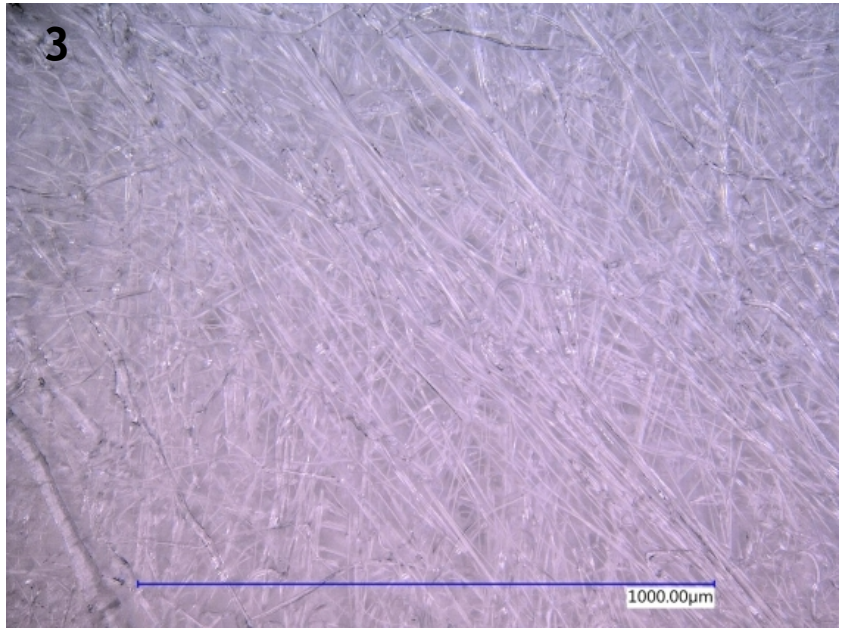


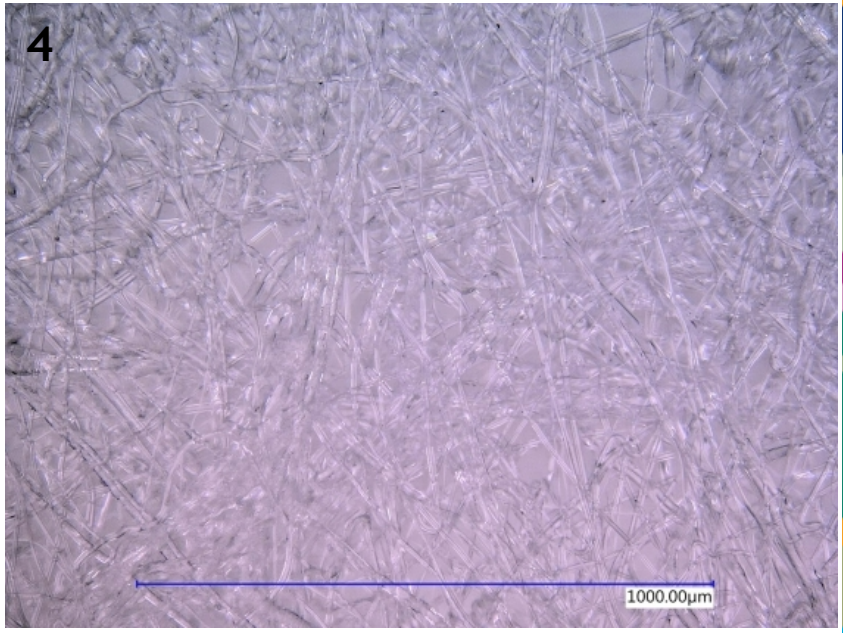
3M 1870+ Aura N95 Mask Layers

Outer face of each layer Control



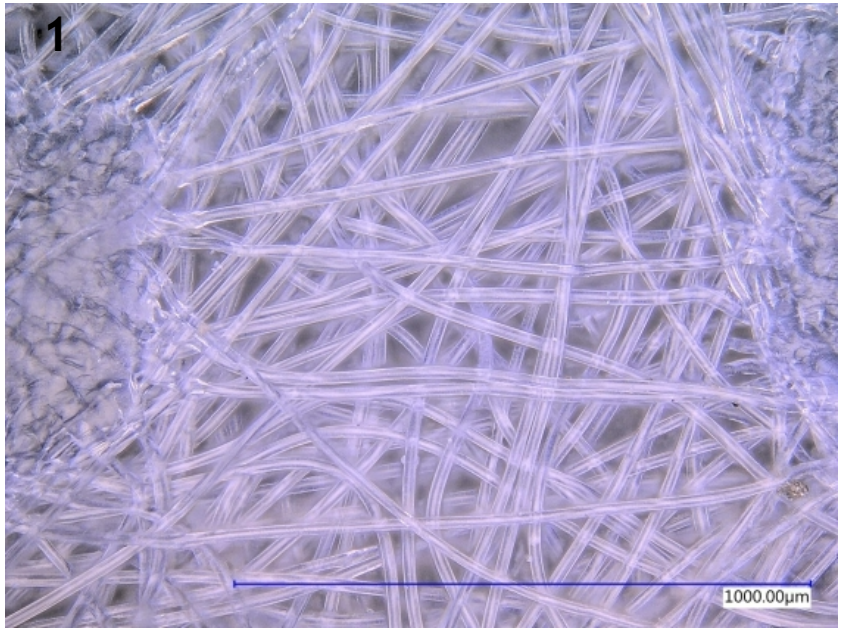


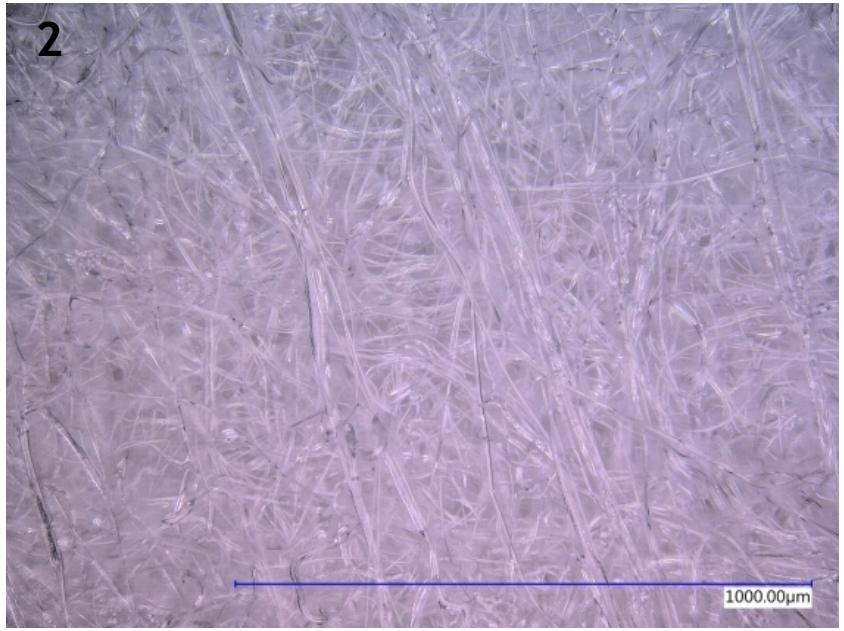




3M 8210+

Outer face of each layer at 250x & new



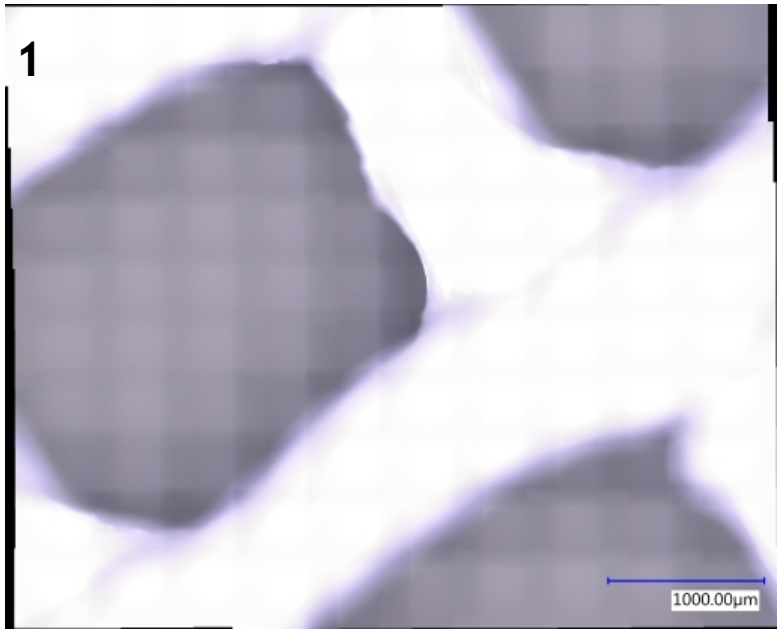


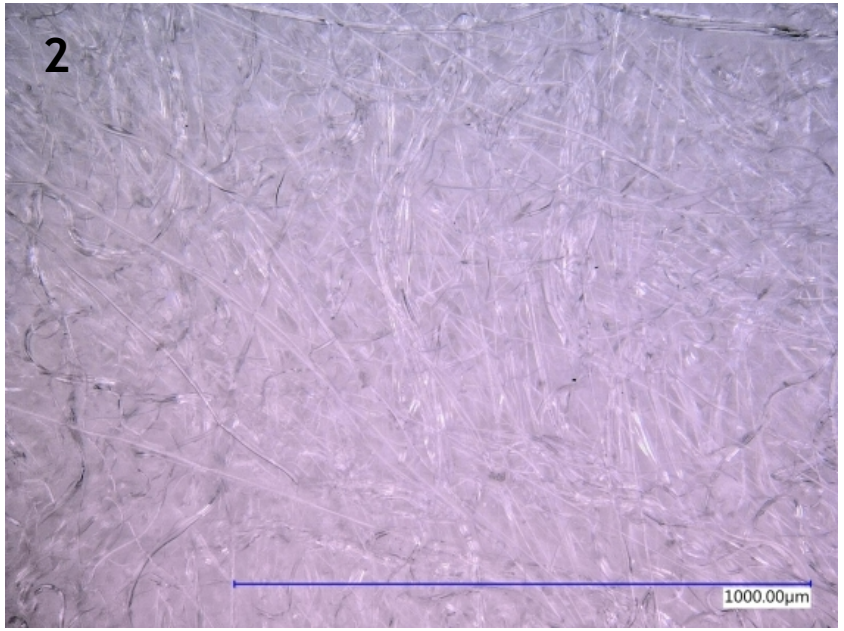
Moldex 2200

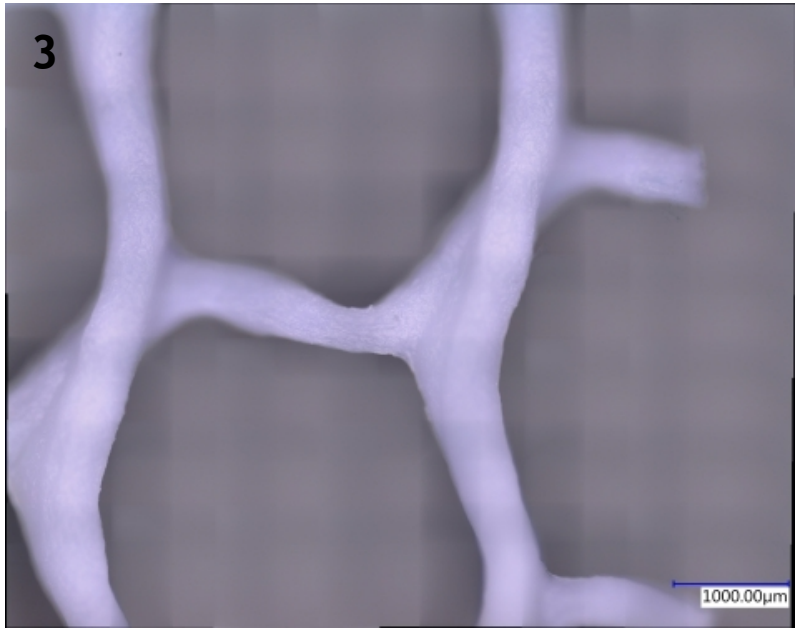
Outer face of each layer

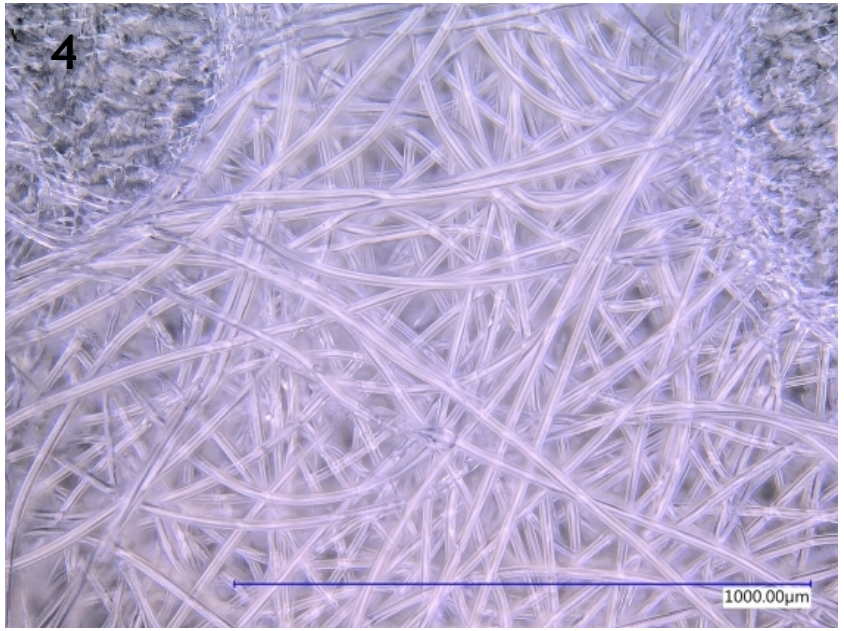
Mesh layers are stitched

Other layers are 250x



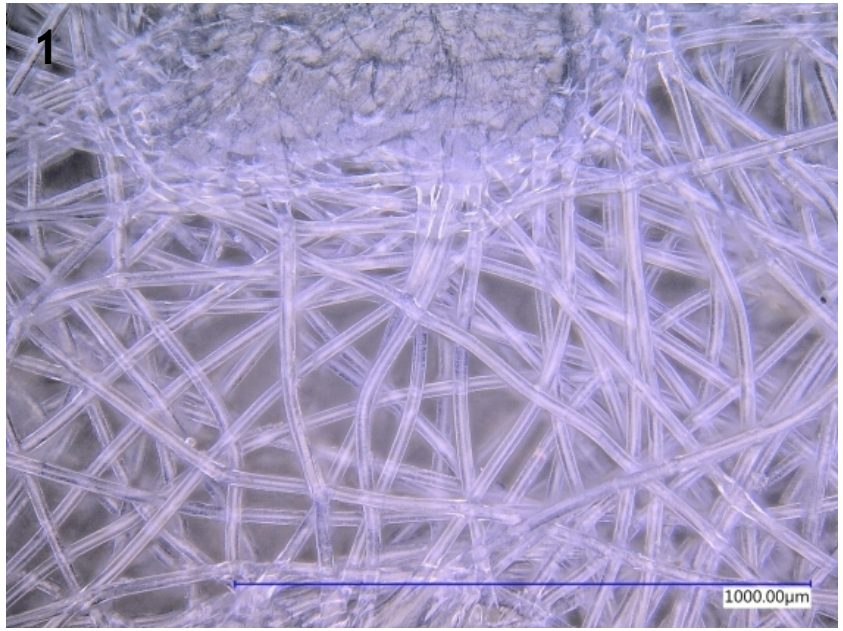


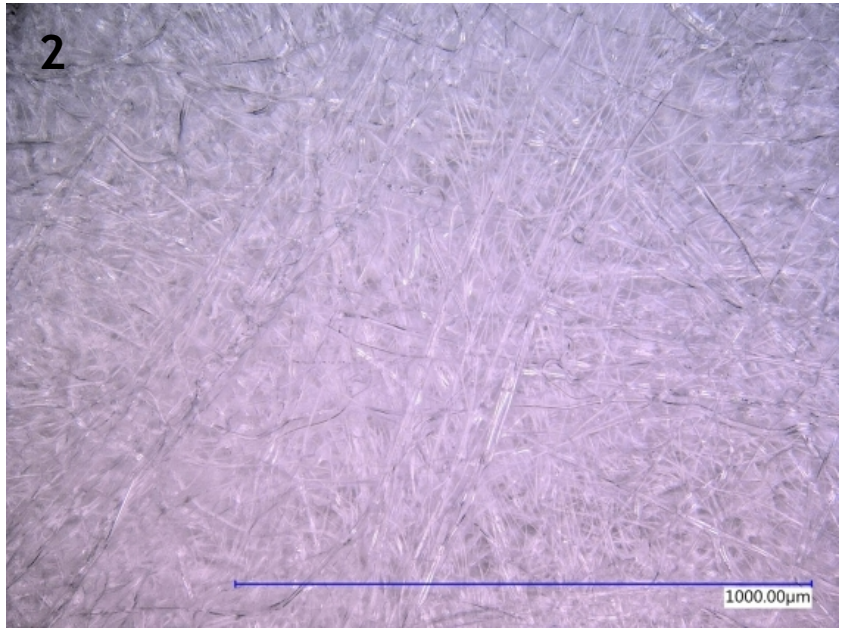


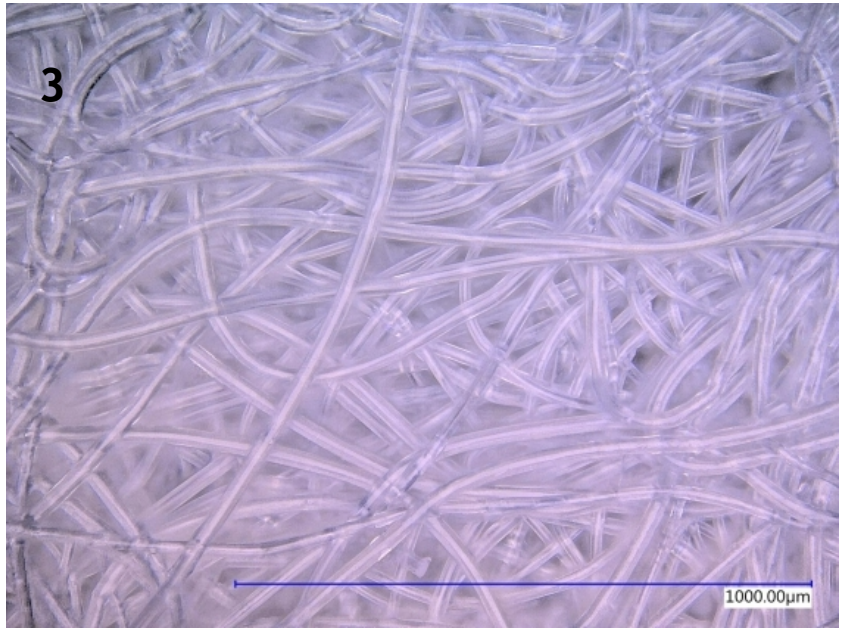


Uline S10479 N95

Outer face of each layer at 250x & new







NP097

1 – outer layer 1 250x

2 – outer layer 2 250s

3 – inner layer 2 250x

4 – outer layer 2 1000x