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Filter Aerosol Measurements for ARM

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ARM

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Abstract Particle Soot Absorption Photometers

The goal of this study was to determine the best filter media for use in Atmospheric Radiation Measurement (ARM) particle soot absorption photometers (PSAPs) following the manufacturer discontinuation of the current filter media. The study comprised multiple experiments to assess four potential replacement filter medium relative to the Pallflex E-70, which is being discontinued, and is documented in ARM's ServiceNow system under ENG0003846. The experiments laid out in the document '180504 Filter Aerosol Measurements for ARM.docx' and several subsequent tests suggest that the Pallflex Emfab media is the best candidate for ongoing ARM filter-based absorbance measurements. Other media were ruled out based on particle capture efficiency for small particles. In tests with Nigrosin, Emfab exceeded all other media. Tests were done measuring reported absorbance for all media in PSAPs operated in parallel sampling under several conditions: ambient air, three sizes of black-dyed PSL (polystyrene latex) spheres, and Nigrosin particles. These tests indicate a different factor of reported absorbance for each media relative to the original Pallflex E70 filter. The factor for the Azumi media was consistent with unpublished work by Ogren (National Oceanic and Atmospheric Administration [NOAA]).

The tests described here were not exhaustive and were complicated by time-varying differences among the PSAPs used. However, it is concluded that they are sufficient to justify ARM switching to Emfab filter media for future ARM PSAP measurements. The remaining store of E70 will be reserved to quantitatively characterize differences between Emfab and E70 (and Azumi?) in both laboratory and field side-by-side tests as put forth in a succeeding ENG. This future work will empirically identify correction factors applicable to Emfab and quantify the uncertainty in comparing the historical E70 measurements with ongoing Emfab measurements. Comparison of PSAP measurements with an independent absolute 'reference' for aerosol absorbance, i.e., photo thermal interferometry or difference measurements of cavity attenuated phase shift extinction (CAPS) minus nephelometry scattering, would be valuable but exceed the scope of ARM Infrastructure. While the characterization of correction factors is required for maintaining and improving accuracy in future absorption measurements, it was beyond the scope of the current study.

Acronyms and Abbreviations

AAE	absorbing Angstrom exponent
AMSG	Aerosol Measurement Science Group
AOS	aerosol observing system
ARM	Atmospheric Radiation Measurement
BMI	Brechtel Manufacturing, Inc.
BNL	Brookhaven National Laboratory
CAPS	cavity attenuated phase shift
CPC	condensation particle counter
DI	deionized
DOE	U.S. Department of Energy
ENG	engineering change request
HEPA	high-efficiency particulate air
LED	light-emitting diode
LPM	liters per minute
NOAA	National Oceanic and Atmospheric Administration
PASS	photoacoustic soot spectrometer
PC	personal computer
PNNL	Pacific Northwest National Laboratory
PSAP	particle soot absorption photometer
PSL	polystyrene latex
PTI	photo thermal interferometer
RH	relative humidity
rgb	red, green, and blue
ROM	read-only memory
SGP	Southern Great Plains
SLPM	standard liter per minute
SMPS	scanning mobility particle sizer
S/N	signal-to-noise ratio
SP2	single-particle soot photometer
SSA	single-scattering albedo
TAP	tricolor absorption photometer
UHSAS	ultra-high-sensitivity aerosol spectrometer
VAP	value-added product

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1.0 Personnel and Roles

The description of roles given below are very approximate. Contributions to this experiment came from all participants (U.S. Department of Energy [DOE] employees unless otherwise noted).

1.1 Experimenters/Analysis

S.R. Springston – Principal Investigator

C. Flynn – Aerosol Translator, Instrument loan, provided E70 filters

A. Sedlacek III – Operation of cavity attenuated phase shift (CAPS) and photo thermal interferometer (PTI), wavelength calibration, aerosol generation

S. Smith – Experimental setup

J. Uin – Operation of ultra-high-sensitivity aerosol spectrometer (UHSAS), nephelometer

C. Salwen – Acquisition software, networking

E. Lewis – Experimental design, advice, modeling

Pedro Leon – Summer intern at Brookhaven National Laboratory (BNL), logistics, instrument preparation

Jake Lindberg – tricolor absorption spectrometer (TAP)

1.2 Advice, Planning, Support

Bill Behrens – Network support

L. Bowerman – BNL Safety Coordinator (X4265)

Pat Sheridan (NOAA) – Instrument loan, provided Azumi filters

Fred Brechtel (Brechtel Manufacturing, Inc. [BMI]) – discussions

Tim Onasch (Aerodyne Research, Inc.) – Discussions/planning, provided Whatman GF-10 filters

2.0 Background

The PSAP and the TAP are fundamentally similar. Both draw air through a sample filter, resulting in deposition of aerosol on its surface. A light source on one side of the filter and detector on the other measure light transmittance over time. The transmittance is normalized to a second blank filter, in series with the sample filter, through which clean air is drawn. The first derivative of the normalized transmittance is used along with area and flow to calculate the light attenuation (in Mm^-1). Going from attenuation to absorbance is subject to much research and varying stratagems involving correction factors for filter loading, multiple absorbance in the filter media, and scattering. The principle correction stratagems are Bond et al. (1999) and Virkkula et al. (2005). ARM provides absorbance data sets calculated using each stratagem for distribution via the ARM Data Center (c1 datastreams).

The PSAP has been operated by ARM (and many others in the global community) for almost 25 years with the same filter media, Pallflex E70-2075W, which is composed of quartz fibers on a cellulose backing. All published corrections factors were developed and measured using the Pallflex E70 media. However, Pall has ceased production of the E70-2075W material. ARM has about a one-year supply remaining for the PSAP and significantly less for the TAP, which uses multiple filters. The makers of the TAP, BMI, ship their instrument with a different medium made by Azumi, but do not explicitly report the correction parameters or even the correction stratagem.

ARM will be forced to switch filter media within the next six months. Over a longer period, ARM will also be forced to replace the existing PSAPs due end of product life. The TAP is the proposed candidate (as detailed in ENG0001134). To provide continuity of measurements over these switches, it is necessary to characterize the correction factors for all candidate media and both instruments such that future measurements can be compared to historic measurements within a known uncertainty. It is beyond the scope of ARM Infrastructure to comprehensively develop a new correction stratagem. This experiment was limited to the selection of a new filter media, not to the migration to TAP. However, the filter results should be applicable to both the PSAP and the TAP.

3.0 Experiments

The ARM PSAP Filter Media Comparison (ENG0003846) discussed here compares the discontinued Pallflex E70 filter media with a number of other, currently available, filter types, with the defined goal of selecting a replacement media. This experiment is related to ENG0001134, which describes the replacement of the PSAP with the TAP, but it is limited to the filter continuity issue. Given the anticipated exhaustion of existing E70 filter stores, the goal of this experiment is to select the best replacement filter from these candidates. Once this is identified, another study will be required to comprehensively evaluate the replacement.

3.1 Filter Media

After discussions between the ARM Aerosol Measurement Science Group (AMSG) and other participants at the last ARM/ASP Science Team Meeting, several candidate filter media were identified (Table 1).

Table 1. Candidate media filter specifications along with the original Pallflex E70.

Filter	Pallflex E70-2075W	Pallflex Emfab	Savillex 5-6 µm Teflon membrane filters	Whatman GF10	Azumi 371M
Deployments	Original PSAP 20+y history ARM to date	Alternative	Alternative	Used in the TEI MAAP (discontinued)	NOAA CLAP BMI TAP
Composition	Borosilicate glass fibers over cellulose fiber backing	Borosilicate microfibers reinforced with woven glass cloth and bonded with PTFE	PTFE (Teflon) fibrous material	Glass (borosilicate) microfiber filters with organic binder to provide mechanical stability	spun-bonded nonwoven fabric 41% glass, 59% polyethylene terephthalate polymerized polyester fibers (<1% “polymerized fluorine”
Thickness (measured/ spec)*	173/76 µm	117/178 µm	100/90 µm	178/350 µm	208/310 µm
Permeability	Infer about 80 L/min/cm^2	68 L/min/cm^2 @ 0.7 bar	Infer 68 L/min/cm^2 @ 0.7 bar	Unclear but used in MAAP	
Efficiency	Not provided by vendor	99.9% 0.3 µm	Not provided by vendor	Not provided by vendor	Not provided by vendor

*Thickness measurements were done with a micrometer tightened to the ratchet torque. This may have distorted the results because of crushing.

Filter source:

- 10-mm Pallflex E70 filters (~300+) were already at BNL. Connor Flynn provided at least 300 more.
- BNL has 47-mm Savillex 5-6 µm Teflon filters and a 10-mm punch. ~200 10-mm blanks were manually punched.
- BNL has 47-mm Pallflex Emfab filters and a 10-mm punch. ~200 10-mm blanks were manually punched.
- Aerodyne/Tim Onasch donated a spool of GF10 filter tape from the MAAP. ~200 10-mm blanks were manually punched.
- NOAA/Allison McComiskey/Pat Sheridan donated ~100(?) 47-mm Azumi filters. ~200 10-mm blanks were manually punched.

3.2 Instruments

3.2.1 PSAPs

Six PSAPs were used throughout this experiment (Table 2). Rather than randomize filters with PSAPs, a decision was made to always use the same PSAP for each media except for initial tests using identical filters in all PSAPs.

Table 2. PSAP origin and assigned filter media.

PSAP S/N	Origin	Assigned Filter Media
046	NOAA/Sheridan	Azumi 371M
077	PNNL/Flynn	Pallflex E70
090	NOAA/Sheridan	Pallflex Emfab
092	NOAA/Sheridan	Savillex 5-µm
107	NOAA/Sheridan	Whatman GF10
110	ARM/AOS02	Pallflex E70

Upon receipt, all PSAPs were visually inspected. Inlet heaters were disconnected. Static leak tests were performed and where necessary, seals were replaced. The internal read-only memory (ROM) was upgraded to V2.03 to allow recording of raw intensities. Internal mass flowmeters were calibrated against the same Defender dry gas calibrator. ‘Spot size’ was measured to the nearest 0.0005” by using machinist gauges in the filter holder. Note that this value may differ from the deposited spot size on the filter. Aperture size is easier to measure precisely and it was felt that this was better than the physically more relevant spot size. The emission spectra of the three light-emitting diodes (LEDs) were measured and recorded using an Ocean Optics spectrometer with a fiber-optic probe. Upon use, the detector gain was adjusted per the PSAP manual to give 200,000 counts for clean filters (if possible). All data were recorded digitally through the RS-232 com port using a software interface written for the ARM aerosol observing systems (AOS).

Note: The PSAPs used varied in age and history of operation. Several experienced intermittent noise during the experiment. In most cases, this appeared to be a problem with the connection to the photo diode detector. Cleaning and remaking the connection improved the signal and reduced, but did not eliminate, the noisy periods. Qualifying tests were done sampling identical air with the same filter. These differences in PSAPs and the random noise changes made systematic tests difficult and interpretation of results challenging.

Connor Flynn processed the data from the raw data files using the measured spot size (aperture) and calibrated flow rates.

3.2.2 Other Instruments

In support of the PSAP measurements, data was taken simultaneously from an ARM 3-wavelength nephelometer, an ARM 3-wavelength CAPS monitor (for most measurements) and two Brechtel TAP instruments (Tom Butcher and operated by Jake Lindberg, BNL). All data except the TAP were recorded using data collection routines from the ARM AOS systems. All data, including those from the TAP, were uploaded to the ARM ftp site. At the end of the experiment, some particle penetration/capture experiments were done with a BNL single-particle soot photometer (SP2; Sedlacek, BNL).

Originally, the experimental design called for using a condensation particle counter (CPC) to measure particle concentrations. During planning, it was pointed out that the surfactant in polystyrene latex (PSL) sphere suspensions would overwhelm the particle counts reported. The use of UHSAS was also planned, but the ARM UHSAS available failed immediately prior to the experiment. A scanning mobility particle sizer (SMPS) could also have been used to separate PSL spheres from surfactant aerosol; however, separating the flow stream of 20+ LPM needed for all instruments was problematic. The original experimental design also discussed the possibility of using the BNL photo thermal interferometer to provide an independent measure of aerosol absorbance, but due to conflicting field campaign obligations, this was not possible. Several ARM photoacoustic soot spectrometer (PASS-3) instruments that had previously been ‘sunsetted’ were available as well for independent measures of aerosol absorbance, but due to their operational history and questionable status, these were not used.

3.3 Test Samples

- Ambient aerosol was sampled from outside air at BNL and diluted ~50% with high-efficiency particulate air (HEPA)-filtered dry air.
- Aerosol was generated using sample standards diluted in deionized (DI) water, aspirated through an aerosol nebulizer and diluted to 20-30 LPM with HEPA-filtered dry air.
- Monodisperse Pure Scattering Aerosol –
  - Thermo Scientific Cat#3200A polystyrene 200 nm
  - Thermo Scientific Cat#3500A polystyrene 500 nm
  - Thermo Scientific Cat#4010A polystyrene 1000 nm
- Monodisperse Absorbing Aerosol –
  - Polysciences Cat#24290 polybead polystyrene black dyed 200 nm
  - Polysciences Cat#24291 polybead polystyrene black dyed 500 nm
  - Polysciences Cat#24287 polybead polystyrene black dyed 1000 nm
- Polydisperse Absorbing Aerosol – Nigrosin (Aldrich Cat #198285)
- Aggregate Absorbing Aerosol – Fullerene Soot (Alfa Aesar Cat #40971, Lot# L20W054).

3.4 Laboratory Setup

Experiments were conducted in room 1-25, building 815 of BNL. Sampling of aerosolized PSL, Nigrosin and Fullerene soot were done with the configuration in Figure 1. All PSAPs were configured to have identical sample line lengths.

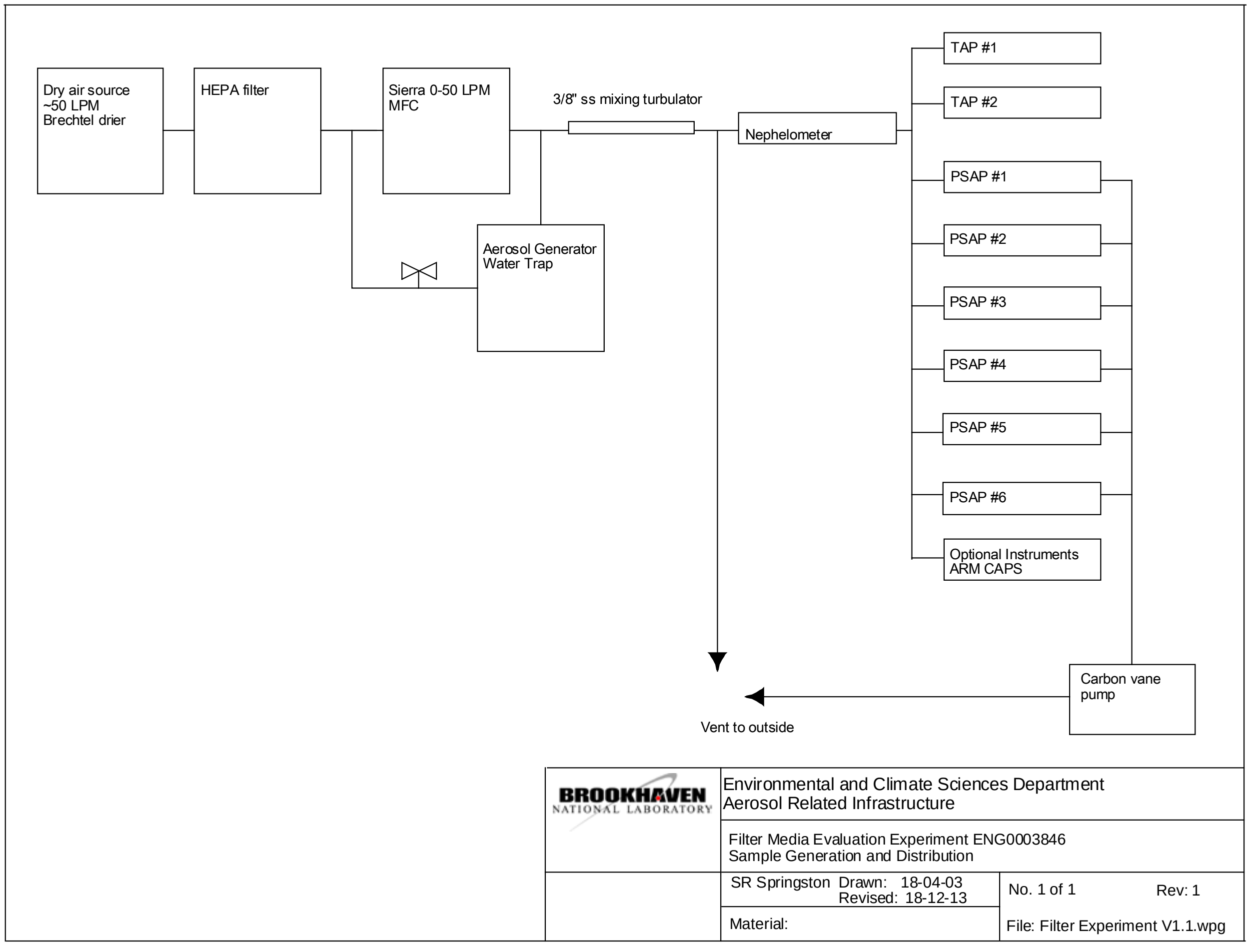


Figure 1. System configuration for the sampling of aerosolized PSL, Nigrosin, and Fullerene soot.

3.5 Experiment History

A table of experimental periods is provided in Appendix B.

3.6 Selection Criteria

The first-tier performance characteristics required for a candidate replacement filter medium defined in the original proposal are:

- Mechanical capture efficiency for aerosols
- Permeability to air flow
- Optical transparency
- Absorbance coefficients that could be related to the original E70.

These criteria were considered paramount in the experimental design. Without all four, a candidate medium would be unusable and therefore eliminated. The first three characteristics are relatively easy to assess and were accomplished in these experiments. The fourth is much more complicated to specify, let alone measure. Being able to relate future measurements with a different medium to the historical archive measured on E70 filters is paramount.

In addition, a second tier of criteria (each of which is a component of the fourth criterion above) was identified:

- Filter response as a function of analyte diameter for a model system (dyed PSL spheres)
- Filter response as a function of filter loading for a model system (dyed PSL spheres, Nigrosin)
- Filter response to a pure scatterer (undyed PSL spheres)
- Filter response for calculation of additional parameters such as the single-scattering albedo (SSA) and absorbing Angstrom exponent (AAE).

It is important to emphasize that identifying which medium gave results closest to “truth” was beyond the scope of this study and thus NOT a selection criteria.

3.7 Data and Record Keeping

During the experiments, preliminary results, plots, and presentations were shared on a Google drive:

https://drive.google.com/drive/folders/1fDfQUqmQrLEqBSPV825u7tuwy28RrE_k

A daily laboratory notebook was maintained. This was regularly scanned into pdf format and is available on the same Google drive.

Raw data from all instruments were transferred to ARM and are at:

ftp://ftp.arm.gov/pub/users/cflynn/psap_study/

4.0 Key Results

4.1 Particle Capture Efficiency

Collection efficiency is crucial to filter-based techniques. Both the PSAP and TAP use the ratio of light intensity measurements between a sample and reference filter that are plumbed in series. This allows common-mode rejection of any changes in light source, detector, and filter media changes with environment. However, particles that are not captured on the sample filter but are captured on the reference filter affect the resulting signal effectively 2X, i.e., a 95% capture efficiency would result in a diminution of the resulting signal to 90% of the correct value. Because capture efficiency is linked to particle size and the size spectrum of absorbing particles is unknown, even a well-characterized capture efficiency determined as a function of size cannot be used to correct for a capture efficiency < 100%.

The original experimental design was to monitor the raw intensity of both the sample and reference cells as aerosol was sampled, in effect using both cells as single-beam photometers. This experiment was carried out twice for ambient air, and once for 200-nm PSL spheres, and once for Nigrosin (Figure 2).

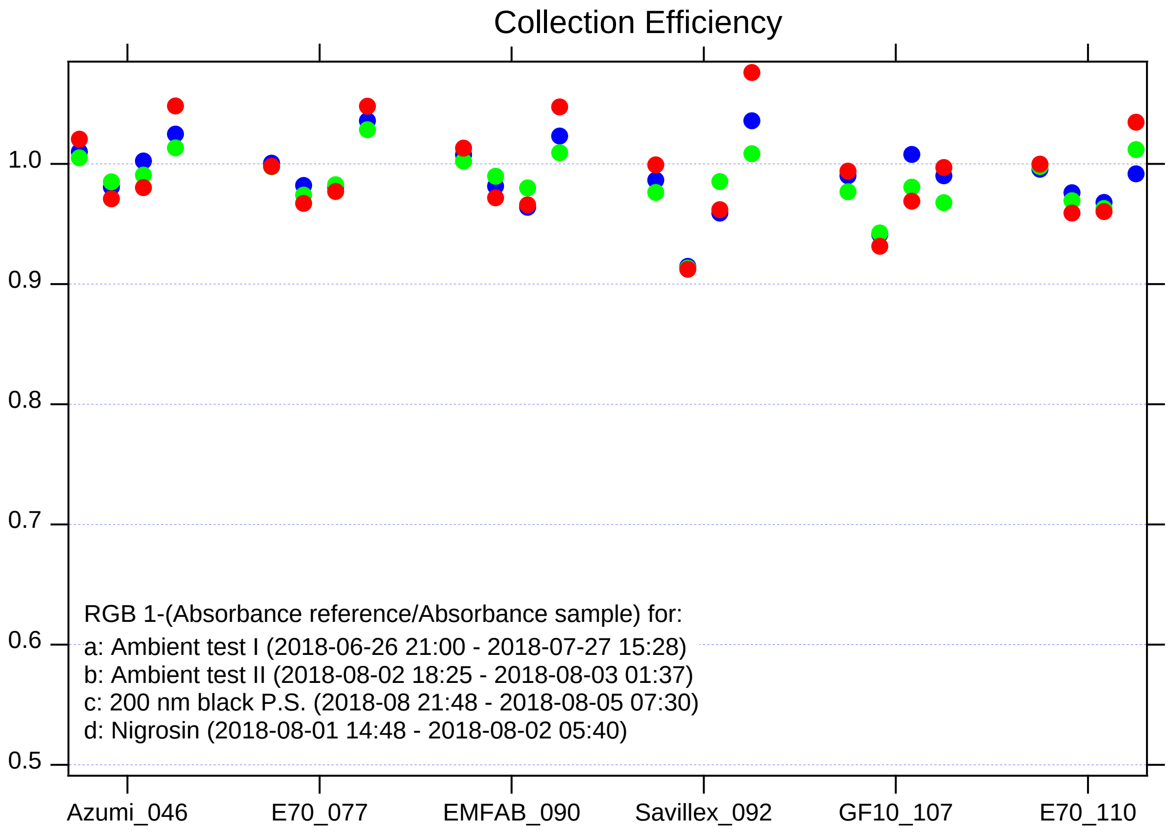


Figure 2, Particle capture efficiency results for the six filter types.

Using the PSAP as two independent single-beam photometers was problematic, as drift in the detector gave collection efficiencies > 1 almost half the time – a physically impossible situation.

A second collection efficiency experiment was performed to measure the time required to reduce transmittance from 1.0 for a new filter to 0.7 using Fullerene soot as a surrogate for small absorbing aerosol. At that time the BNL SP2, which can measure particle concentrations and size distributions downstream of the collection filter, was available. This experiment showed dramatic difference in size transmission between filters (Figure 3).

The qualitative conclusion of this was that Savillex 5-µm, Azumi, and Whatman GF10 filters passed a mode of successively smaller particles (i.e., empirically better in this order.) The low signal count for Emfab and E70 was interpreted as a high collection, efficiency approximating 1 (but at the artificially low flow rate of 120 cm^3/min.).

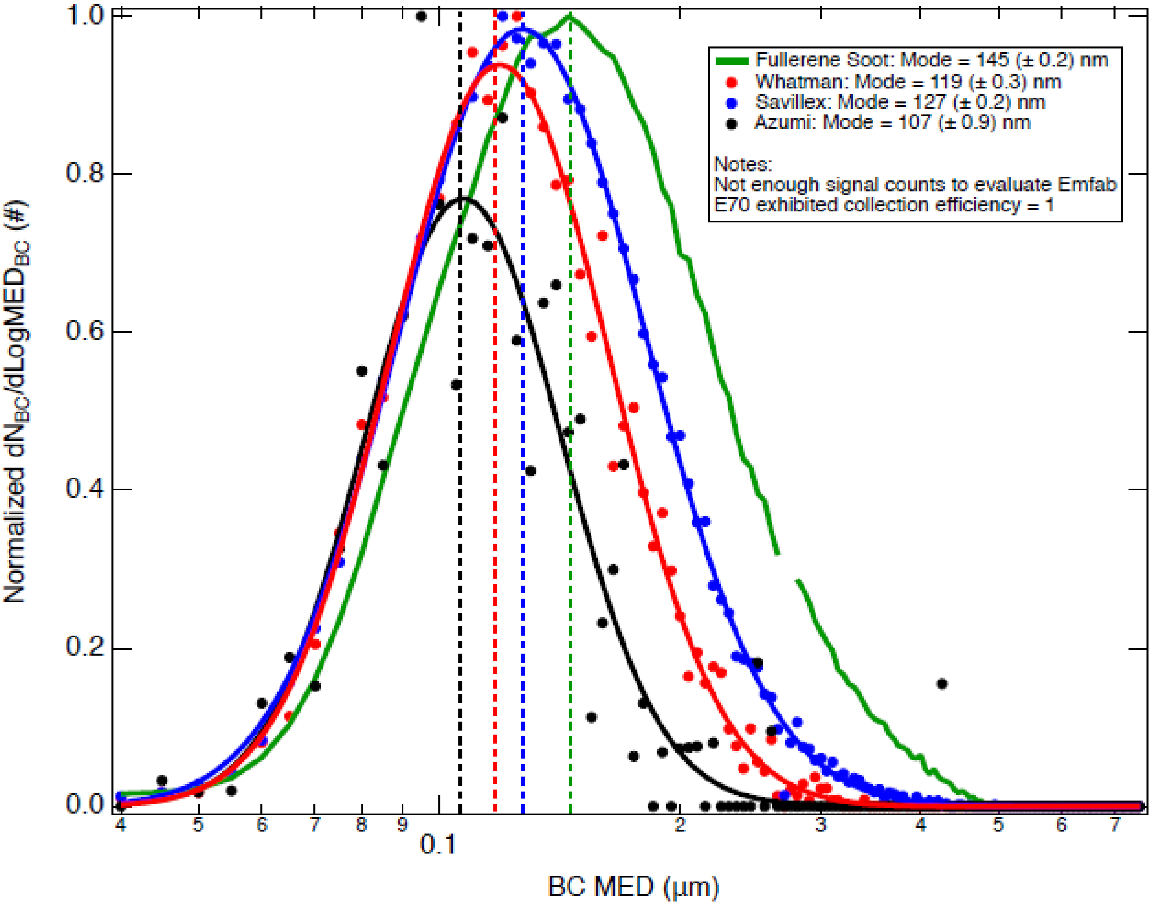


Figure 3. Size transmission results between filters.

A slightly different experiment was repeated under nominal PSAP flow conditions and using only the E70, Azumi, and Emfab media (since the Savillex and Azumi were clearly deficient). E70 passed ~0.14 particles/s, Azumi passed ~0.06 particles/s, and Emfab passed 0.02 particles/s.

Based on these results, The Whatman GF10 and Savillex media are unacceptable. Azumi and Emfab both provide substantially better collection efficiency, with Emfab better than Azumi.

4.2 Permeability

Permeability is used to refer to resistance of the media to air flow. Highly permeable media would have a low pressure drop across the filter. PSAPs are historically operated at ~1 standard liter per minute (SLPM) sample flows. The maximum allowable pressure drop is limited by volatility of samples and differential removal of adsorbed and absorbed water. Because the PSAP, TAP, and other filter instruments measure the time rate of change of loading, even minute changes in the integrated loading dominate the signal.

The permeability of the filters was measured by first setting the flow to 1 SLPM with an E70 in both the sample and reference holder and then replacing both sample and reference filters with a candidate (SN077 and SN110 were controls and the E70s were replaced on these). Without adjusting the flow valve, the new flows were recorded. A relative measure of permeability was taken as the ratio of flows after and before changing media. None of the filters was as porous as the E70 media, but all were within 25% of the E70 (Figure 4). No disqualifications were obvious from this experiment.

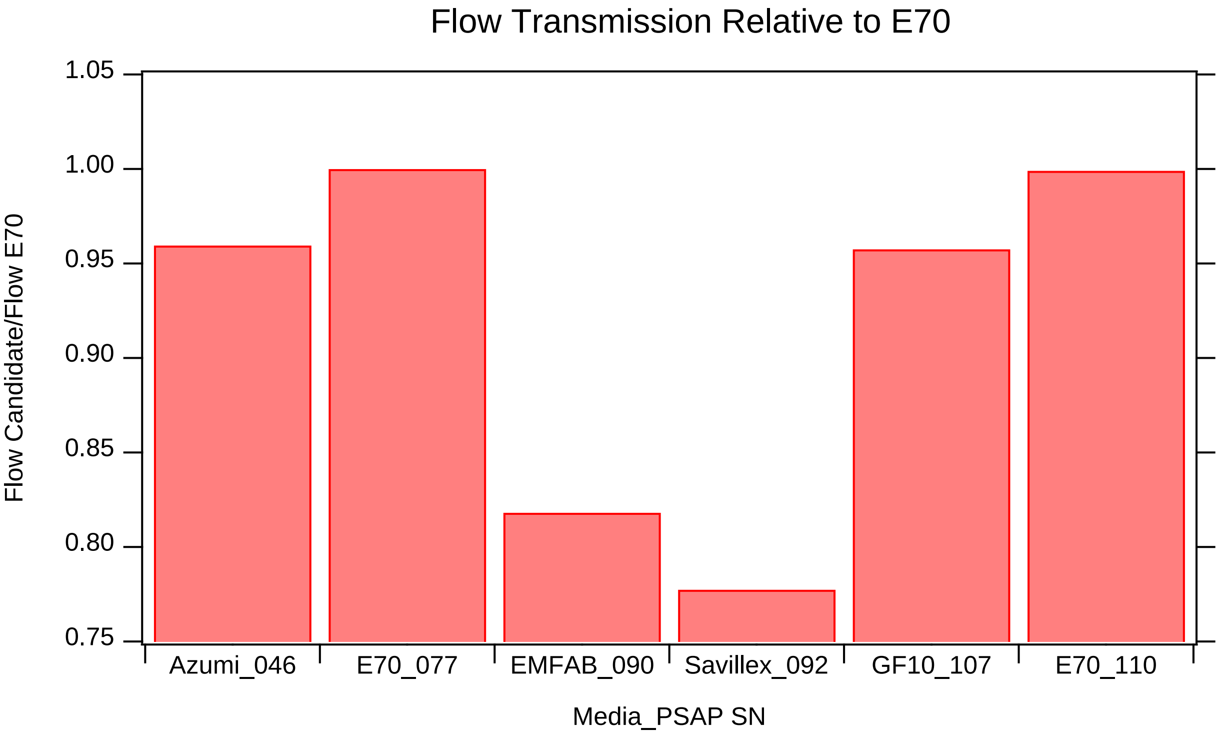


Figure 4. Flow transmission relative to the E70 filter.

4.3 Optical Transparency

To a first approximation, the signal/noise of the PSAP measurements is determined by the relative transparency of the filter; i.e., it is easier to see the small change from an incremental aerosol loading on a highly transparent filter than one that is relatively opaque.

As expected from visual observation, the Savillex is the most transparent (Figure 5). Emfab, Azumi, and Whatman GF10 are less transparent, about 40% less than the E70. The red, green, and blue (rgb) differences appear to be within the uncertainty of the measurement (less than the scatter of sample versus reference measurements) and were not judged to be significant.

These results were confirmed by looking at the signal noise when measuring zero (HEPA-filtered) air with an E70 filter, then switching to a candidate filter, readjusting the flow to 1 LPM, and adjusting the gain as described in the manual. Emfab transmitted slightly less light than Azumi as shown above, but it showed a reduction in noise over E70 while the Azumi had the same noise level. These differences in noise for all candidate filters relative to E70 were relatively small and there were no clear disqualifications.

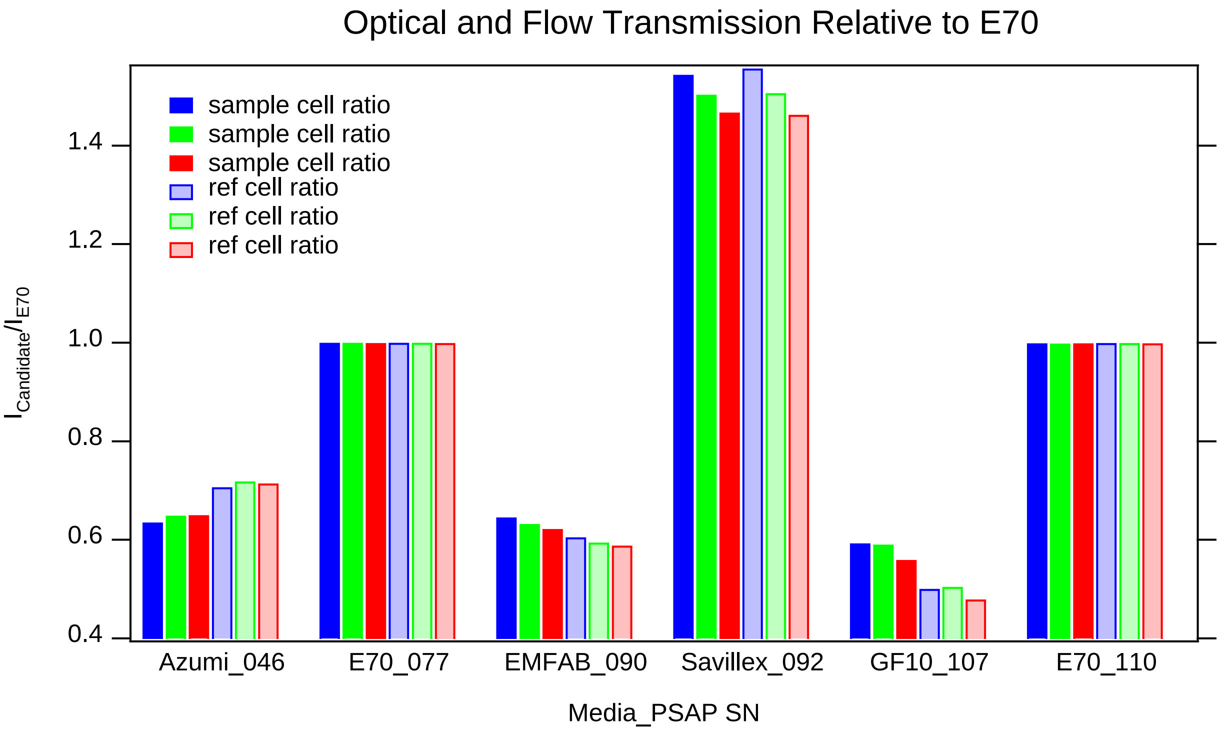


Figure 5. Optical and flow transmission relative to the E70 filter.

4.4 Performance Relative to E70

Results of PSAPs operated with assigned filters sampling ambient air (diluted 50% with dry HEPA-filtered air) showed excellent correlation. Typical results for the green absorbance from three time periods are shown below, along with the correlations with the values for E70 (Figure 6).

Note that unpublished results from Ogren showed a ratio of 1.301 for Azumi/E70 for ambient air in Boulder versus 1.327 measured at Brookhaven.

Measurements taken with three sizes of black-dyed PSL spheres, diameters 200, 500, and 1000 nm, exhibited similar trends among the different filter media, and each had a tight correlation with E70 (Figures 7 and 8). Note that the concentration changed over time, presumably due to settling of material in the aerosolizer reservoir.

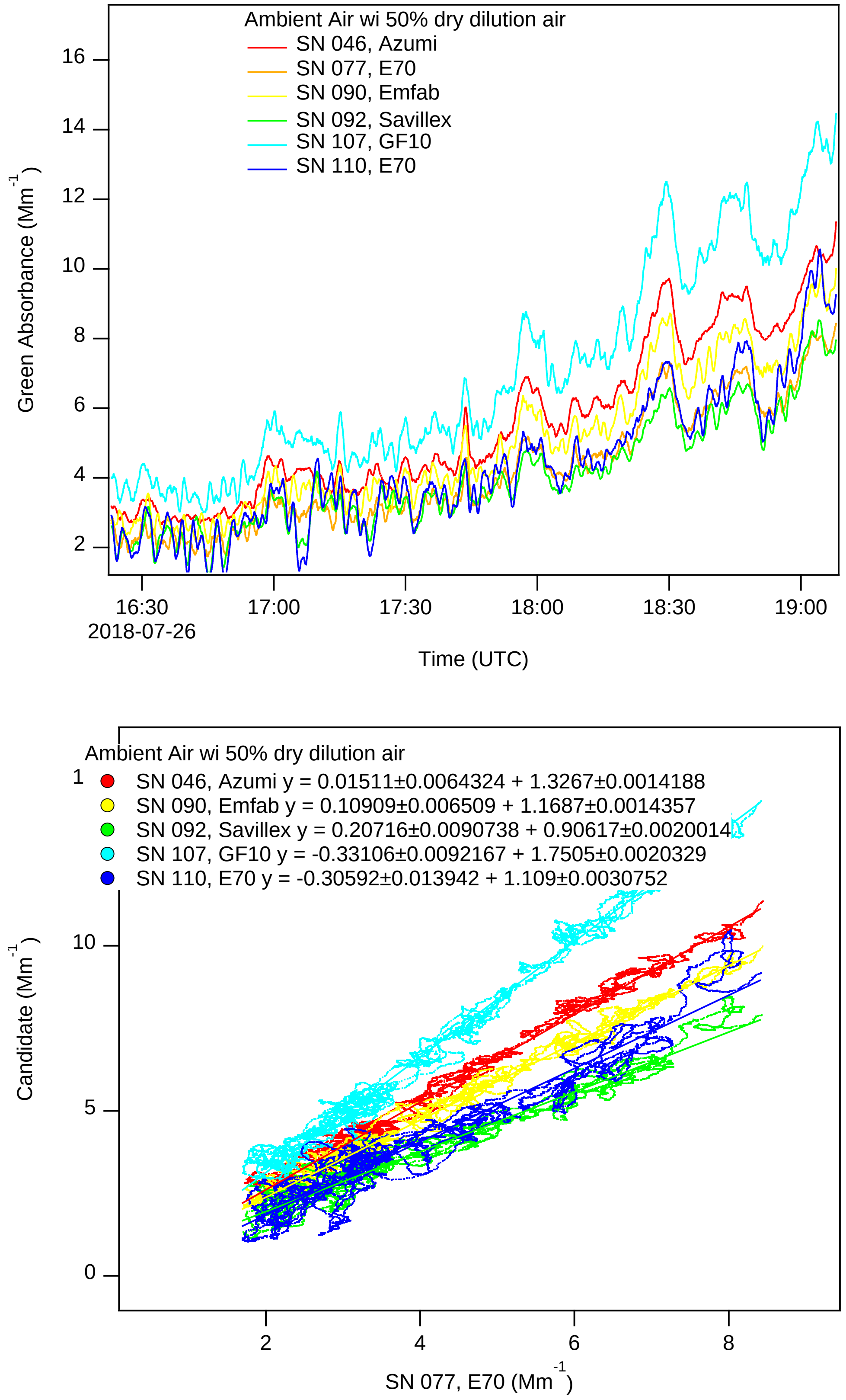


Figure 6. A) Ambient air time series and B) correlation plots for different media.

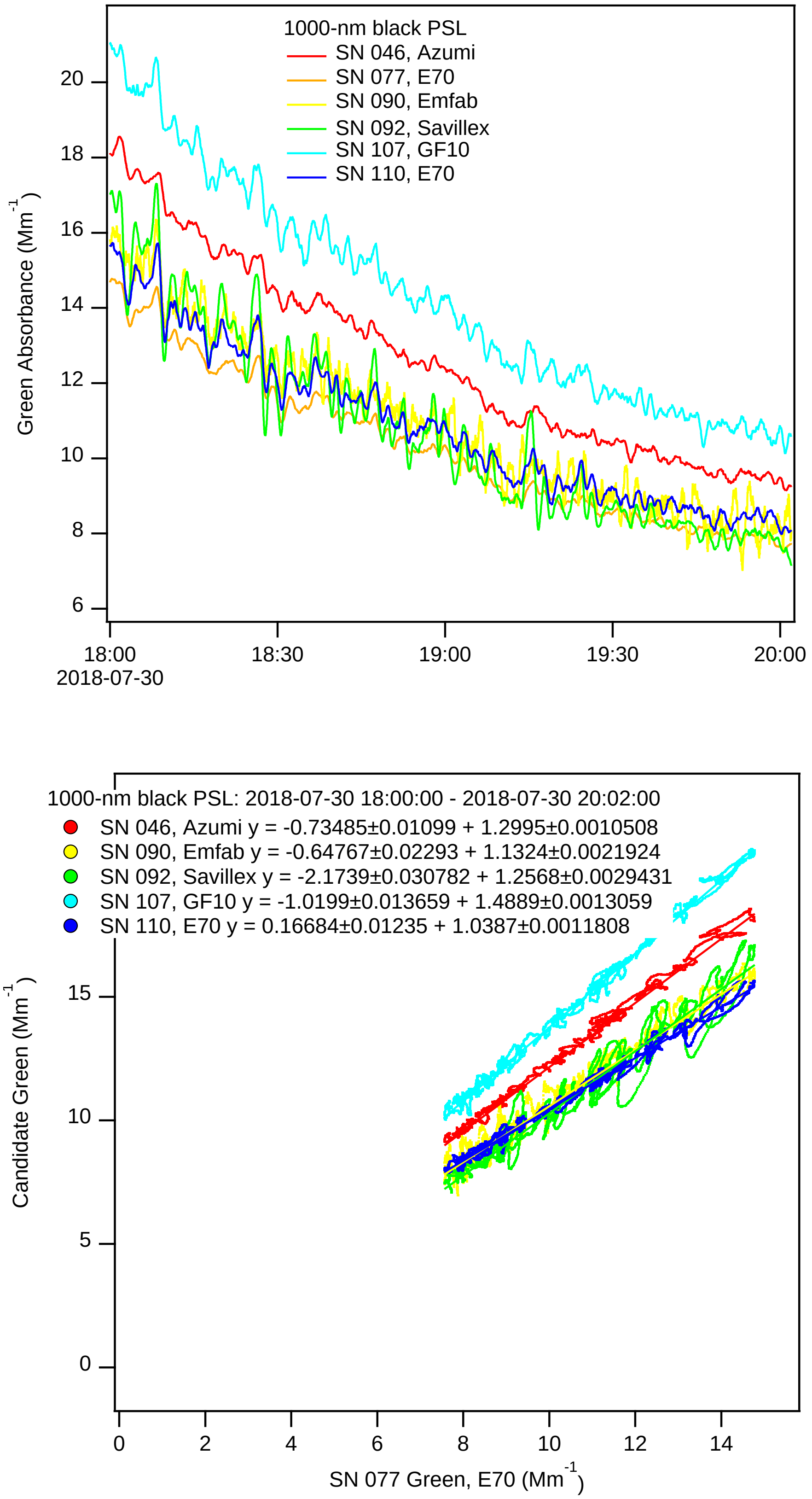


Figure 7. A) Black 1000-µm PSL time series and B) Correlation plots for different media.

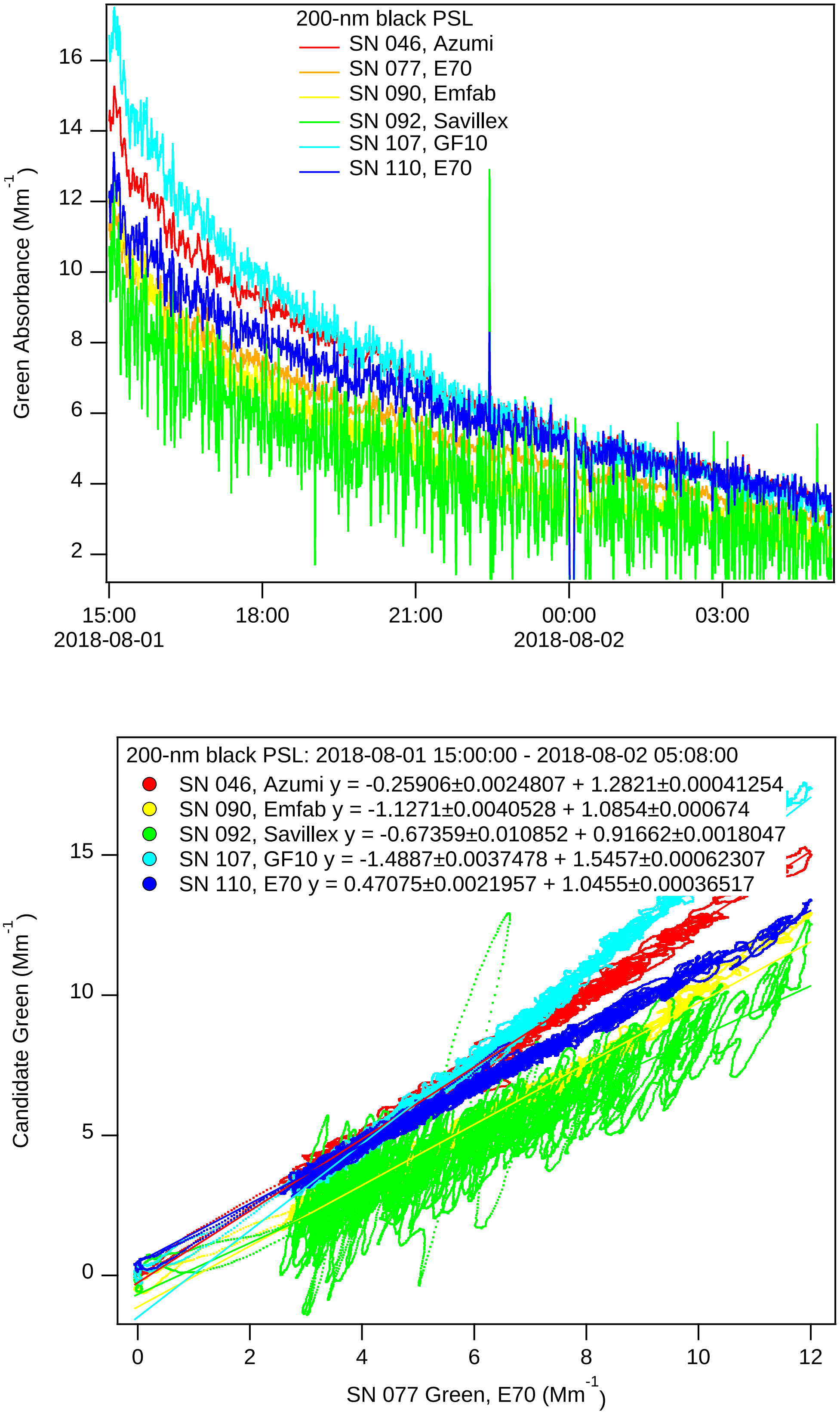


Figure 8, A) Black 200-µm PSL time series and B) Correlation plots for different media.

Correlation plots between the filters were complicated by noise shifts in instruments during the course of the experiment. Loading factors also varied but the trend and, importantly, the ratios (slopes) of each media relative to E70, were consistent.

Data here were processed with 60-s averaging and application of Weiss, Bond corrections.

4.5 Additional Experiments

The experiments described in this ENG were designed to look primarily at crucial ‘mechanical’ filter characteristics, i.e., particle capture efficiency, flow permeability, and optical transparency, poor behavior in any of which being cause for disqualification. These critical, potentially disqualifying measurements were completed and reported here. Additional experiments were designed to examine other items, i.e., correction factors based on particle size, correlations with E70 for real samples, and differences in loading factor corrections. Some experiments were successfully completed here whereas others could not be completed due to instrument failure or unavailability. For instance, the size distributions of ambient and polydisperse standards was not measured because of failure of the UHSAS. An independent determination of aerosol absorbance using the BNL photo thermal interferometer (PTI) and a supporting difference measurement of total extinction and scattering (CAPS–nephelometer) was originally considered (although not promised in the ENG design) but not fully executed because the PTI was unavailable due to prior commitments. The CAPS–nephelometer data set is available for only a limited period due to channel failures on the CAPS.

4.6 Additional Analysis

As described in the ENG, a full analysis of the planned experimental data set was beyond the scope and design of this experiment. However, the measured data set is available for additional analysis.

The results displayed and discussed above were for only the green wavelength; additional analyses with red and blue wavelengths have not been completed. Flynn and Sedlacek have looked at the absorbing Angstrom exponent (AAE) from the different filters, and single-scattering albedo (SSA) was calculated using the nephelometer measurements of scattering. Both analyses showed substantial differences between the filters. Some instrument variability contributed to these differences, but given the limited scope of the experiments it is difficult to evaluate their significance. Both AAE and SSA calculations are particularly sensitive to the correction factors (and stratagem). Whether the uncertainties for AAE and SSA value-added products (VAPs) can be reduced or even quantified is an open question.

During the permeability tests with Nigrosin, filters were loaded to beyond $Tr < 0.7$, the minimum value for which the manufacturer’s corrections apply, to study application of the Weiss transmission correction factor (incorporated in the Bond correction method). That analysis has not yet been completed.

5.0 Filter Selection for ARM

The experiments described above are sufficient to conclude that the Pallflex Emfab material is the best replacement for the Pallflex E70 media even though the experiments described above were not an exhaustive laboratory study of filter differences. This recommendation is based on:

- Particle retention by Emfab media is better than other media including the original E70
- Correlation of results closer to E70 than either GF10 or Azumi. This held for ambient samples and black PSL. Judged from a constant response ratio with the E70, it appears a single multiplicative value may be sufficient to map Emfab response onto the historical E70 data record
- Emfab optical transparency second to only Savillex and the original E70 (Savillex was eliminated due to poor particle retention)
- Emfab composition is the most similar to the original E70. Both are glass fibers on a substrate (cellulose in the original and woven glass cloth for Emfab). This was judged important, along with the common manufacturer. Undoubtedly the nature of the fiber material relates to performance and the physical deposition of aerosol as well as optical properties
- Mechanical stability of the Emfab appeared good. The measured thickness was thinner than all filters except for the Savillex. No deformation was noted as has been suspected in E70s. This is important in airborne operation during altitude changes when deformation may cause appreciable shifts in signal, and
- Permeability of Emfab is within 20% of the original E70. This was the worst of the candidates except for Savillex, but was within what was considered acceptable.

No tests were done to isolate effects of humidity on performance. The E70 filters have a strong RH dependence and the temperature dependence is thought to be related to water adsorbing/desorbing from the cellulose backing. The effect of humidity is a major complication for the PSAP. Mitigating strategies include heating the block (NOAA) and Nafion drying of the sample (ARM AOS). Neither are ideal as heating affects volatile components and drying imposes additional tabulation with the potential for sample losses. The woven glass backing of the Emfab would be expected to be less affected by RH in the airstream. The hydrophobicity of the PTFE Savillex filters might be advantageous, but the poor particle retention eliminated Savillex as a candidate. The Whatman GF10 consists of microfibers bound with an unspecified organic binder with unknown hydrophobicity. Azumi is 41% glass co-spun with polyethylene terephthalate polymerized polyester fibers.

5.1 Future Path

As described above, one filter (Emfab) appears the best candidate for succeeding the Pallflex E70. While Emfab performs well under limited ambient and model conditions, additional laboratory and field tests are required to characterize its performance relative to E70 (characterization versus a ‘true’ absorbance measure is beyond the scope of this next step).

5.2 ARM Approval of Selection and Closeout of ENG0003846

The Watchlist and Approval List members of ENG0003846 (and the AMSG) will review the results described here. If a consensus to adopt the Emfab filter is achieved, ARM should switch media in an ordered fashion and preserve remaining stores of E70s both for ongoing characterization and for future comparisons. It is proposed that the switch out be done at the next ARM field campaign (AFC) for mobile facilities and at the end of a quarter for fixed sites.

5.3 Ambient Tests at SGP: Emfab versus E70 (versus Azumi)

It is proposed that a second PSAP be added to the Southern Great Plains (SGP) AOS to measure ambient aerosols for ~1 year using a rotating schedule of the two filters (E70 and Emfab) between the two PSAPs to quantitatively assess systematic differences between the two filter media over a wide temporal span of conditions separate from any systematic differences in the PSAPs. SGP has relatively light aerosol loadings, but it does have supporting instrumentation necessary to tease out fundamental differences based on aerosol size, loading, and composition. SGP can also easily accommodate guest instrumentation such as a reference absorbance measure (PTI). Inclusion of the Azumi filter in these tests may be considered as NOAA is using this media in their instruments.

5.4 Laboratory Tests: Emfab versus E70 (versus Azumi)

Laboratory experiments using generated standards are also recommended. Within a laboratory setting one can conduct controlled loading experiments, compare filters using size-selected particles, and assess the scattering artifact on the PSAP signal.

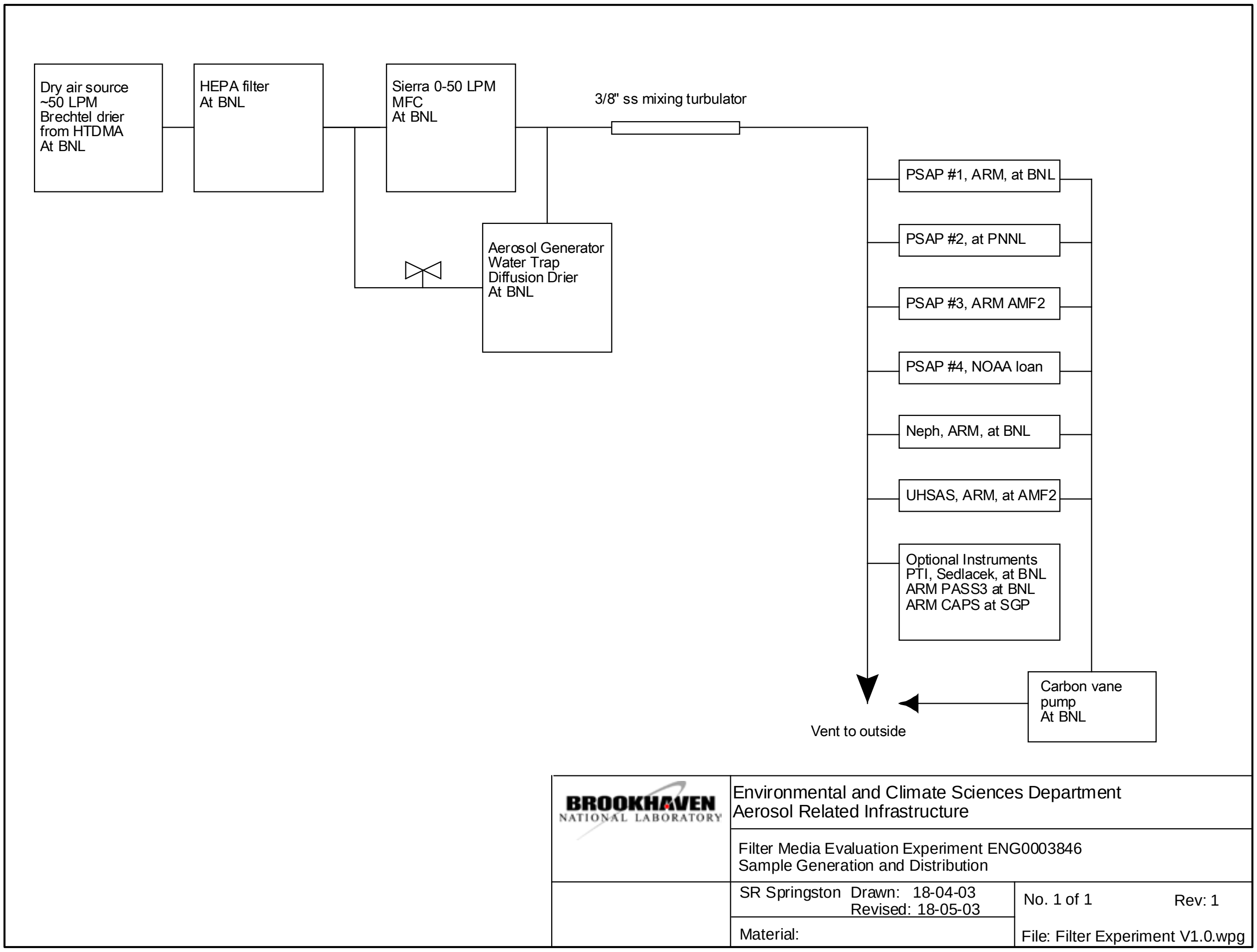
5.5 Next Step ENG

With the completion of this preliminary experiment (ENG0003846), a new ENG will be proposed for this future work.

Appendix A

Laboratory Experiment

The following arrangement is proposed to simultaneously measure laboratory-generated aerosols under controlled conditions:



With this design, it is important that there is enough sample to see a significant signal. Ernie Lewis has performed a simple calculation to determine how much dyed PSL is necessary to reduce the transmission in a PSAP from 1.0 to 0.5 given a total manifold flow of 20 LPM. His calculation indicated about 16 mm^3 (16 µL) of 2.7% P.S. would meet this condition. For 0.4 µm-diameter polystyrene spheres aspirated into 20 LPM for 30 minutes, this translates to 21,000 cm^{-3} — not an unreasonable value. However, it is desirable to test this result experimentally before the experiment commences.

A.1 Data Plan

The Tier One instruments (PSAPs, nephelometer, and CPC) are all ARM baseline instruments that have existing National Instruments Vis written at BNL. These acquire raw data from the instruments and operate from a single PC (6 serial ports required). Hardware and software are available at BNL.

The Tier Two supplemental instruments vary in data requirements. The PTI would be a PI-operated instrument with its own datastream. The PASS-3, CAPS, and UHSAS all have ARM raw datastreams for acquiring raw data on a PC.

All raw data would be submitted to ARM, presumably using the Online Metadata Editor, as external data sets.

A.2 Data Processing

Tier One instruments would require some level of mentor processing to get final form data. In-house processing routines are available for Tier One instruments.

A.3 Data Analysis

Correlation plots of new filters to the original Pallflex E70 filters will be made. This may be sufficient to answer the questions of filter differences and successor selection, but it is doubtful the answer will be so simple.

A.4 Resources Required

Most if not all instruments are in hand or readily available without compromising existing ARM activities. BNL will have several summer students who can work under direct supervision of instrument mentors. Cindy Salwen is available to set up the data acquisition computer and instrument interfaces. Scott Smith is available to set up the air drier, aerosol generator, and sample manifold. BNL has two laboratory facilities where bench space is available and outside access to vent the exhaust. Labor to supervise is expected from instrument mentors (Sedlacek and Springston). The aerosol translator, Connor Flynn, has expressed interest in participating. Since the actual laboratory experiments are well constrained, we expect roughly 2-3 weeks of set up and 2-3 weeks of mentor/technician-supervised operation by summer students. Post-experiment processing to engineering data sets should require an additional 1-2 weeks. This level of effort is somewhat beyond the scope of existing mentor support by ARM. But at this time, we expect to perform the experiment without additional support beyond existing mentor funding.

A.5 Filter Selection Criteria for ARM

After conducting experiments, what are the criteria for selecting a new filter media? Conversely what are the best experiments to judge these criteria? Seven criteria are listed below along with which experiments measure these criteria. Following the experiment, each candidate filter should be ranked as to meeting each criterion. Final selection may or may not be obvious if there is not a clear winner or if all candidates fare unacceptably.

A.5.1 Criterion 1 – Porosity

Any candidate filter must be able to pass ~1 LPM with available pressure drop (absolute pressure of vacuum is ~0.5 - 0.7 atm but this vacuum is throttled down in the PSAP and is usually about 0.1 atm across the filter). Excessive pressure drop could lead to volatilization of deposited aerosols. Setting the PSAP flow to 1 LPM with a Pall filter and then measuring the flow through a candidate under identical conditions is a relative indication of air porosity. All four candidate filters appear to meet this standard in cursory tests.

A.5.2 Criterion 2 – Particle Collection Efficiency

Any candidate filter must collect absorbing and scattering aerosol with nearly unit efficiency. The particle collection efficiency must be >99%. A measure of PCE can be done with a candidate filter in a PSAP. As the sample filter is run from Tr = 1.0 to Tr =0.7, the reference filter intensity can be monitored. This should decrease by less than 0.5%. A second measure of efficiency would be to monitor upstream/downstream of the PSAP with a CPC, but this has little efficacy for isolating absorbing particles.

A.5.3 Criterion 3 – Optical Transparency

Lower transparency leads to higher noise in the resulting signal. A candidate filter must have a S/N ratio of at least 0.75 of the original Pall filters at all three wavelengths. Using the PSAP as an absorbance meter does not work since I0 would be intensity without a filter and that goes off scale. The best way in our experience is to measure the signal noise for HEPA-filtered air.

A.5.4 Criterion 4 – Uncorrected Absorbance on Candidate Relative to Pall as a Function of Particle Size

It is a given that the size distribution of absorbing aerosol is unknown. Kondo et al. have demonstrated that Bond/Weiss/Ogren correction factors change as a function of aerosol size. Ideally that change with size should be a minimum. For achieving data continuity, it is simpler and the change for a candidate filter should be the same as for Pall filters. To measure this, the nominal absorbance (without loading or correction factors) for a candidate filter is measured to the Pall filter for three different monodisperse, dyed aerosols, and Nigrosin. This experiment would be done at Tr > 0.95 to minimize any differences in the loading corrections. Ideally the ratio as a function of aerosol size should have a slope of 0 and an intercept of 1. Intercept <> 1 can be accommodated. Indeed, Ogren has done this experiment for ambient air comparing Azumi and Pall. The slope <> 0 would indicate uncorrectable differences between candidate and Pall. Low values could bound the differences but not ideally.

A.5.5 Criterion 5 – Loading Factor for 200 nm Black P.S. and Nigrosin

Loading factor corrections are an empirically measured factor to account for particles shading earlier deposits. It is calculated as a function of Tr and could well differ for filter media. I suggest measuring uncorrected absorbance ratios between a candidate and Pall filters as the transmission goes from 1 to ~0.5. Most likely the Tr will not decrease identically on the two filters. Again the slope will ideally be 0 or whatever is the minimum. An intercept of 1 would be ideal (identical with Pall) but a non-1 intercept could be accommodated.

A.5.6 Criterion 6 – Scattering Effect

PSAPs actually measure a decrease in transmission over time. This decrease is due to absorbance and scatter in a complicated fashion. Bond empirically measured a 2% correction factor for scattering in that 2% of the independently measured scattering (without truncation correction) should be subtracted from the PSAP signal. This was measured on Pall filters with a white aerosol. This fraction could be different on a candidate filter. Repeating the experiment in Criterion 4 but using white polystyrene beads of the same size while simultaneously measuring scattering with a nephelometer will show the relative differences for the candidate filters relative to Pall.

These five criteria can be measured in the laboratory using an aerosol generator, dry dilution air, a downstream nephelometer, and optionally a UHSAS.

A.5.7 Criterion 7 – Correlation in Ambient Sampling

Comparable results in ambient air between two PSAPs with different filters will be the ultimate criteria. The results from Criteria 4-6 should indicate how well results from a candidate filter can be related to the original Pall filters. But Nigrosin and polystyrene beads are only surrogates for ambient aerosols. Unpublished results from Ogren indicate highly correlated results between Pall and Azumi filters. At least a week of ambient monitoring will be attempted while the experiment is set up with multiple PSAPs. Correlation plots will be the initial analysis tool. Supplemental measurements (neph, CAPS, PTI, UHSAS) should aid in the interpretation of differences.

Following the laboratory study it is expected that one filter will be a clear candidate for succeeding the Pallflex E70. It is proposed that a second PSAP be added to the SGP AOS to measure ambient aerosols for ~1 year using a rotating schedule of the two filters between the two PSAPs to quantitatively assess systematic differences between the two filter media over a wide temporal span of conditions separate from any systematic differences in the PSAPs.

Appendix B

Experiment Schedule

TEST	Date/Time	PSAP/Filter	Red	Green	Blue
	(YYMMDD hh:mm:ss)		(Mm^{-1})	(Mm^{-1})	(Mm^{-1})
	Up to 2018-07-23 16:31 Tests and debugging of PSAPs				
1	S - 180723 16:31	046/E70			
		077/E70			
	Dry, filtered air, 15 LPM				
	Open split	090/E70			
		092/E70			
		107/E70			
	F - 180723 20:05	110/E70			
Test	S - 180723 20:13	046/E70			
		077/E70			
	Smoke test	090/E70			
		092/E70			
		107/E70			
	F - 180723 ~20:25	110/E70			
1(cont)	S - 180723 ~21:00	046/E70			

		077/E70	
	Continue Dry, filtered air, 15 LPM Open split	090/E70	
		092/E70	
		107/E70	
	F - 180724 12:40	110/E70	
T Test	S - 180724 ~12:42	046/E70	29.2C
		077/E70	29.1C
	Measure internal Ts	090/E70	29.7C
	Tamb = 22.5-23.1 C	092/E70	30.0C
		107/E70	28.1C
	F - 180724 13:15	110/E70	29.4C
2	S - 180724 13:38:00	046/E70	
		077/E70	
	Inside ambient air	090/E70	
	w/50% dry dilution air	092/E70	
	(do not use)	107/E70	
	F - 180724 17:36:00	110/E70	
3	S - 180724 17:37:00	046/E70	
		077/E70	
	Outside ambient air	090/E70	
	w/50% dry dilution air	092/E70	
	(mower @17:37)	107/E70	
	F - 180725 16:25:00	110/E70	

4 (cont.)	S - 180725 16:25:00	046/E70
		077/E70
	Smoke test (3x each smaller)	090/E70
	w/50% dry dilution air	092/E70
		107/E70
	F - 180725 16:46:00	110/E70
5	S - 180725 19:17:00	046/E70
	Set Tr=1, F=1LPM,	077/E70
	Continue Dry, filtered air, 15 LPM	
	Open split	090/E70
	measure Is for E70	092/E70
		107/E70
	F - 180725 20:35	110/E70
5	S - 180725 20:35	046/Azumi
		077/E70
	Continue Dry, filtered air, 15 LPM	
	Open split	090/Emfab
	measure F, Is for E70,cand.	092/Savillex
	then adj gains	107/Whatman
	F - 180725 21:15	110/E70
5 (cont.)	S - 180725 21:15	046/Azumi
		077/E70
	Continue Dry, filtered air, 15 LPM	
	Open split	090/Emfab

		092/Savillex
		107/Whatman
	F - 180726 13:09	110/E70
6	S - 180726 13:21	046/Azumi
		077/E70
	Outside ambient	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180726 20:30	110/E70
6 (cont)	S - 180726 20:38	046/Azumi
		077/E70
	Smoke test	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180727 15:35	110/E70
7	S - 180730 15:13:00	046/Azumi
		077/E70
	200nm black PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180726 16:56:00	110/E70
8	S - 180730 17:46:00	046/Azumi
		077/E70
	1000nm black PSL	090/Emfab

	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180730 20:05:00	110/E70
9	S - 180731 12:44:00	046/Azumi
		077/E70
	1000nm black PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 13:16:00	110/E70
10	S - 180731 13:47:00	046/Azumi
		077/E70
	500nm black PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 14:19:00	110/E70
11	S - 180731 14:53:00	046/Azumi
		077/E70
	200nm black PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 15:51:00	110/E70
12	S - 180731 17:50:00	046/Azumi
		077/E70
	200nm white PSL	090/Emfab

	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 18:20:00	110/E70
13	S - 180731 18:52:00	046/Azumi
		077/E70
	500nm white PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 19:20:00	110/E70
14	S - 180731 21:13:00	046/Azumi
		077/E70
	1000nm white PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180731 21:30:00	110/E70
15	S - 180801 14:07:00	046/Azumi
		077/E70
	200nm black PSL	090/Emfab
	w/50% dry dilution air	092/Savillex
	loading experiment	107/Whatman
	F - 180802 11:23:00	110/E70
16	S - 180802 17:02:00	046/Azumi
		077/E70
	Nigrosin	090/Emfab

	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 12:26:00	110/E70
17	S - 180803 15:14:00	046/Azumi
		077/E70
	Nigrosin, higher conc.	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 15:27:00	110/E70
18	S - 180803 15:28:00	046/Azumi
		077/E70
	Nigrosin, diluted conc.	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 15:43:00	110/E70
19	S - 180803 15:44:00	046/Azumi
		077/E70
	Nigrosin, changed conc.	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 15:50:00	110/E70
20	S - 180803 15:51:00	046/Azumi
		077/E70
	Nigrosin, changed conc.	090/Emfab

	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 15:54:00	110/E70
21	S - 180803 15:55:00	046/Azumi
		077/E70
	Nigrosin, changed conc.	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 16:08:00	110/E70
22	S - 180803 17:20:00	046/Azumi
		077/E70
	Nigrosin, changed conc.	090/Emfab
	w/50% dry dilution air	092/Savillex
		107/Whatman
	F - 180803 17:45:00	110/E70
22	S - 180803 19:52:00	046/Azumi
		077/E70
	Changed filters, amb air	090/Emfab
	w/50% dry dilution air	092/Savillex
	over weekend	107/Whatman
	F - 180806 13:51	110/E70

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