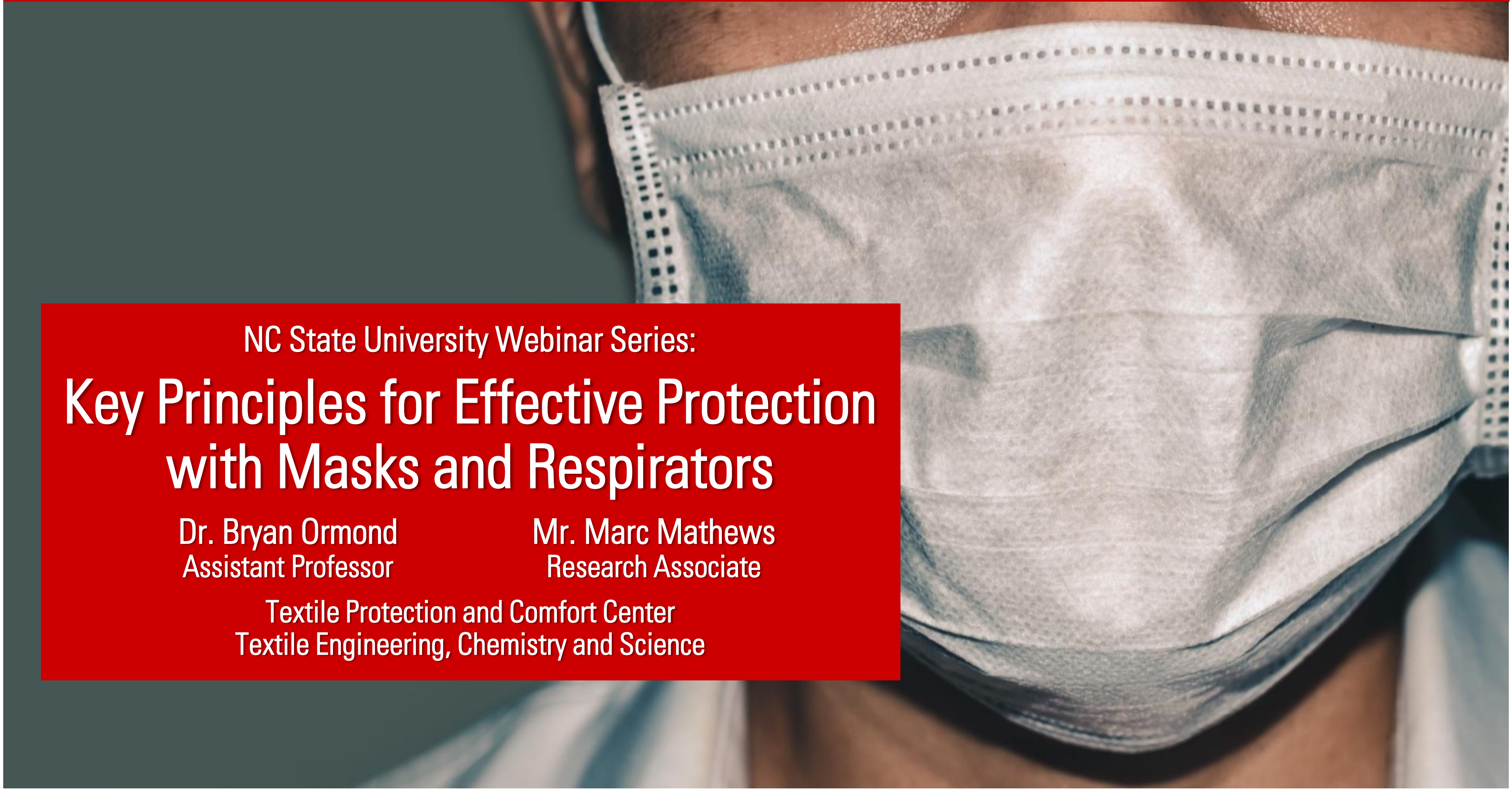

NC State University Webinar Series:

Key Principles for Effective Protection with Masks and Respirators

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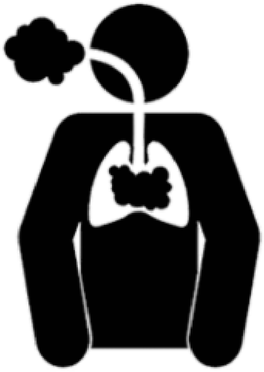
Safety is the absence of risk

- There are two fundamental ways to accomplish safety
  - Control hazard
  - Control exposure
- Different methods and standards are appropriate depending on the situation
  - In the workplace
  - In the world

Typical Risk Assessment

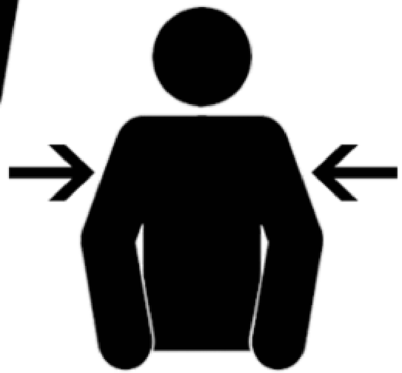
- A hazardous chemical or pathogen is only a potential risk
- It becomes an actual risk only upon exposure
- So no matter how hazardous a substance is, it is not a risk without exposure

Importance of Route of Entry



- Susceptibility greatly influenced by exposed surface area
  - Eyes – 0.0002 m^2
  - Skin – 1.5 to 2.0 m^2
  - Respiratory tract – 50 to 100 m^2

- Importance for protection and susceptibility
  1) Vapor/particulate exposure to respiratory tract
  2) Liquid exposure to skin
  3) Vapor/particulate exposure to skin



Atmosphere-Supplied Respirators

- Provides a clean source of breathing air that is completely separated from the contaminated environment

- Self-Contained Breathing Apparatus (SCBA)
  - Provides 30-60 minutes of clean air, but weight also adds physiological burden
- Highest form of respiratory protection
  - Chemicals above values deemed immediately dangerous to life and health (IDLH)

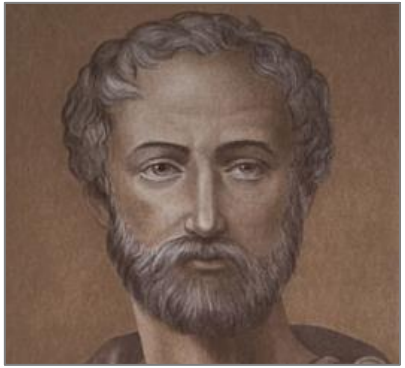
Air-Purifying Respiratory Protection

- A filter is used to purify contaminated air as the individual inhales
- Two basic types
    - Air-Purifying Respirator (APR)
    - Powered Air-Purifying Respirator (PAPR)
- Most cartridges contain activated carbon
    - Activation process increases surface area
    - Normal cartridge contains 100-200 grams with surface areas of 500-1400 m^2 per gram
- Longer usage than SCBA, but cannot be used in oxygen deficient atmosphere




Early Respiratory Protection – Pre 1800s

- Pliny the Elder (23-79 AD)
  - Roman philosopher and naturalist
  - Made use of loose animal bladder skins to filter dust from being inhaled
- Leonardo da Vinci (1452-1519)
  - Recommended the use of wet cloths over the mouth and nose as a form of protection against inhaling harmful agents
  - Designed masks to be used underwater
- Plague Masks (1600s)
  - Worn by doctors who identified the plague
  - Resembled large bird beaks and were loaded with aromatic plants and incense



https://www.fastcompany.com/90479846/the-untold-origin-story-of-the-n95-mask

https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html

Respirator Development in the 1800s

- Lewis Haslett (1847-48)
  - Invented the “lung protector,” which was the first respirator to be patented in the U.S.
- John Stenhouse (1854)
  - Built the first respirator capable of capturing toxic gases from the air, pioneering the use of charcoal in a wide variety of air purifying devices
- John Tyndall (1871)
  - Developed the “fireman’s respirator” which used cotton wool saturated with glycerin, lime, and charcoal

https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html

Respirator Development in the 1800s

- George Nealy (1877)
  - The Nealy Smoke Mask used a series of water-saturated sponges and a bag of water attached to a neck strap
  - The wearer could squeeze the bag of water to re-saturate the sponges to filter out some of the smoke
- Hutson Hurd (1879)
  - Improved on the design of the Haslett respirator and pioneered the cup-shaped mask
  - The air purifying device was in use until the 1970s
- First surgical masks (1897)
  - Handkerchief only designed to prevent doctors from coughing or sneezing droplets onto wounds during surgery

https://www.fastcompany.com/90479846/the-untold-origin-story-of-the-n95-mask

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Respirator Development in the 1900s

- Manchurian Plague (1910-1911)
  - Broke out in territory between China and Russia
  - High lethality and quick acting
- Dr. Lien-teh Wu determined the plague was spread through the air
  - Improved on surgical masks by adding cotton and gauze to add several layers around the face to filter
  - Could be constructed by hand out of materials that were cheap and in ready supply

https://www.fastcompany.com/90479846/the-untold-origin-story-of-the-n95-mask

Respirator Development in the 1900s

- United States Bureau of Mines (USBM) established in 1910
  - Mission was to address the high fatality rate of mineworkers
  - Initiated the first respirator certification program in 1919

- MSA Safety Company (1920)
  - Manufactured the Gibbs breathing apparatus
  - Closed-circuit self-contained breathing apparatus operated on compressed oxygen and a soda lime scrubber to remove carbon dioxide

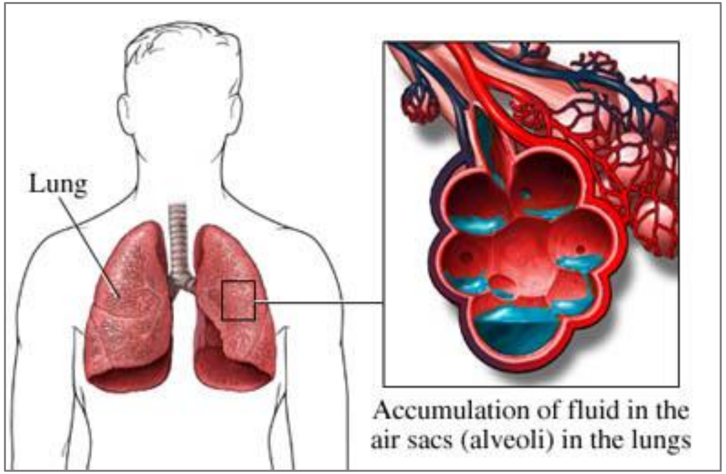
https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html

Influence of World War I

- New kinds of threats to soldiers
  - Chemical warfare gases
  - Combat equipment did not include respirators
- Non-lethal irritant gases
  - Lachrymators (Tear Gas)
  - Sternutators (Sneezing Gas)
- Difficult to generate sufficiently toxic concentrations
- First use of chlorine gas on the battlefield
  - April 22, 1915 near Ypres, Belgium
  - Over 5,500 cylinders opened
  - Generated a gas cloud 50 feet tall by 4 miles wide

Route of Exposure and Mechanism of Action

- Respiratory tract is the main route of exposure for chlorine
- Chlorine reacts with moisture in lungs to from irritating acids
- Death occurs from pulmonary edema
  - Lungs fill with liquid
  - Victims exhibit blue lips and face



First Respirators Used on the Battlefield

Black Veiling Respirator

- Cotton waste packed in black veiling material
- Soaked in sodium hyposulfite, sodium bicarbonate, and glycerol
- Only effective for 5-10 minutes before needing to be re-soaked in ‘hypo’ solution

Military Development

Hypo Helmet

- Soaked in sodium phenate solution to provide protection from phosgene
- Incorporated exhalation valve and tight-fitting eye pieces

P Helmet and PH Helmet

- Provided full face protection
- Easier to simply pull overhead instead of tying around face
- Soaked in same ‘hypo’ solution

Military Development

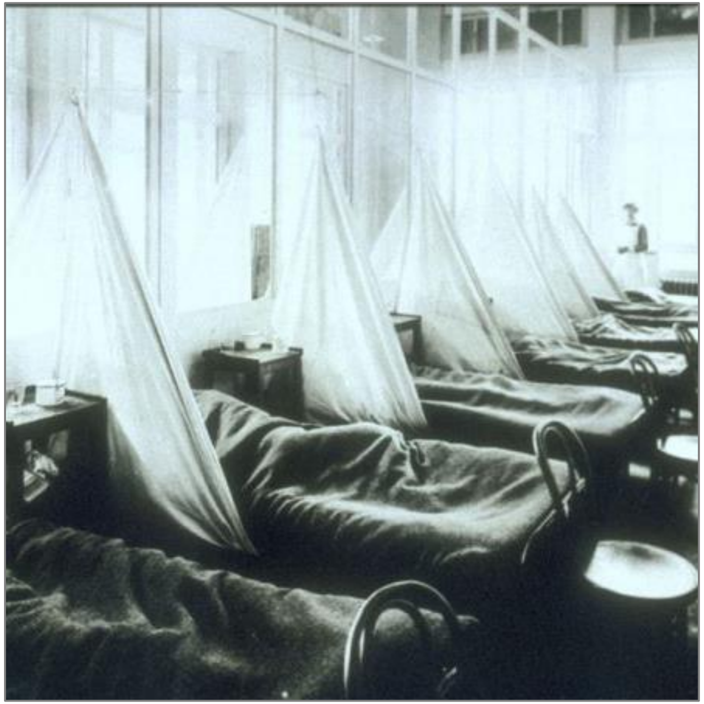
Large Box and Small Box Respirators

- Solid sorbents to sequester agents instead of neutralize
- Large Box was cumbersome, so the Small Box was developed

German Gummimaske (Rubber Mask)

- Canister filled with charcoal to capture chemicals
- Canister pulled mask away from the face of the soldier

Influenza Pandemic of 1918



- January 1918, unusual flu activity reported in Haskell County, Kansas
  - Spread to Fort Riley by March where over 100 soldiers were sick
  - Soldiers then aided in the spread of the virus to other military bases and countries
- **First Wave – "Three-Day Fever"**
  - Rarely fatal and set off few alarms
  - Bound in both the upper and lower respiratory tract
  - By July 1918 it was decided that the threat was over

https://www.ecohealthalliance.org/2018/05/outbreak-pandemic-strikes?gclid=EAIaIQobChMI09DgstXz6QIVoINaBR2F4w7REAAYASAAEgIJoPD_BwE

Influenza Pandemic of 1918

- **Second Wave – Much more deadly**
  - September 1918 - Camp Devens in Massachusetts
    - Over 1,543 soldiers diagnosed in single day - spread to Boston and then onward
  - The virus operated much quicker with much more severe symptoms
    - Coughing up blood or bleeding from the ears, nose, eyes
- Response
  - San Francisco Board of Health recommending the use of masks in public spaces
  - Chicago, along with many other cities across the United States, closed theaters, houses of worship, night schools, and prohibit public gatherings
  - Committee of the American Public Health Association encouraged stores and factories to stagger opening and closing hours and for people to walk to work when possible instead of using public transport to prevent overcrowding

https://www.cdc.gov/flu/pandemic-resources/1918-commemoration/pandemic-timeline-1918.htm

https://www.ecohealthalliance.org/2018/05/outbreak-pandemic-strikes?gclid=EAIaIQobChMI09DgstXz6QIVoINaBR2F4w7REAAYASAAEgIJoPD_BwE

Influenza Pandemic of 1918

- **Third Wave – Not quite as bad**
  - False sense of security from the spread slowing combined with celebrations following Armistice Day in November 1918
  - Subsides in the summer of 1919

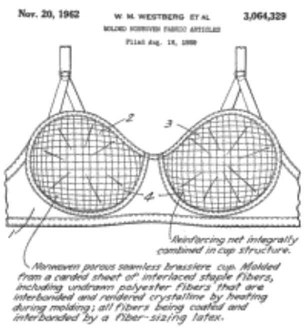
https://www.cdc.gov/flu/pandemic-resources/1918-commemoration/pandemic-timeline-1918.htm

Respirator Development – 1920s to Present

- Throughout WWI and WWII scientists developed and improved on respirator designs, fit, and efficacy
- One major issue for the rubber/elastomeric masks was the filters
  - Negative pressure air-purifying respirators add considerable physiological burden to breathing
  - Can also impact psychologically

Development of N95 Respirator

- Sara Little Turnbull
  - Designer/Consultant for 3M - ~1960
  - She began encouraging 3M to expand and develop their nonwoven business and their molding technology
  - She initially worked on a molded bra cup and ultimately transitioned that design over to a protective face mask
- Although this new mask could not block pathogens, 3M developed it into the dust mask known today
- Eventually, it was brought back to the healthcare field



https://designmuseumfoundation.org/ask-why/

Respirator Development – 1920s to Present

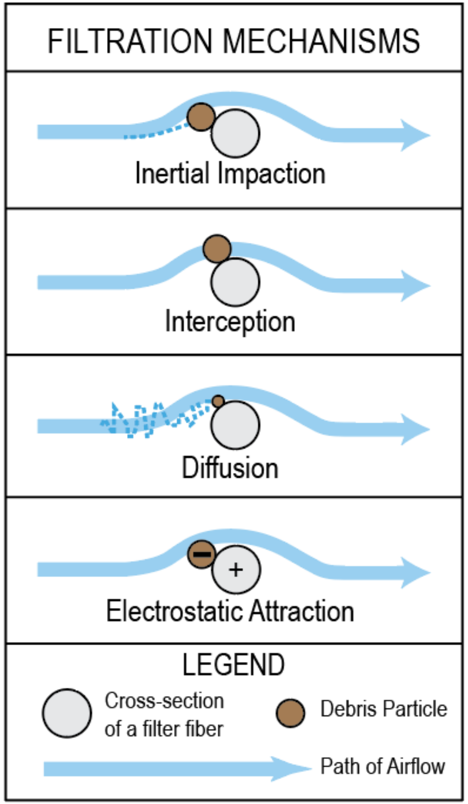
- While designs, technology, and materials have improved, the largest impacts have been in the development of the standards, requirements, and certifications
- Occupational Safety and Health Act of 1970
  - Occupational Safety and Health Administration (OSHA)
    - Allowed for mandatory instead of advisory guidance
  - National Institute for Occupational Safety and Health (NIOSH)
    - Research body focused on the health, safety, and empowerment of workers

Respirator Certification Regulation

- The importance of tight and proper fit as well as fit testing of respiratory equipment increased due to mandatory nature
- New respirator certification regulation 42 CFR 84 (July 1995)
  - Included new approval concept and performance requirements
  - Provided assessment of the effectiveness of the filter based upon its efficiency to remove particulates of the most penetrating particle size regardless of the particulate composition or toxicity

https://www.cdc.gov/niosh/npptl/Respiratory-Protection-history.html

Particle Filtration Mechanisms

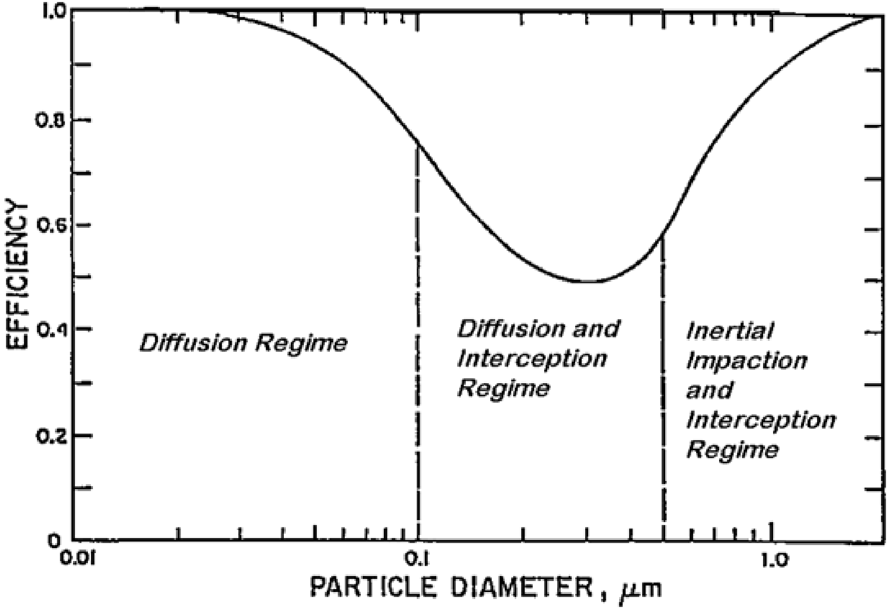


- Fiber diameter, porosity, and filter thickness all paly a role in a filter's ability to collect particles
- Three mechanical collection mechanisms for all filters:
  - Inertial impaction – collects larger particles that have too much inertia to follow the air flow around a fiber
  - Interception – collects larger particles when they come close to the fiber and are intercepted
  - Diffusion – collects small particles due to random motions that cause the particles to encounter the fiber surface
- Electrostatic attraction – only applies to charged filters and collects oppositely charged particles (does not favor particle sizes)

https://blogs.cdc.gov/niosh-science-blog/2009/10/14/n95/

Why 0.3 micron?

- The most penetrating particle size (MPPS) is the most difficult size of particle to capture due to efficacy of the mechanisms

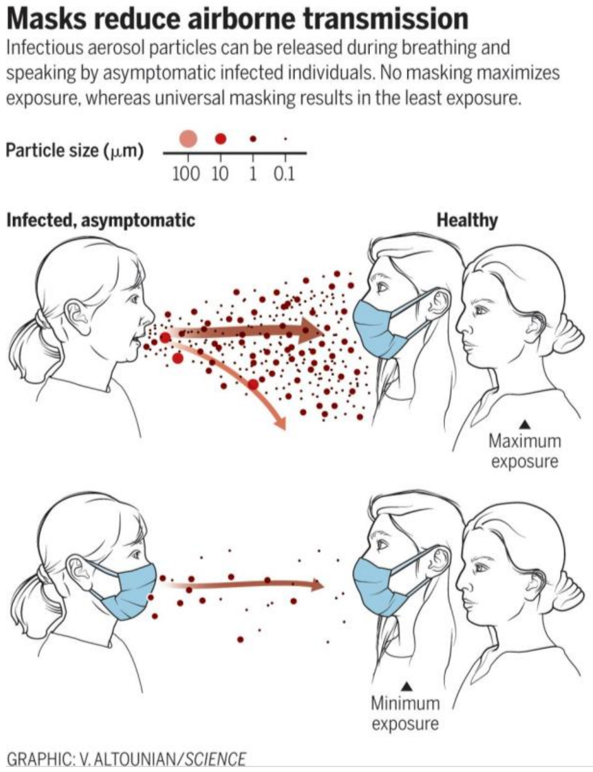


- Testing/certifying respirators around this value provides confidence that all other particle sizes would be captured more efficiently
- MPPS is typically between 0.1-0.4µm
  - Dust and pollen are typically >2.5µm
  - Coronavirus

https://blogs.cdc.gov/niosh-science-blog/2009/10/14/n95/

Spread of Respiratory Infections

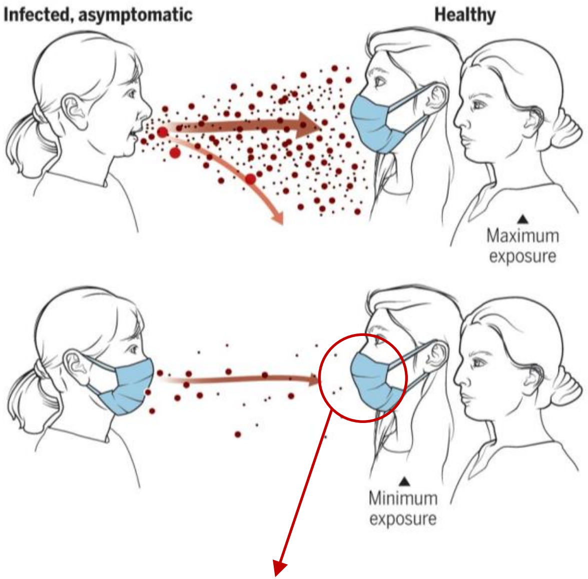
- Transmission occurs through virus-containing droplets (> 5 to 10 μm) and aerosols (≤ 5 μm) exhaled from infected individuals during breathing, speaking, coughing, and sneezing
- Leads to two transmission pathways
  - Larger droplets will undergo gravitational settling onto surfaces and become contact hazards
  - Smaller droplets will evaporate quicker and can be carried by air currents
- Example: A 100-μm droplet will settle to the ground from 8 ft in 4.6 seconds whereas a 1-μm aerosol particle will take 12.4 hours



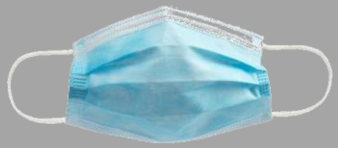
Kimberly A. Prather, Chia C. Wang, Robert T. SCHOOLEY, "Reducing transmission of SARS-CoV-2," Published online 27 MAY 2020, DOI: 10.1126/science.Abc6197

Reasons for Protective Masks

- Reason #1: For the mask to limit the spread of droplets from the wearer to other individuals
  - Dealing with mostly larger particles/aerosols/droplets
  - Surgical masks and cloth mask can be very effective
  - An N95 with an exhaust valve defeats this purpose
- Reason #2: For the mask to limit the wearer's exposure to aerosols
  - Mostly focused on smaller aerosols
  - Requires efficient filtration material and effective seal to the face
  - A properly fit N95 is very effective



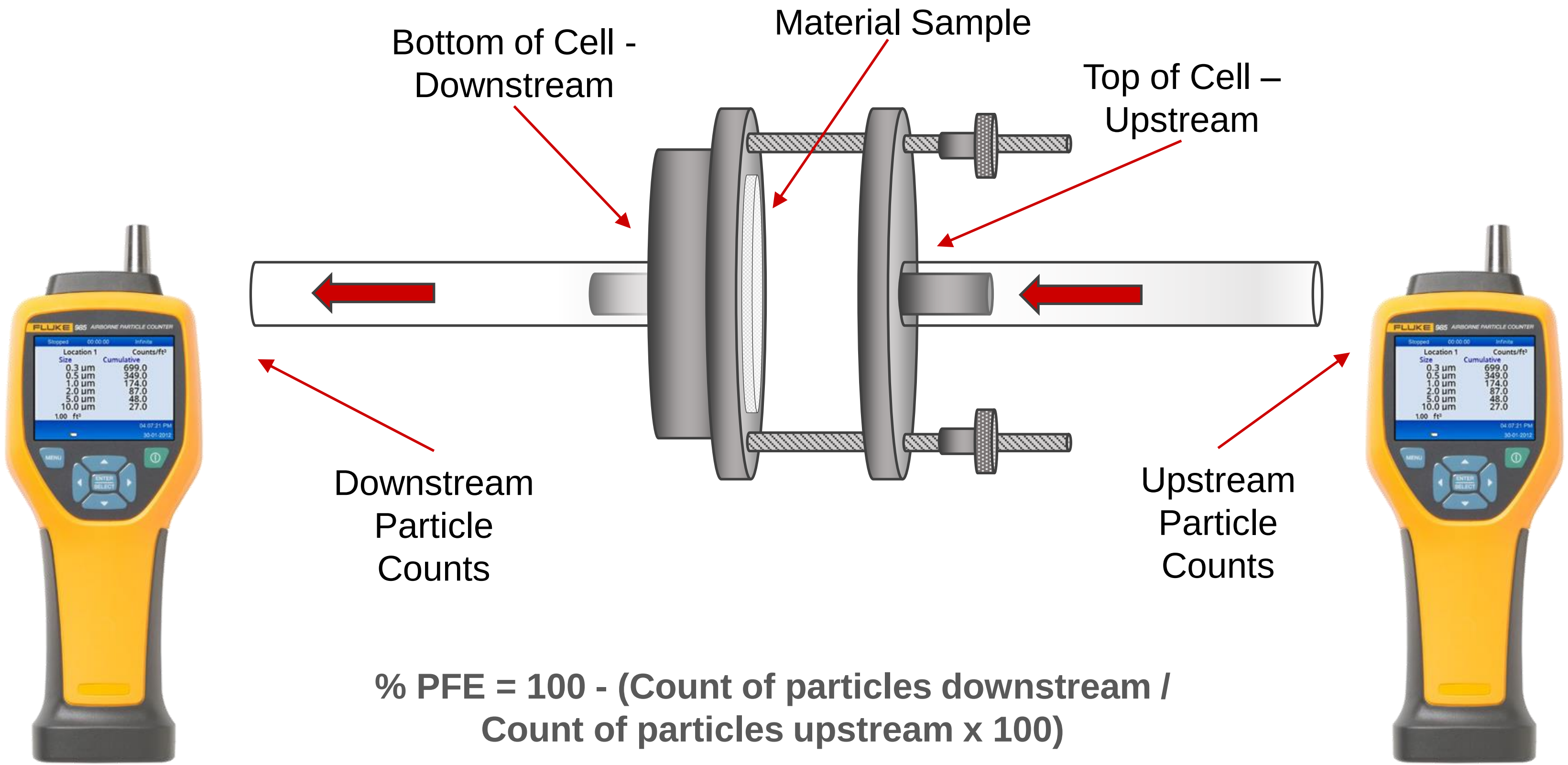
For minimum exposure, an N95 would be more likely here

	Non-Medical Face Mask 	Surgical Mask 	N95 Respirator 
Testing and Approval	None	Cleared by the U.S. FDA	Approved by NIOSH 42 CFR Part 84
Intended Use and Purpose	May not provide protection from fluids or may not filter particles. May help to protect others from the wearer's respiratory emissions	Fluid resistant, provides protection against large droplets, splashes, or sprays. Protects the patient from the wearer's respiratory emissions.	Reduces wearer's exposure to particles including small particle aerosols and large droplets (non-oil aerosols)
Face Seal Fit	Loose-fitting	Loose-fitting	Tight-fitting
Fit Testing Requirement	No	No	Yes
Filtration	Does NOT provide the wearer with a reliable level of protection from inhaling smaller airborne particles and is not considered respiratory protection	Does NOT provide the wearer with a reliable level of protection from inhaling smaller airborne particles and is not considered respiratory protection	Filters out at least 95% of airborne particles (large and small)
Leakage	Leakage occurs around the edge of the mask	Leakage occurs around the edge of the mask	When properly fitted and donned, minimal leakage occurs

Critical Factors for Respirators/Face Masks

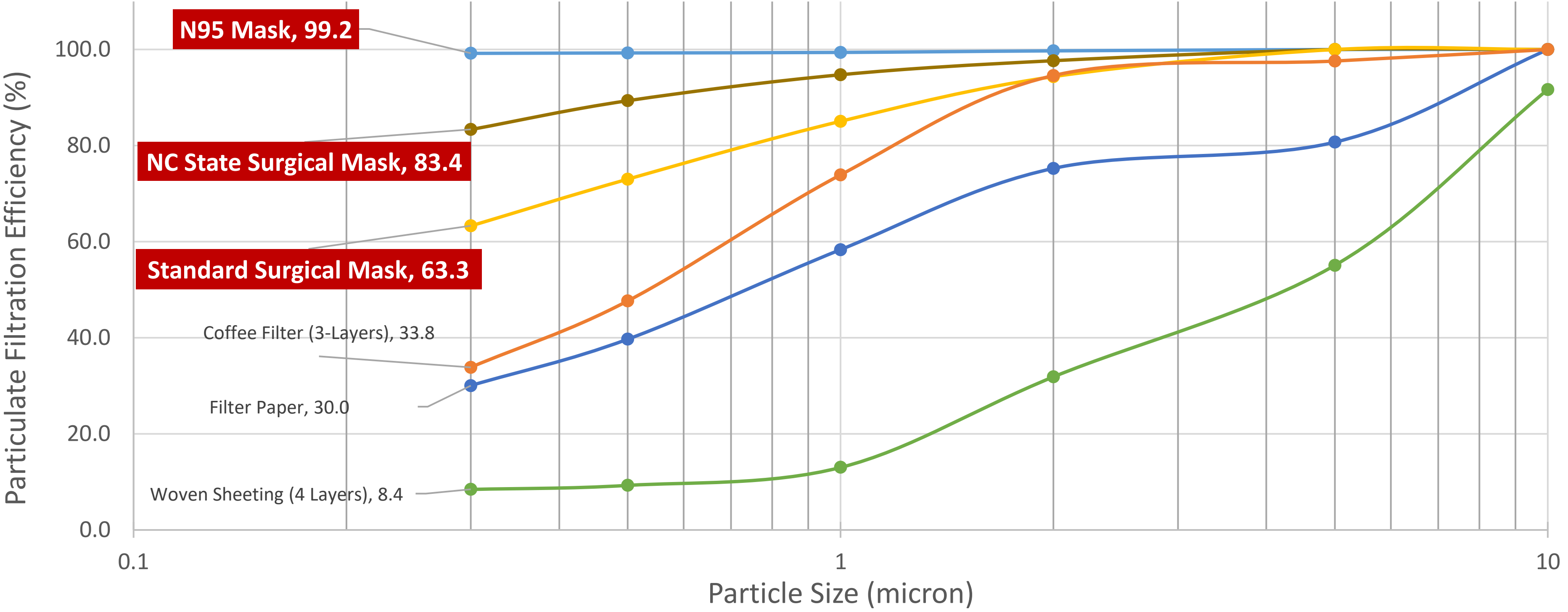
- To address both reasons for face masks, three critical factors must be considered
  - #1: Material Filtration Efficiency
  - #2: Effective Fit and Seal of Face Mask
  - #3: Sufficient Breathability

Material Particulate Filtration Test Cell



% PFE = 100 - (Count of particles downstream / Count of particles upstream x 100)

Material Particulate Filtration Efficiency Testing

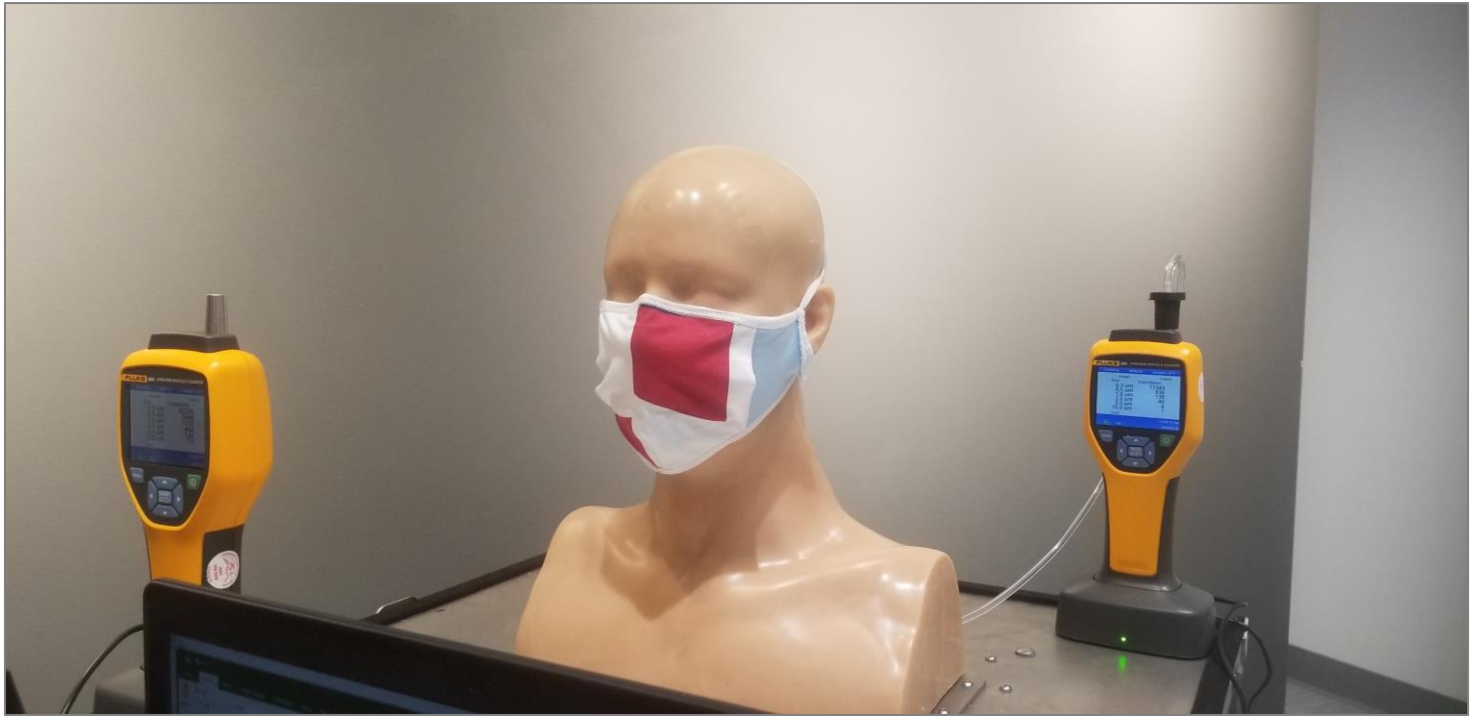


% PFE = 100 - (Count of particles downstream / Count of particles upstream x 100)

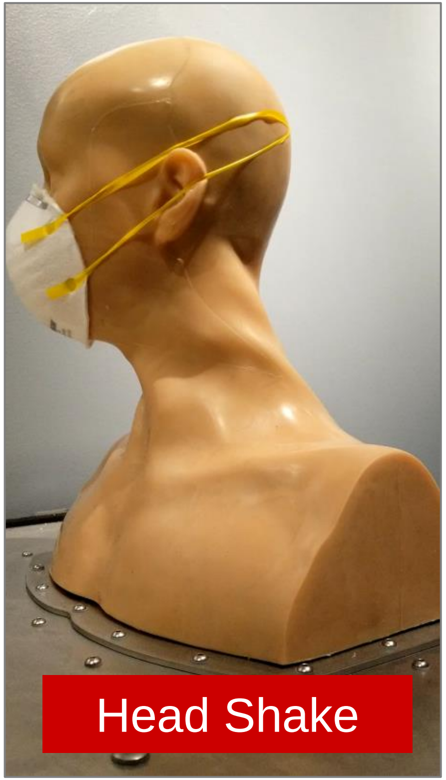
Animatronic Headform Evaluation

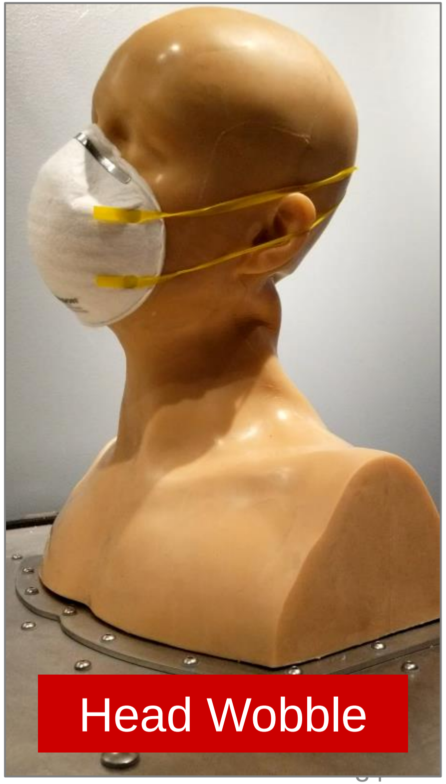
- After ensuring adequate material filtration performance, face mask fit must be evaluated
- Typically conducted with human subjects during respirator fit testing (EHS) – would require IRB for research/testing
- TPACC’s Animatronic Headform Evaluation
  - Headform with silicone skin to provide realistic seal to the face
  - Programmable movements include nod, shake, wobble, and jaw bite at two speeds
  - Programmable breathing patterns, volumes, and rates
  - Measure particle counts (0.3-10 μm) both outside and inside face mask

Dynamic Headform Assessment of Mask Performance and Face Seal

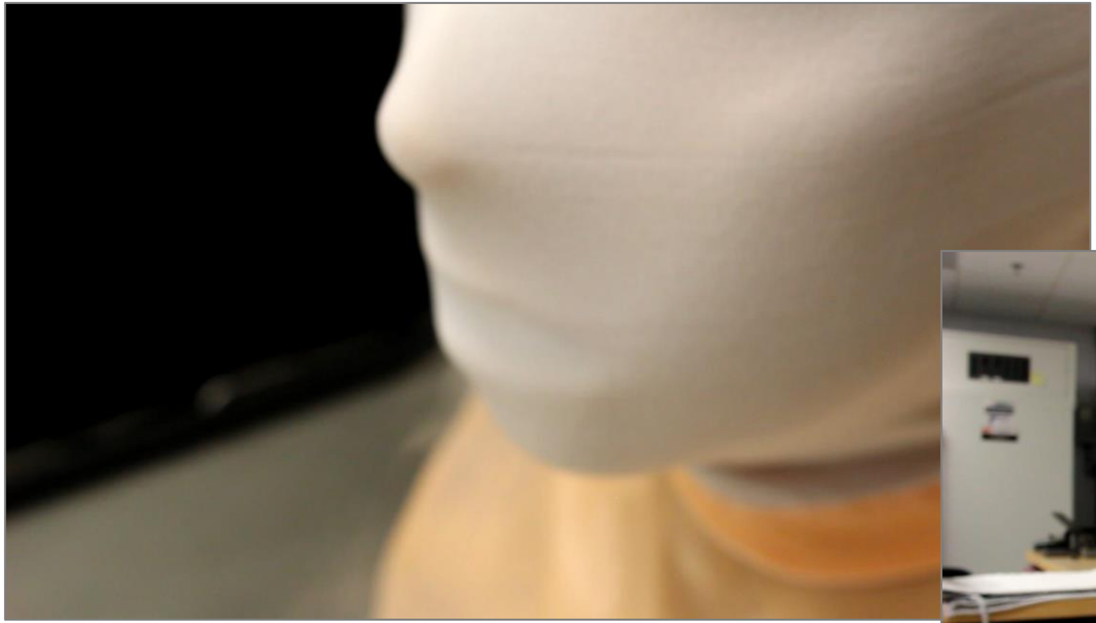


Programmable Motions





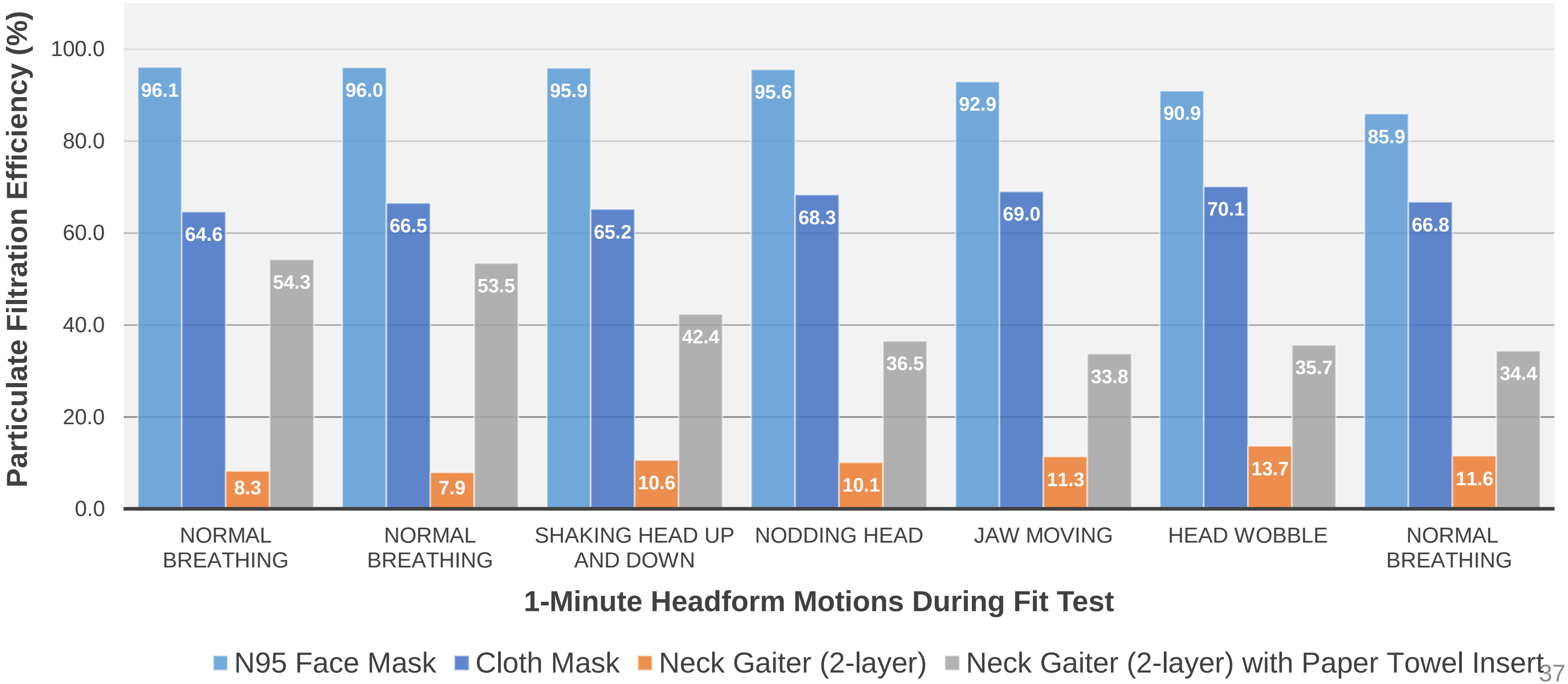
Programmable Breathing Parameters



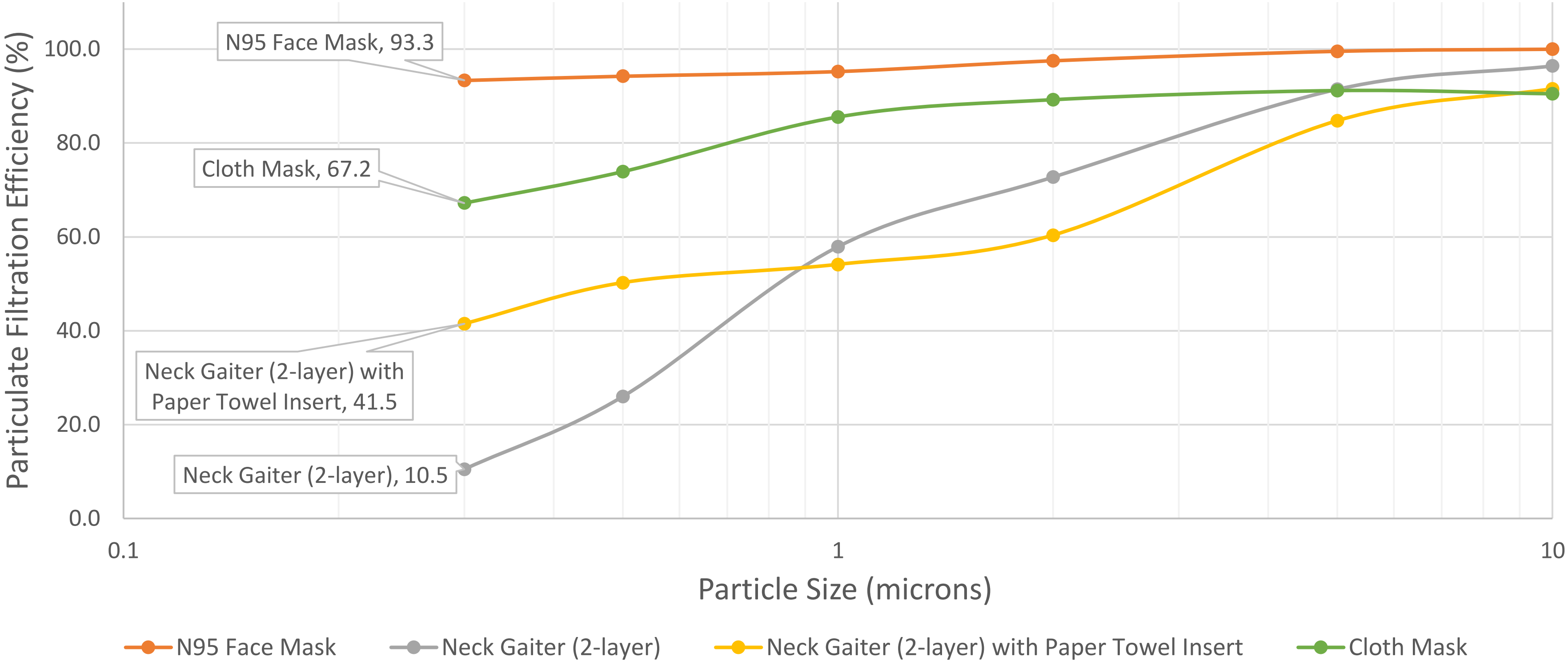
Current Headform Protocol

- Designed to mimic the 7-minute respirator fit testing protocols
  - Normal breathing – 1 minute
  - Normal breathing – 1 minute (substitute for deep breathing)
  - Shaking head side to side – 1 minute
  - Nod head up and down – 1 minute
  - Moving jaw up and down to simulate talking – 1 minute
  - Head wobble – 1 minute (substitute for bending over)
  - Normal breathing – 1 minute

Evaluation of Face Mask Fit on Headform

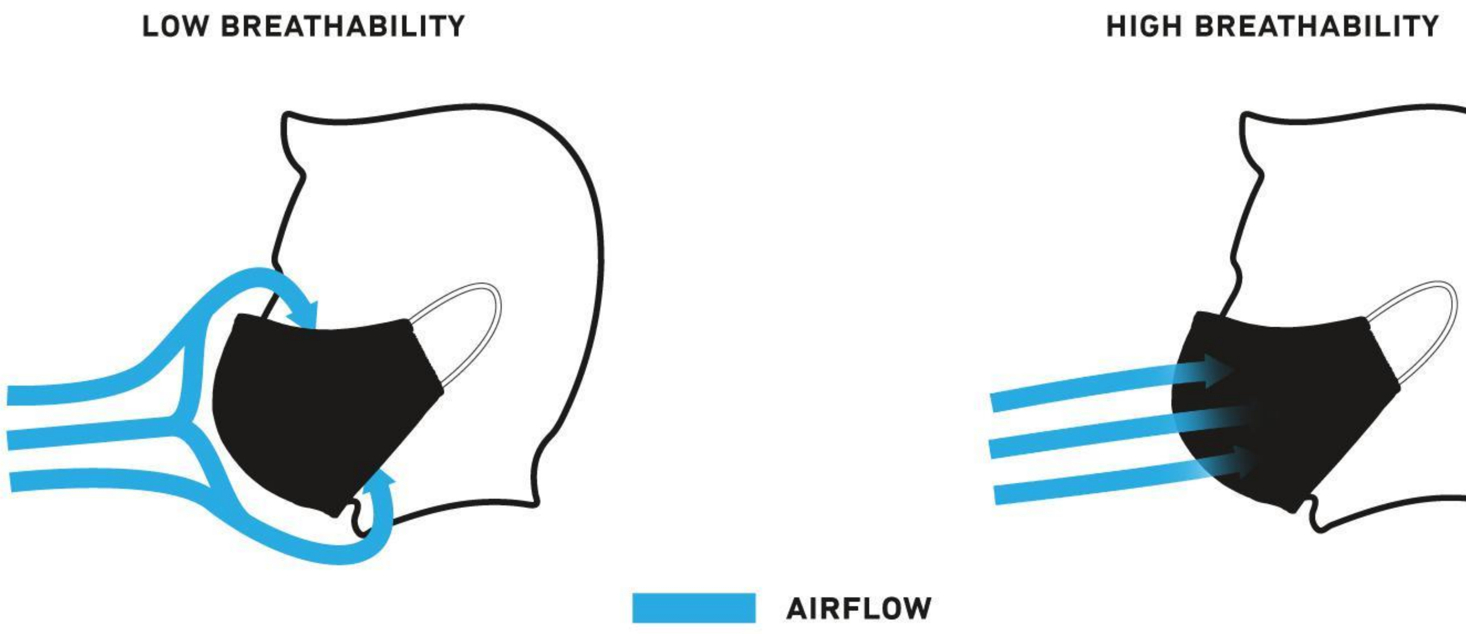


Particle Filtration Efficiency of Face Masks

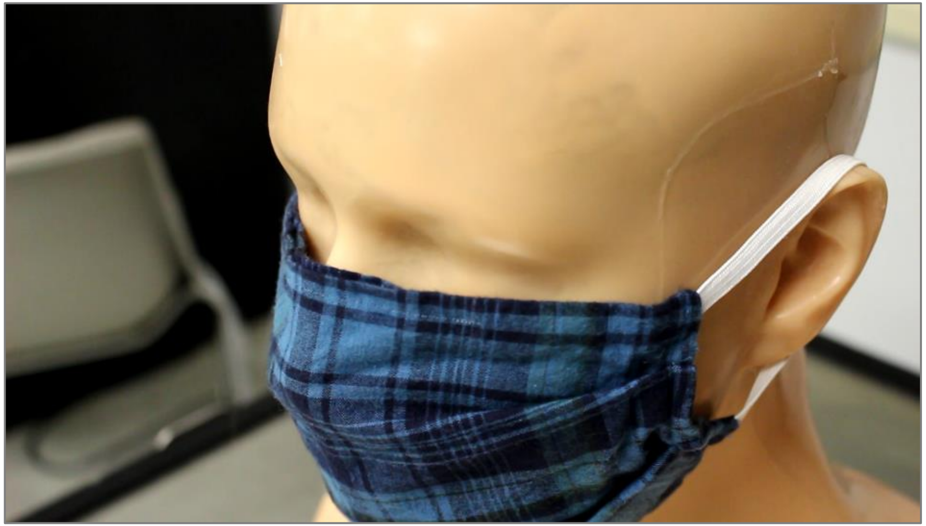


% PFE = 100 - (Count of particles downstream / Count of particles upstream x 100)

Measuring Face Mask Breathability



Fit and Breathability

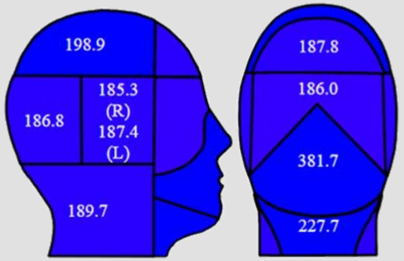


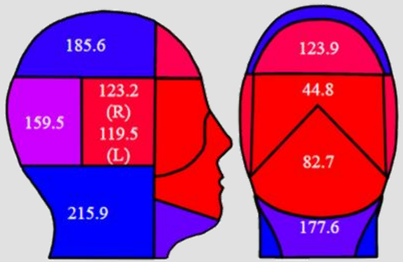
- Air will take the path of least resistance, so improper fit or poor breathability will negate the best filtration material

Fit and Breathability

Heat and Moisture Transfer

- Thermal Sweating Head Form
- Nine independently controlled head zones
    - Temperature
    - Sweating
- Capability of breathing at various rates
    - Nose and mouth
- Used to measure
    - Insulation
    - Evaporative resistance



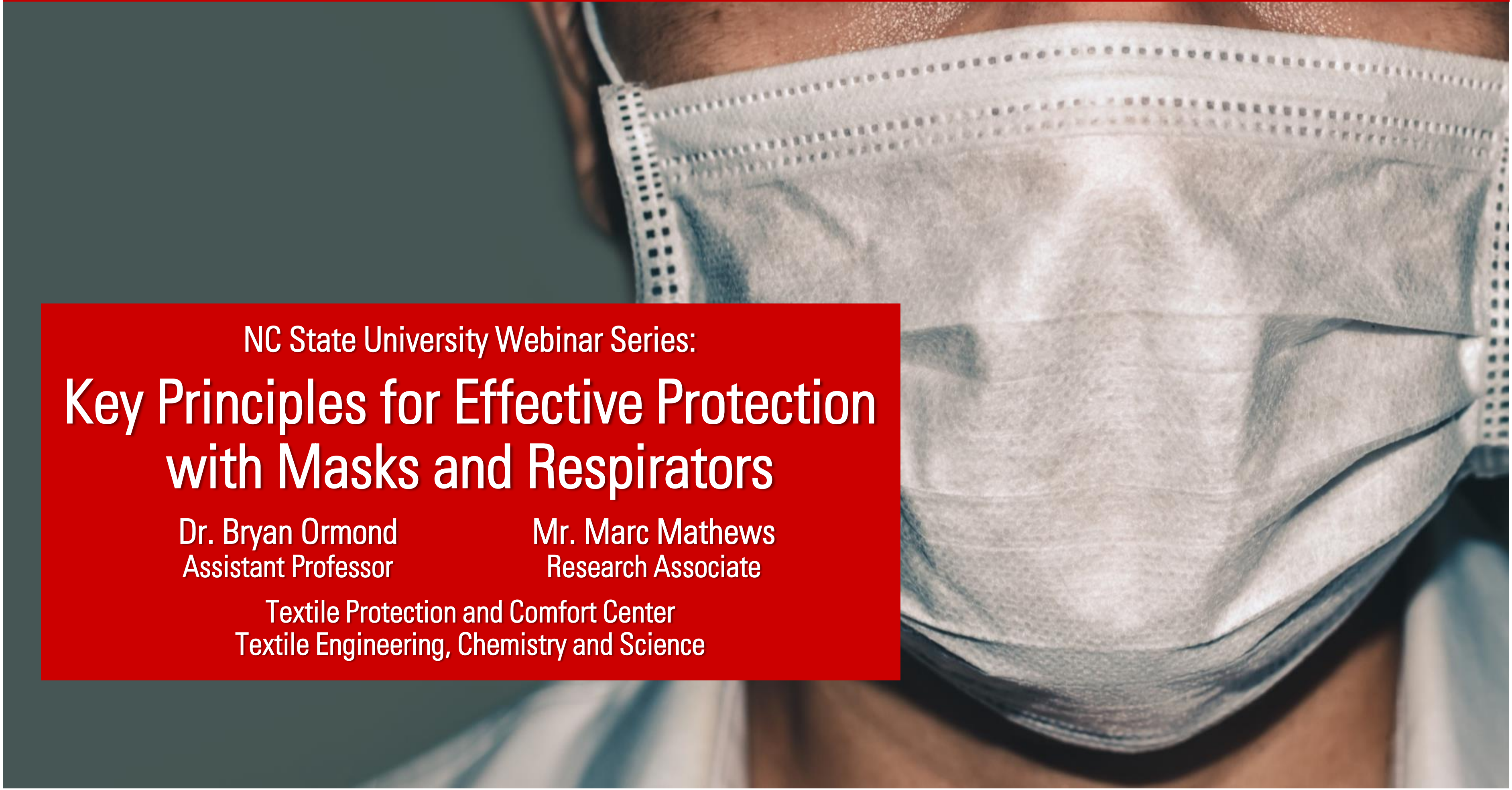


Takeaway Concepts

- Protection of the respiratory system is critical to limiting an individual's exposure to hazardous substances
- Respiratory protection comes in different types depending on the specific needs of the user
  - There is no single "one mask fits every application"
- Surgical and cloth masks are not respirators and are not intended to provide respiratory protection to the wearer
  - Their intent is to limit the spread of disease by inhibiting aerosols and droplets coming from the wearer

Takeaway Concepts

- Even the most efficient filtration material can be ineffective if the fit and seal to the face is poor
- Filtration efficiency and breathability are often competing variables that must be balanced
- Many parallels exist between the historical response to crises and our current situation



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