Ceramic Filter Development Program at LLNL

36th International Nuclear Air Cleaning Conference – Salt Lake City

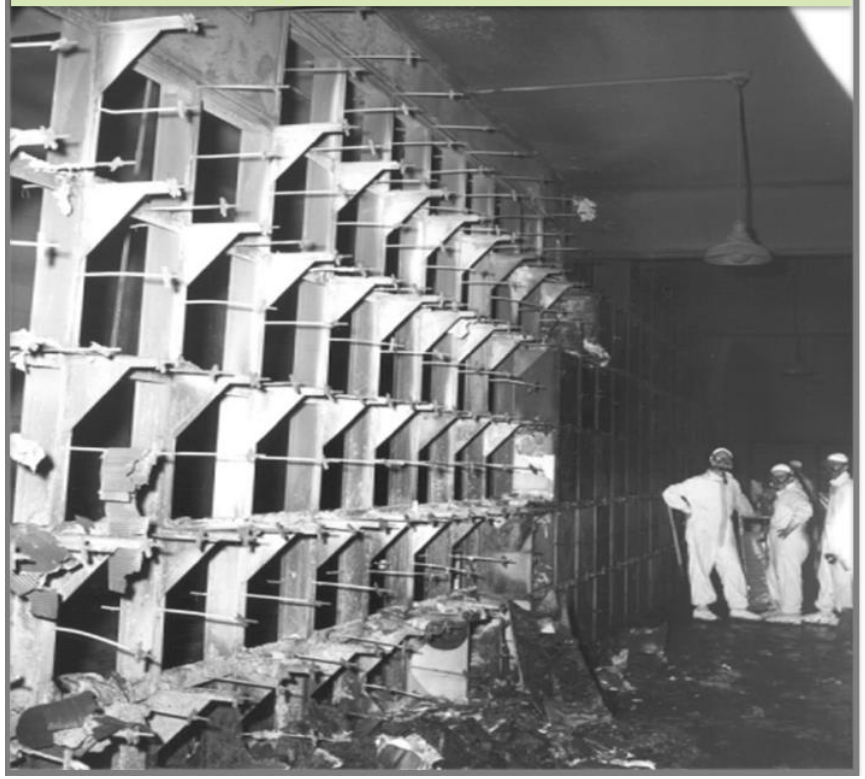
Andrew Hoff *et al.*
Ceramics & Polymers Engineering

LLNL-PRES-836357
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Goals: Lower nuclear facility costs, maintain safety

Destroyed filter bank after a fire



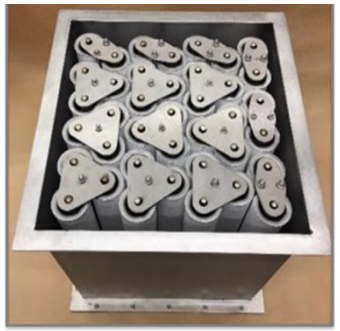
Water damage to filters following a fire

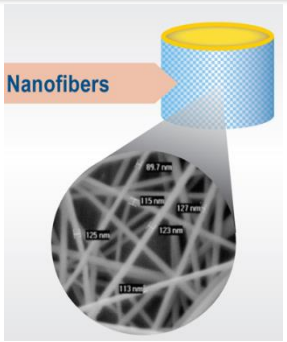
Ceramic filters perform at higher temperatures and are likely to reduce reliance on fire suppression systems

Overview of LLNL ceramic filter development

Ceramic Filters
(Mark Mitchell)

- Ceramic **HEPA** Filters
  - HEPA Overwrap (J. Haslam)
  - MTC Media (J. Kelly, M. Ross)
  - Advanced Manufacturing (M. Ceron, A. Troksa)
- Ceramic **Prefilters**
  - Sealants
    External (A. Hoff)
    Internal (M. Ross)





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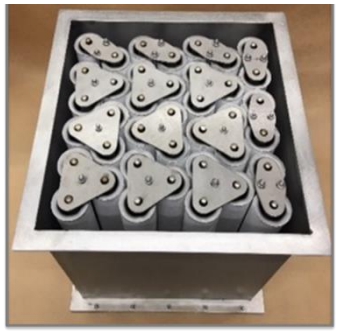
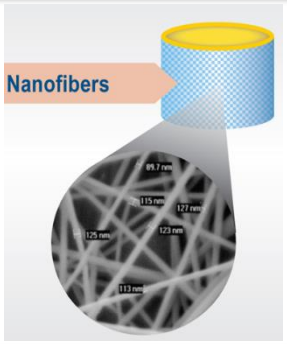
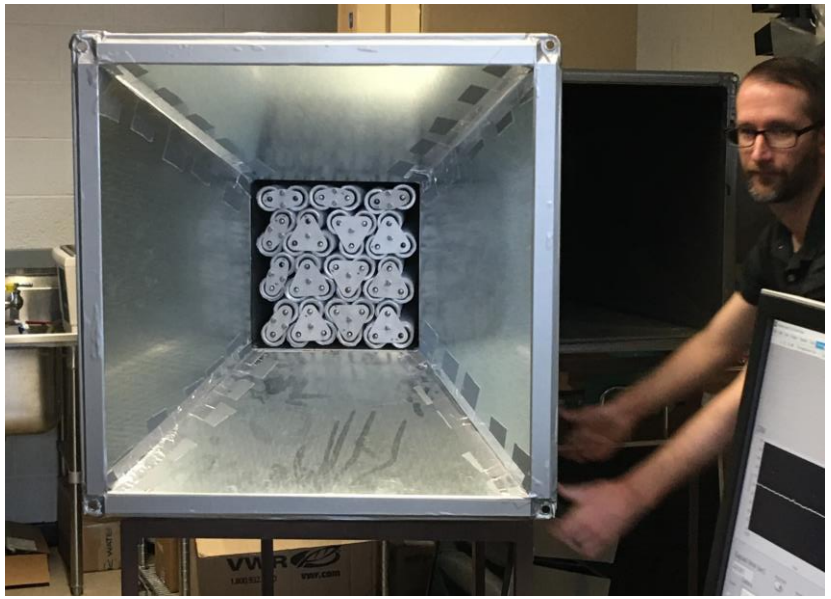


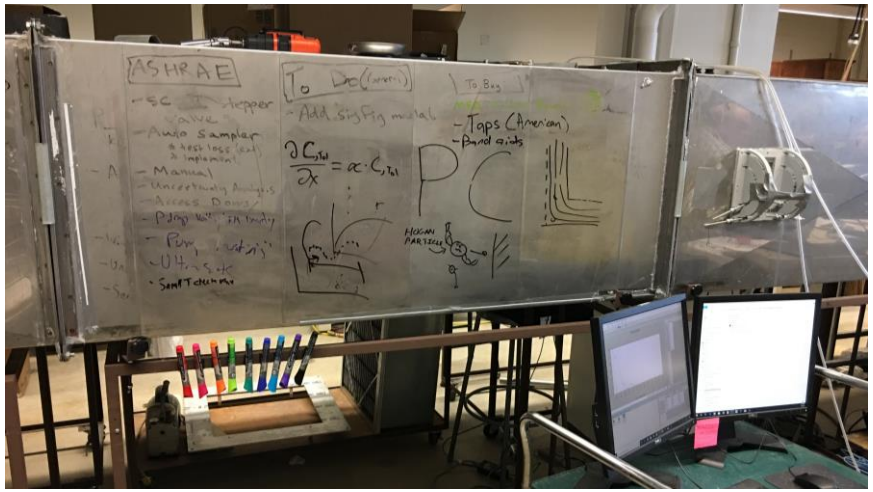


Performance Testing

1. Baseline Particle Efficiency, 250 cfm
2. Exposure to 500°C/1hr/Air
3. Measure post heat treatment Particle Efficiency



Prototype Filter in Test Section



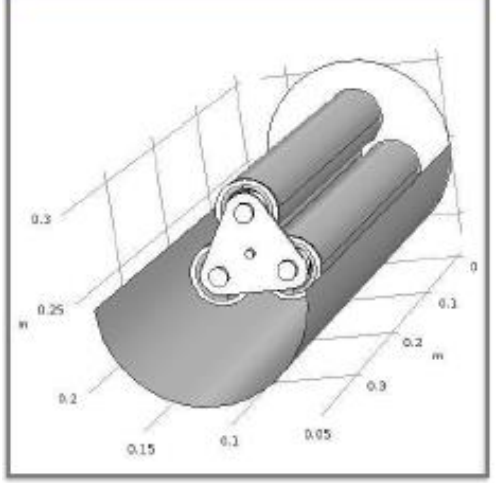
Univ. of Minnesota –
Particle Calibration Lab

HEPA overwrap – fiberglass media on porous ceramic substrate

- Primary driver of design work
- Explored various support tubes
  - Porous ceramic tubes
  - Desired features: smooth exterior, minimal impact on pressure drop, robust strength
  - Selected Filtros Kellundite/Ceramically Bonded Alumina tubes
- Conventional fiberglass media (HEPA and sub-HEPA grades)
- Ceramic nanofiber media development
  - Flakes under overwrap, cast filter media

Filter prototype of patented design

Filter tubes with media overwrap

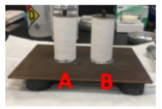
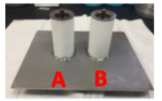


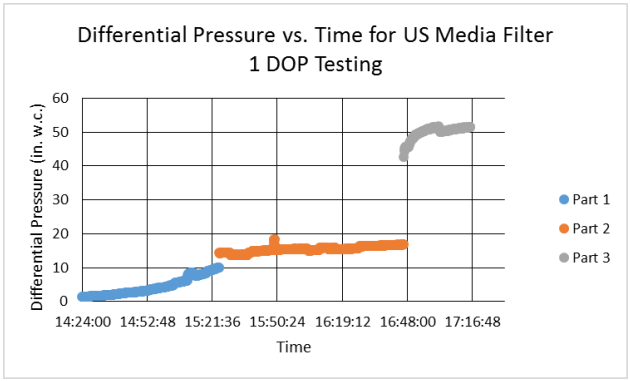
Cast filter media

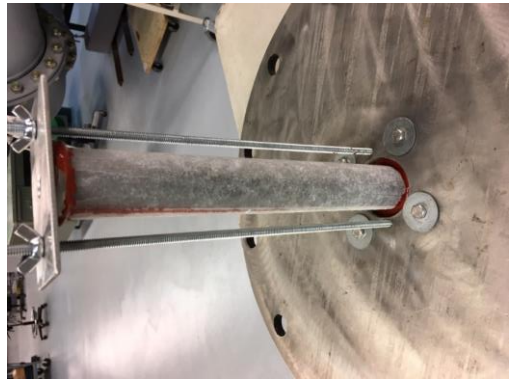
Cast filter media overwrap

Examples of Aerosol (DOP/PAO) filtration efficiency testing

- Pressure drop
  - Measurements have typically been higher than desired (i.e., < 1” w.c.)
  - Depends on the specific substrate and media combination
  - Filters tested up to 50” w.c. without failing
- Filtration efficiency
  - Can meet 99.97% HEPA efficiency requirement, but quality improvements necessary
  - Need quality improvements
  - Assumed to be variable sealing quality

Sample		Flowrate [cfm]	dP [in-H_2O]	Upstream particle ρ [µg/m³]	Downstream particle ρ [µg/m³]	Efficiency (%)	
Pyro Putty (653) 	A	6.2	9.2	30.2	0.21	99.3	Before mHTTU
	A	4.4	6.4	30.6	1.05	96.6	2.7 % After mHTTU
	B	6.5	8.8	30.4	0.49	98.4	Before mHTTU
	B	4.6	5.6	30.1	1.68	94.4	4.0 % After mHTTU
Composite Mixture (325-D: 55 wt% SS) 	A	4.5	6.8	30.5	0.02	99.9	Before mHTTU
	A	4.5	7.2	31.0	0.12	99.6	0.3 % After mHTTU
	B	4.5	6.8	30.4	0.06	99.8	Before mHTTU
	B	4.5	6.7	30.1	0.15	99.5	0.3 % After mHTTU

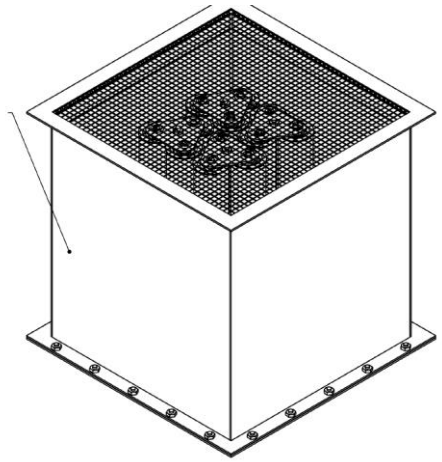


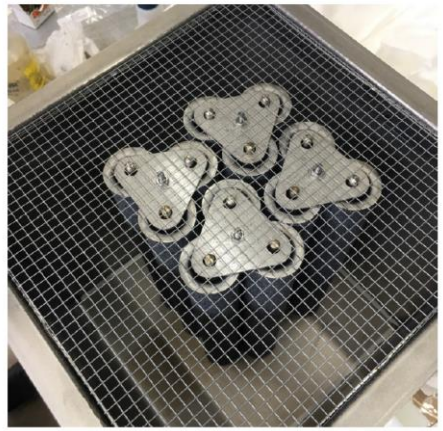


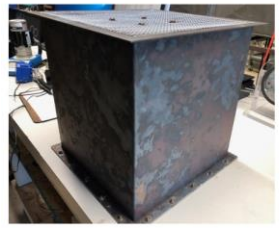
Sub-par and variable results drive filter media and sealant development to achieve desired quality and performance

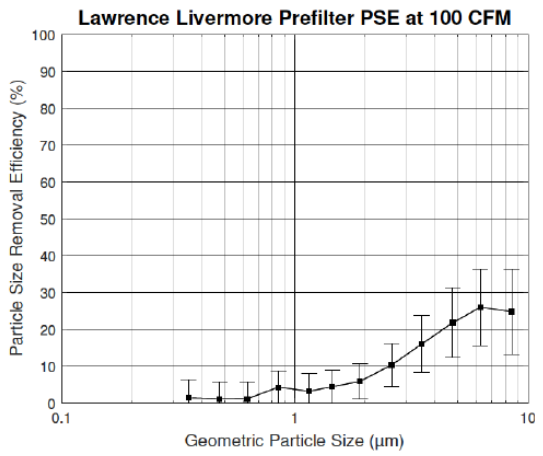
Ceramic prefilter – porous ceramics tubes (without overwrap)

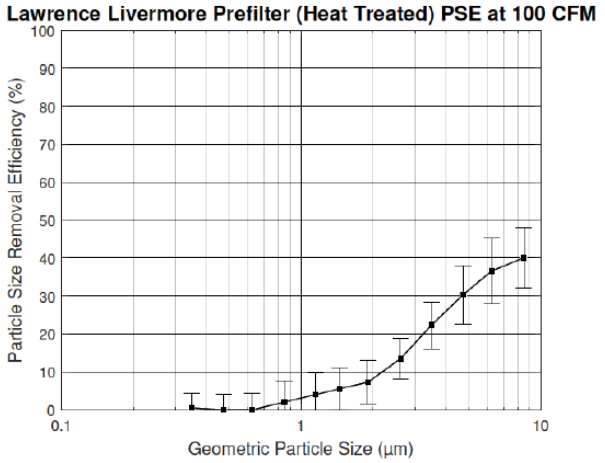
- Value proposition
  - Faster to market than HEPA filter (builds upon HEPA filter design)
  - Arrest embers to protect downstream components (e.g., conventional HEPA filter)
- Results
  - No filter degradation by ASHRAE 52.2 test after 1 hr, 500°C thermal exposure
- Research areas
  - Improve housing design (e.g., screen, HEPA media gasket, double-walled counter bore)
  - Internal sealant development
  - External gasket development









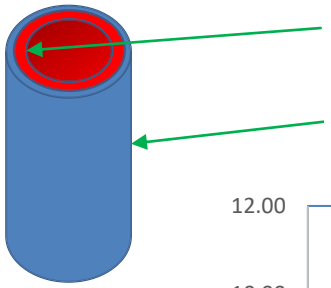


Hybrid Filter/Absorber

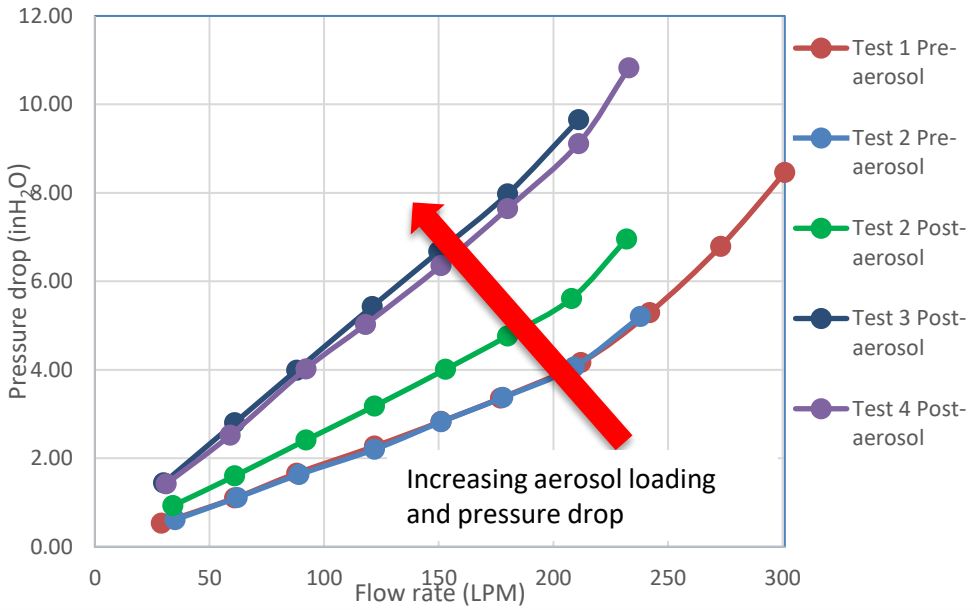
- Include gaseous radioisotope absorber (SNL) into high temperature filter (application to Thermal Test Facility & others)

Basic Ceramic Filter Element

Incorporate Absorber



Flow rates (LPM)	Test 1 Efficiency Setup 1	Test 1 Efficiency Setup 2	Test 2 Efficiency	Test 3 Efficiency	Test 4 Efficiency
56	99.97%	99.95%	99.79%	99.77%	N/A
183	99.97%	99.98%	99.86%	99.91%	99.92%
260	N/A	99.996%	N/A	N/A	N/A



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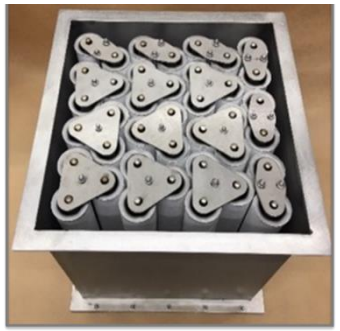
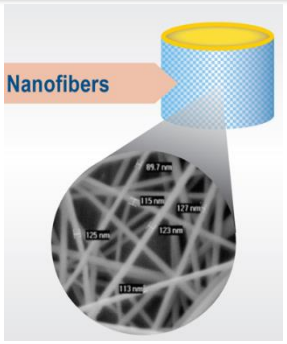
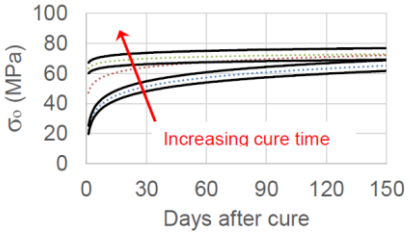
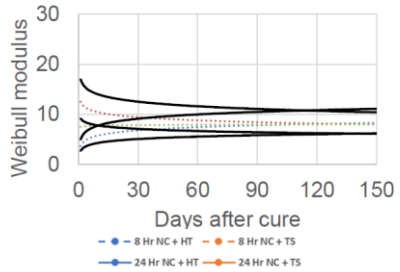


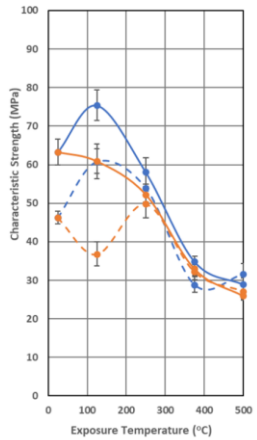


Internal Sealant Development

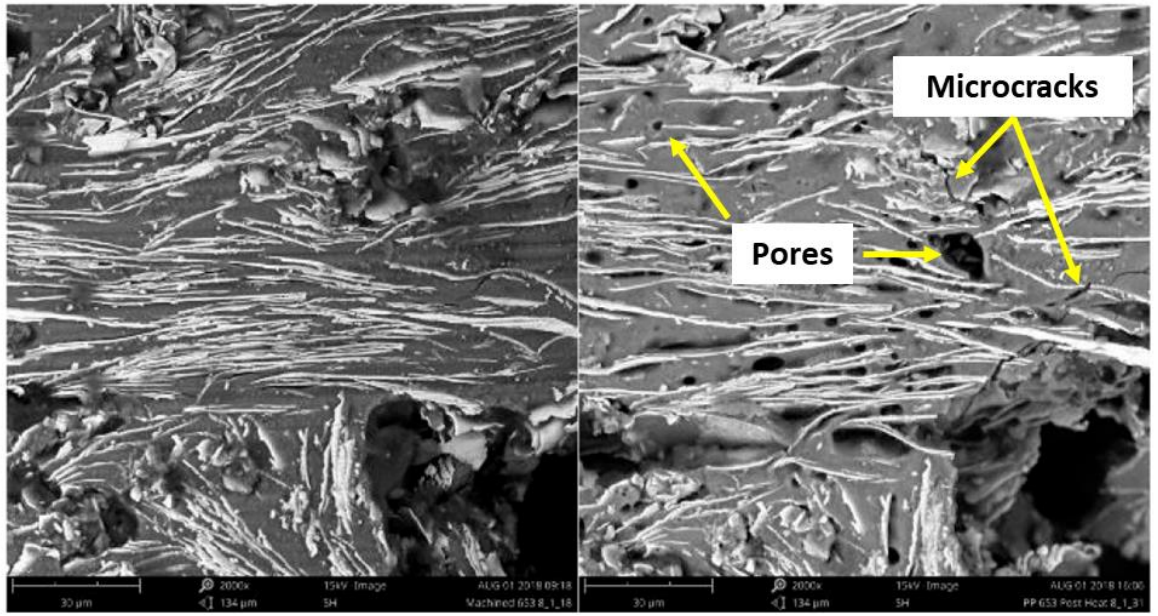
- Commercial sealants
  - Screened commercial materials
  - Selected PyroPutty 653
  - Found sensitivity to water and humidity
- Research areas
  - Microstructure, thermal property testing, mechanical property testing
  - Accelerated aging studies (85°C, 85% RH, 250-1000 hrs)
  - Exploration of other commercial sealants
  - New sealant formulation development







Cured | 1 hr, 500°C exposure



External Sealant Development

- Explored internal intumescent sealants as external sealants (e.g., edge insertion into trough)
- None of the sealants explored to date have had robust seal after a 1 hr, 500°C thermal exposure
  - Might hold sufficient seal with a bolted design, similar to gasketed designs
- Ongoing research to explore high-temperature gasket materials (bolting, torque requirements)

(a) Before: trough

(b) Before: with knife-edge

(c) After: knife-edge

(d) After: trough

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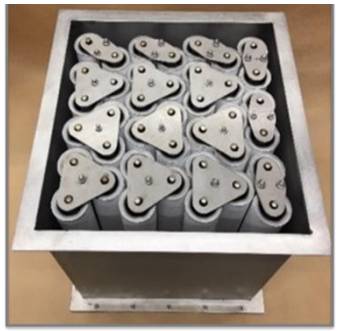
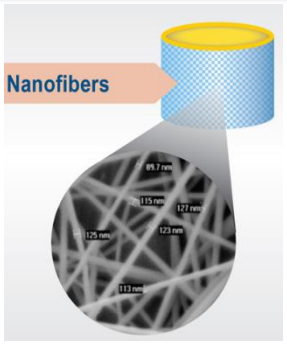
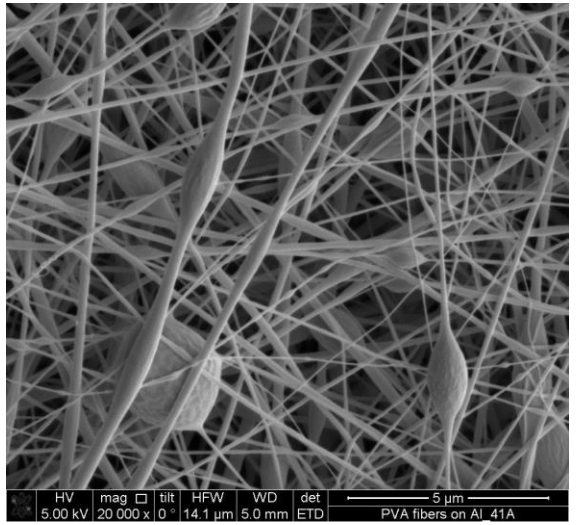
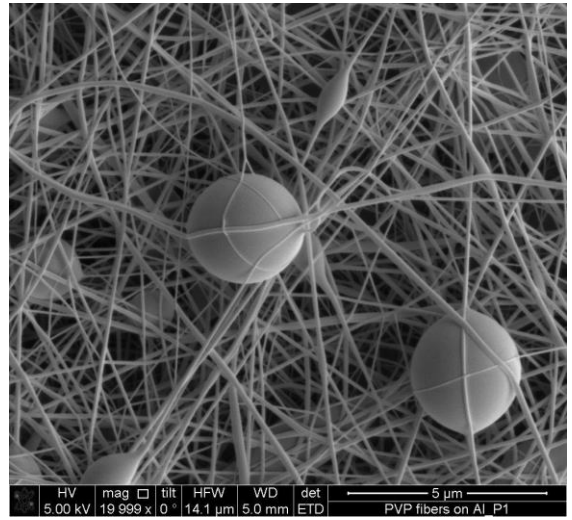


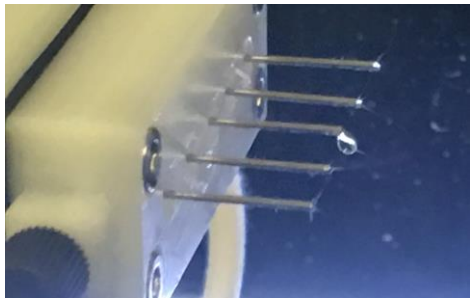


Ceramic HEPA Filter – Development of Ceramic Nanofiber Filter Media

- Refining process parameters for larger, robust filter media
- Equipment
  - Scanning deposition head
  - Rotating Collector: 200 mm x 310mm
  - Multi-head capability for faster deposition







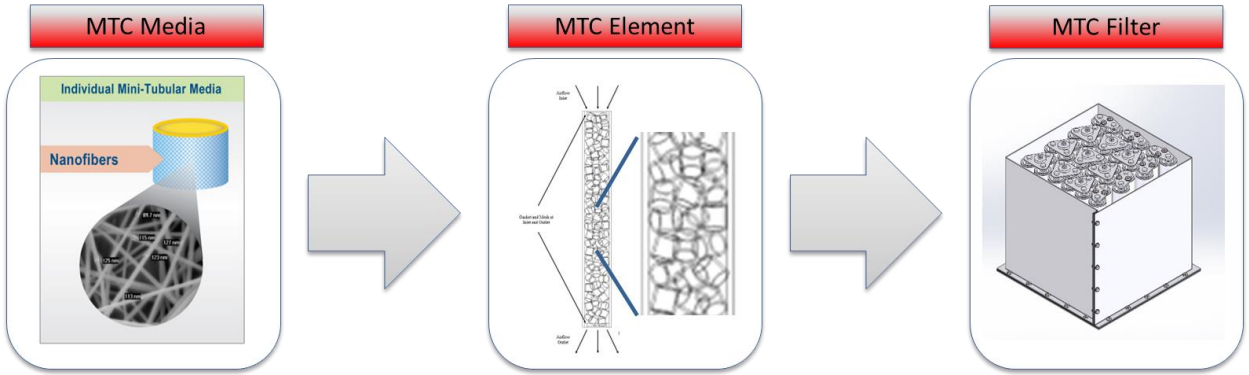
Rotating Collector

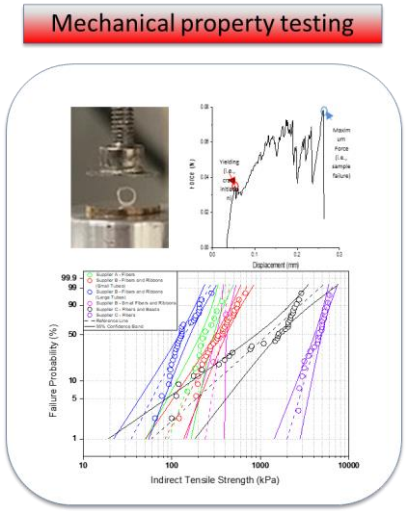
-James Kelly
-Michael Ross
-others

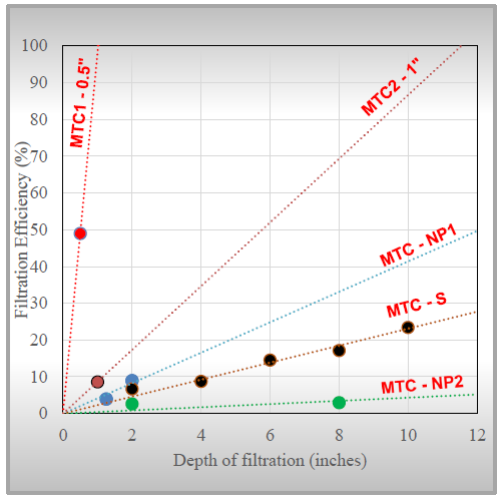
Commercial electrospinning equipment produces larger area deposition

MTC filters

- Value preposition
  - Easier implementation of ceramic nanofibers for improved filtration performance
  - Scale quantity instead of size
  - Low pressure drop (cross flow + permeation)
- Research areas
  - Formulation and processing development
  - Nanoporous vs. nanofibrous microstructures
  - Pilot-scale media production
    - Nanofiber production with different commercial electrospinning systems
    - Post-processing automation



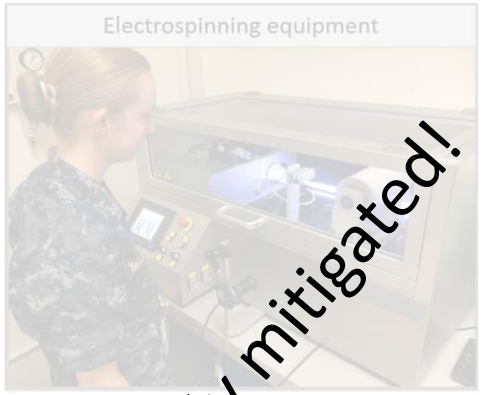


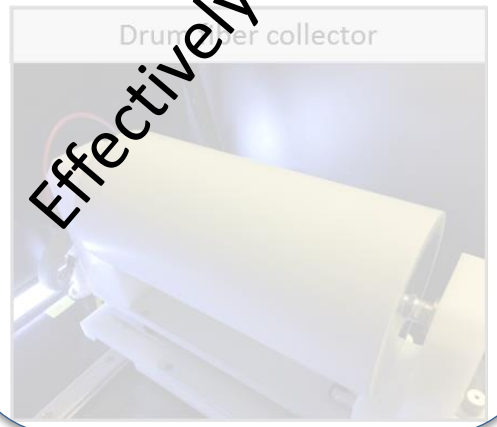


Design concepts are emerging, but need to scale processes for rapid prototyping/testing more configurations

Competing bottlenecks to enable rapid prototyping

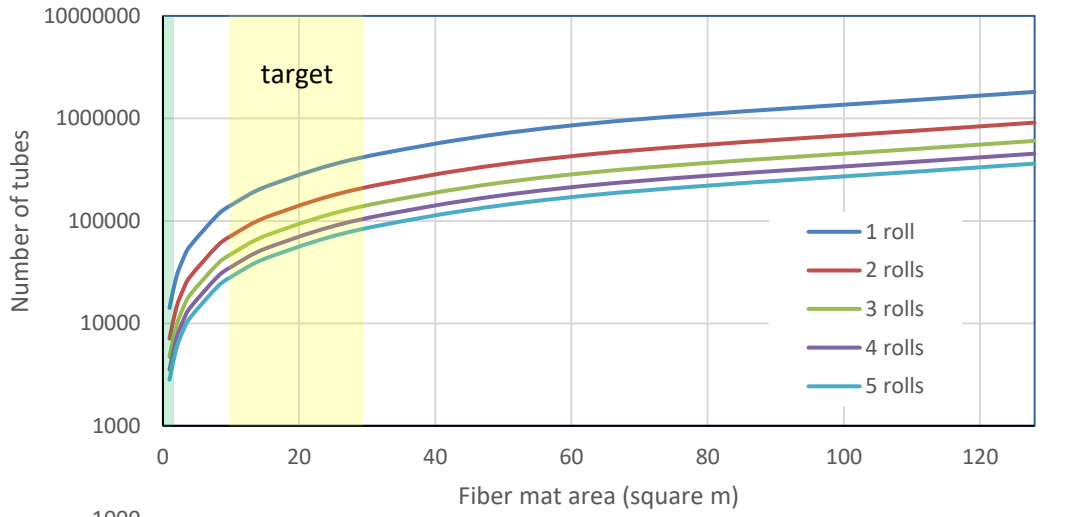
Electrospinning media

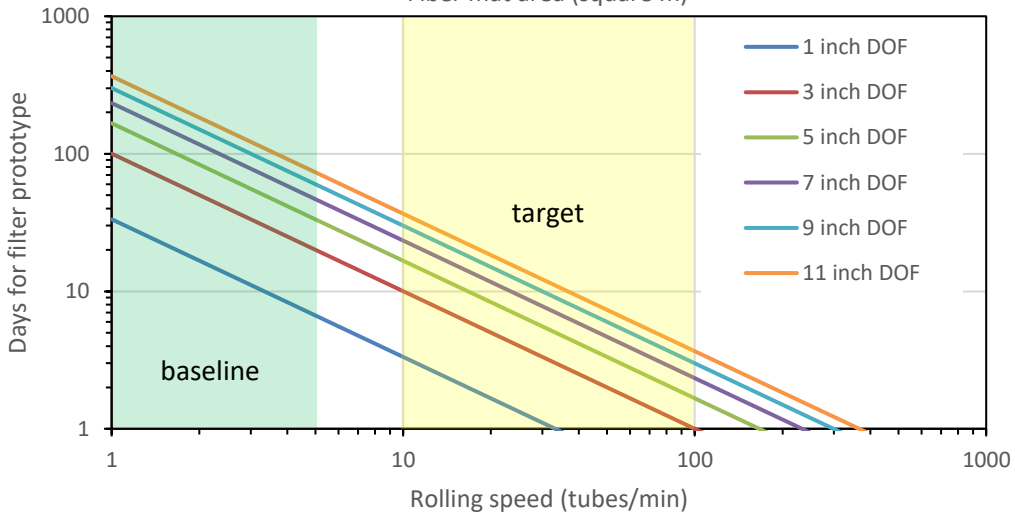




Effectively mitigated!

Post-processing





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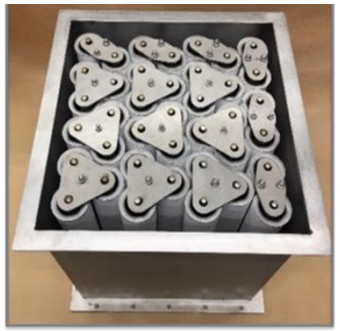
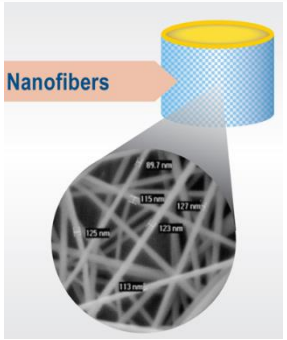
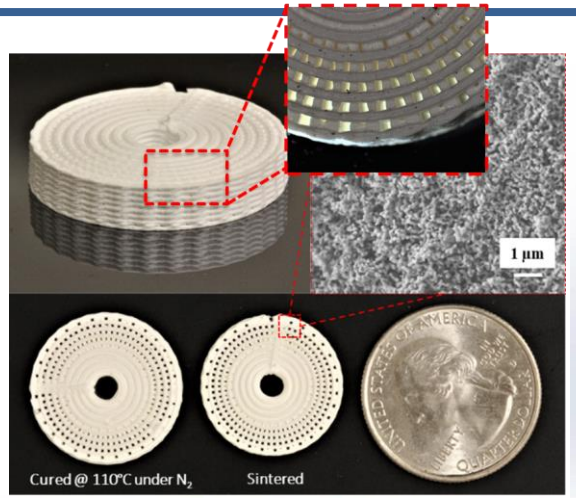
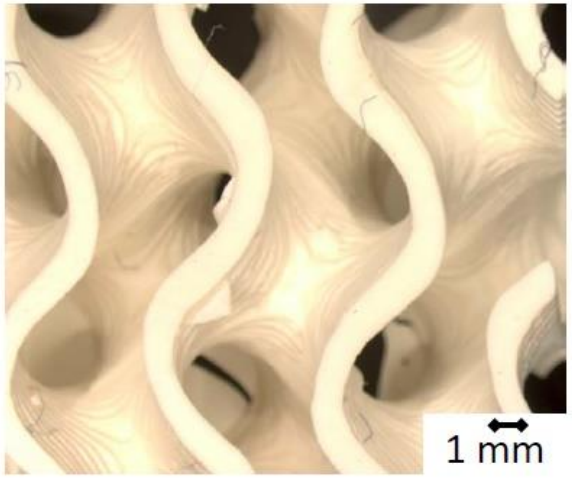
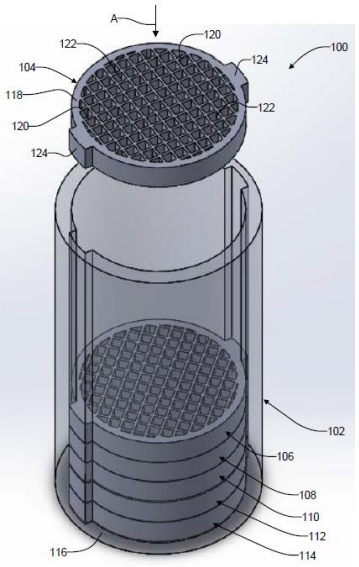


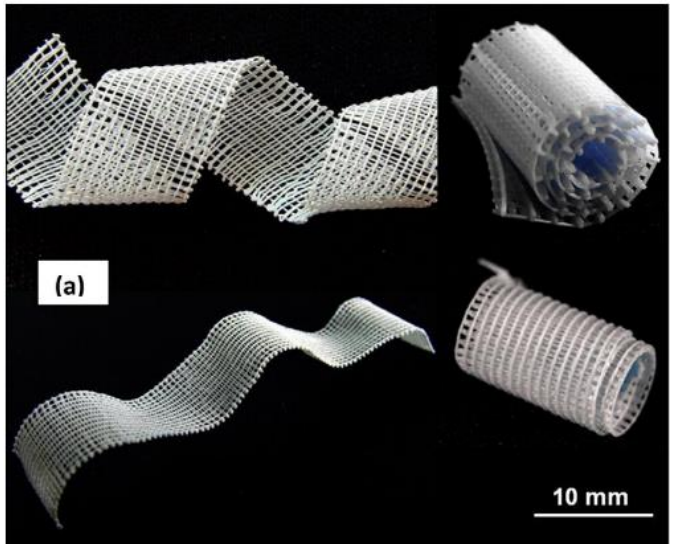


Advanced manufactured supports for fibrous filter media

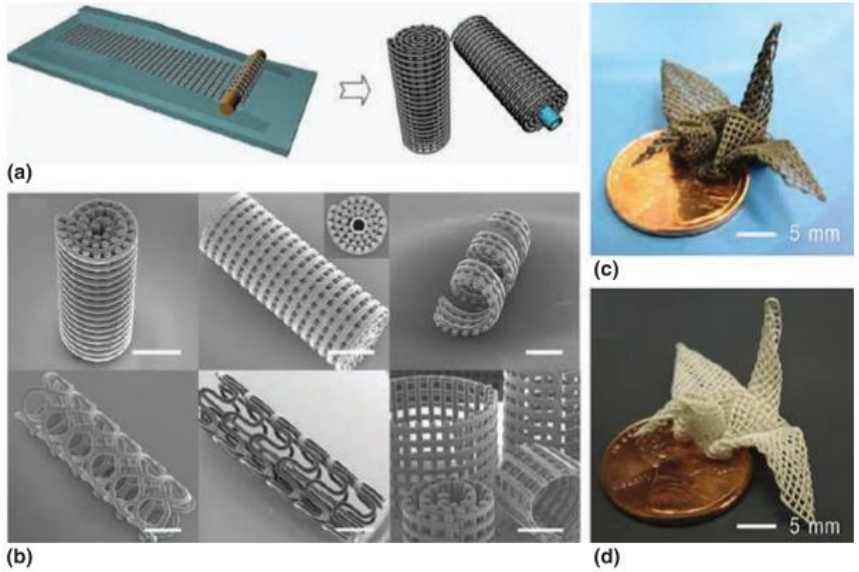




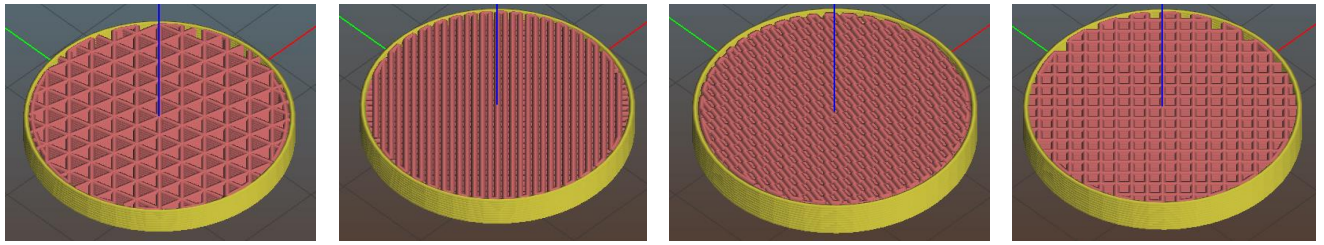


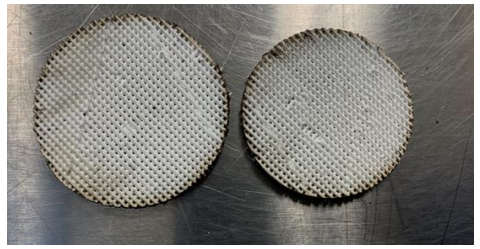


Y. de Hazan, M. Thänert, M. Trunec, J. Misak, Robotic deposition of 3d nanocomposite and ceramic fiber architectures via UV curable colloidal inks, J. Eur. Ceram. Soc. 32 (2012) 1187–1198..



B.Y. Ahn, D. Shoji, C.J. Hansen, E. Hong, D.C. Dunand, J.A. Lewis, Printed origami structures, Adv. Mater. 22 (2010) 2251–2254.





Nanoporous microstructures were found to lack MTC filtration efficacy, but enable new fiber support concepts

NSR&D and the Student/Intern Pipeline

- College students conduct hands-on research to minimize consequences of nuclear facility accidents
- Gain experience with nuclear facilities and relevant topics
- Students: Daniel Freeman, Leo Taranta Slack, Samuel Lee, Hunter Brooks, Delaney Fitzsimmons, Brian Deemer, Nick Brodine, Josh Clemons, Christina Santa Lucia, Jamie Maguire, Michael Ross, Brandon Bogle, Wesley Russell, Seth Thompson, Alejandro Urdaneta-Carrera, Hannah Eshelman, Jenna Ynzunza

Brian Deemer (SBD safety analyst), Michael Ross (NSR&D), Delaney Fitzsimmons (former Superblock system engineer), and their teammates with Dr. James Kelly

Amanda Olla (NSR&D, gaskets)

Andrew Wood (SBD safety analyst), Juan Nagengast (Superblock system engineer), and teammate