Jet Propulsion Laboratory
California Institute of Technology

Analysis of CO_2 Composite Spray Cleaning System Results

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Outline

- Overview of Experiment
- Cleanlogix SnoPen
- Spore Work
- Fluorescent Particles
- Analysis
- Conclusions

Objectives

Develop an effective cleaning method that will produce a surface free of spores by using a CO_2 composite spray system to remove sub-micron particles

1. Construct, assemble, and test CO_2 jet cleaning method
2. Demonstrate and validate its ability to achieve sterility on hardware material surfaces
3. Evaluate and select an optical analytical method for surface sub-micron particle cleaning verification
4. Demonstrate and verify cleaning effectiveness for sub-micron particles

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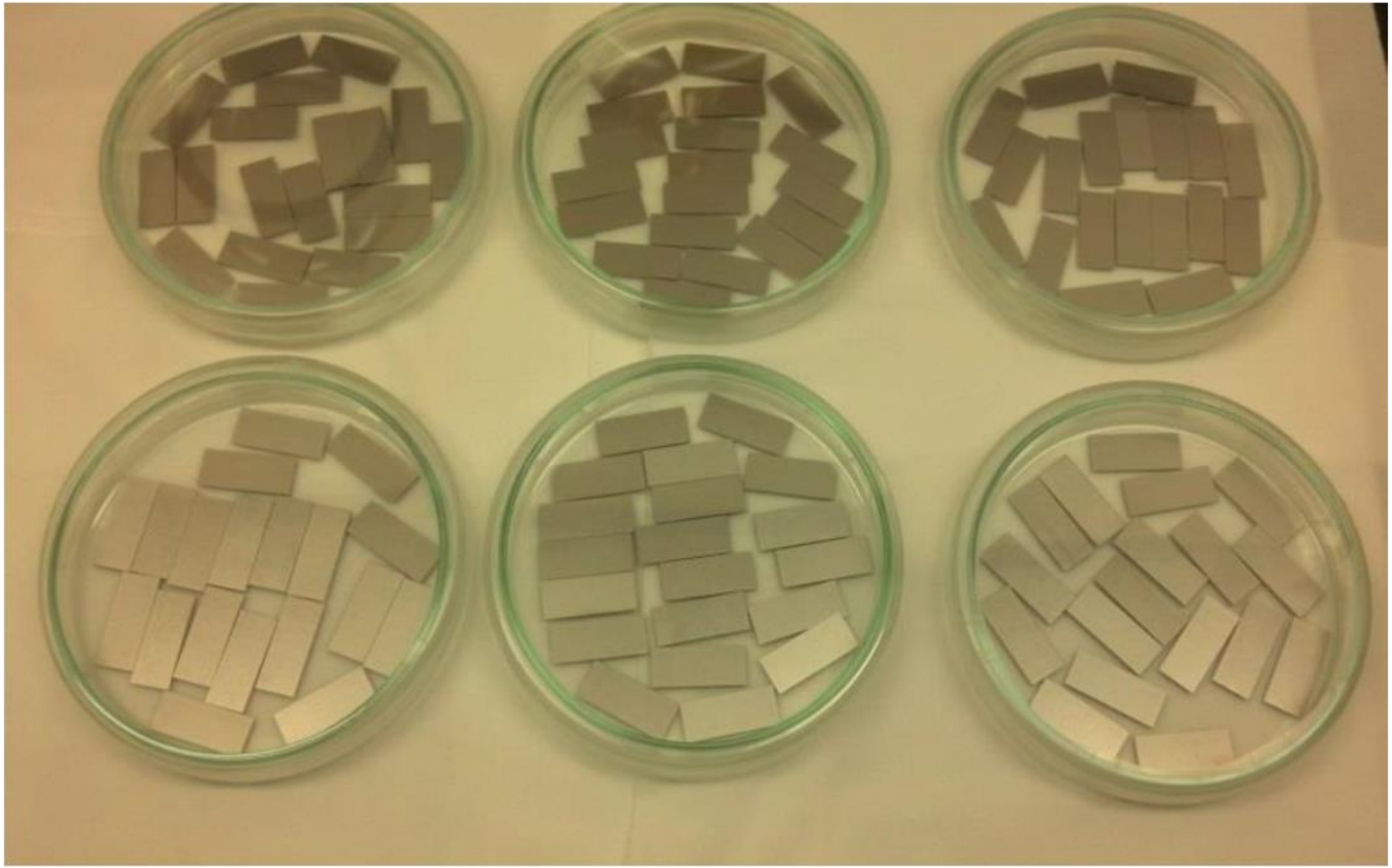
Pre-Cleaning



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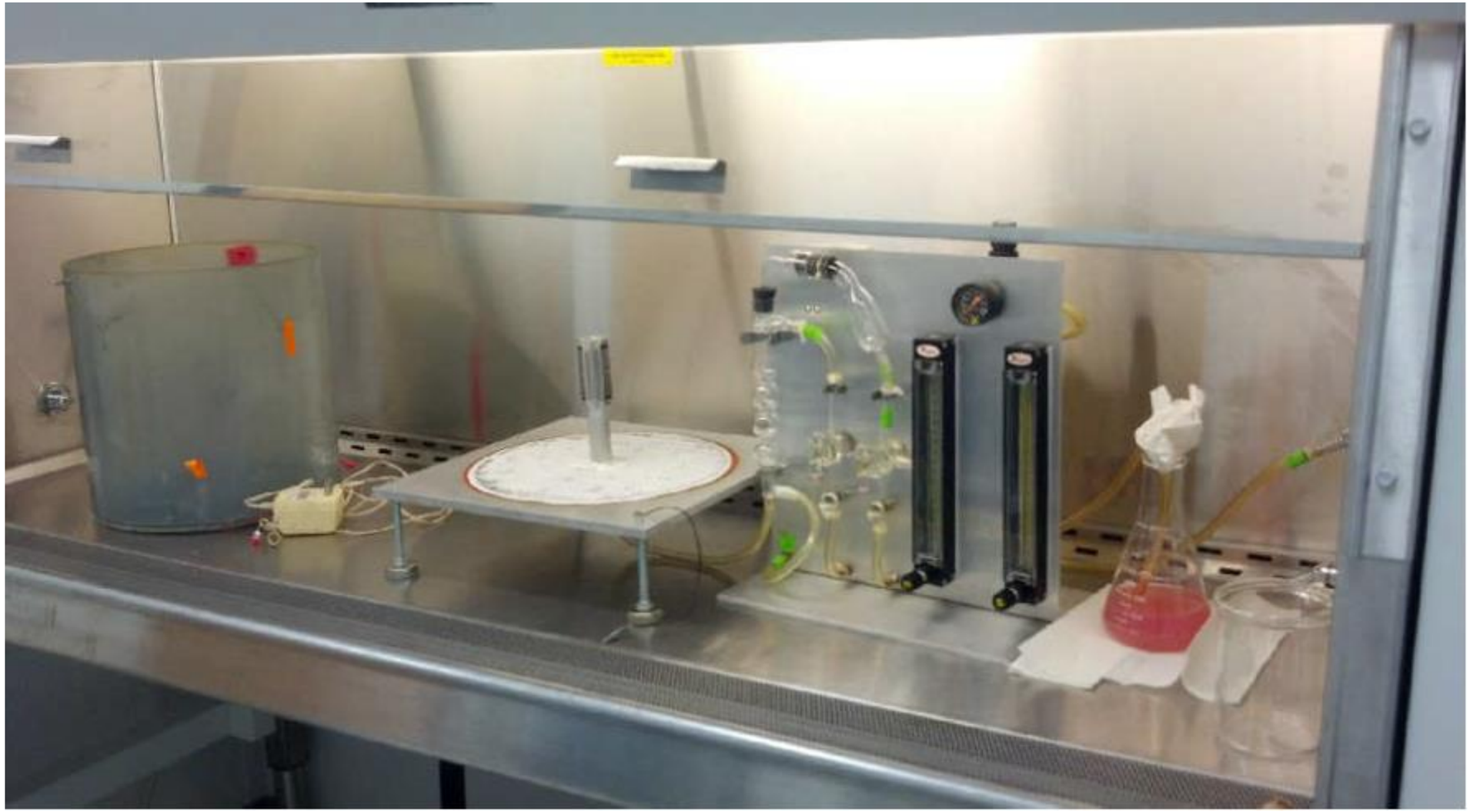
Aerosol Deposition (Dry Deposition)

Simulates natural fallout



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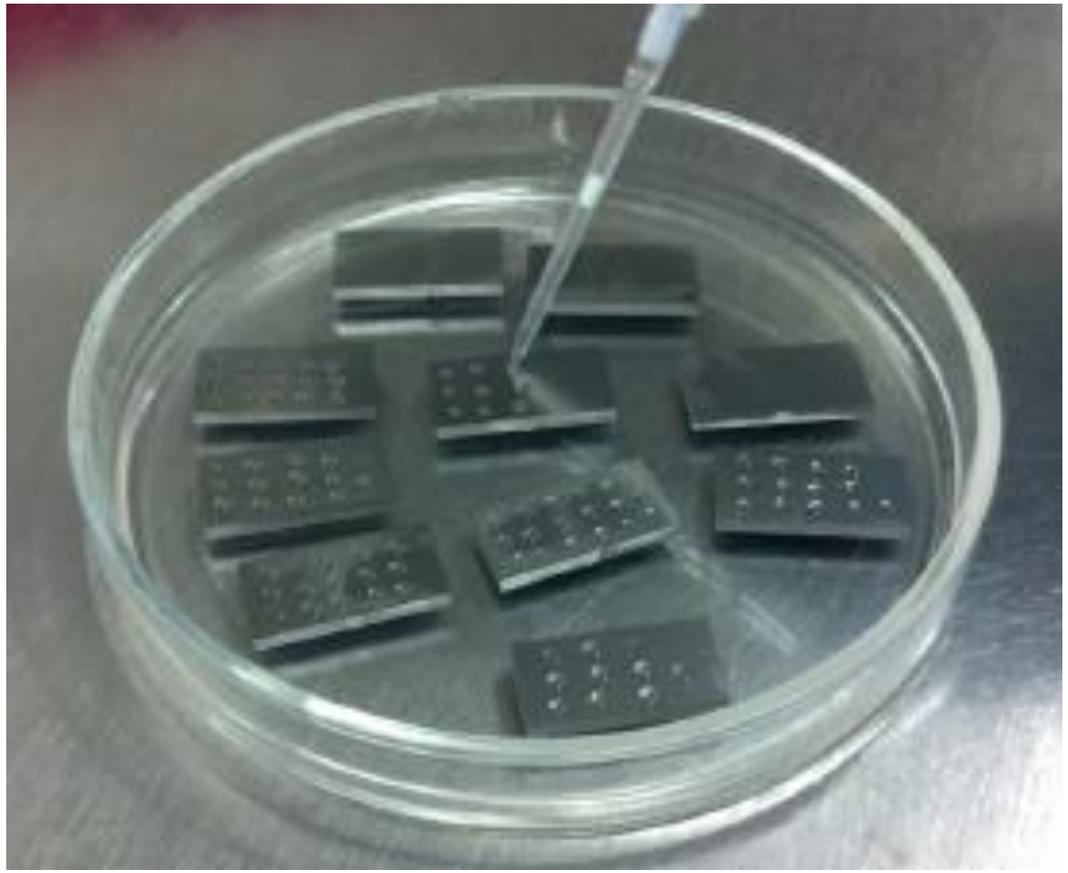
Droplet Deposition (Wet Deposition)



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CO_2 SnoPen Lab Set Up

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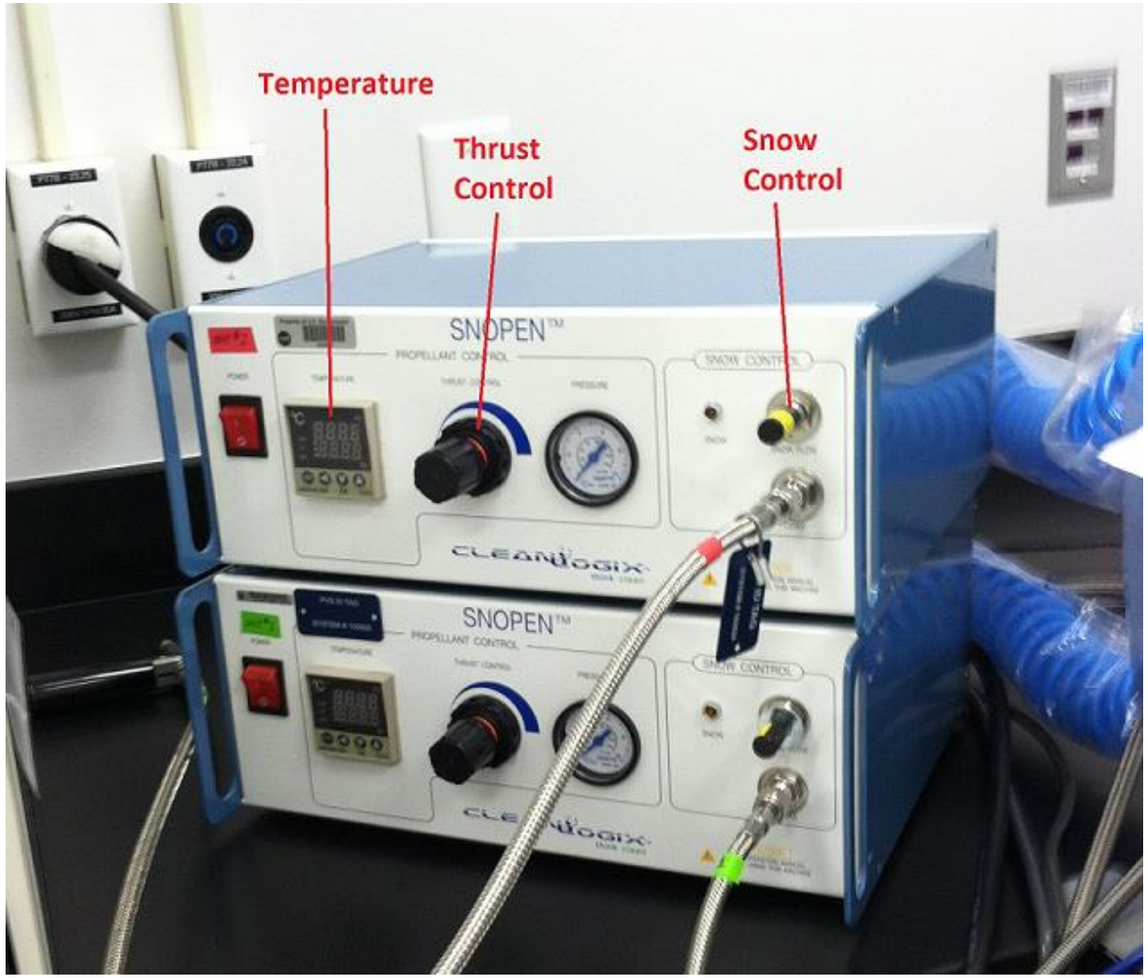
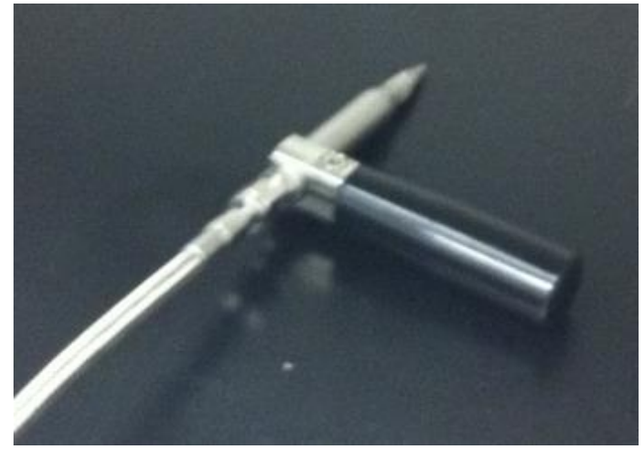
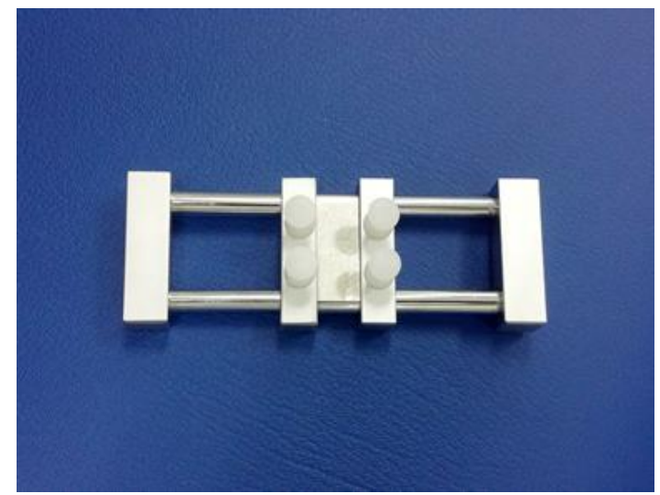
CO_2 SnoPen





SnoPen nozzle with handle

coupon holder



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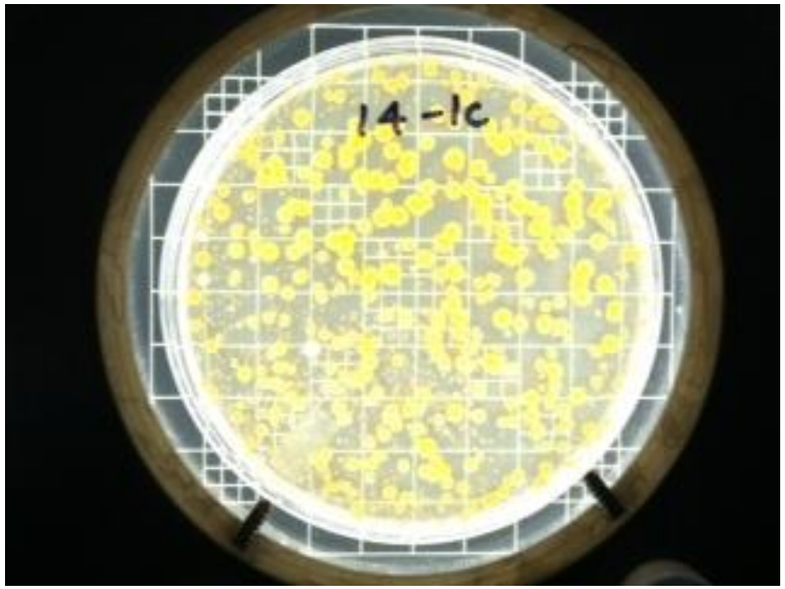
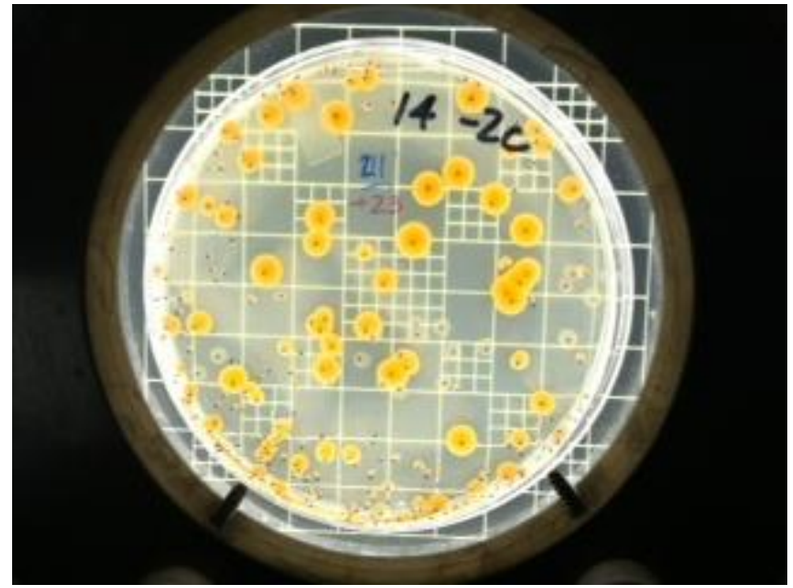
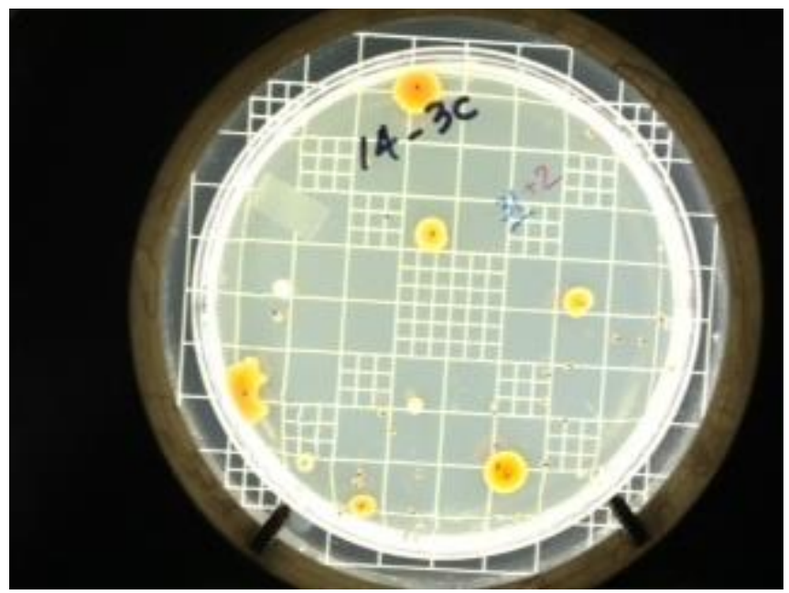
Optimal Process Parameters Defined

- Propellant (N_2) temperature = 130ºC
- Propellant (N_2) pressure = 40 psi
- CO_2 beam diameter = 1.5 mm
- CO_2 concentration = 1.3 – 1.65 lbs/hour
- Angle of incidence = 45º
- Distance from nozzle to substrate = 0.5 inch
- Spray pattern = uni-directional, horizontal/vertical
- # of passes = 3
- Time = 8 to 10 minutes

Spore Colony Counting







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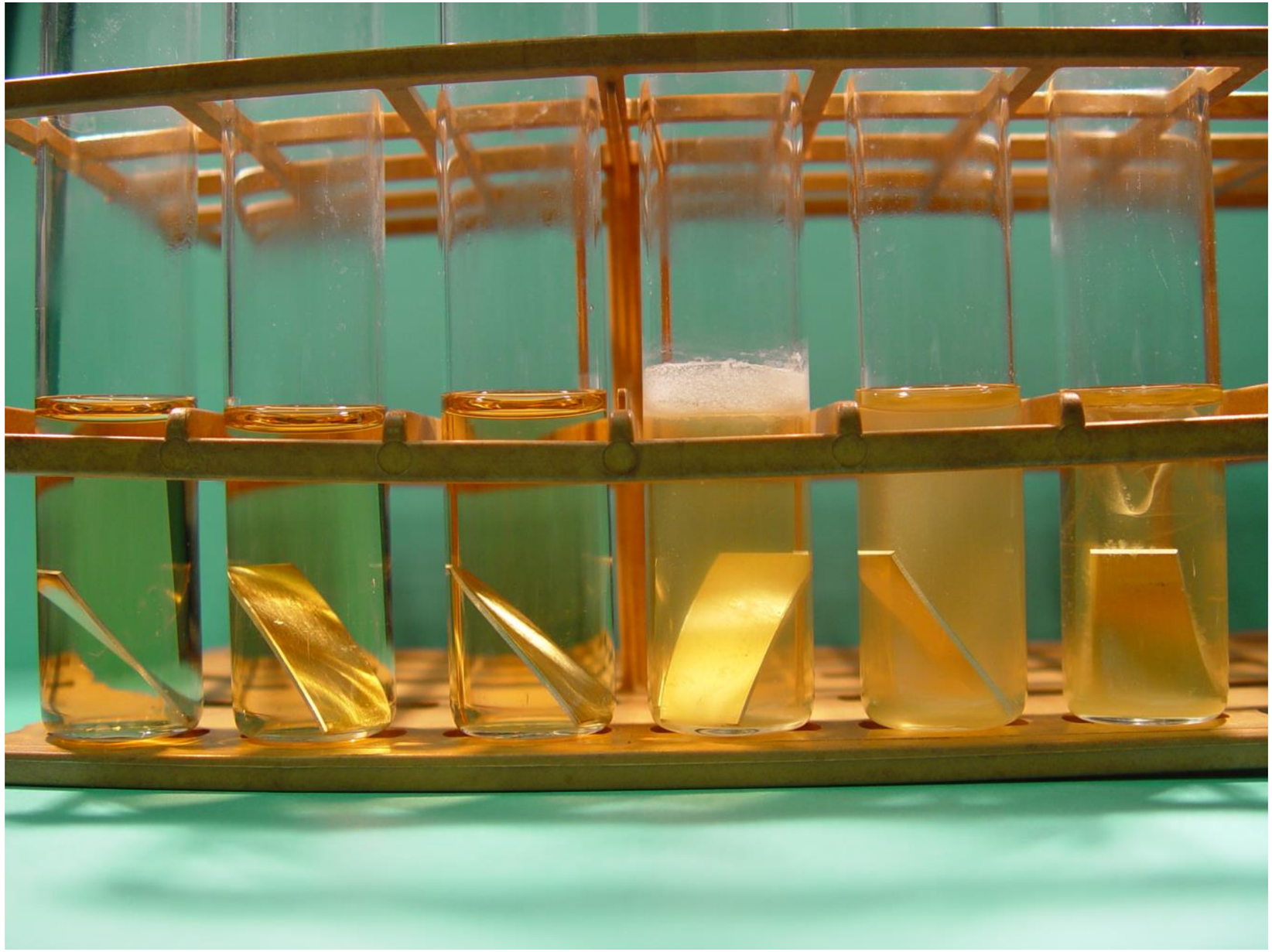
Tryptic Soy Broth Sterility Test



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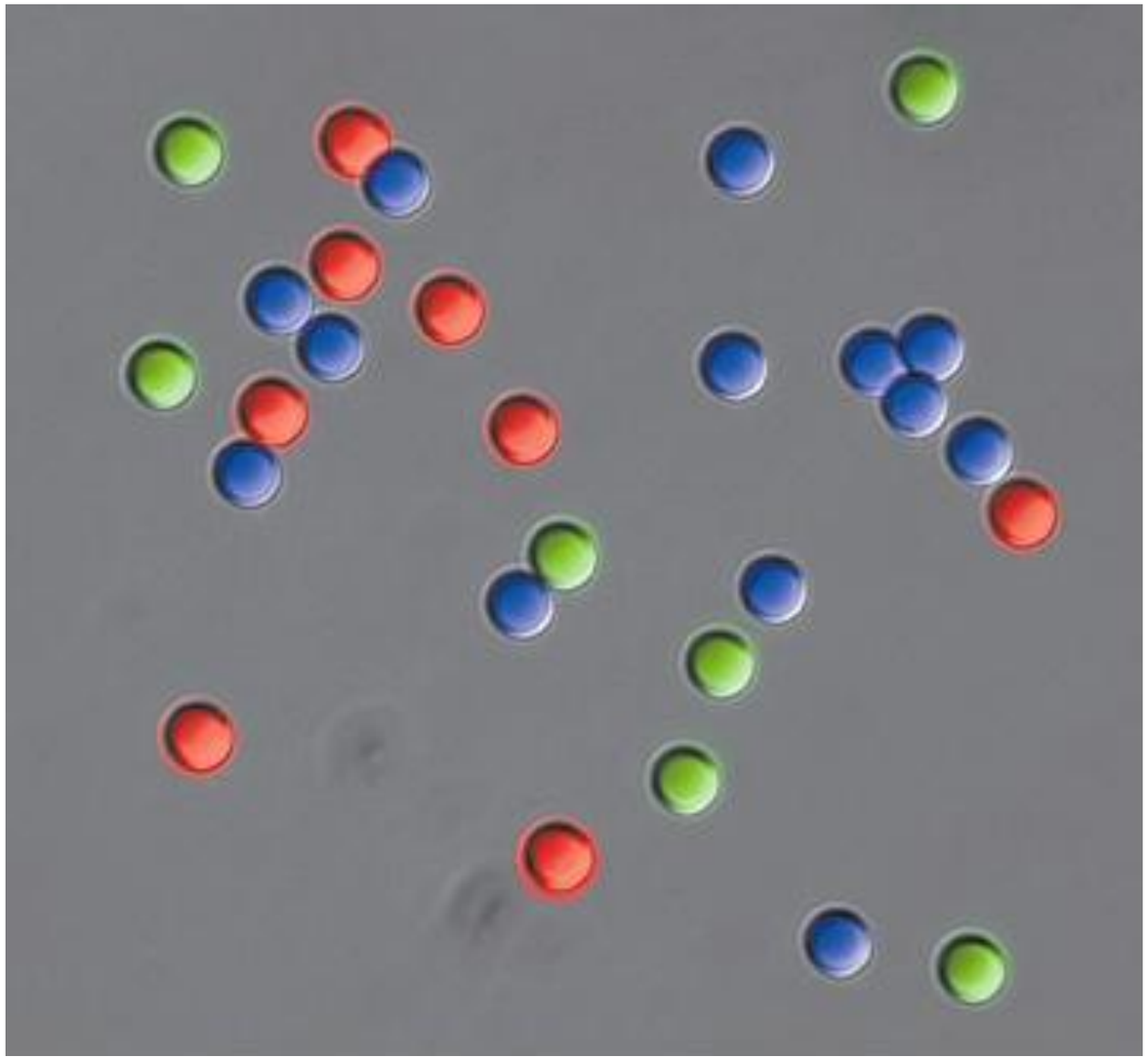
Fluorescent Polystyrene Microparticles



- FluoSpheres® Aldehyde-Sulfate Microspheres, 1.0µm, yellow-green fluorescent (505/515), 2% solids
- FluoSpheres® Carboxylate Modified Microspheres, 0.5µm, yellow-green fluorescent (505/515), 2% solids
- FluoSpheres® Sulfate Microspheres, 0.2µm, yellow-green fluorescent (505/515), 2% solids

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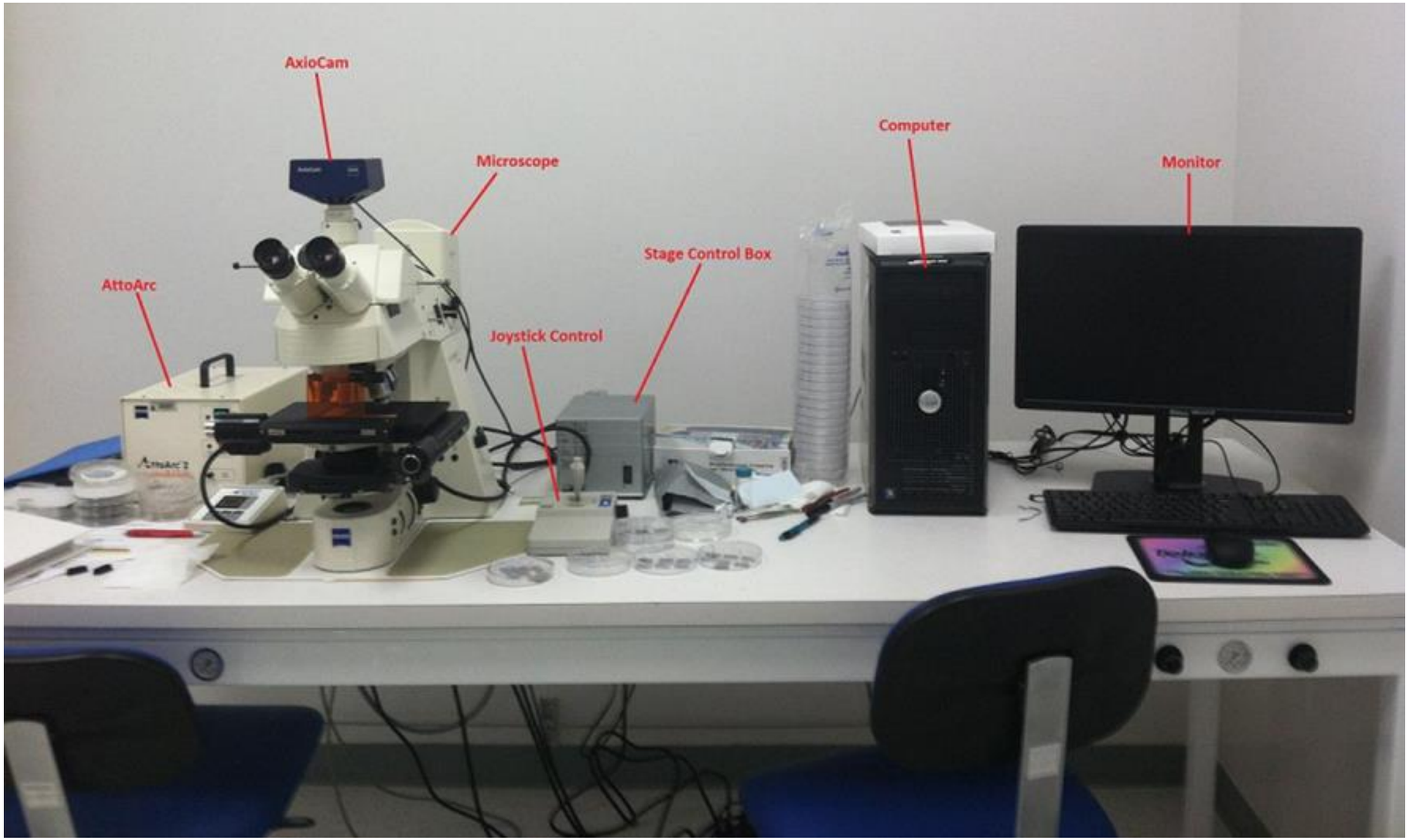
Microscope Set Up



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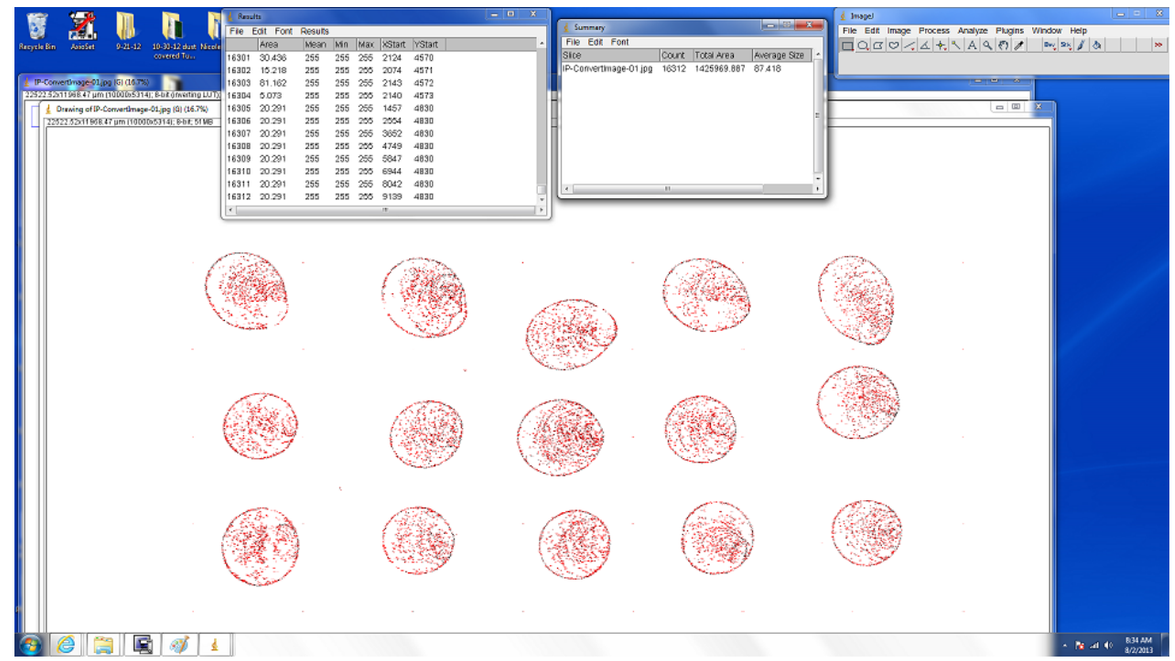
Scanning and Image Stitching

Zeiss Mosaix

ImageJ particle counting



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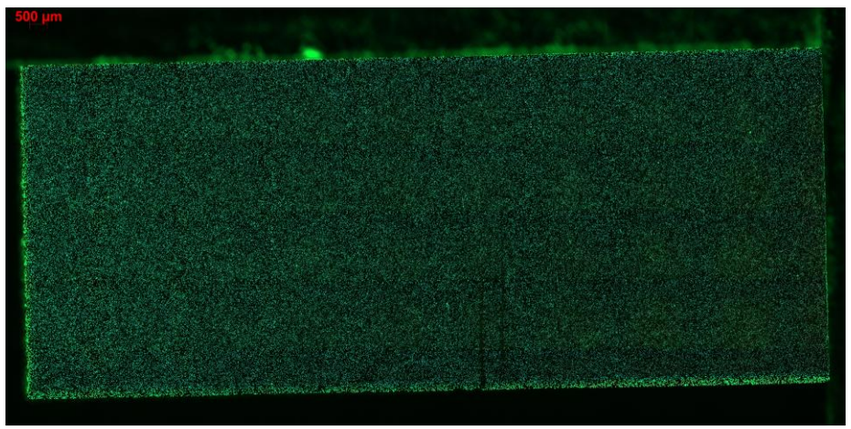
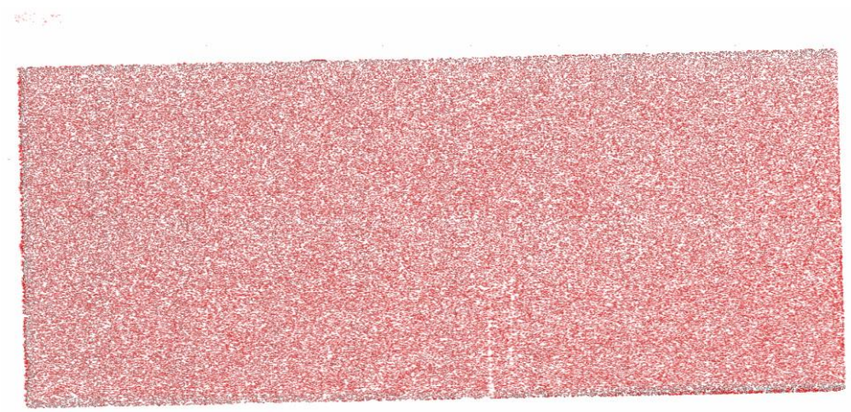
1µm Fluorescent Particles on Nitinol

Aerosol Deposition Pre-cleaned image

Scan Image



ImageJ Analyzed Image



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1µm Fluorescent Particles on Nitinol

Aerosol Deposition Post-cleaned image

Scan Image

ImageJ Analyzed Image

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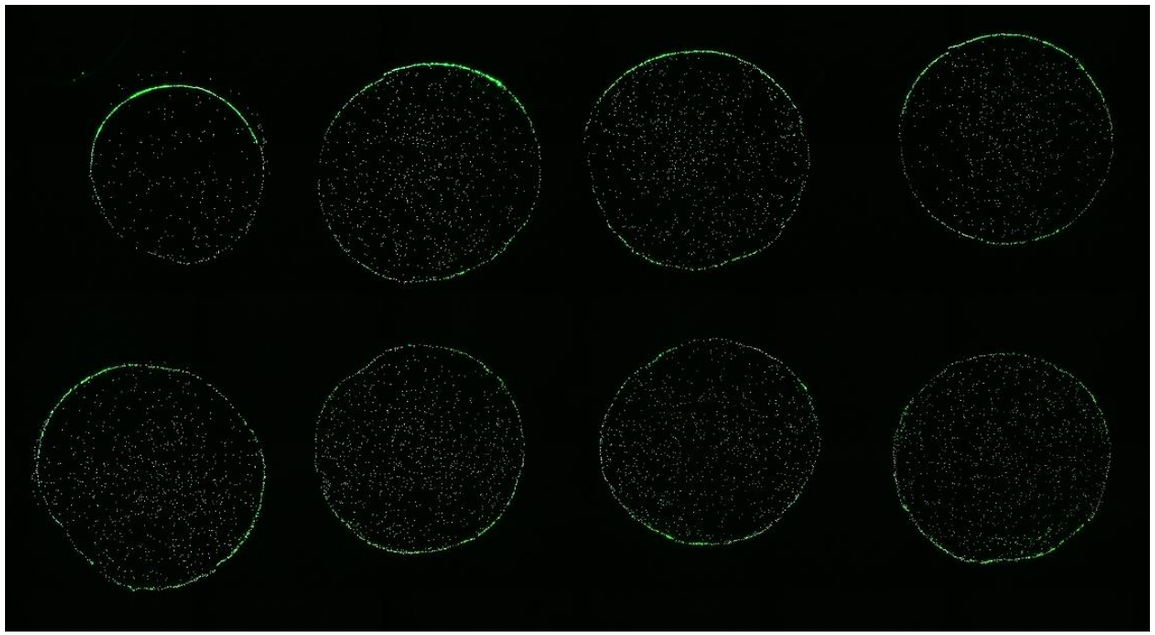
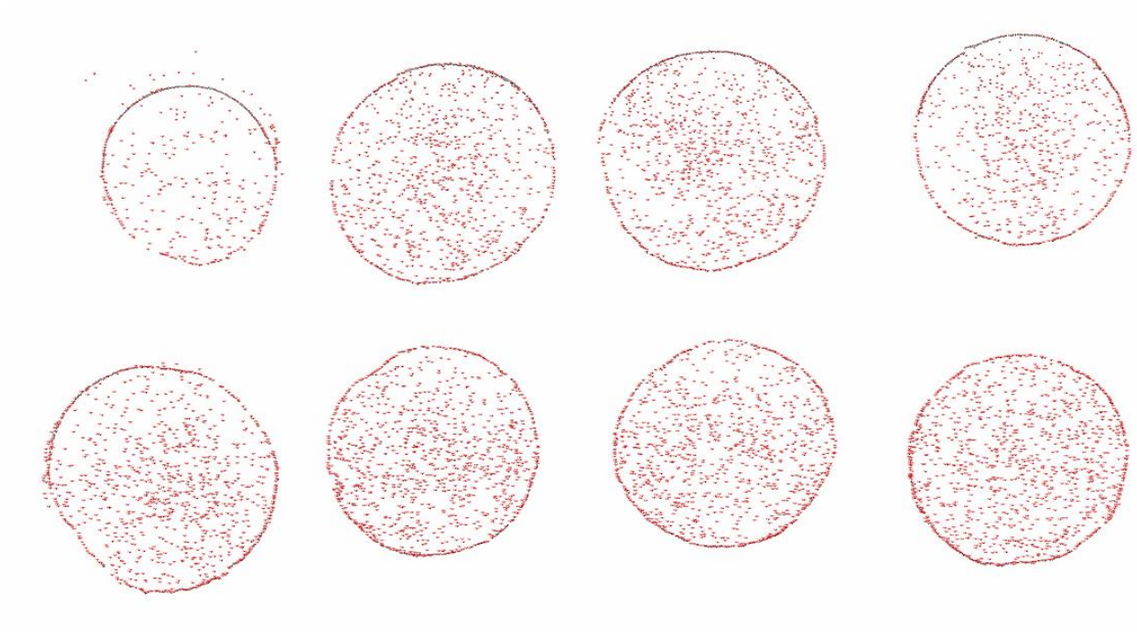
1µm Fluorescent Particles on Nitinol

Droplet Deposition Pre-cleaned image

Scan Image



ImageJ Analyzed Image



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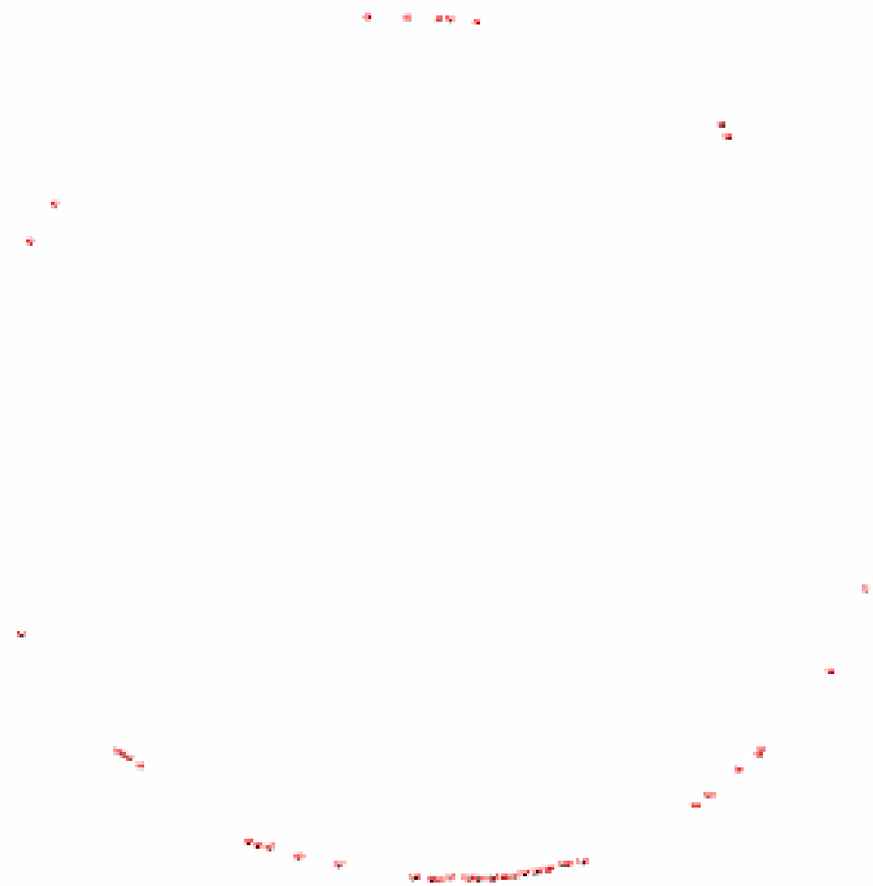
1µm Fluorescent Particles on Nitinol

ImageJ analyzed post CO_2 cleaned image zoomed image of single droplet



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Summary of Previous Study

- Planetary Protection's dry heat microbial reduction process receives a 4-log reduction credit against the bioburden.
- With the CO_2 SnoPen we are capable of getting to sterility for aerosol deposited spores and able to match the 4-log reduction for droplet deposited spores
- For sub-micron particles the CO_2 SnoPen is able to clean almost all the particles for aerosol deposited contaminants and is able to clean about 1 to 2 logs for droplet deposited contaminants.
  - For droplet deposited sub-micron contaminants, majority of the droplet seems to get removed. The only contaminants that remain seem to be the edges. It might be possible to remove these remaining particles by increasing cleaning time.

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Aerosol Deposition Fluorescent Particles on Nitinol rms 3 Results

Particle Size	Before (# of particles)	After (# of particles)	Log Reduction	Percent Removal
1.0µm	9.54e4 6.90e4 7.79e4	26 6 8	3.56 4.06 3.99	99.972 99.991 99.989
0.5µm	1.33e5 1.30e5 1.21e5	0 2 0	5.12 4.81 5.08	100 99.998 100
0.2µm	3.43e5 1.82e5 1.39e5	20 11 5	4.23 4.22 4.44	99.994 99.993 99.996

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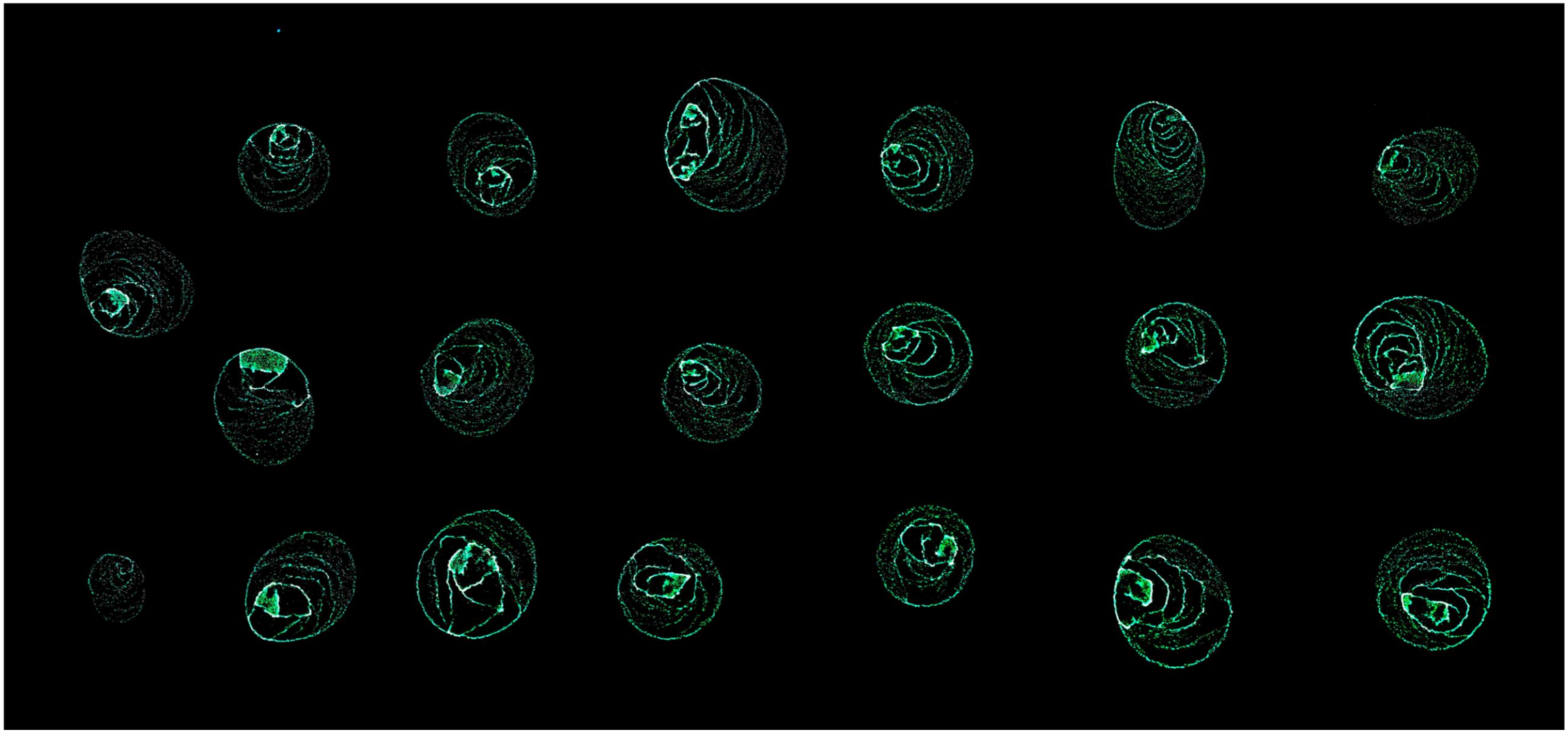
1µm Droplet Deposition - Stainless Steel

(Deposited 10^5) Representative scan image



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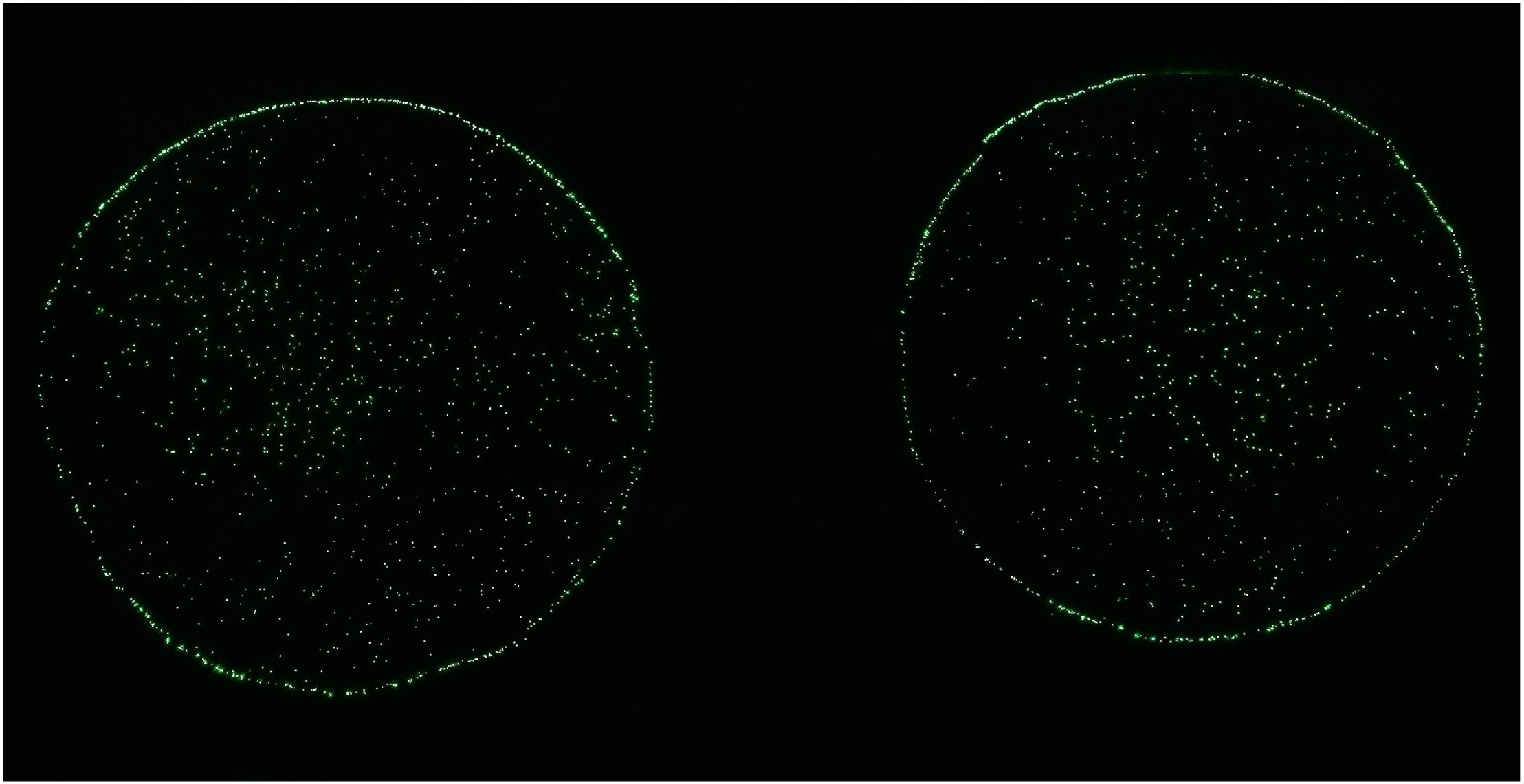
1µm Droplet Deposition - Nitinol

(Deposited 10^3) 50% ethanol



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Droplet Deposition Fluorescent Particles on Nitinol rms 3 Results

Particle Size	Before (# of particles)	After (# of particles)	Log Reduction	Percent Removal
1.0µm	1.39e3	196	0.85	85.899
	2.42e3	261	0.97	89.259
	1.42e3	150	0.98	89.436
	7.66e3	32	2.38	99.582
	8.17e3	4	3.31	99.951
	7.59e3	50	2.18	99.341
	4.47e4	132	2.53	99.704
	5.10e4	691	1.87	98.645
	4.94e4	193	2.41	99.609

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Droplet Deposition Fluorescent Particles on Nitinol rms 3 Results

Particle Size	Before (# of particles)	After (# of particles)	Log Reduction	Percent Removal
0.5µm	1.03e3	83	1.09	91.941
	1.30e3	116	1.05	91.076
	9.30e2	105	0.95	88.709
	7.68e3	185	1.62	97.591
	7.56e3	185	1.61	97.552
	7.22e3	307	1.37	95.747
	3.09e4	333	1.97	98.922
	4.48e4	1411	1.50	96.850
	4.56e4	1045	1.64	97.708
	1.49e3	419	0.55	71.935
	6.55e2	9	1.86	98.625
	7.85e2	439	0.25	44.076
	6.22e3	367	1.23	94.101
	1.48e4	118	2.10	99.204
	4.76e3	53	1.95	98.887
	7.59e3	2851	0.43	62.427
	1.32e4	3116	0.63	76.329
	1.05e4	857	1.09	91.863

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Droplet Deposition Fluorescent Particles on Nitinol rms 3 Results

Particle Size	Before (# of particles)	After (# of particles)	Log Reduction	Percent Removal
0.2µm	1.17e3	328	0.55	71.869
	4.09e2	380	0.03	7.090
	4.77e2	385	0.09	19.287
	6.73e3	2052	0.52	69.509
	2.28e3	814	0.45	64.219
	2.71e3	1218	0.35	55.088
	2.97e3	1159	0.41	61.002
	1.67e4	5423	0.49	67.598
	3.65e3	2144	0.23	41.211

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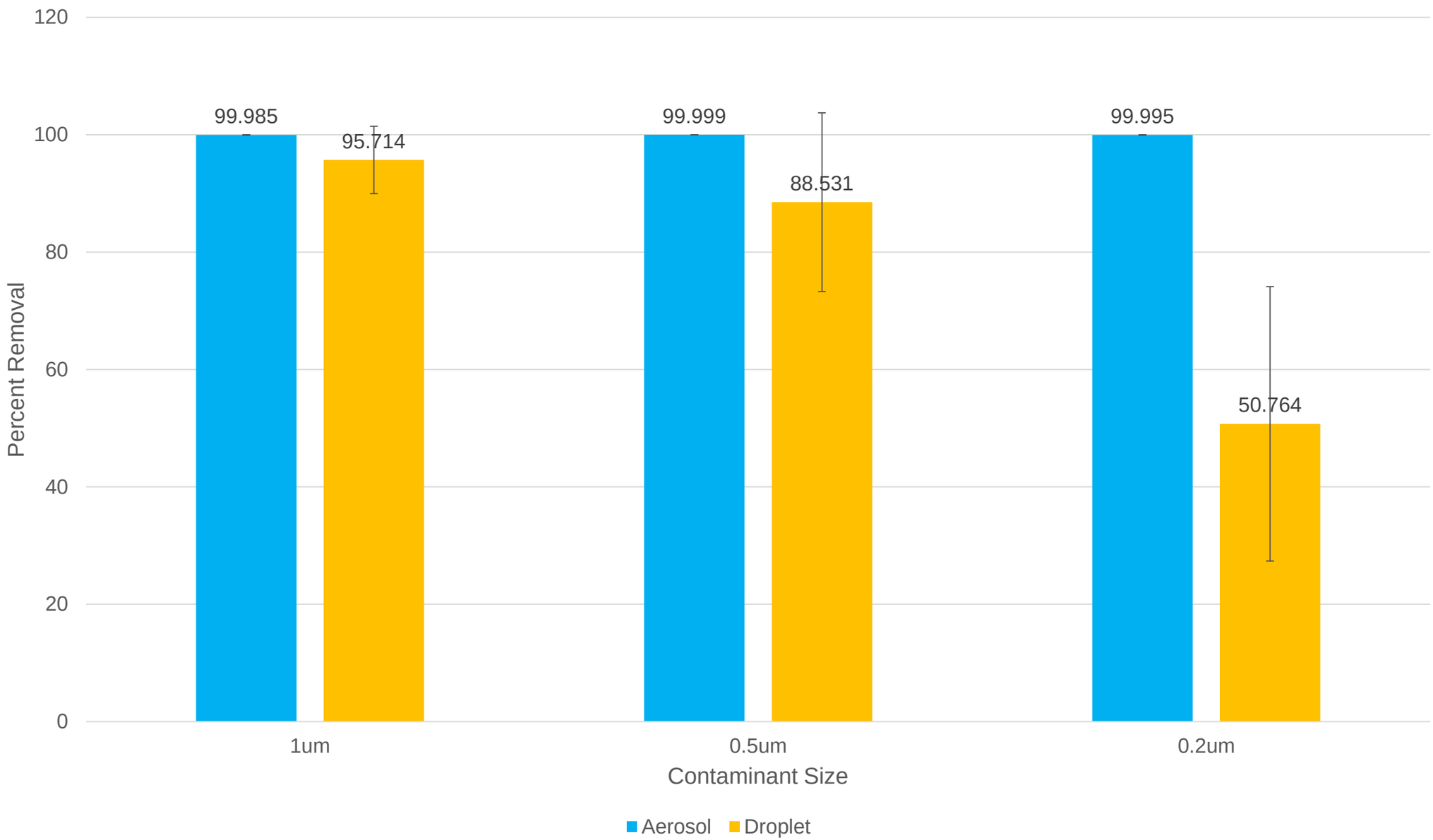
Fluorescent Particles Percent Removal on Nitinol rms 3



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Spore Study on Nitinol

Substrate	Deposition	Before (cfu)	After (cfu)	Log Red.	Percent Removal
Nitinol rms 14	Aerosol	8.93e5	0 0 0	Sterile Sterile Sterile	100 100 100
Nitinol rms 14	Droplet (100% water)	2.32e6	0 0 1	Not sterile Not sterile 6.37	100 100 99.999
Nitinol rms 3	Droplet (100% water)	1.04e6	1 0 0	6.02 Sterile Sterile	99.999 100 100
Nitinol rms 3	Droplet (50% ethanol)	5.58e5	25 52 1 29 8 84	4.35 4.03 5.75 4.28 4.84 3.82	99.995 99.990 99.999 99.994 99.998 99.984

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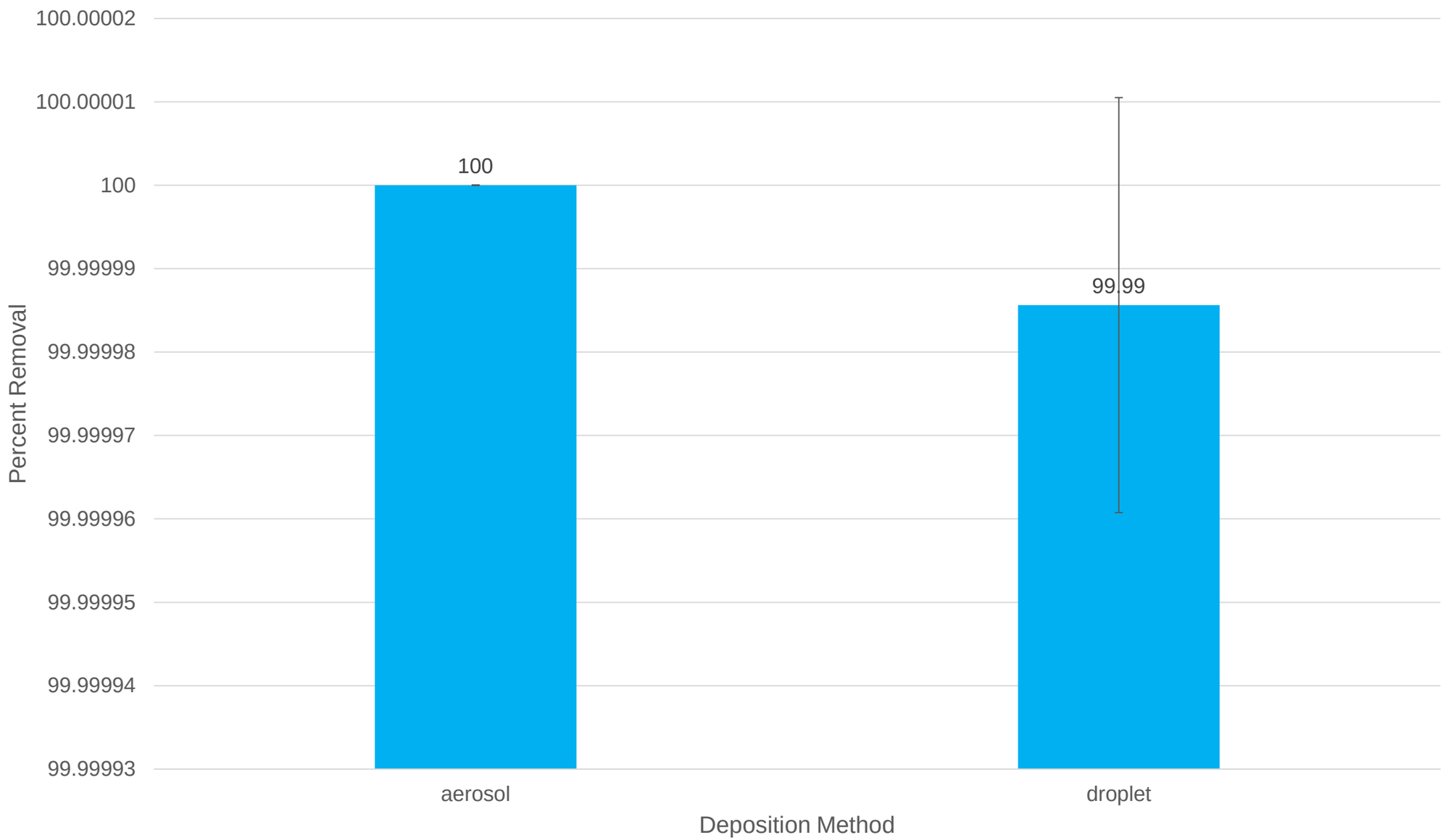
Comparison of Deposition Method for Spores on Nitinol rms 14



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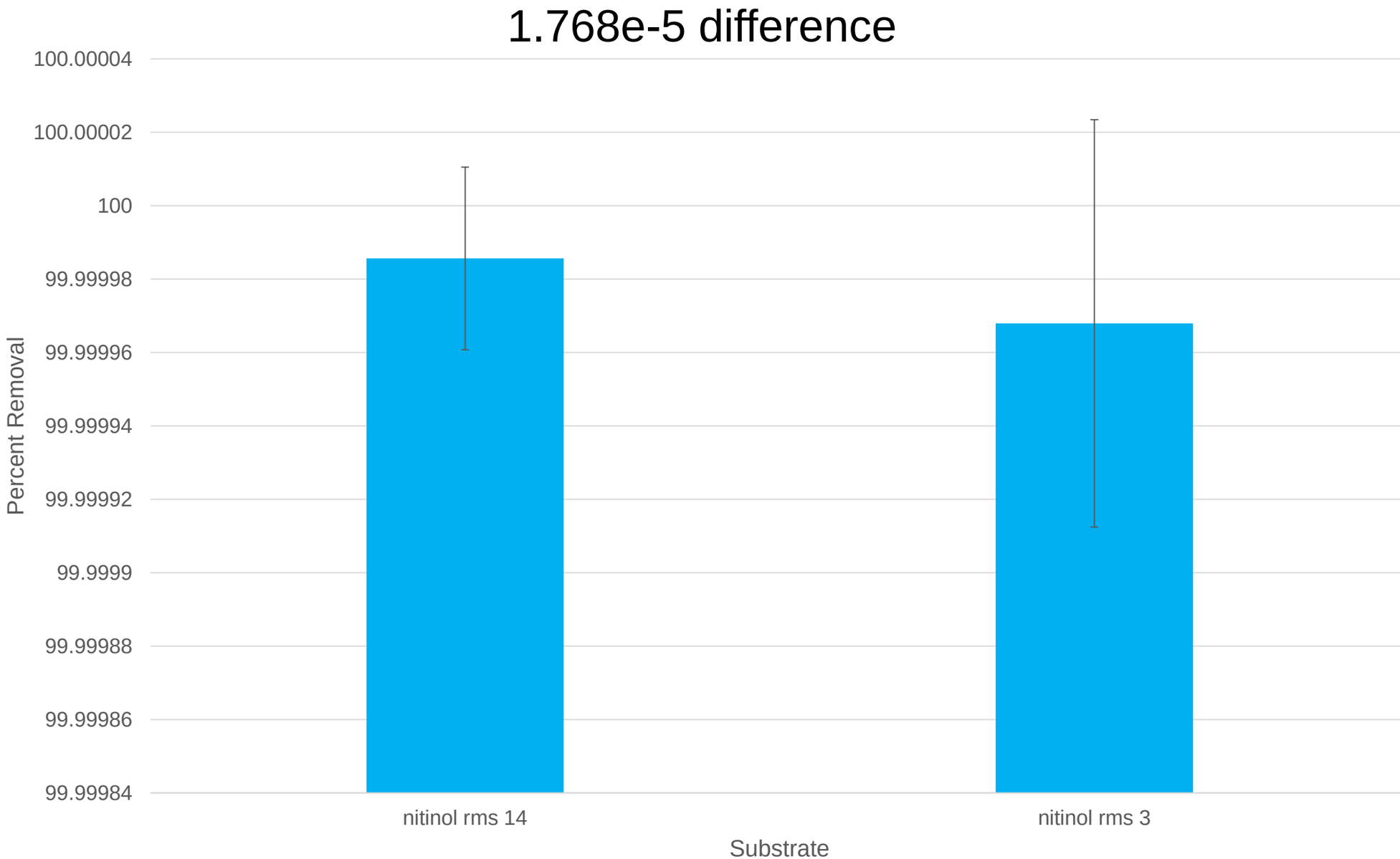
Comparison of Surface Roughness for Wet Deposited Spores on Nitinol rms 3



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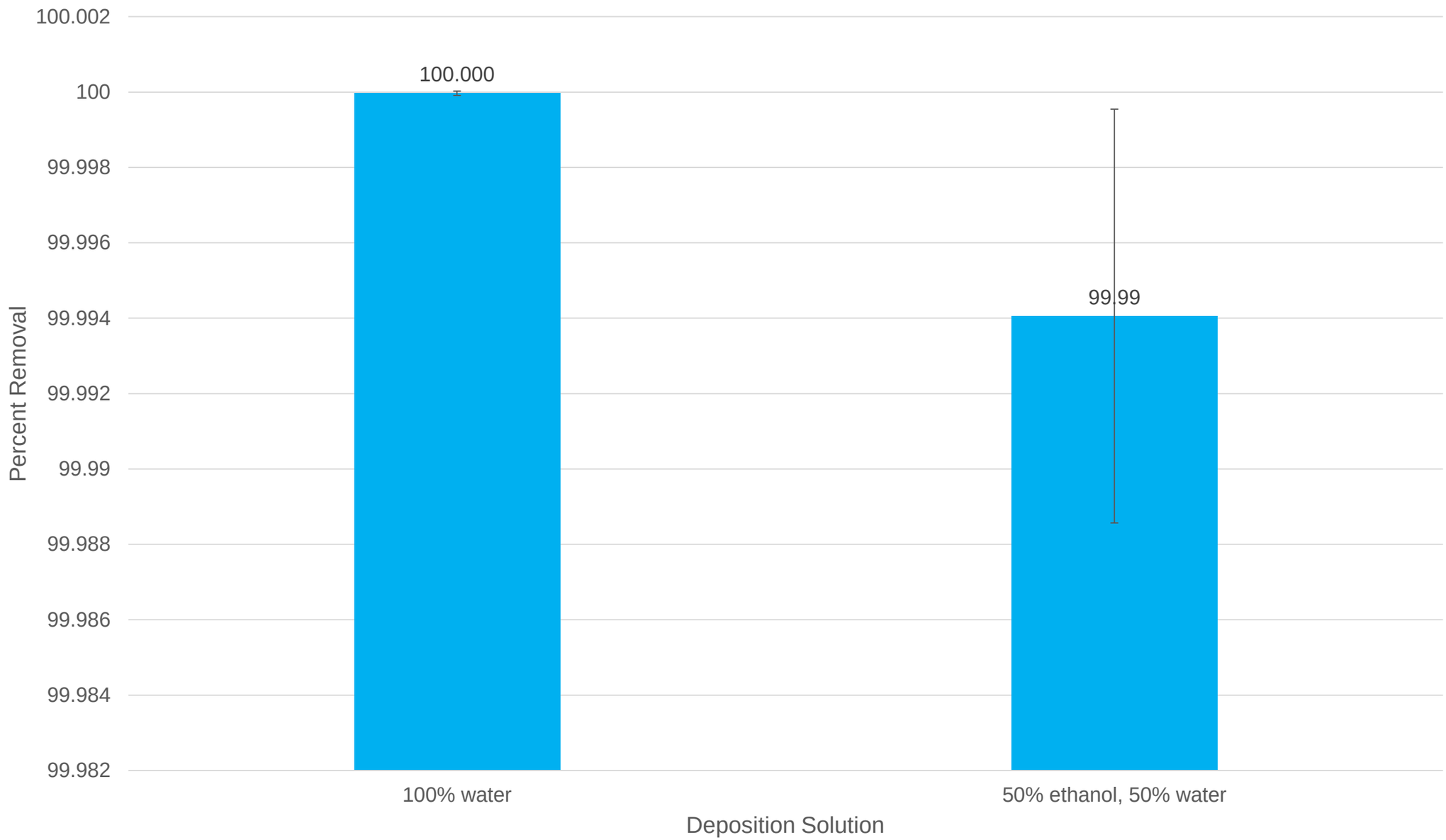
Comparison of Spore Suspension Solution for Wet Dep. On Nitinol rms 3



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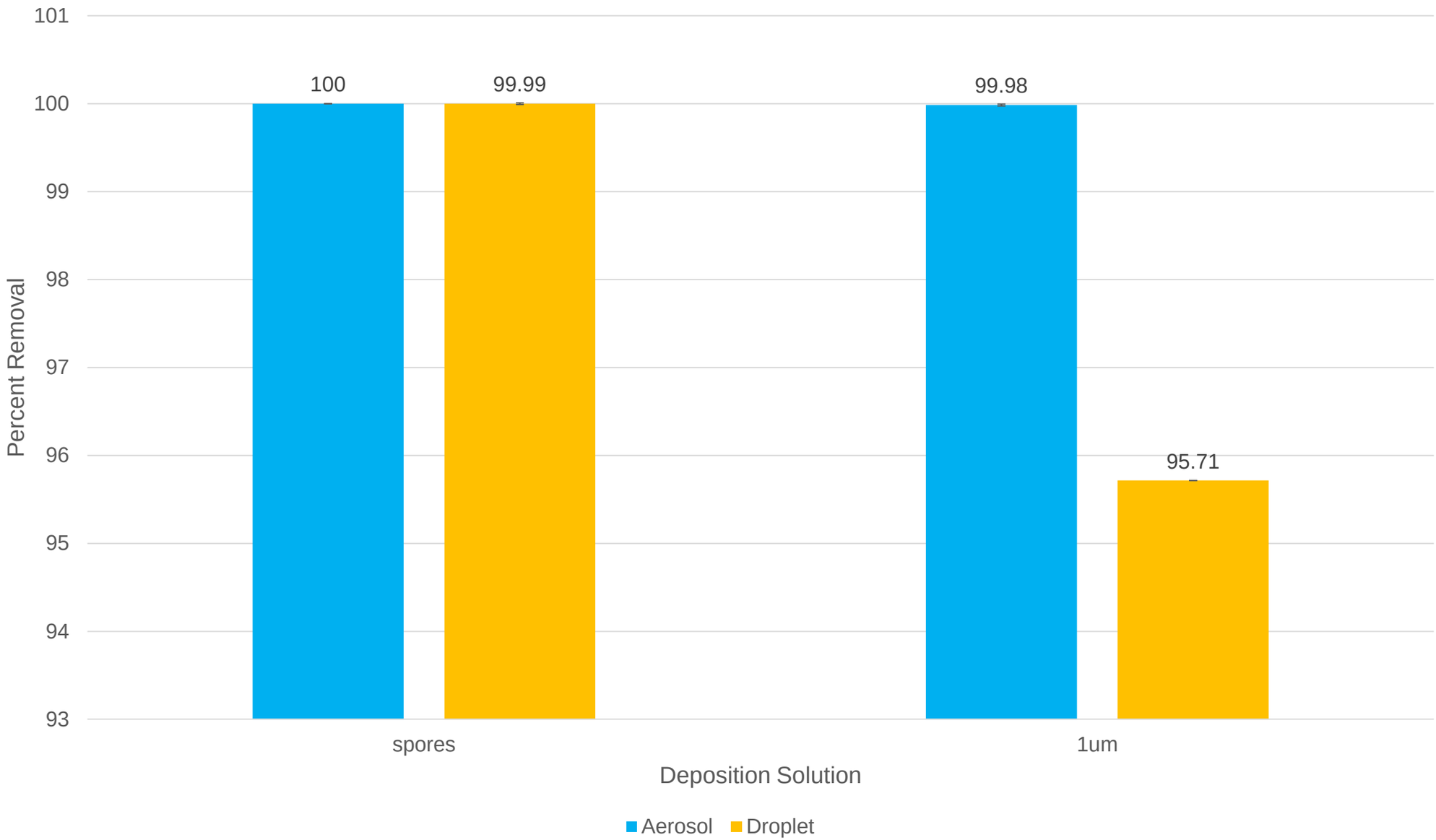
Spore and Fluorescent Particle Comparison on Nitinol



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Summary

- Spore contamination is more easily cleaned than submicron fluorescent particles
- CO_2 jet cleaning using the Cleanlogix SnoPen is an effective method for achieving planetary protection requirements
- Spore contaminants and 1µm fluorescent particles have similar cleaning results
- Aerosol deposited fluorescent particles have a high removal percentage but droplet deposited fluorescent particles have a much lower removal percentage

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Acknowledgements

Shirley Chung

Ying Lin

Melynda Jaramillo

David Jackson

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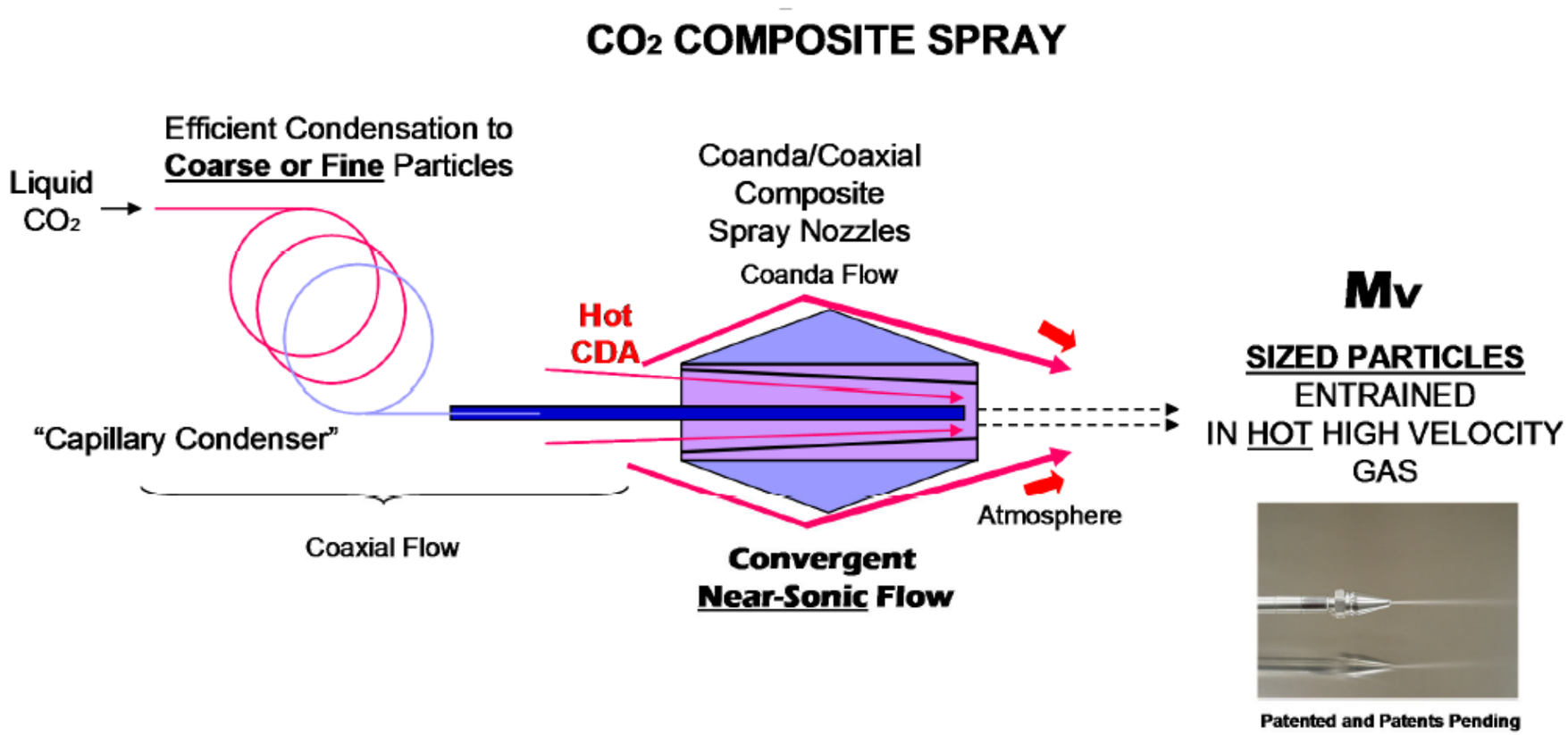
Back Up Slides

CO_2 Composite Spray Technology



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Spore Cleaning Data on Al6061

Substrate	Deposition method	# spores before cleaning	# spores after cleaning	Log reduction
Al6061 rms 5.5	aerosol	1.36E+05	6	4.34
Al6061 rms 5.5	aerosol	1.36E+05	4	4.56
Al6061 rms 5.5	aerosol	1.36E+05	0	sterile
Al6061 rms 5.5	droplet	1.58E+06	90	4.24
Al6061 rms 5.5	droplet	1.58E+06	3	5.80
Al6061 rms 5.5	droplet	1.58E+06	20	4.90
Polished Al rms 2	aerosol	2.91E+06	3	6.07
Polished Al rms 2	aerosol	2.91E+06	3	6.07
Polished Al rms 2	aerosol	2.91E+06	8	5.59
Polished Al rms 2	droplet	7.13E+05	44	4.21
Polished Al rms 2	droplet	7.13E+05	20	4.55
Polished Al rms 2	droplet	7.13E+05	33	4.34
Anodized clear	aerosol	3.21E+06	43	4.88
Anodized clear	aerosol	3.21E+06	55	4.77
Anodized clear	aerosol	3.21E+06	26	5.09
Anodized clear	droplet	7.71E+05	53	4.17
Anodized clear	droplet	7.71E+05	23	4.53
Anodized clear	droplet	7.71E+05	28	4.45

Rms =surface roughness in root mean square micro-inches

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Spore Cleaning Data on Nitinol

Substrate	Deposition method	# spores before cleaning	# spores after cleaning	Log reduction
Nitinol, rms 14	aerosol	8.93E+05	0	sterile
Nitinol, rms 14	aerosol	8.93E+05	0	sterile
Nitinol, rms 14	aerosol	8.93E+05	0	sterile
Nitinol, rms 14	droplet	2.32E+06	0	not sterile
Nitinol, rms 14	droplet	2.32E+06	0	not sterile
Nitinol, rms 14	droplet	2.32E+06	1	6.27
Nitinol, rms 3	droplet	1.04E+06	1	5.92
Nitinol, rms 3	droplet	1.04E+06	0	sterile
Nitinol, rms 3	droplet	1.04E+06	0	sterile

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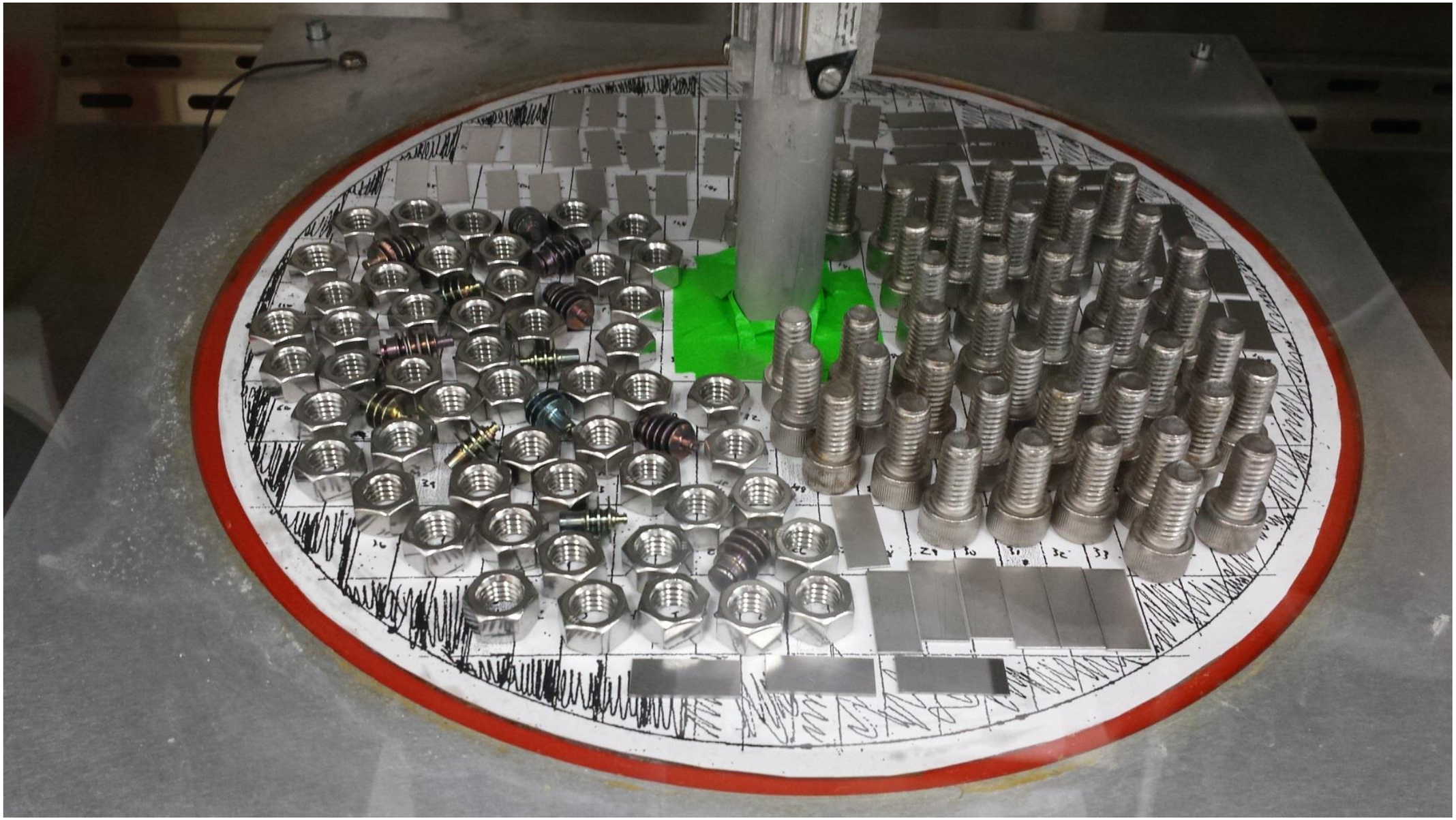
Aerosol Deposition on 3D Substrates



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Nitinol Plugs

Old Design

New Design

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3D Substrate Cleaning Data

3D Part	Deposition method	# spores before cleaning	# spores after cleaning	Log reduction
Stainless Steel Bolts	aerosol	3.23E+05	5	4.81
Stainless Steel Bolts	aerosol	3.23E+05	5	4.81
Stainless Steel Bolts	aerosol	3.23E+05	4	4.94
Stainless Steel Bolts	aerosol	3.23E+05	11	4.46
Stainless Steel Bolts	aerosol	3.23E+05	4	4.94
Stainless Steel Bolts	aerosol	3.23E+05	14	4.37
Stainless Steel Nuts	aerosol	1.33E+05	6	4.35
Stainless Steel Nuts	aerosol	1.33E+05	0	not sterile
Stainless Steel Nuts	aerosol	1.33E+05	1	5.03
Stainless Steel Nuts	aerosol	1.33E+05	0	not sterile
Stainless Steel Nuts	aerosol	1.33E+05	0	not sterile
Stainless Steel Nuts	aerosol	1.33E+05	4	4.52
Nitinol plugs - old design	aerosol	1.29E+05	0	sterile
Nitinol plugs - old design	aerosol	1.29E+05	0	not sterile
Nitinol plugs - old design	aerosol	1.29E+05	5	4.41
Nitinol plugs - new design	aerosol	1.17E+05	0	sterile
Nitinol plugs - new design	aerosol	1.17E+05	0	sterile
Nitinol plugs - new design	aerosol	1.17E+05	1	5.07

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1µm Fluorescent Particles

Aerosol Deposition

Material	Before Cleaning	After Cleaning	Log Reduction	Negative Control
Nitinol	9.54E+04 6.90E+04 7.79E+04	8 5 1	4.08 4.14 4.89	41±19
Titanium	7.64E+04 9.93E+04 7.31E+04	4 0 8	4.28 5.00 3.96	16±1
Stainless Steel	9.55E+04 9.25E+04 9.46E+04	26 6 8	3.57 4.19 4.07	46±8

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0.5µm Fluorescent Particles on Nitinol

Aerosol Deposition

Before Cleaning	After Cleaning	Log Reduction
1.33E+05	0	5.12
1.30E+05	2	4.81
1.21E+05	0	5.08

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0.2µm Fluorescent Particles on Nitinol

Aerosol Deposition

Before Cleaning	After Cleaning	Log Reduction
3.43E+05	20	4.23
1.82E+05	11	4.22
1.39E+05	5	4.44

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1µm Fluorescent Particles on Nitinol

Droplet Deposition

Before Cleaning	After Cleaning	Log Reduction
1.39E+03	196	0.85
2.43E+03	261	0.97
1.42E+03	150	0.98
7.66E+03	32	2.38
8.17E+03	4	3.31
7.59E+03	50	2.18
4.47E+04	132	2.53
5.10E+04	691	1.87
4.94E+04	193	2.41

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0.5µm Fluorescent Particles on Nitinol

Droplet Deposition

Before Cleaning	After Cleaning	Log Reduction
1.03E+03	83	1.10
1.30E+03	116	0.95
9.30E+02	105	0.95
7.68E+03	185	1.62
7.56E+03	185	1.61
7.22E+03	307	1.37
3.09E+04	333	1.97
4.48E+04	1411	1.50
4.56E+04	1045	1.64

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