Particle Morphology Results from the Smoke Aerosol Measurement Experiment-Reflight

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Particle Morphology Results from the Smoke Aerosol Measurement Experiment-Reflight

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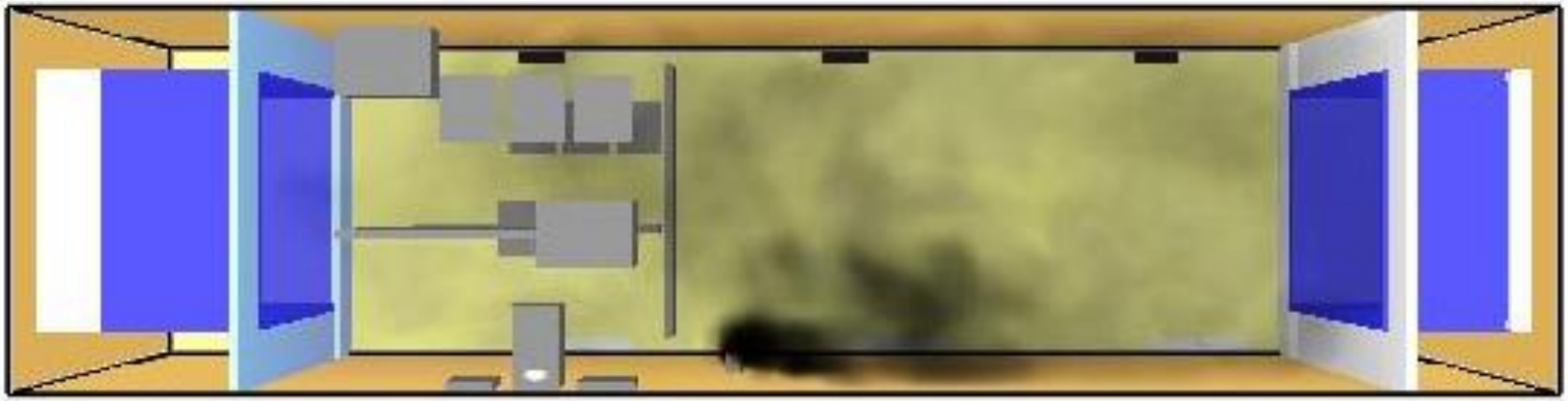
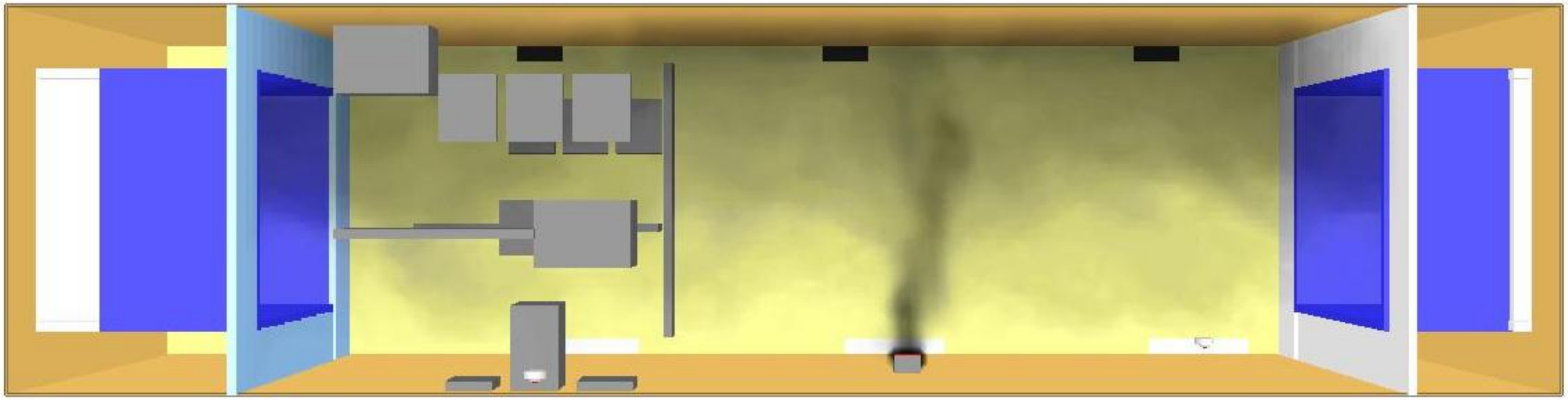
Smoke Detection:
Destiny Smoke Detection Simulation-25% Soot
effect of gravity

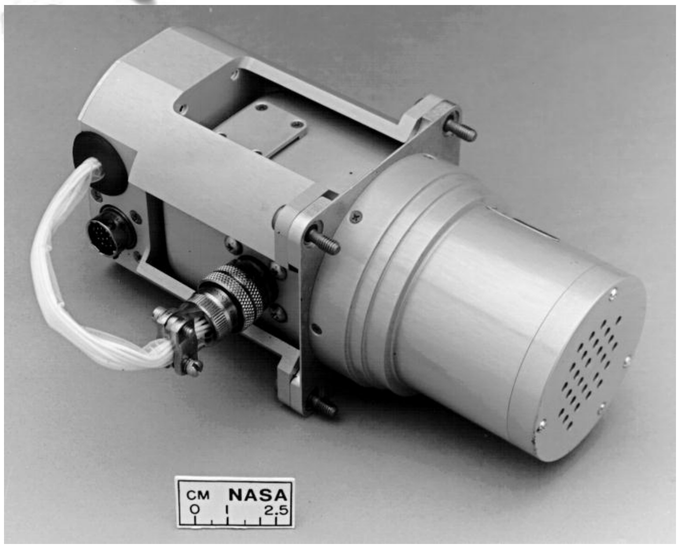


Low-gravity



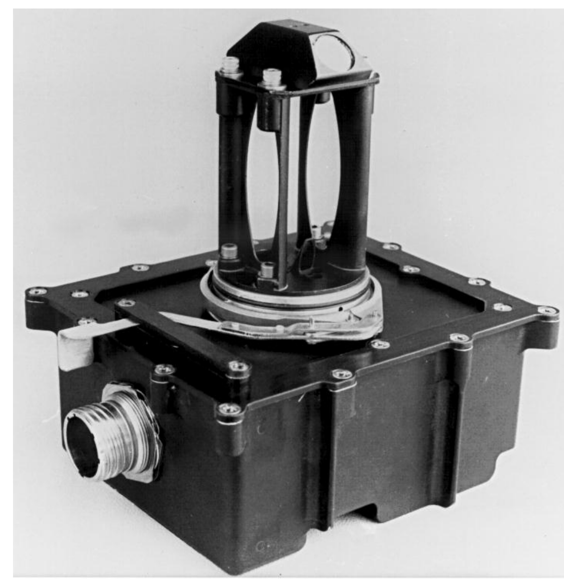
Normal-gravity

Background: Spacecraft Fire Detection



STS Detector: sensitive < 1 micron

- dual-chamber ionization with inertial separator which rejects particles larger than 1-2 microns.
- fairly large power consumption (9 Watts)
- Installed in avionics air returns
- Developed in the late 70's when Ionization detectors were prevalent
- Decades of service with very few false alarms and no alarms.

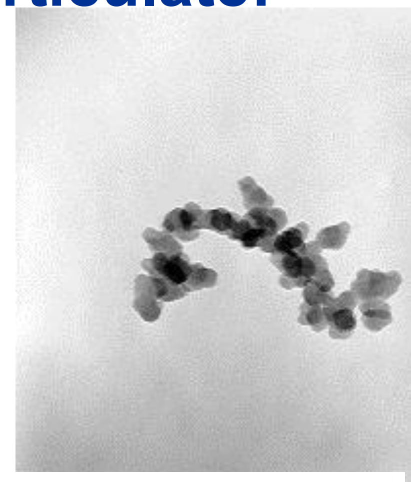


ISS detector: sensitive > 0.5 micron

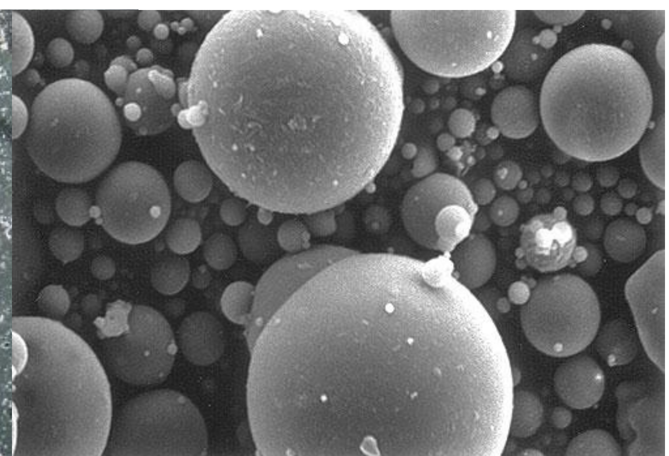
- 2-pass IR laser-diode forward-scattering detector (30 degrees) minimum reported sensitivity is 0.3 µm.
- Low power (1.5 W)
- Installed in air ducts and in cabin area (with light shroud)
- Developed in the 90's and took advantage of the availability of stable diode light sources.
- Years of continuous ISS service with some false alarms and no alarms.

Background: Types of Smoke

"Smoke" encompasses several types of particulate:



- Condensed steam/vapor
- Ash
- Soot
- Recondensed polymer solids
- Recondensed polymer liquids

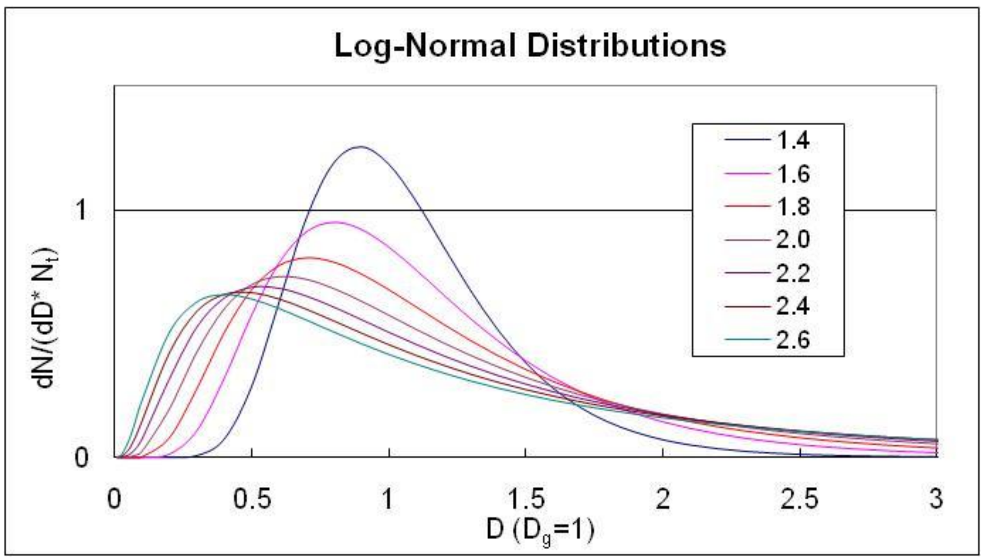


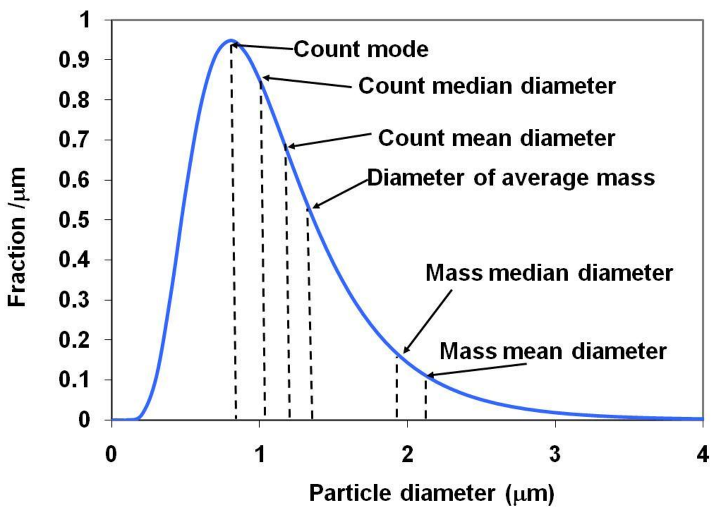
Log-Normal Distribution

$$f_N(D) = \frac{N_t}{(2\pi)^{1/2} D \ln\sigma_g} \exp\left(-\frac{(\ln D - \ln D_g)^2}{2\ln^2\sigma_g} \right)$$

Number is dominated by the smaller particles

Mass is dominated by the larger particles (tail)



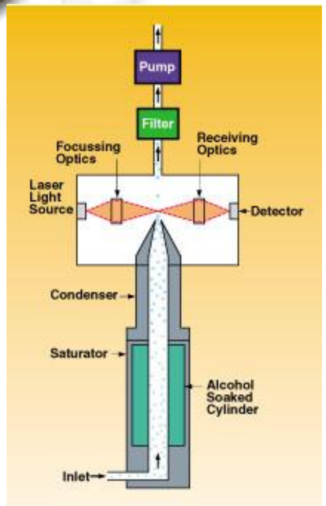


Log-normal distribution σ_g = 1.6, D_g= 1

SAME Experimental Diagnostic Measurements

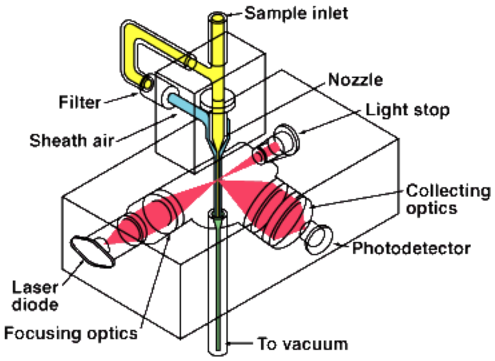
All measure moments of the particle size distribution

$$M_i = \int D^i f_N(D)\,dD$$



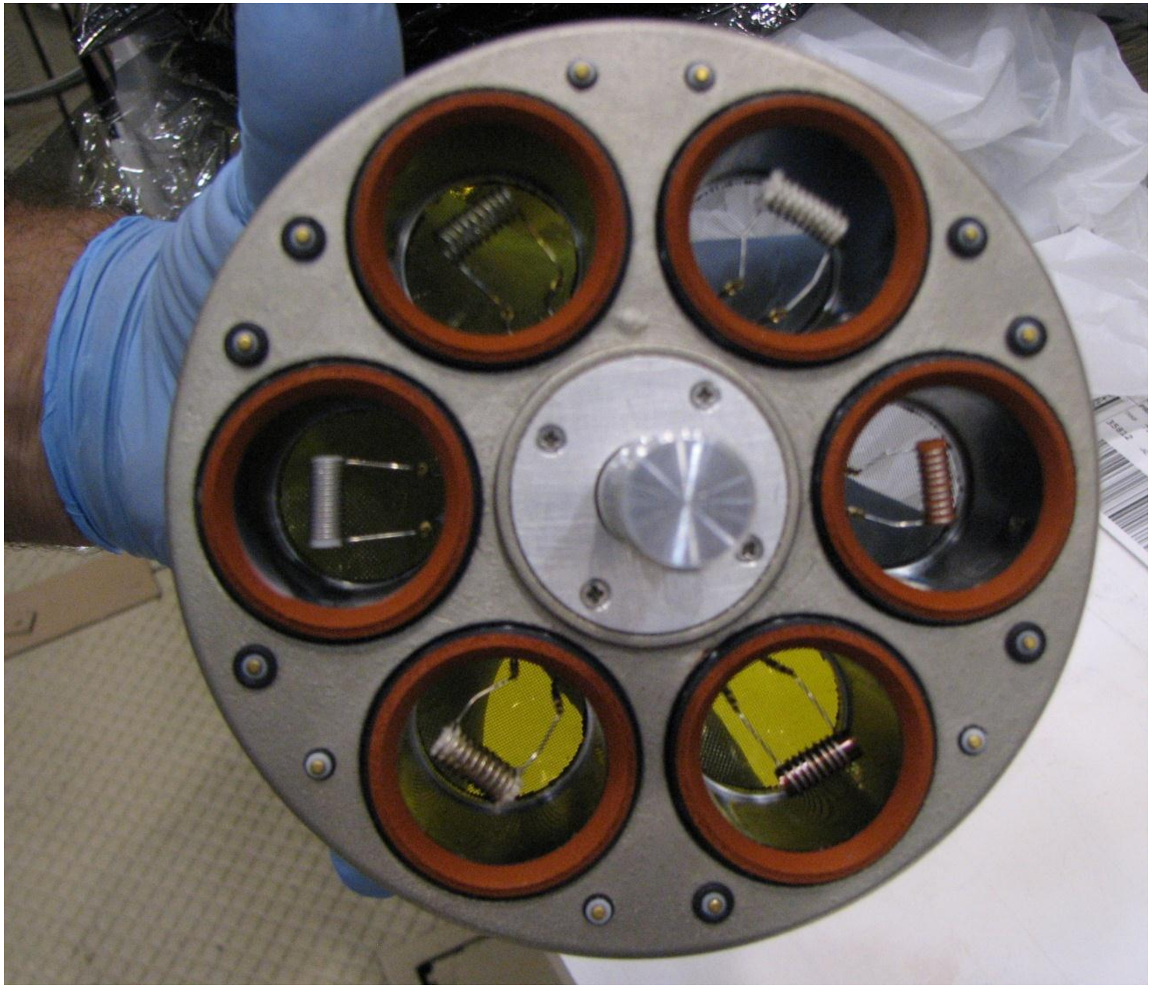
Zeroth Moment:
TSI PTrak™

First Moment:
First Alert™
Smoke Detector



Third Moment:
TSI Dust Trak™

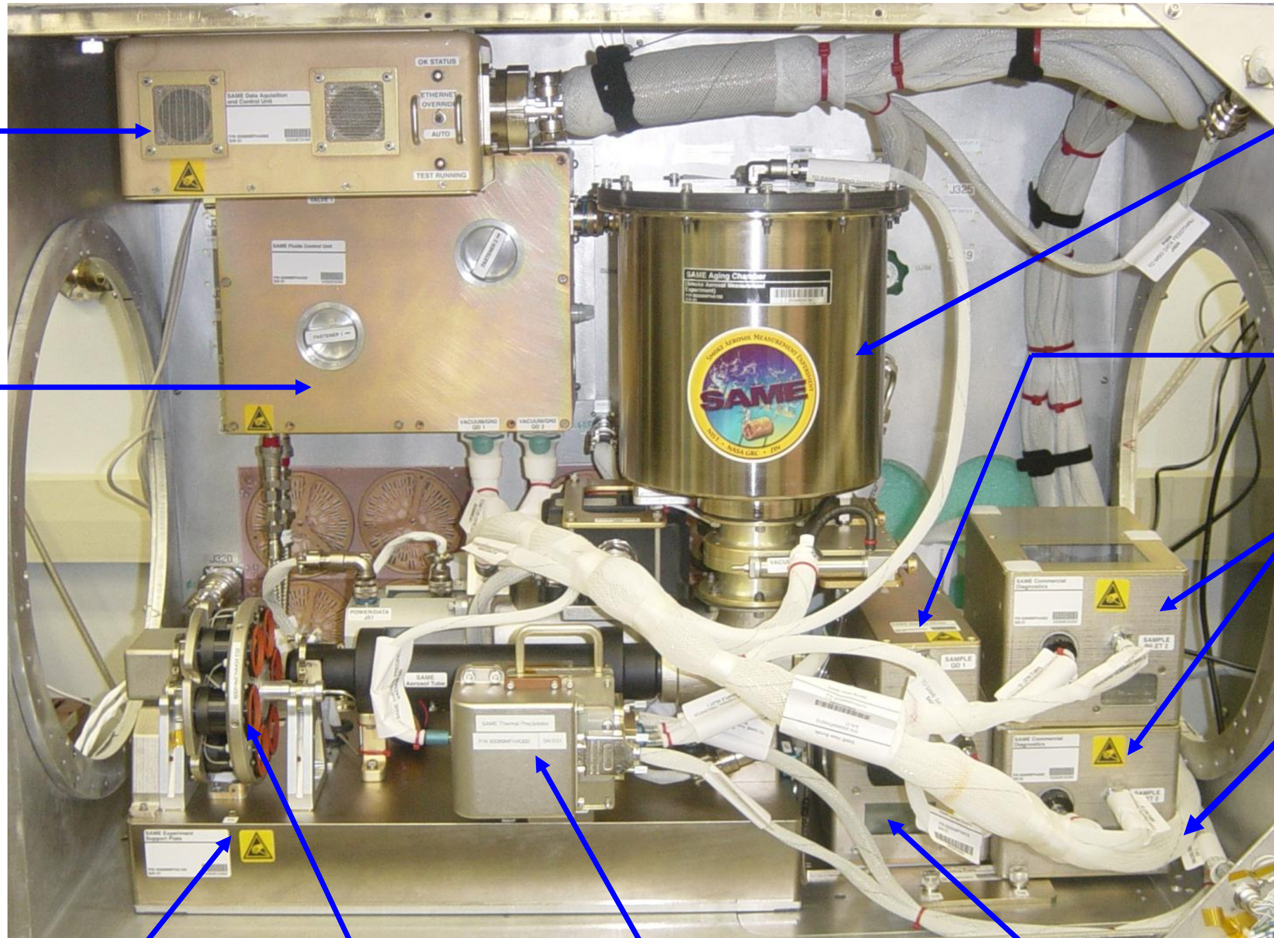
SAME Sample Carousel



Sample Materials:

Silicone
Teflon
Kapton
LampWick
Pyrell
DBP

SAME in MSG (mockup)



Data Acquisition and Control Unit

Fluids Control Unit

Aging Chamber

Sample Diluter

Commercial Diagnostics

Hose Bundle

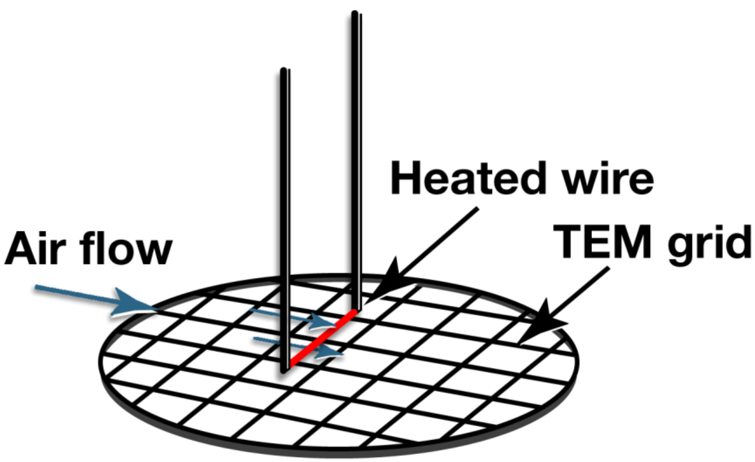
Experiment Support Plate

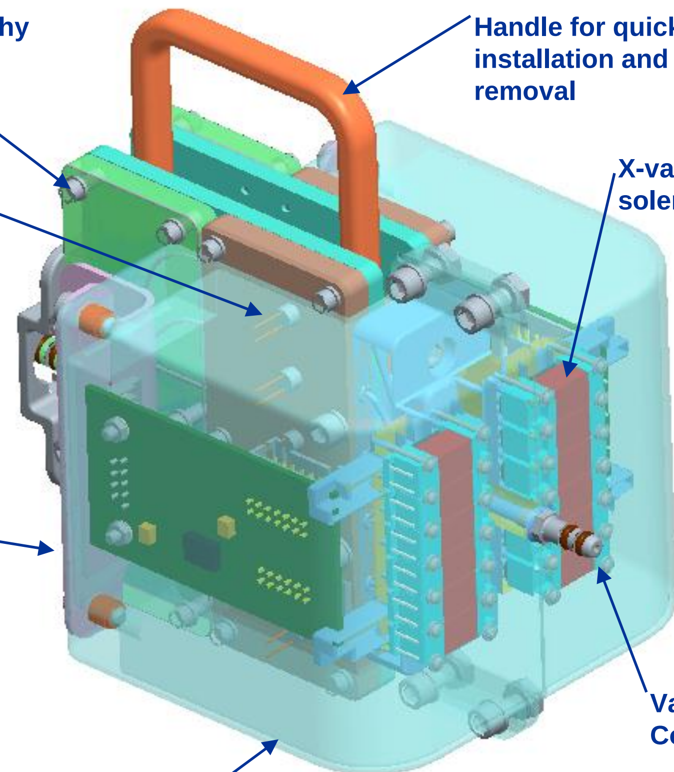
Sample Carousel

Thermal Precipitator

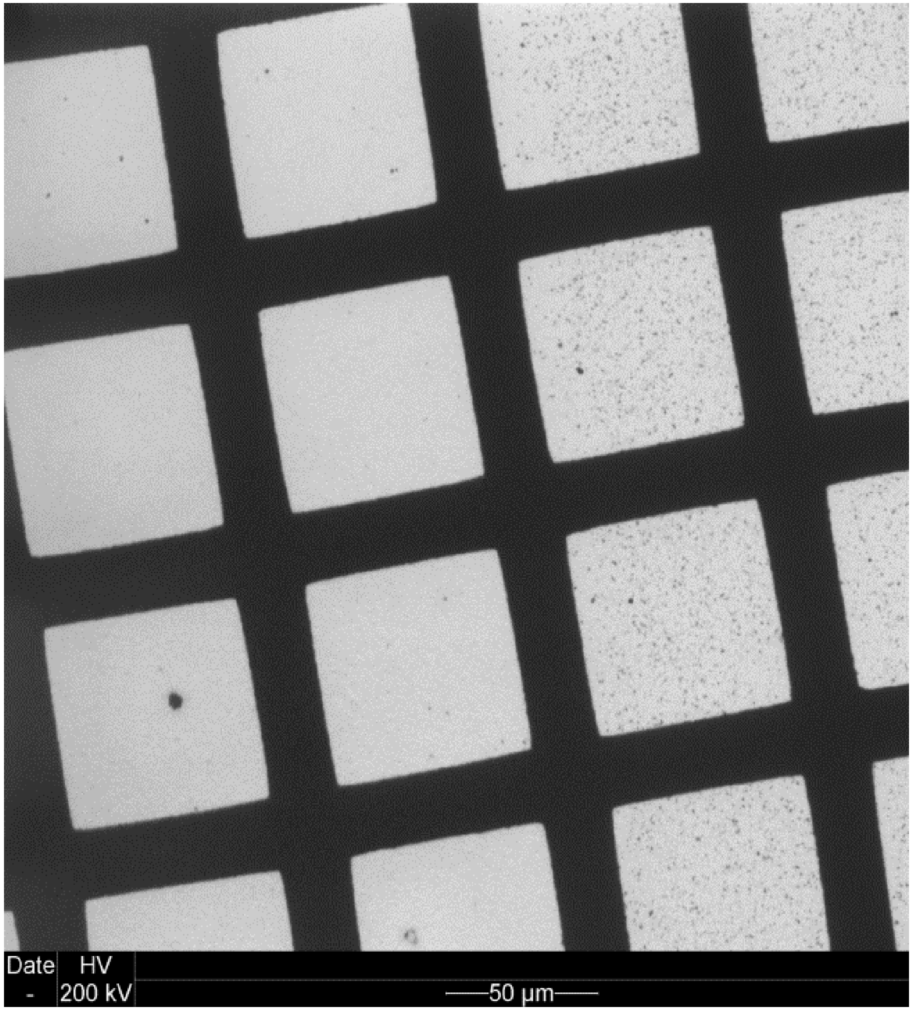
P-Trak Enclosure

SAME Particle Capture



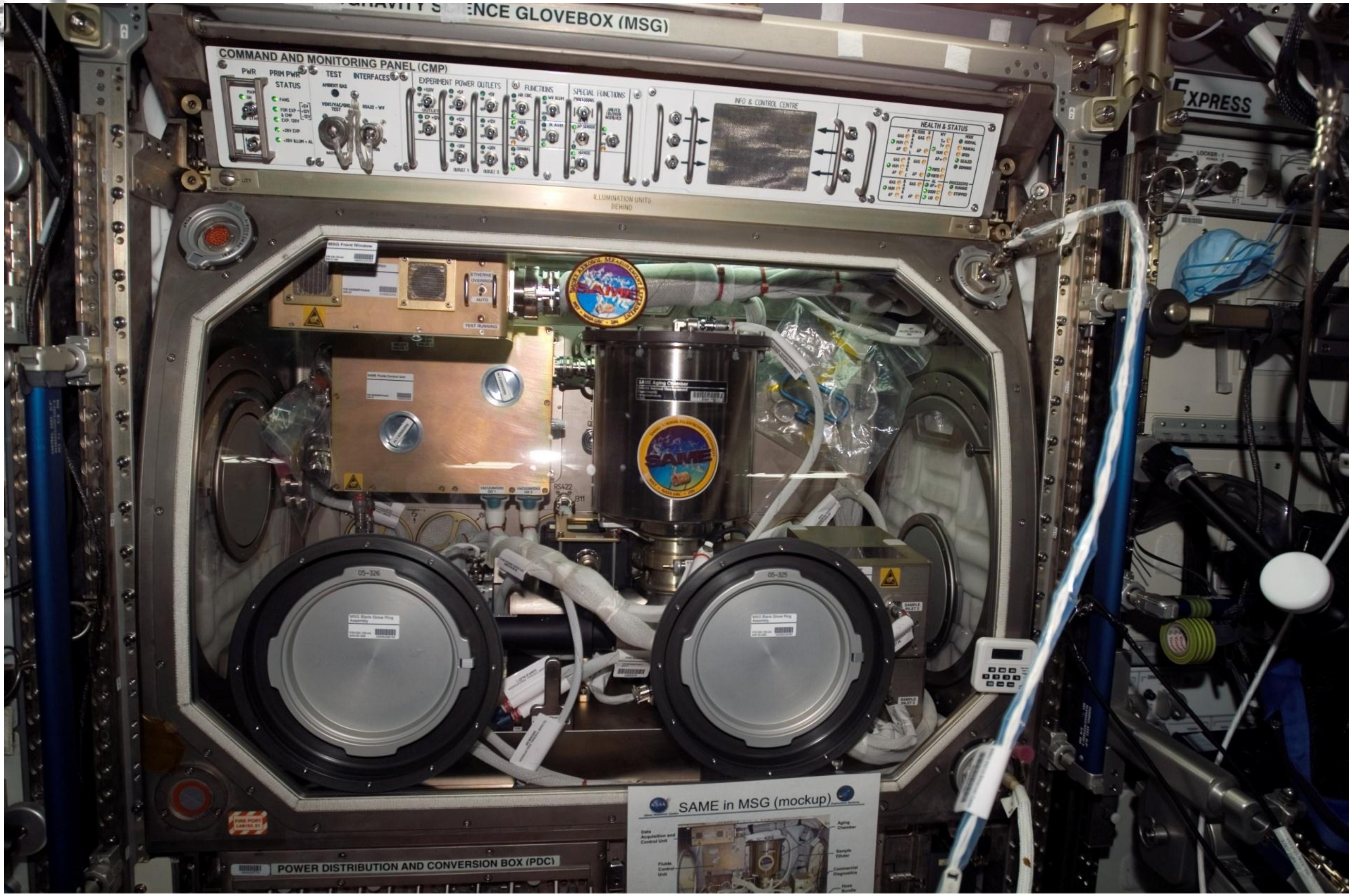


TEM Results



Overview image showing deposition boundary

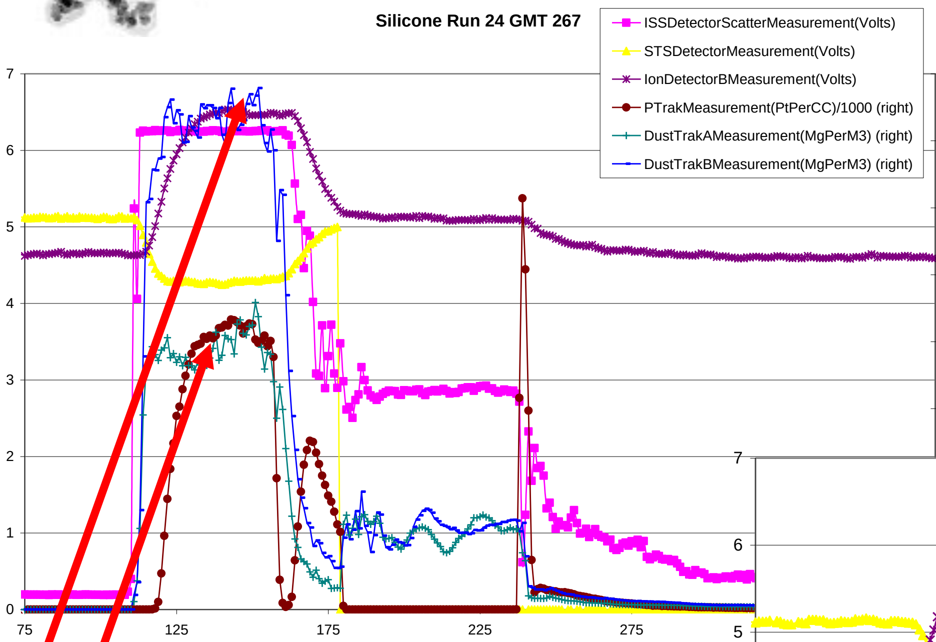
SAME Hardware on orbit



ISS015E26265

SAME Raw Data

Two Dust Traks were used one with a 10 micron cut off and one with a 1 micron cutoff. The difference between the two gives an indication of the particle size distribution.

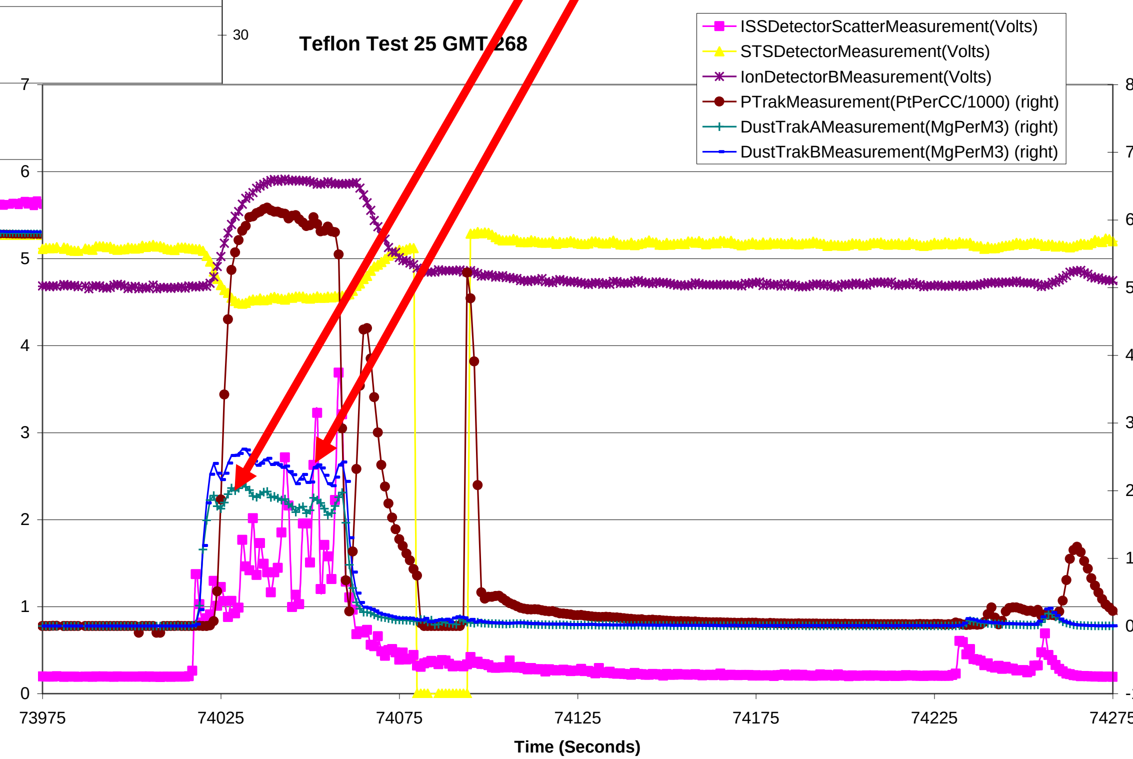


Silicone Rubber:

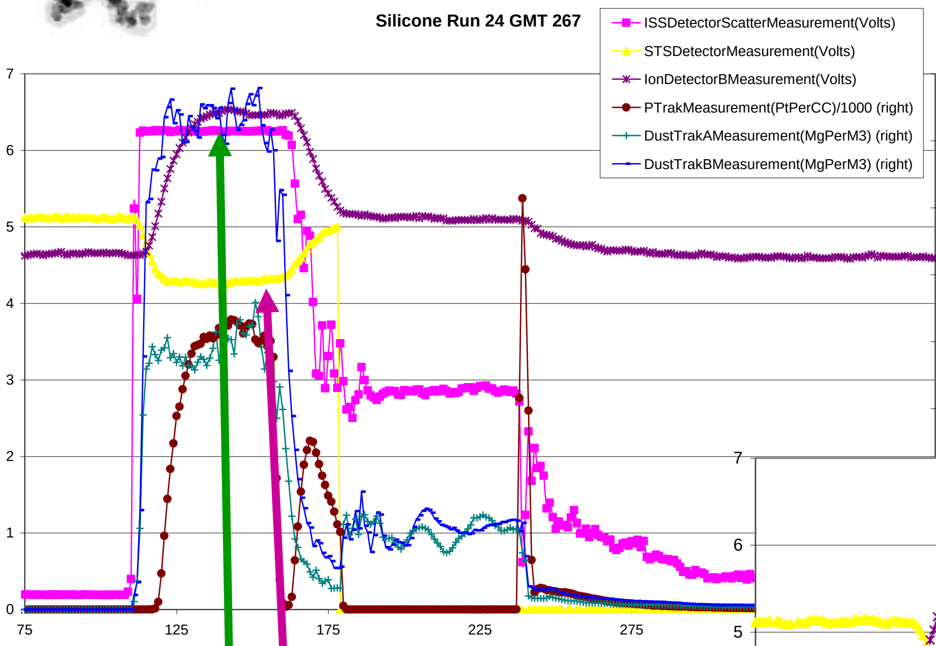
Note difference in Dust Traks indicating large particles

Teflon:

Note similarity in Dust Traks indicating smaller particles

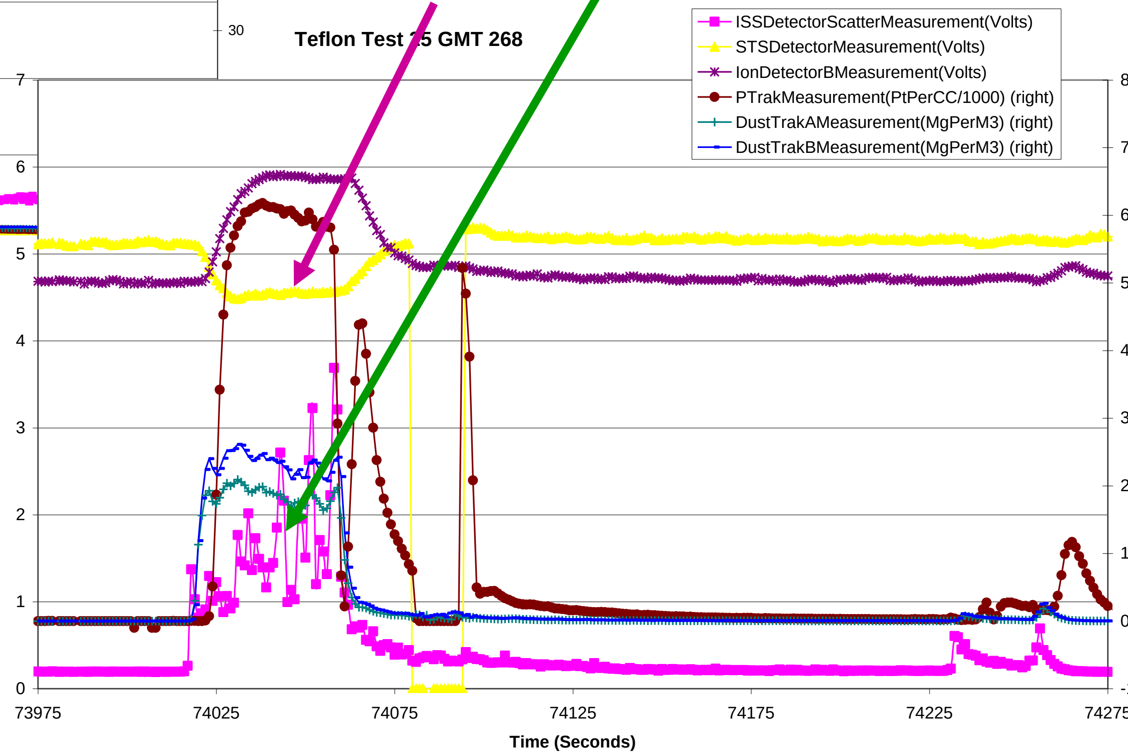


SAME Raw Data



Teflon:

Note weak scattering (ISS) detector signal but ionization (STS) is still strong

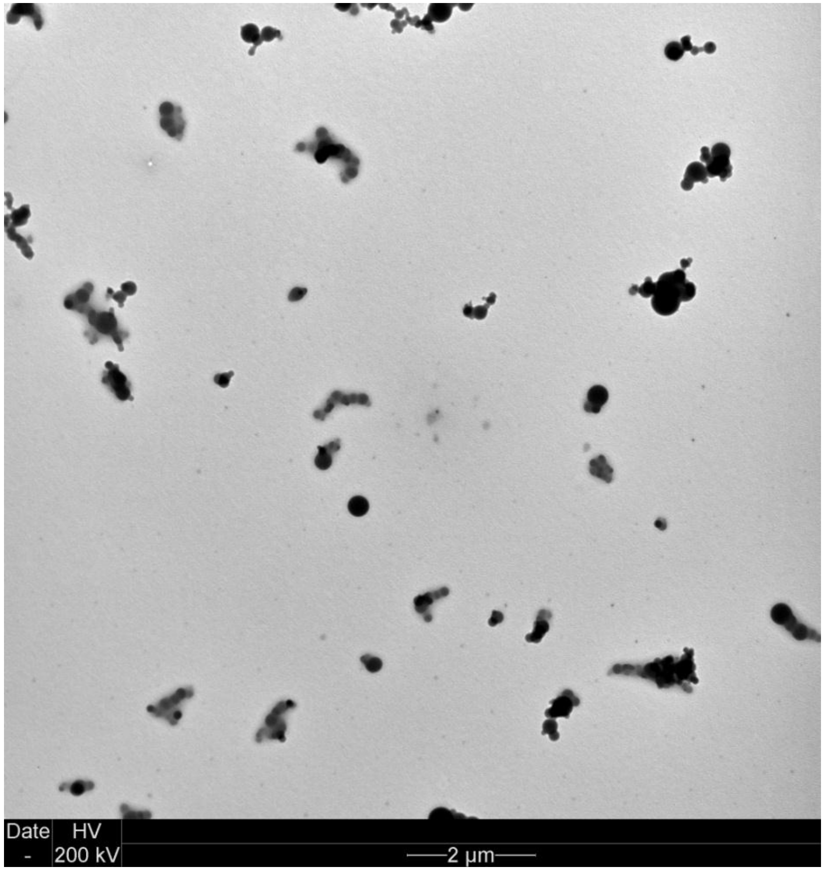


Silicone Rubber:

Note strong signal on both smoke detectors

TEM Results

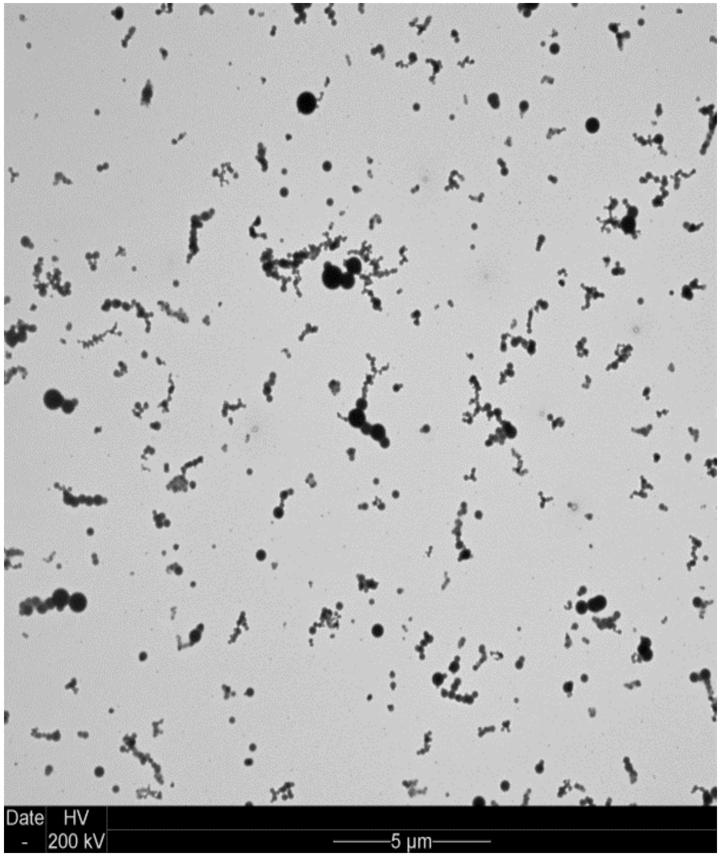
5 microns

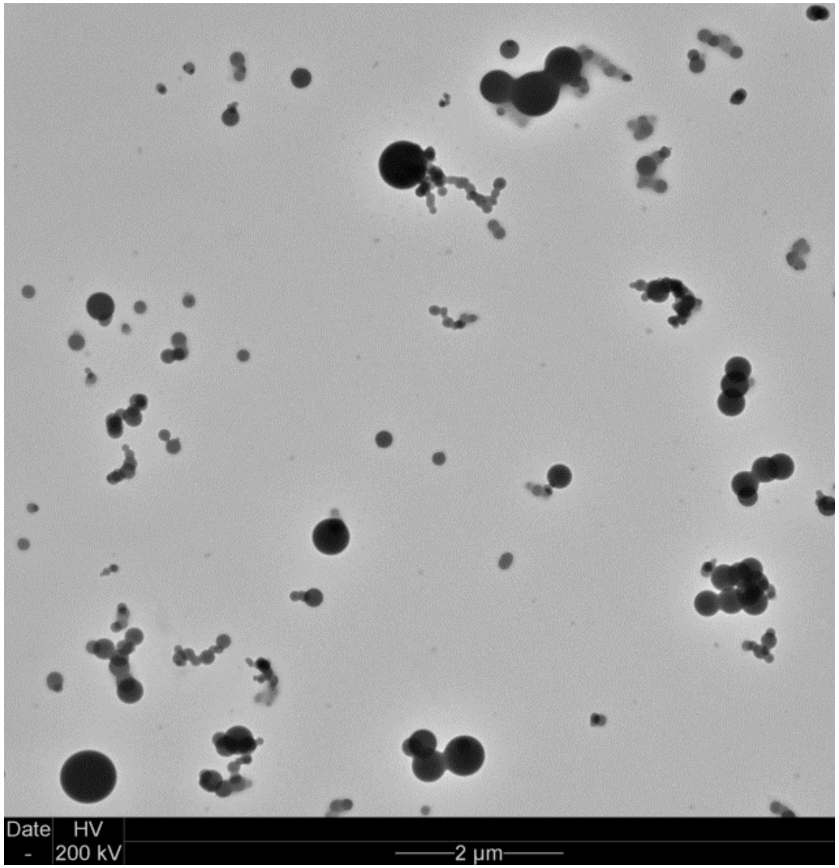


2 microns

Baseline Temperature Pyrell (Run 74)

TEM Results



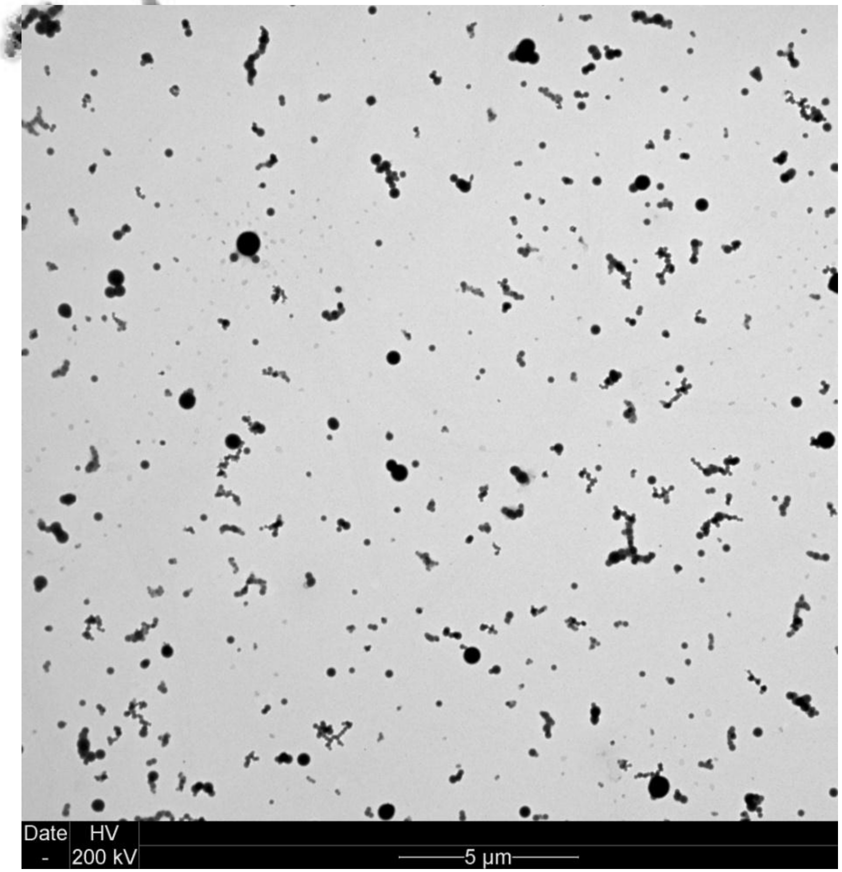


5 microns

2 microns

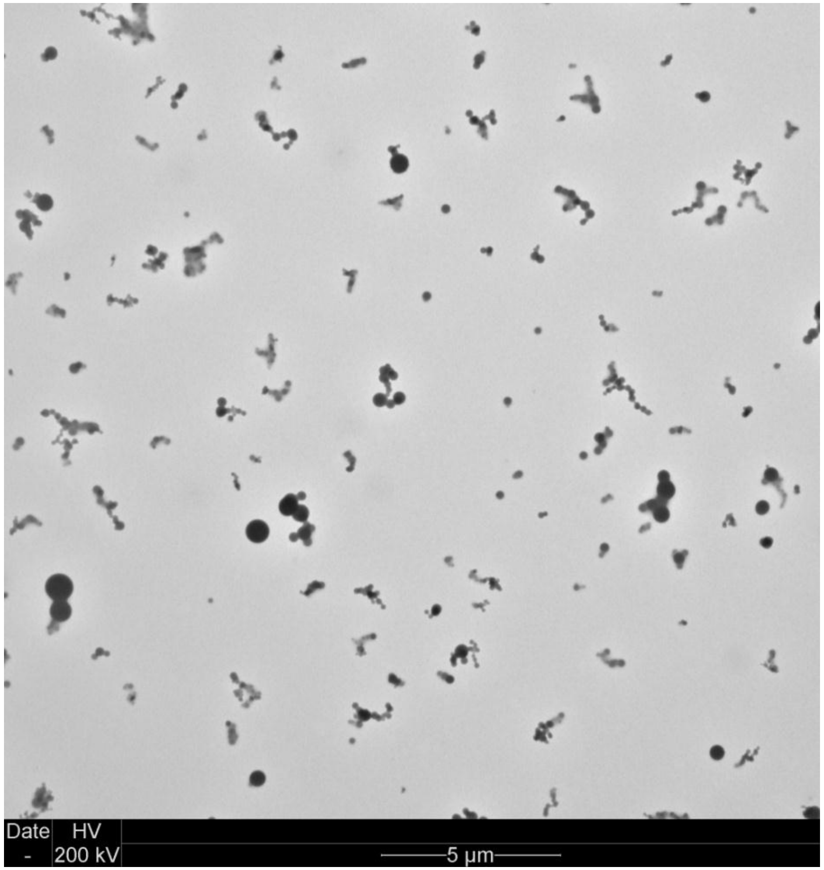
High Temperature Pyrell (Run 64)

TEM Results



5 microns

Pre aging

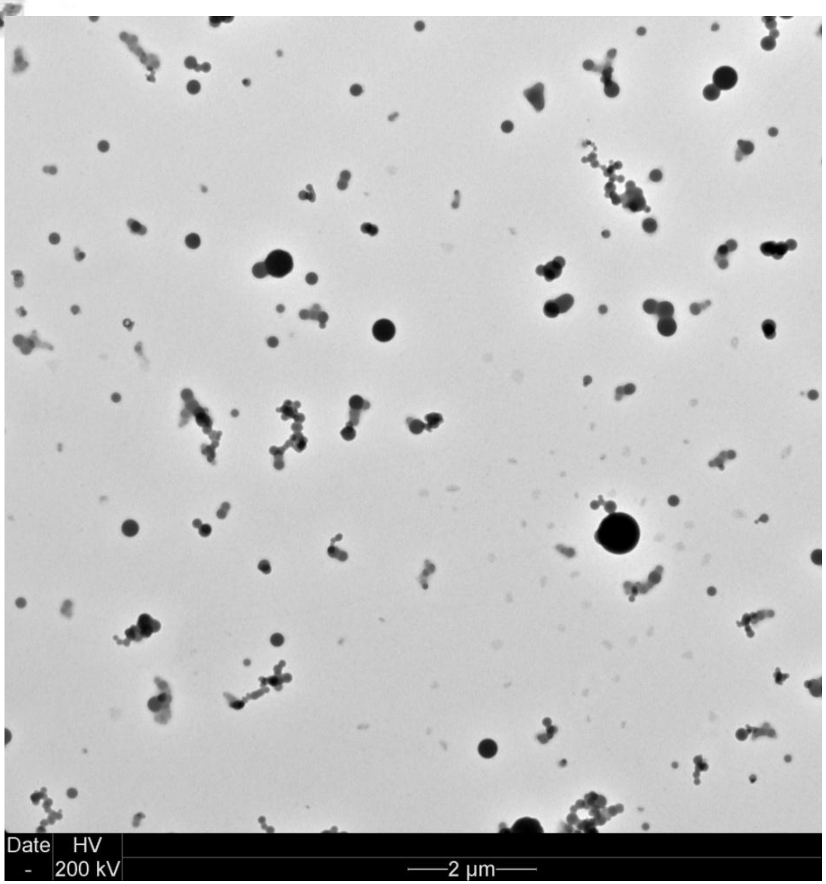


Post aging

5 microns

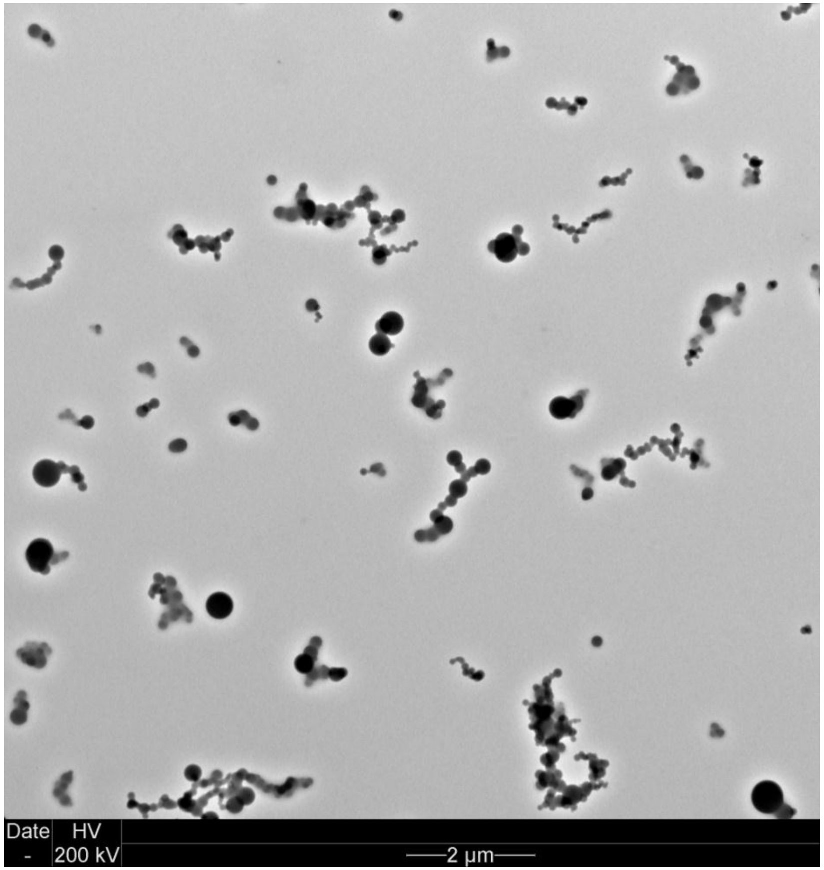
High Temperature Pyrell: 480 second aging run (Run 84)

TEM Results



Pre aging

2 microns

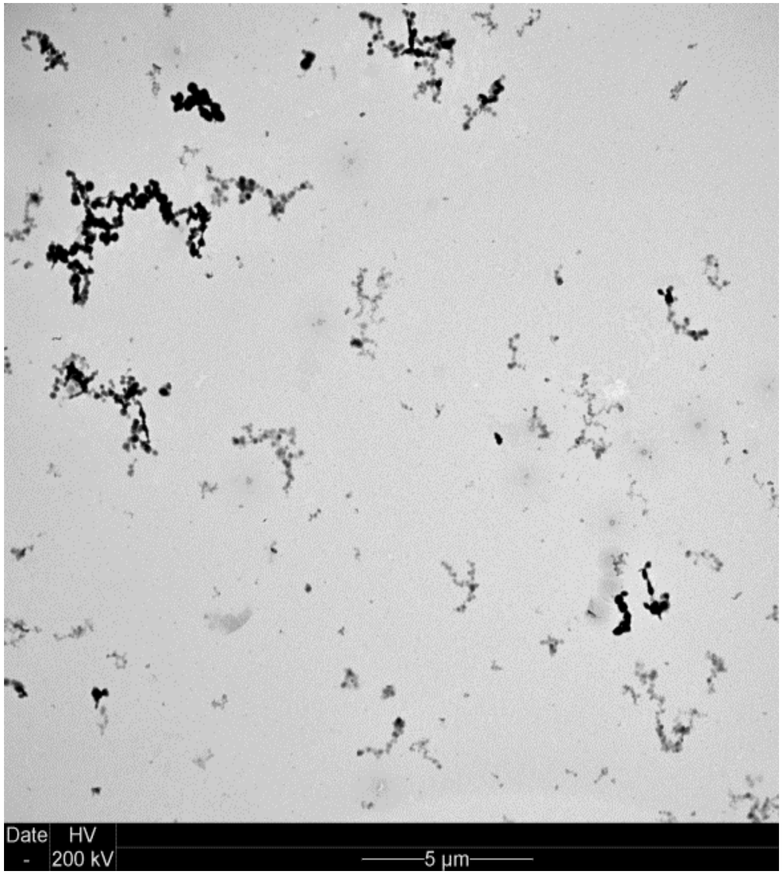


Post aging

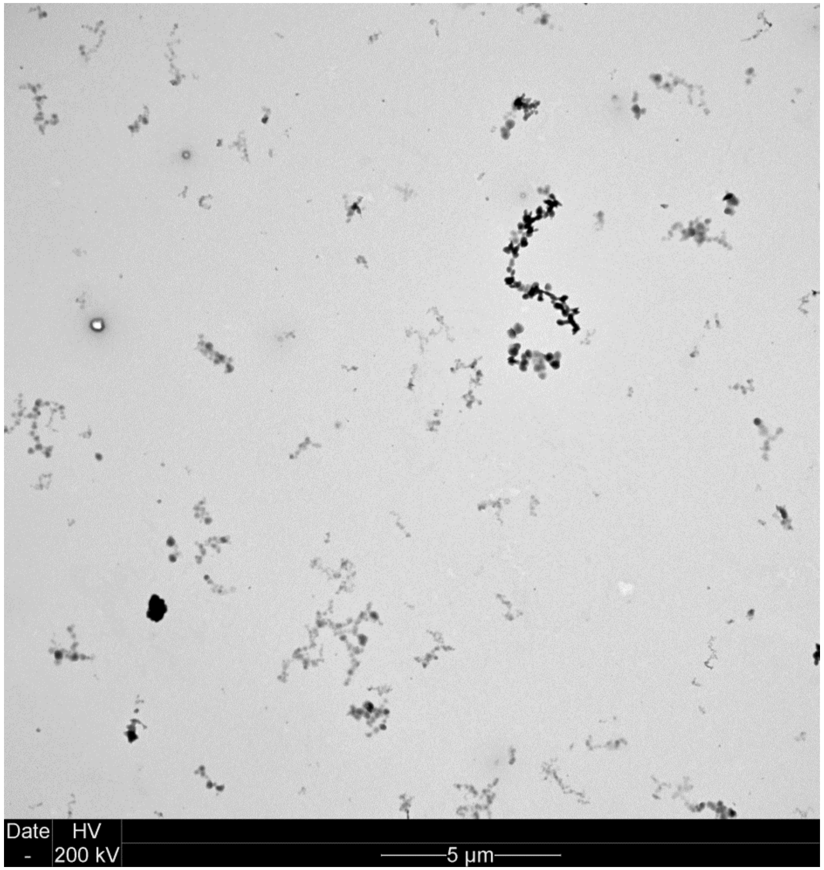
2 microns

High Temperature Pyrell: 480 second aging run (Run 84)

TEM Results

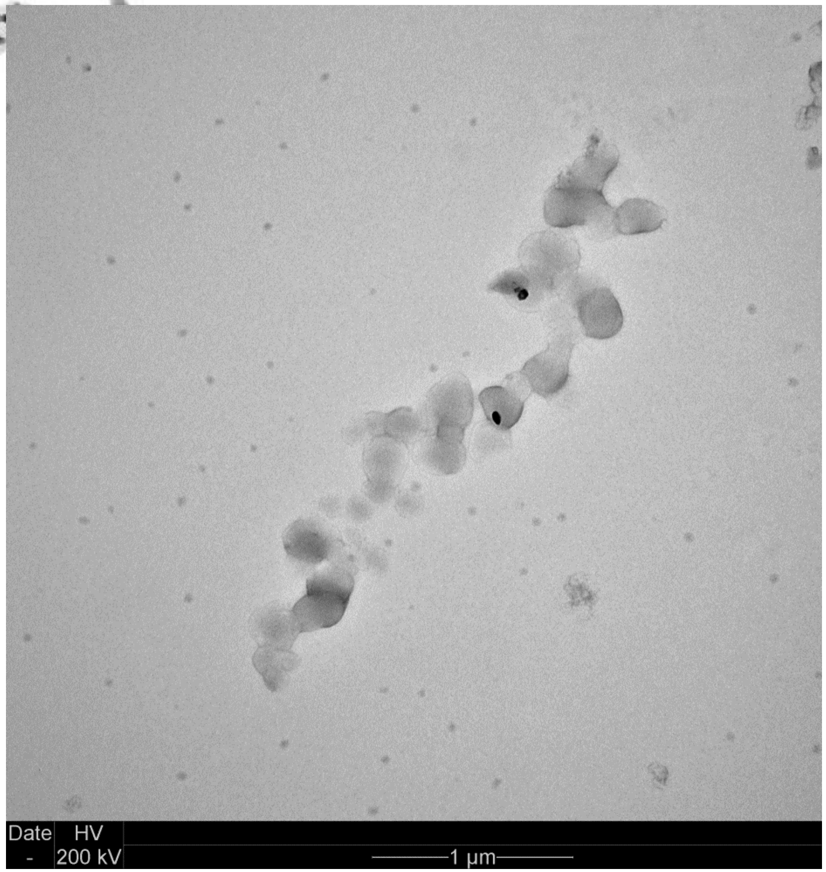


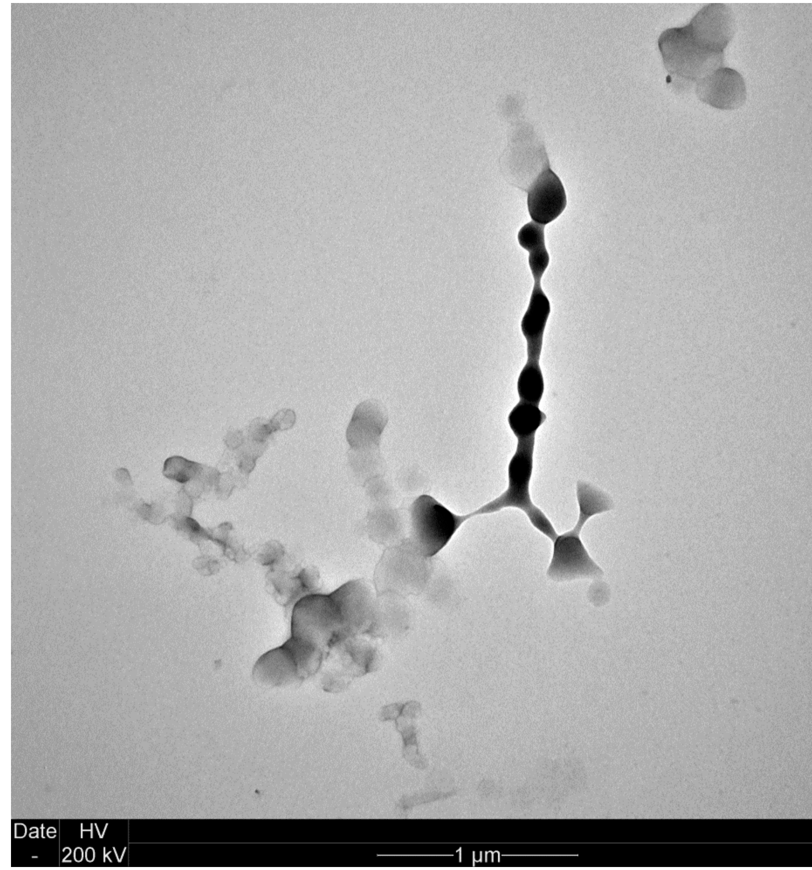
5 microns



5 microns

Baseline Temp Teflon (Run 56)





1 micron

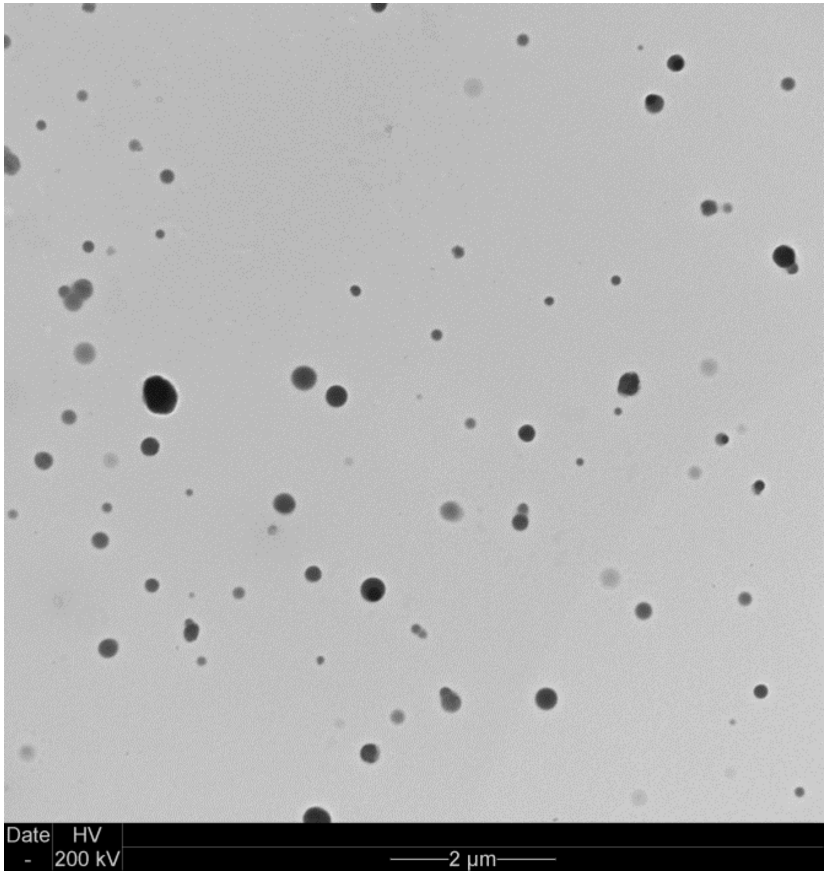
1 micron

Baseline Temp Teflon (Run 56)
Note evidence of electron beam interaction in right hand image

TEM Results

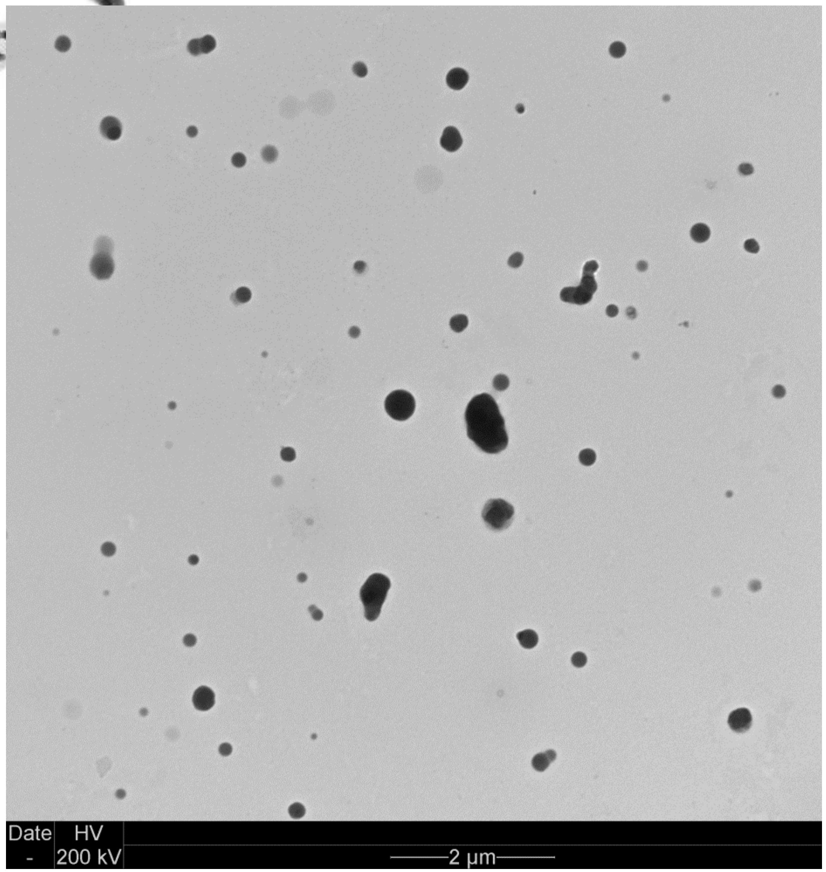
2 microns

Mid Temp Kapton (Run 75)

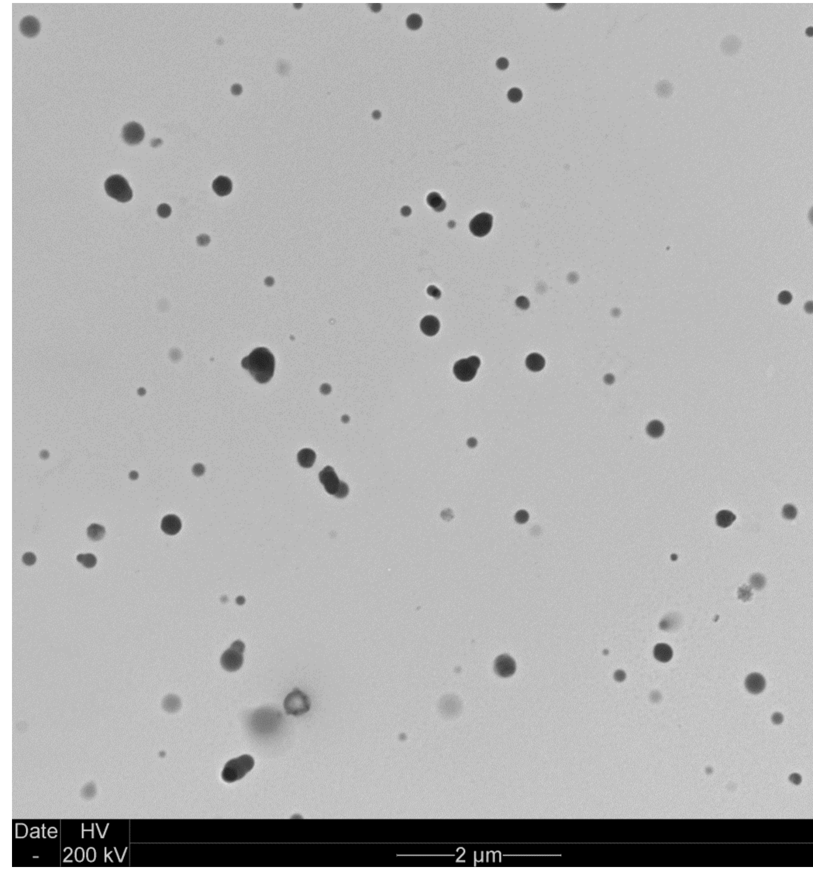


2 microns

High Temperature Kapton (Run 62)



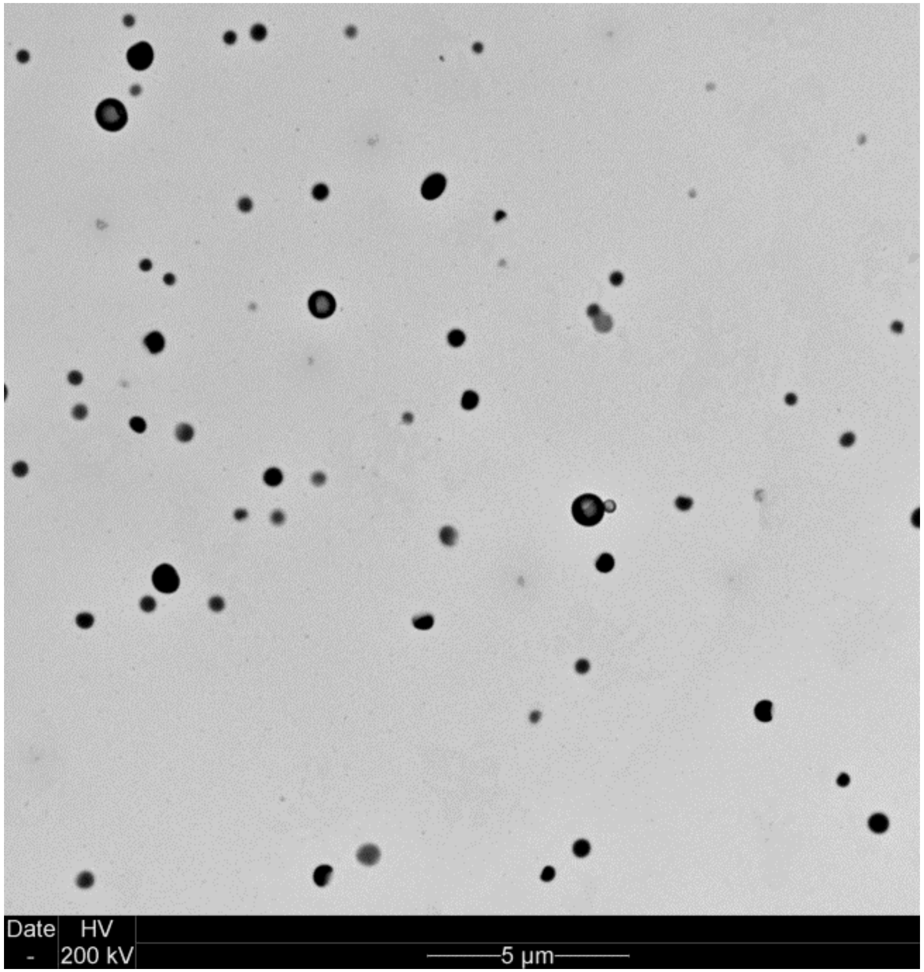
2 microns



2 microns

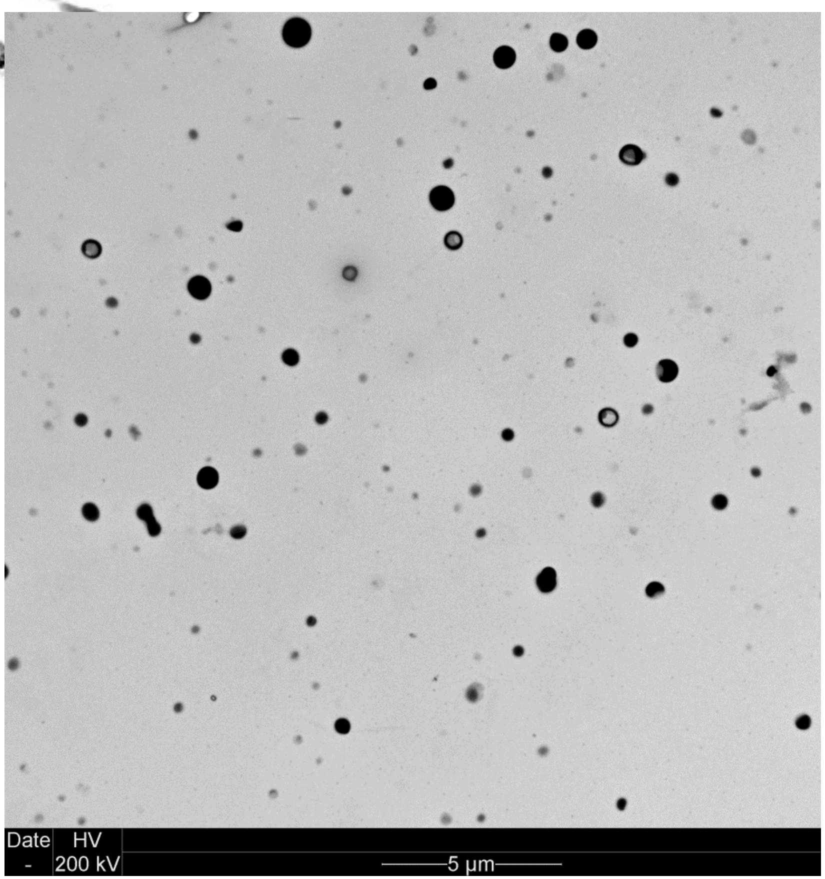
High Temperature Kapton (Run 62)

TEM Results

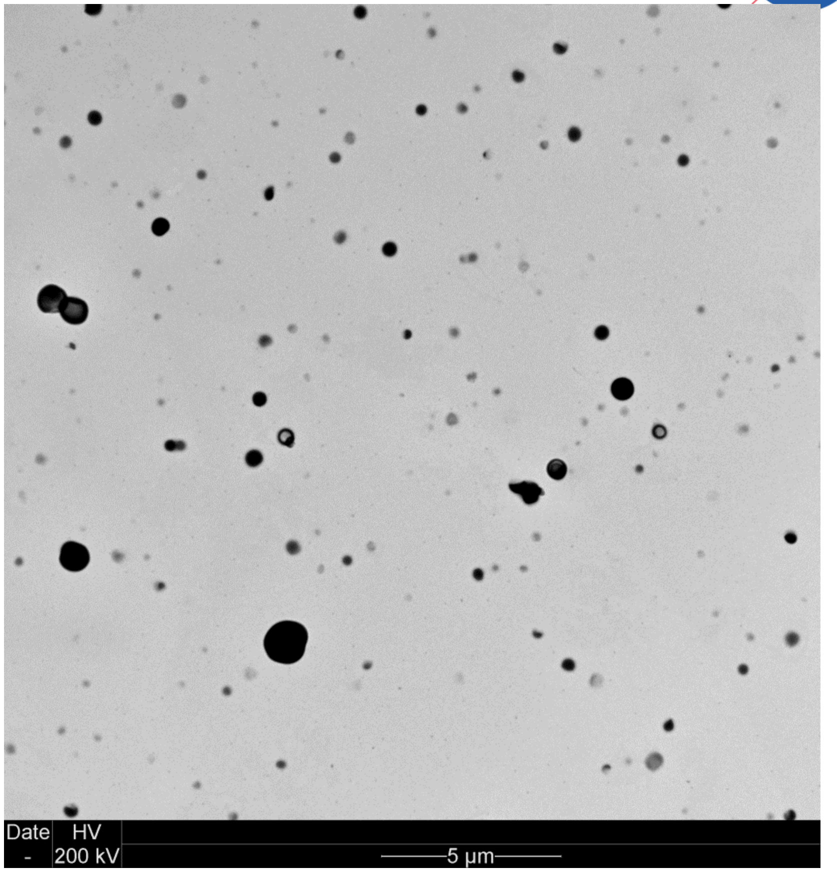


5 microns

High Temperature Lamp wick (Run 54)

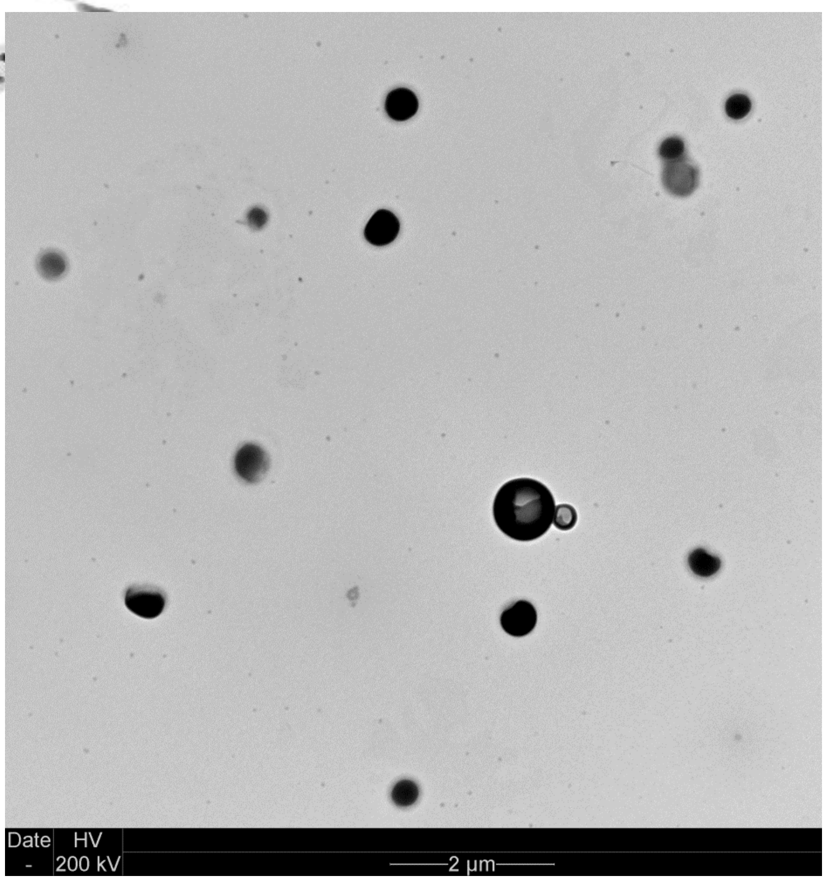


5 microns

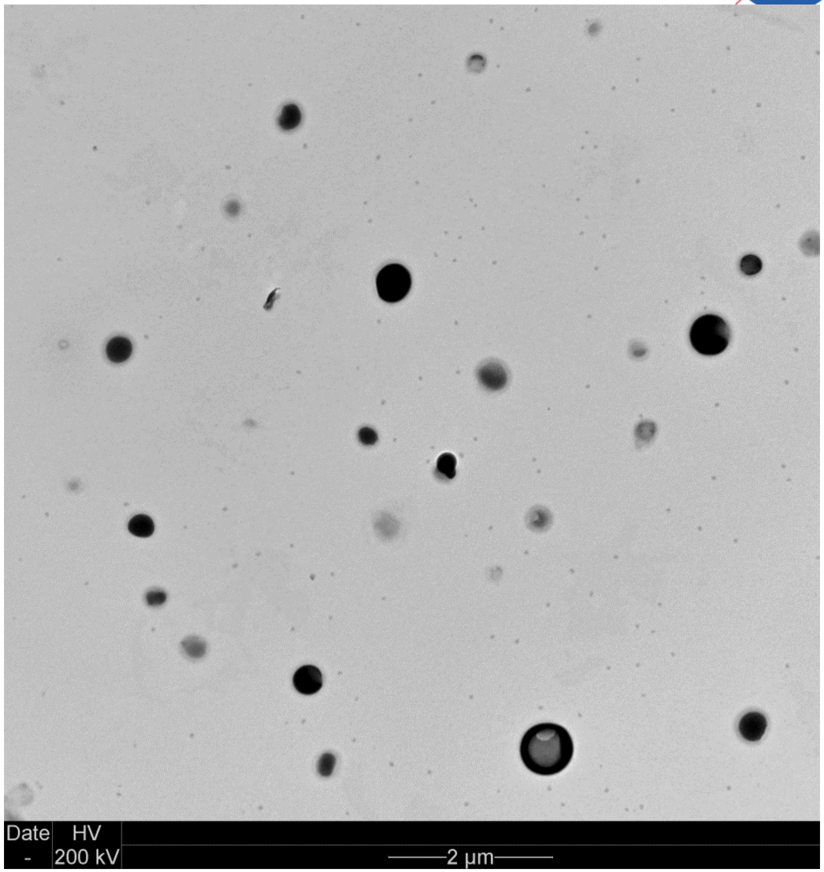


5 microns

High Temperature Lamp wick (Run 54)



2 microns



2 microns

High Temperature Lamp wick (Run 54)

TEM Results

TEM revealed several particle morphologies

Teflon and Pyrell: Aggregates

- **Teflon aggregates: numerous primaries of same dimension**
- **Pyrell Aggregates: Primaries widely distributed in size**

Kapton: single particles

- **Low temperature: produced very small and low TEM density particles**
- **High temperature: TEM density increased**

Silicone: No Tem visible particles

Lamp wick: Single particles, typically large

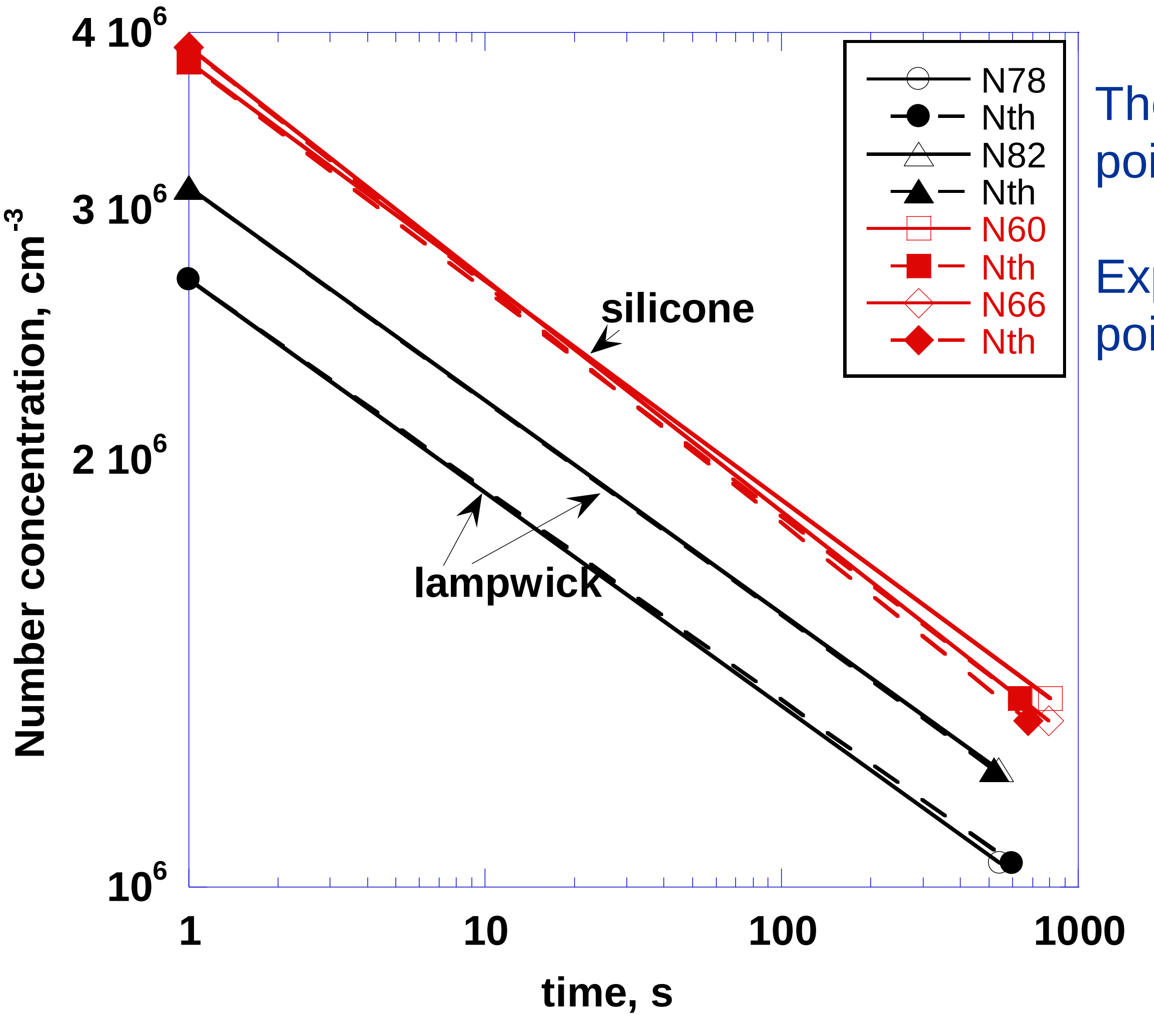
Aging showed a distinct elimination of the smallest particles

SAME-1&R Results

	Geometric Mean Diam. (nm)	Arithmetic Mean Diam. (nm)	Diam. of Average Mass (nm)	σ_g
Kapton	47	62	106	2.07
Kapton aged	102	121	169	1.79
Lamp wick	103	142	271	2.23
Lamp wick aged	269	308	401	1.67
Silicone	152	221	468	2.38
Silicone aged	320	400	628	1.96
Teflon	93	111	173	2.08
Teflon aged	80	115	237	2.34
Pyrell	177	227	377	2.03
Pyrell aged	348	400	529	1.70

SAME Aging Results

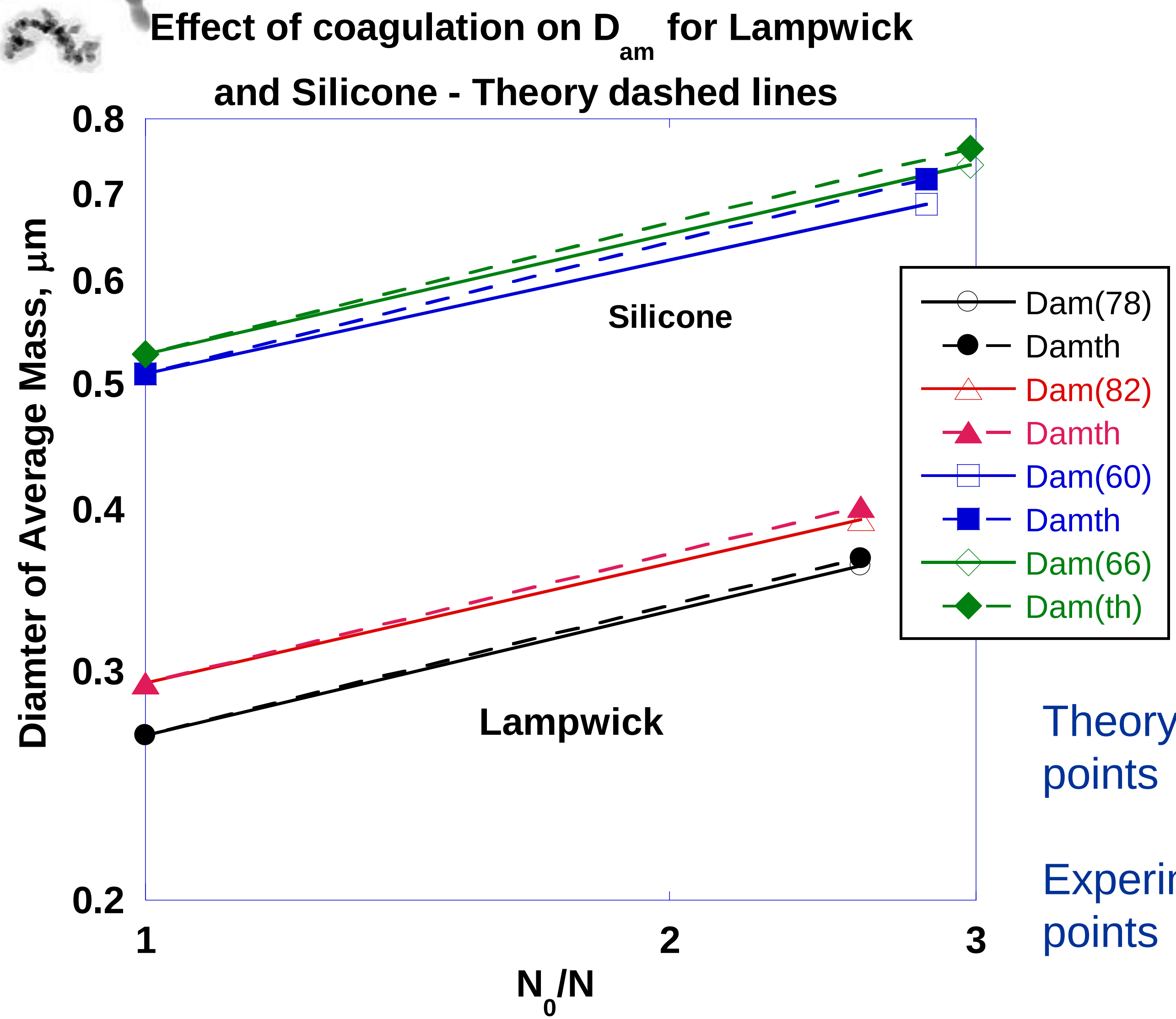
Comparison of measured and predicted concentration after aging for lampwick and silicone smokes



Theory: Dashed line, Solid points

Experimental: Solid Line, Open points

SAME Aging Results

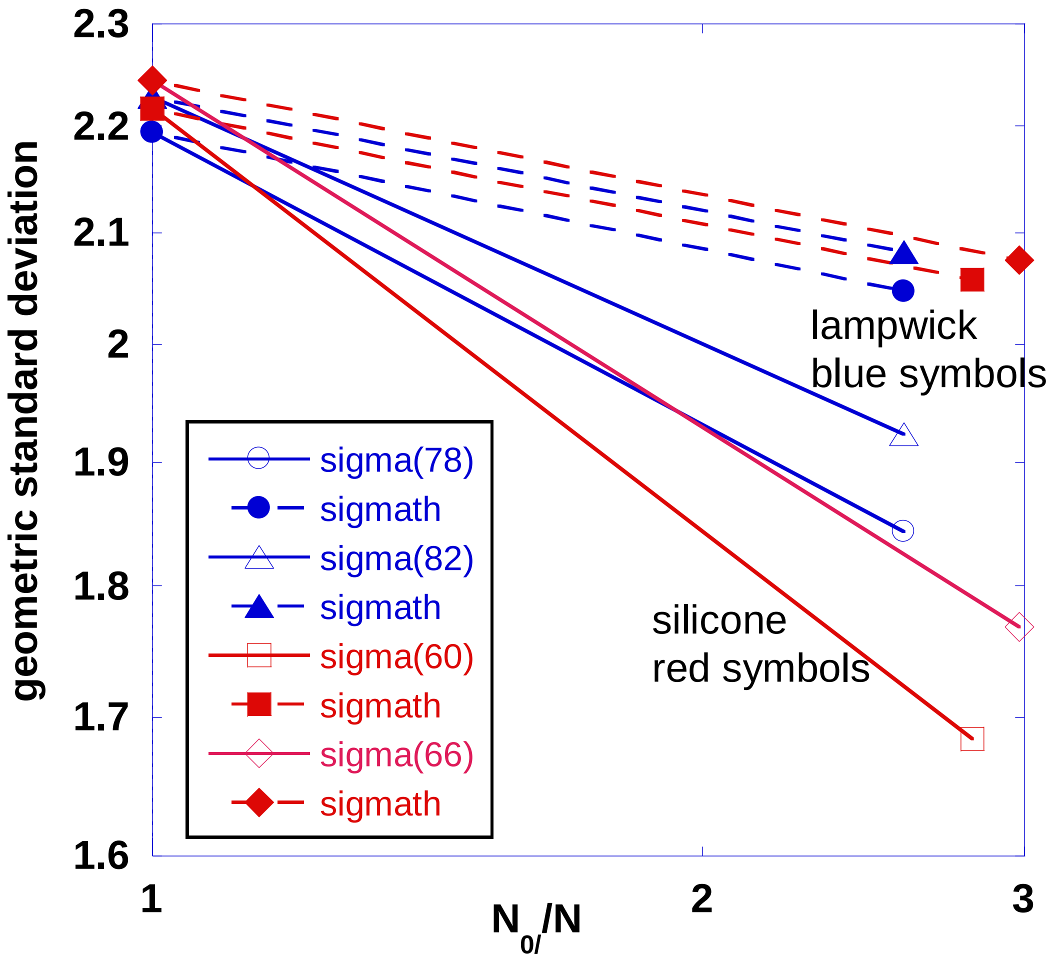


Theory: Dashed line, Solid points

Experimental: Solid Line, Open points

SAME Aging Results

Effect of coagulation on σ_g for lampwick and silcone smoke - prediction values indicated by dashed lines



Theory: Dashed line, Solid points

Experimental: Solid Line, Open points

SAME Aging Results

- For spacecraft materials, number counts decreased by a factor of 1.7 to 2.7 over 800 seconds.
- The measured and predicted number decreases agree within about 20 %.
- The best agreement between experiment and prediction is D_{avm} - agree within 4 %.
- The decrease in the geometric standard deviation is typically more than a factor of two greater than the predicted change.
- Aging results are relevant to partially sealed volumes and low air flow conditions.
- In all cases, aging resulted in approximately a factor of two decrease in number concentration and a factor of two increase in the number mean diameter with the exception of teflon

Conclusions

- **For the conditions tested, the materials emit most of their particulate in the submicron range.**
- **The ISS detector showed a relatively weak signal for some Teflon runs doubtless a result of the particle size.**
- **Particle morphology varies widely across the range of expected sample materials. Dependence on a single angle scattering device will be difficult.**
- **Aging results consistent with theory for number count and D_{avm} but not for σ_g**

Implications and Future Work

- **Dust rejection may be achievable by detecting at the sub-micron level.**
- **Given the effects of aging and the slow mixing seen in spacecraft, it is probably unwise to focus entirely on small particle sizes for fire detection**
- **Size selective smoke detection will improve reliability and false alarm rejection. Either by classifying the particles or by measuring multiple moments.**