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# Filtration Performance Results: Sierra Peaks Material #4

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This draft document summarizes results, to date, for the best performing material provided by Sierra Peaks for testing under a New Mexico Small Business Assistance contract (#14355). Efforts are still ongoing and final results are susceptible to change. All questions/comments may be sent to: maomana@sandia.gov

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## 1. System Description

Sandia National Laboratories (SNL) assessed the filtration performance of materials from Sierra Peaks to identify alternatives which may perform similarly to materials used in FDA-approved N95 respirators. This work is meant to characterize the aerosol performance of materials to give Sierra Peaks information for them to determine if they elect to submit masks made using these materials for follow-on N95 certification testing at an accredited facility. The R&D testbed used is a large-scale filtration system designed to test commercial filter boxes. System modifications were performed to simulate, where possible, parameters defined by the National Institute for Occupational Safety and Health (NIOSH) for certification of filter materials for N95 respirators (NIOSH 2019).

The system is a pull-through design. Air enters through a Laminar Flow Element (LFE) and the volumetric flow is measured based on the pressure drop across the LFE. Pressure is measured via a Pressure Transducer (PT). The air then passes through a High Efficiency Particulate Air (HEPA) filter to purge the air of ambient airborne particulates. Test aerosol is injected into the flow shortly after and mixing is induced via a coarse mesh. The airflow is allowed to fully develop prior to arriving at the test section. The aerosol then passes through the test material mounted in a box in the test section. Pressure drop across the test article is measured and aerosol sampling probes measure the aerosol concentrations upstream and downstream of the sample. The air passes through a second HEPA filter prior to being exhausted to ambient by a blower.

A Topas aerosol generator is used to produce the test aerosol from Sodium Chloride (NaCl) dissolved in deionized (DI) water. Generated aerosol passes through a heated mixing chamber and a desiccant dryer to produce nanosized solid-state particulates. A dilution loop allows for the aerosol concentration to be regulated. The aerosol sampling probes upstream and downstream of the test section are aligned with the flow path. These are ducted directly to the aerosol sizing and counting instruments.

A Laser Aerosol Spectrometer (LAS) was used for data collection in the original configuration of the system and was also used for initial testing in this project. Because the lower measurement range for the LAS is 90 nanometers (nm), the LAS was switched out for a more complicated Scanning Mobility Particle Sizer (SMPS) spectrometer system. The SMPS is comprised of an Electrostatic Classifier (EC), Differential Mobility Analyzer (DMA), and a Condensation Particle Counter (CPC). This enabled data collection at 75 nm, the particle size called out in the NIOSH guidelines.

## 2. Methodology

In order to accommodate the fast turnaround required for this project, a quick-sealing process to mount filter materials was developed. Test materials were used in their intended mask geometry by mounting both halves of a mask onto custom filter holders made from medium density fiberboard. These holders were then mounted and sealed to a box which was inserted into the testbed. For all testing, the side of the mask intended to be the exterior surface (away from user) is facing upstream (towards the incoming aerosol) to assess its ability to protect the wearer. The filter holder geometries were first tested without filter media in place to verify that no artificial pressure drop or efficiency was being induced by the selected geometry and thus biasing the testing. Reference images for the mounting method are displayed in Figure 1.

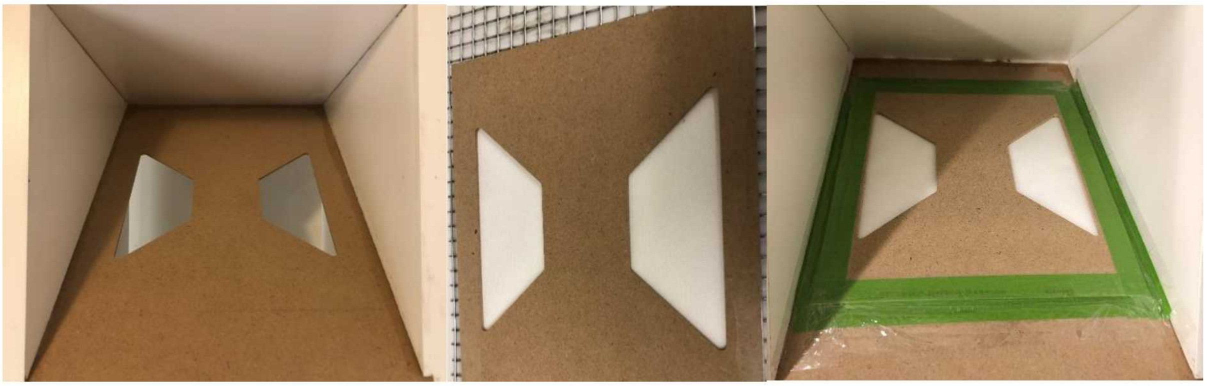

**Figure 1: (Left) Permanent mounts were sealed in place and allowed to cure prior to use. (Middle) Test materials were mounted on the back of the filter holder along the seams. (Right) The mask was aligned and held in place with painter's tape, followed by 2 layers of heavy-duty packing tape to seal the edges.**

The two filter face velocities considered for this testing were referenced from a study funded by NIOSH (Rengasamy et al. 2010). These rates were verified to approximate the filter face velocities achieved if the flowrates and surface areas in the NIOSH standard were used. The surface area exposed by the filter holder, coupled with the desired filter face velocities of 5.5 cm/s for low flow and 16.5 cm/s for high flow, were used to determine the necessary volumetric flow rates through SNL's system. All initial testing was done in low flow conditions. A summary of the instrumentation used during testing is provided in Table 1.

**Table 1: Summary of instrumentation used for testing**

| Row | Measurement | NIOSH Guidance (If Any) | Instrument | Description |
|---|---|---|---|---|
| 1 | Air Flow | 2% accuracy | 1. Laminar Flow Element: Mo. No. Z50MH10-125F<br>2. Laminar Flow Element: Mo. No. Z50MC2-2F | Both: Last Calibrated 2013. The LFE typically used in the testbed had a flow range that was too large for the necessary testing parameters. |
| 2 | Pressure | 2% accuracy | 1. Pressure Transducer: Omega Mo. No. PX653-03D5V<br>2. Pressure Transducer: Omega Mo. No. PX653-10D5V<br>3. Pressure Transducer: Omega Mo. No. PX653-10D5V | PTs 1 and 2 were calibrated by the manufacturer and verified in-house to provide 2% accuracy.<br>1. Calibrated 3/16/20. Measures up to 3 in. of $H_2O$<br>2. Calibrated 3/16/20. Measures up to 10 in. of $H_2O$<br>3. Not recently calibrated. Measures up to 10 in. of $H_2O$ |

| | | | | |
|---|---|---|---|---|
| 3 | Aerosol Generation | 2% NaCl solution in DI $H_2O$. Particle Size Distribution (PSD) with a median count diameter of 75 nm, Standard Deviation of 1.86. | TOPAS Mo. No. ATM 241 | Generates a polydisperse aerosol ranging from 10's of nanometers to ~0.5 microns. A 2% NaCl (Fisher BioReagents BP358-121, Lot 177083) solution in DI $H_2O$ (Culligan) was used. |
| 4 | Data Acquisition | N/A | NI Mo. No. eDAQ-9188XT | Calibrated by the manufacturer 11/21/19. |
| 5 | Particle sizing/counting | N/A | 1. TSI Laser Aerosol Spectrometer Mo. No. 3340A<br>2. TSI Electrostatic Classifier Mo. No. 3082<br>3. TSI Neutralizer Mo. No. 3088<br>4. TSI Differential Mobility Analyzer Mo. No. 3081<br>5. TSI Condensation Particle Counter Mo. No. 3787 | Instrument 1 was calibrated by the manufacturer 2/6/20. The remaining instruments were collectively calibrated 2/15/19 by the manufacturer and were unused prior to this testing. They are 2 months out of calibration. |
| 6 | Climate Parameters | 1. Samples preconditioned at a Relative Humidity (RH) of 85 ±5%and temperature of 38 ±2.5 °C<br>2. Testbed to be maintained at a RH of 30 ±10% and temperature of 25 ±5 °C | 1. N/A<br>2. RH and temperature sensors are internal to the TSI 3082. | 1. Samples were not preconditioned during this work.<br>2. RH and temperature were measured but not regulated for SMPS measurements. |

The filtration system was intended for use with the LAS to probe filter efficiency as a function of particle size for the most penetrating size regime. Its sampling range was set to 90 nm to 1000 nm in order to use existing data analysis methods. All initial results were attained using this calibrated instrument. Low flow measurements of Material #4 were performed for two independent test box articles, with five efficiency measurements per article. Each efficiency measurement is calculated from an upstream and downstream measurement of the aerosol concentration. Duplicate testing of Material #4 was also performed at the high flow condition. Triplicate testing at the low flow condition was then performed for three certified N95 respirators (same make and model for all runs) to quantify their filtration efficiencies under the testing parameters generated by SNL's R&D testbed. Measurement uncertainties were propagated accordingly for all computations.

The LAS was then swapped for a SMPS (instruments 2-5 in Table 1 row 5) to collect data at the particle size tested in the NIOSH standard (75 nm). The instrument sampled a size range of 10 nm – 400 nm for all testing. N95 respirators and Material #4 were retested and the results compared with the LAS data where possible. Good agreement between the LAS and SMPS data was observed.

## 3. Results and Discussion

Data collected using the LAS was processed and particle sizes with insufficient counts downstream were discarded. This ensured reported data was statistically significant. Average efficiencies for Material #4, for each configuration tested, showed high repeatability and exhibited minimal sensitivity to different filter face velocities (Figure 2).

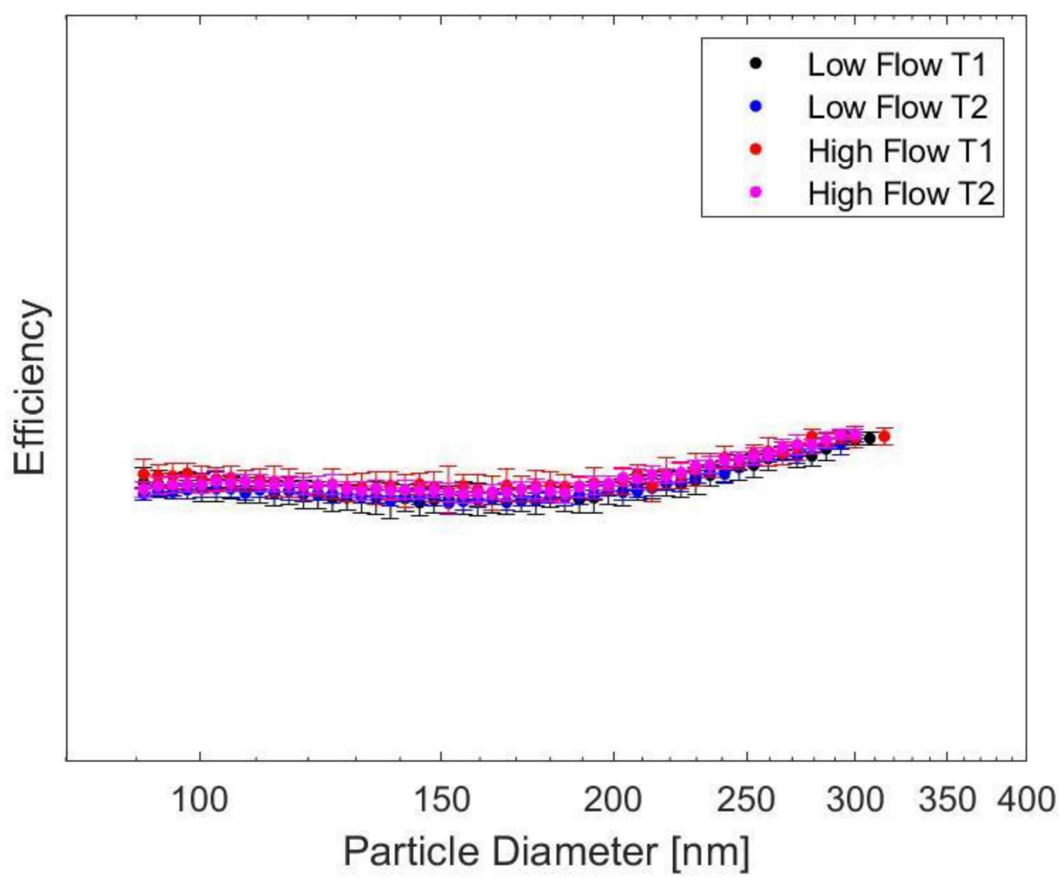


**Figure 2: Two independent test articles were used and tested at low flow and high flow conditions. The results exhibited high repeatability. Care was taken to ensure no filter loading was observed.**

Triplicate testing for one make and model of N95 respirator was then conducted to serve as a control reference. Due to the limited availability of Personal Protective Equipment (PPE), only the test article labeled "Sample 1" was guaranteed to be a pristine sample. The other two were unused, but the quality of handling/storage prior to testing was not known. Most of the average efficiencies computed from this testing fell within each other's error bars, displaying good correlation (Figure 3).

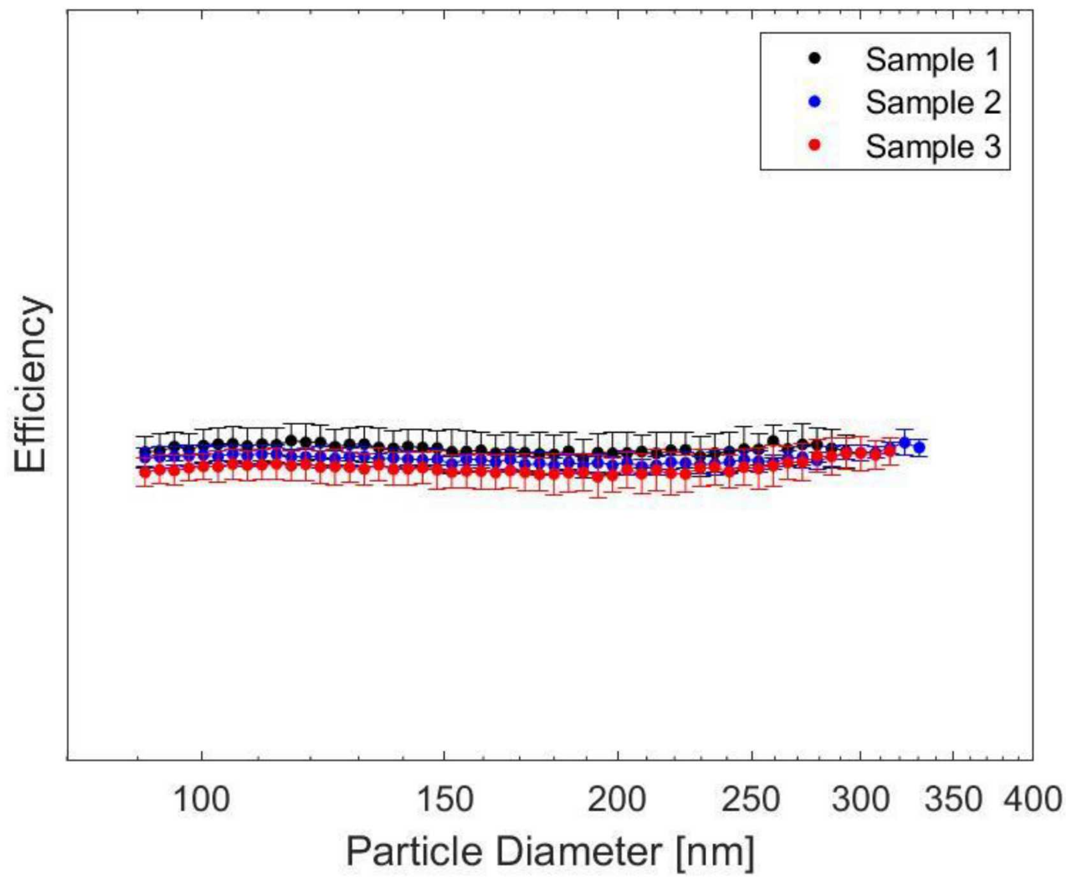


**Figure 3: Sample 1 was a pristine N95 respirator sample that received minimal handling prior to testing. Sample 2 was used for a fit test by one individual prior to testing. Sample 3 was a clean control sample but the amount of handling and method of storage prior to testing was not known.**

The filtration performance was compared between Material #4 and the control N95 respirator by calculating the net average efficiency of Material #4 at low flow conditions and comparing against the N95 clean control sample data. This was done to provide the most conservative estimate of Material #4's performance. The difference in efficiency percentages as a function of particle size was plotted (Figure 4).

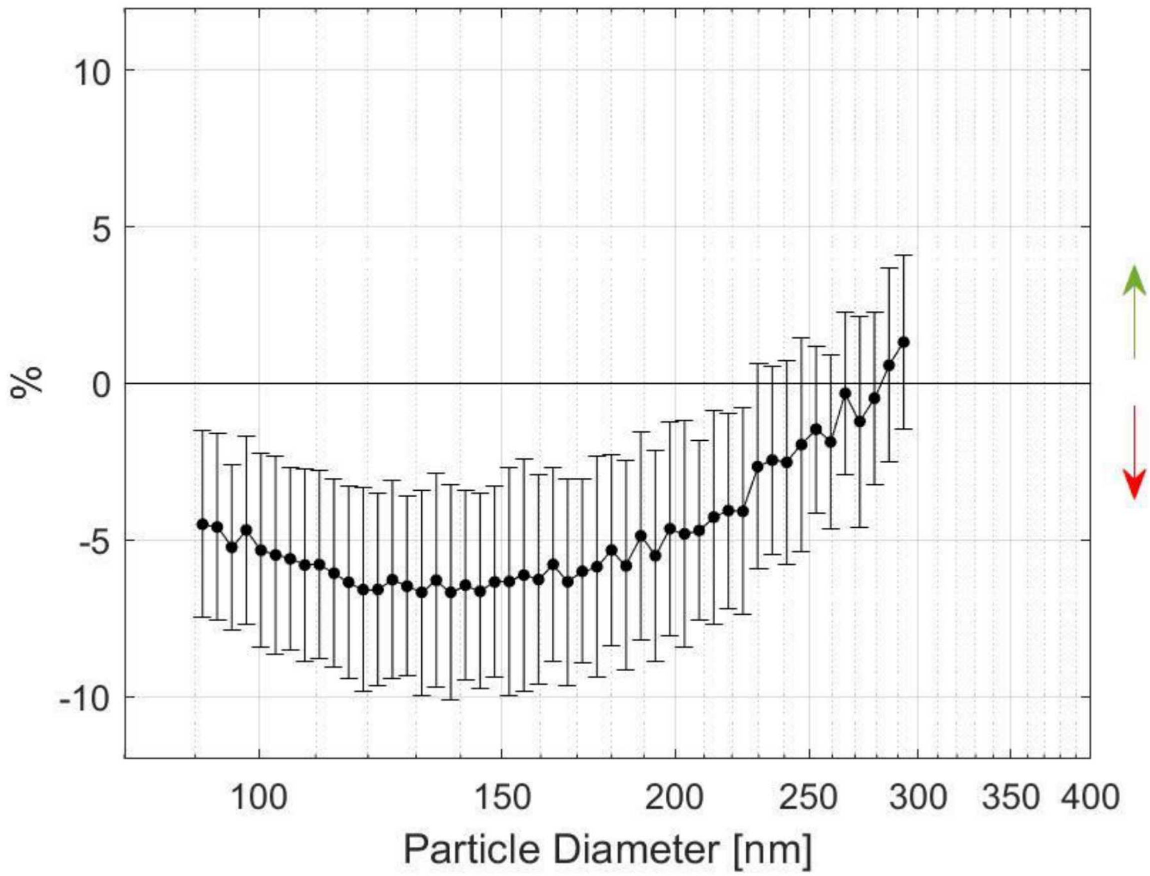


**Figure 4: The difference in efficiencies between Material #4 versus the N95 control was plotted as a function of particle size ($E_{M4}$-$E_{N95}$). The lower-half of the graph (red-arrow) indicate where Material #4 underperformed and the upper-half (green-arrow) indicates where better performance was observed from Material #4.**

Values on the y-axis of less than zero (indicated by the red arrow) signify where Material #4 is underperforming compared to the control N95 respirator, and the values greater than zero (indicated by the green arrow) highlights where it outperforms the control respirator. For the particle size range tested, Material #4 underperformed by an average of 5 ±3%.

NIOSH (2019) uses a monodisperse aerosol of 75 nm to conduct its testing. Efficiency is calculated as the difference in the amount of aerosol that should have been deposited on the mask over a certain period of time versus how much was actually deposited. To test samples at the same particle size, the LAS was swapped for the SMPS system. Three efficiency measurements for one test article of Material #4 (fresh sample) and one test article of a control sample (Sample 2 from Figure 3) were performed at low and high flow; the calculated efficiencies were compared against those from LAS measurements.

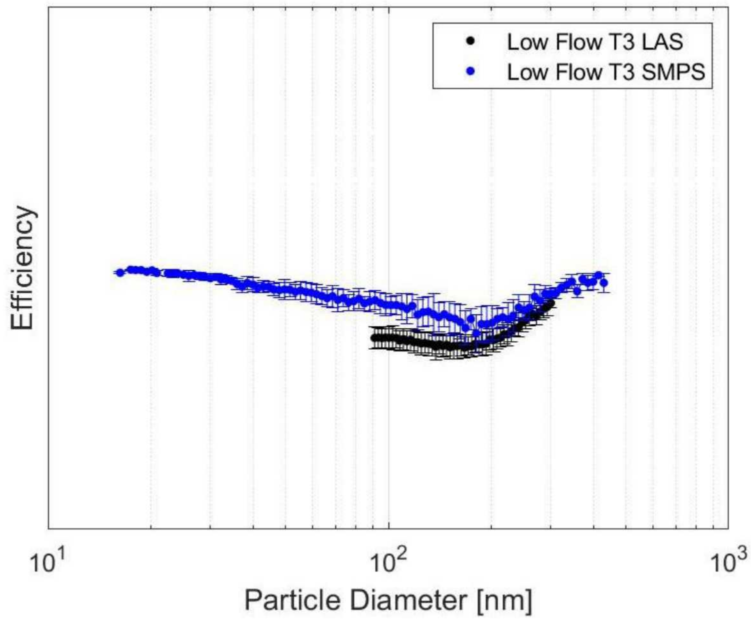


**Figure 5: The performance of the Material #4 sample during SMPS testing outperformed the average efficiencies of the LAS measurements. This anomaly in results may be attributable to a variation in the singular Material #4 sample tested with an SMPS. Additional test articles of this material have not been tested with an SMPS so the source of this discrepancy has not been determined.**

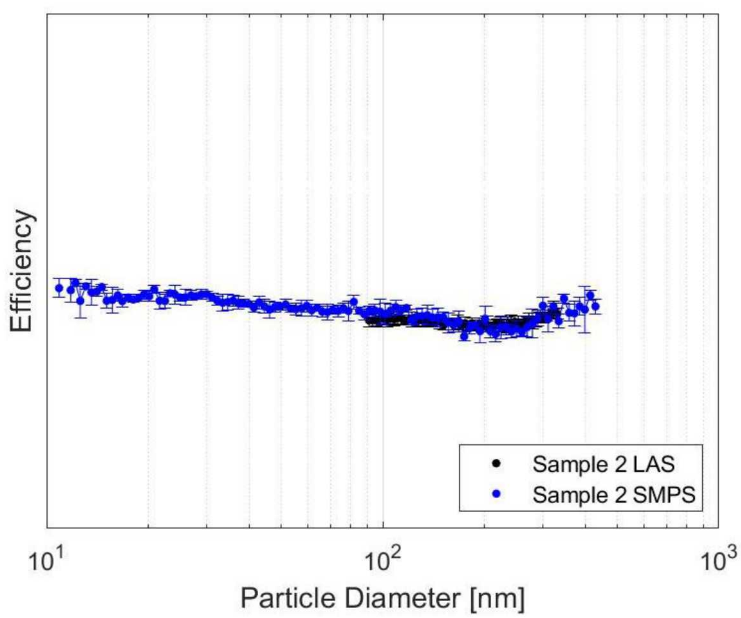


**Figure 6: Testing of the N95 mask, Sample 2 from Figure 3, at low flow with both instruments yielded results with strong correlation. No filter loading was observed. The presence of filter loading would be signaled by a noticeable increase in the pressure drop and efficiencies over the course of subsequent measurements, neither occurred.**

The replicability of efficiencies for the same sample using both instruments (Figure 6) indicates the discrepancy in Figure 5 may be a single sample anomaly. Further testing of Material #4 is warranted to better understand observed results. The preliminary SMPS results between Material #4 and the N95 control (Sample 2) are compared in Figure 7, using the same method as in Figure 4.

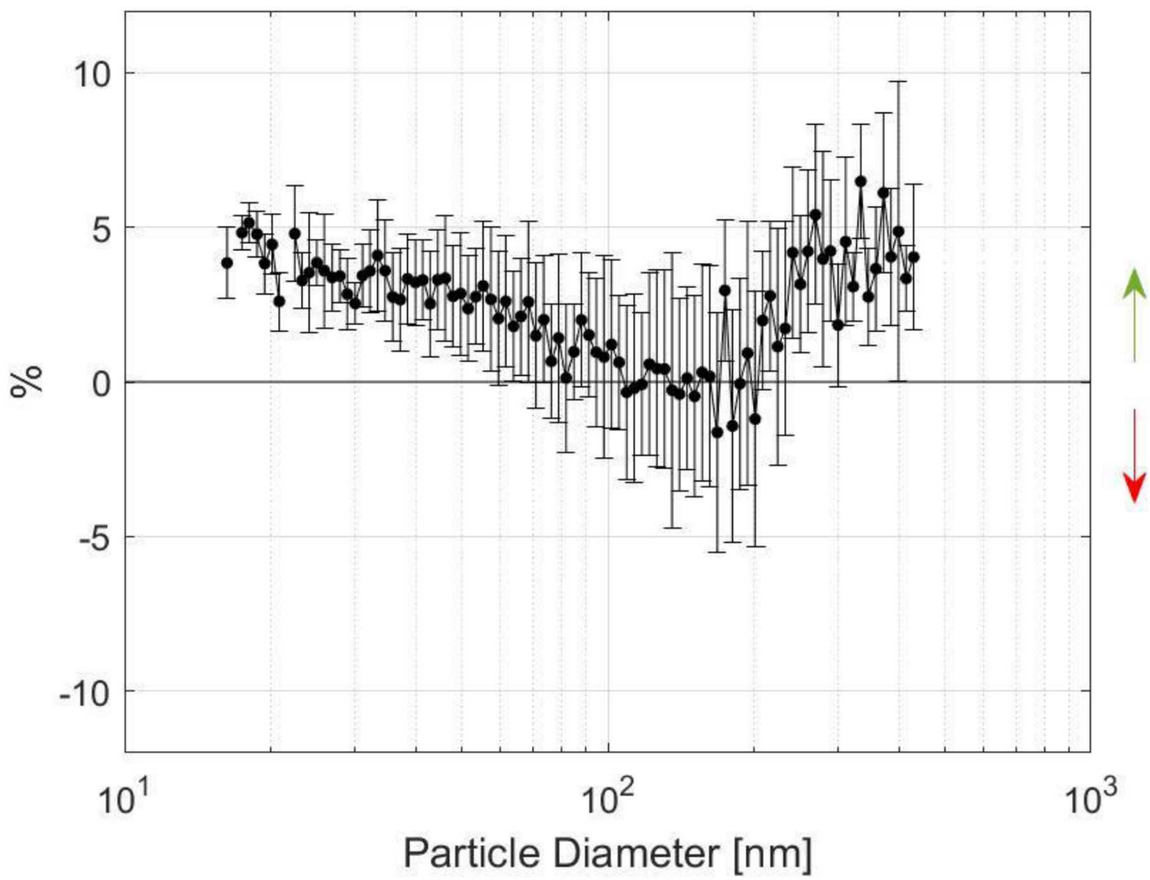


**Figure 7: Comparison of efficiency results between Material #4 and Sample 2 using SMPS data. The SMPS was able to provide statistically significant data at smaller and larger particle sizes than the LAS.**

Preliminary results indicate that performance of Material #4 is comparable to a certified N95 respirator when tested under the conditions achievable by SNL during this quick-turnaround project. However, Material #4 consistently showed a substantially higher pressure drop than the control sample for all configurations. This may make it tiresome to use in terms of breathability. Average values of the pressure drop measured across test articles are provided in Table 2.

**Table 2: Average Pressure Drop for Each Configuration Tested**

| Sample | Instrument | Flow Setting | Average Pressure (PT1) [in. of $H_2O$] | Average Pressure (PT3) [in. of $H_2O$] |
|---|---|---|---|---|
| M4 T1 | LAS | Low | N/A | 6.3 |
| M4 T1 | LAS | High | N/A | 6.2 |
| M4 T2 | LAS | Low | N/A | 5.8 |
| M4 T2 | LAS | High | N/A | 5.7 |
| N95 S1 | LAS | Low | 2.3 | 1.7 |
| N95 S1 | LAS | High | N/A | 3.9 |
| N95 S2 | LAS | Low | 2.3 | 1.7 |
| N95 S2 | LAS | High | N/A | 4.3 |
| N95 S3 | LAS | Low | 2.9 | 2.1 |
| N95 S3 | LAS | High | N/A | 5.1 |
| M4 | SMPS | Low | N/A | 4.9 |
| M4 | SMPS | High | N/A | 9.7 |

Material #4 always maxed out PT1 at its highest reading of 5.5, so PT3 had to be relied upon for a relative comparison. Measurements of the N95 controls were possible with PT1 for low flow conditions. The average RH and temperature measured by the SMPS over all the days of testing showed the ambient RH and temperature of the lab to both fluctuate in the twenties (RH of 20~24% and temperature of 21~26°C, respectively.). There were consistent ambient conditions during all days of testing.

## Summary

The team used an existing R&D filtration system to test a variety of materials at a singular configuration (low flow) with a LAS to identify the best performing material from the set. Once a promising material (Material #4) was identified, the same configuration was retested in triplicate to confirm that the results were replicable. Subsequently, testing was performed at high flow conditions. Control N95 samples were then tested to serve as a benchmark for the efficiency results being measured. Additional testing was carried out with an SMPS to expand upon the size range tested by the LAS. The fast-paced nature of this project did not allow for all desired testing permutations to be conducted.

Material #4 performed the most similar to FDA-approved N95 masks under SNL's testing conditions. This material is the most likely to perform well under testing on a N95 certification system (e.g., TSI Model 8130A Automated Filter Tester) if no other alternative material is identified.

## 4. References

National Institute for Occupational Safety and Health (2019). "Determination of particulate filter efficiency level for N95 series filters against solid particulates for non-powered, air-purifying respirators standard testing procedure (STP)." Procedure no. TEB-APR-STP-0059 Rev. 3.2.

Rengasamy, S., Eimer, B., Shaffer, R.E. (2010). "Simple Respiratory Protection-Evaluation of the Filtration Performance of Cloth Masks and Common Fabric Materials Against 20-1000 nm Size Particles.