Advanced Treatment Process and Analytical Tool for Control of Nanoparticles in UPW

Presented by Microfier, Inc. – Manufacturer of the NanoLyzer and NanoBlocker

ULTRAPURE WATER MICRO 2016

AUSTIN, TEXAS

Arthur J. Ackermann, P.E.   Glen W. Wildermuth, P.E.

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CONTENT

I. The Need to Measure and Control UPW Nanoparticles during the Manufacture of Leading Edge Semiconductor Devices

II. Technology Summary

III. Removing Nanoparticles

IV. Characterization and Quantification of Nanoparticles

- Particle Concentration
- Charge Characteristics
- Elemental Concentration
- Morphology

V. Troubleshooting Case Study

There is a Need to Measure and Control UPW Nanoparticles during the Manufacture of Leading Edge Semiconductor Devices

- As integrated circuits have continued to grow more complex, reduced UPW particle contamination has always been required to improve yields.

- ITRS 2016 Requirement - less than 1,000 particles per liter at a critical particle size of 11 nm.

- Power Law predicts large concentration of 1 to 10 nm particles.

- Metrology is needed to directly measure particle concentration below 20nm. Optical particle counters have a minimum detection of 20 nm with a sensitivity of only 3 to 5%

- Metrology needed to better identify elemental constituents for particles below 100 nm.

Microfier Technology is Based on Electrical Principles and Particle Chemistry.

- **Ultrapure water is a non-conductive fluid**

Therefore: electromagnetic field can be established in UPW

- **Particles in ultrapure water have electrical charge**

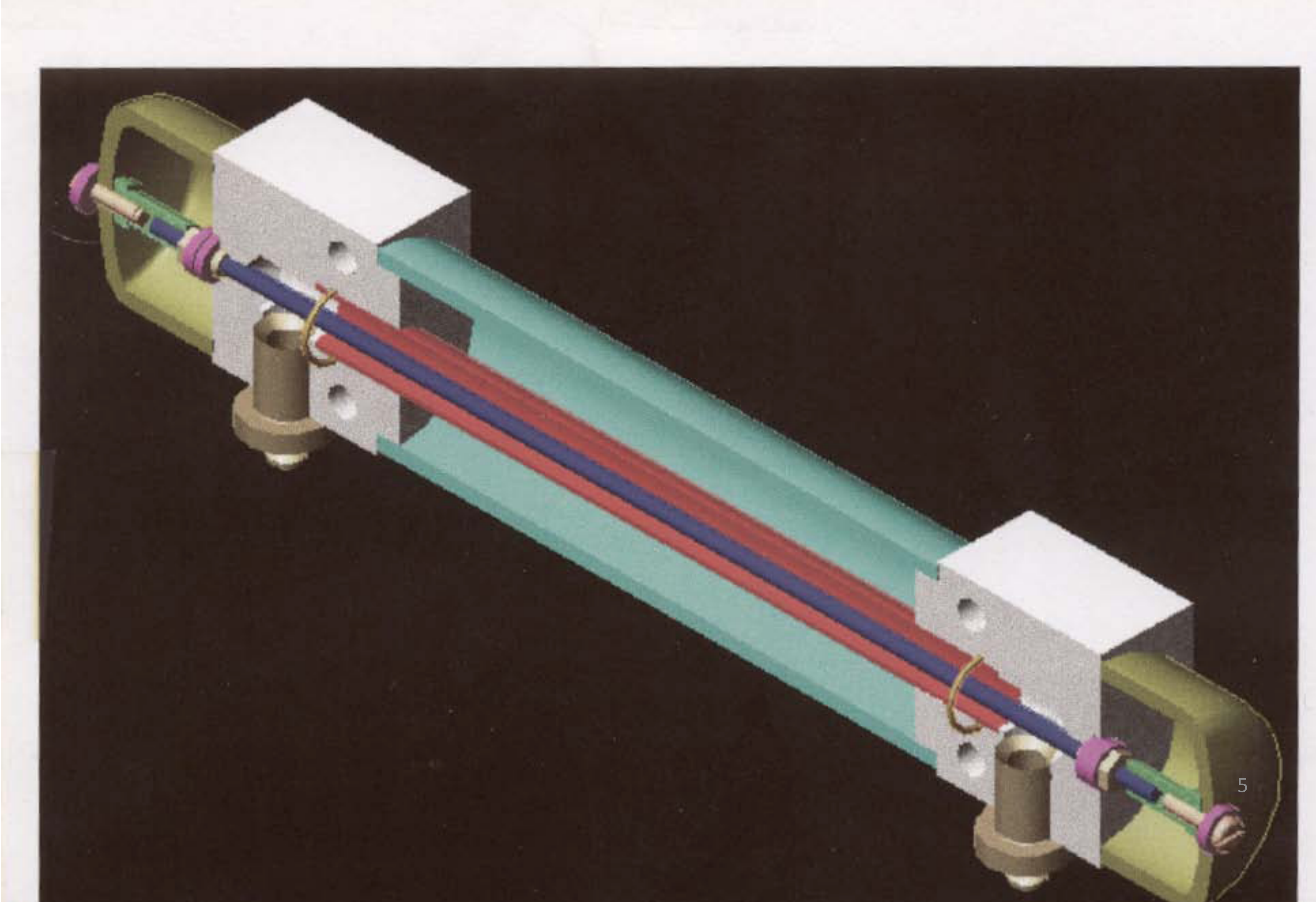
(due to ionization or the collection of charges on hydrophobic interface)

Therefore: particles can be mobilized based on $F = qE$

(force on particle = particle charge X electrical field strength)

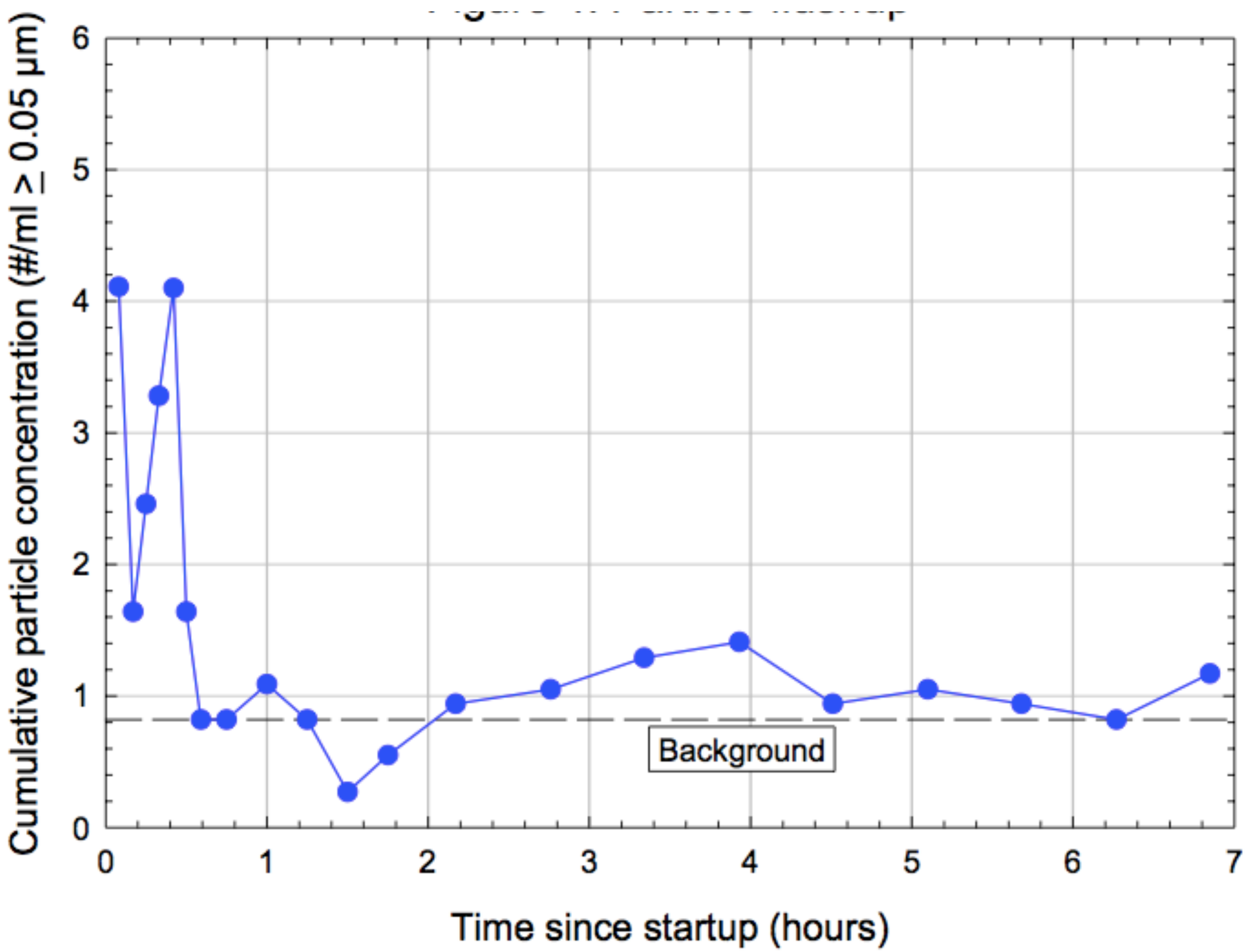
- **The coaxial electrical design and laminar flow conditions remove charged particles.**

Coaxial Design with Laminar Flow is a Patented, Efficient Technology for Removing Particles from UPW.

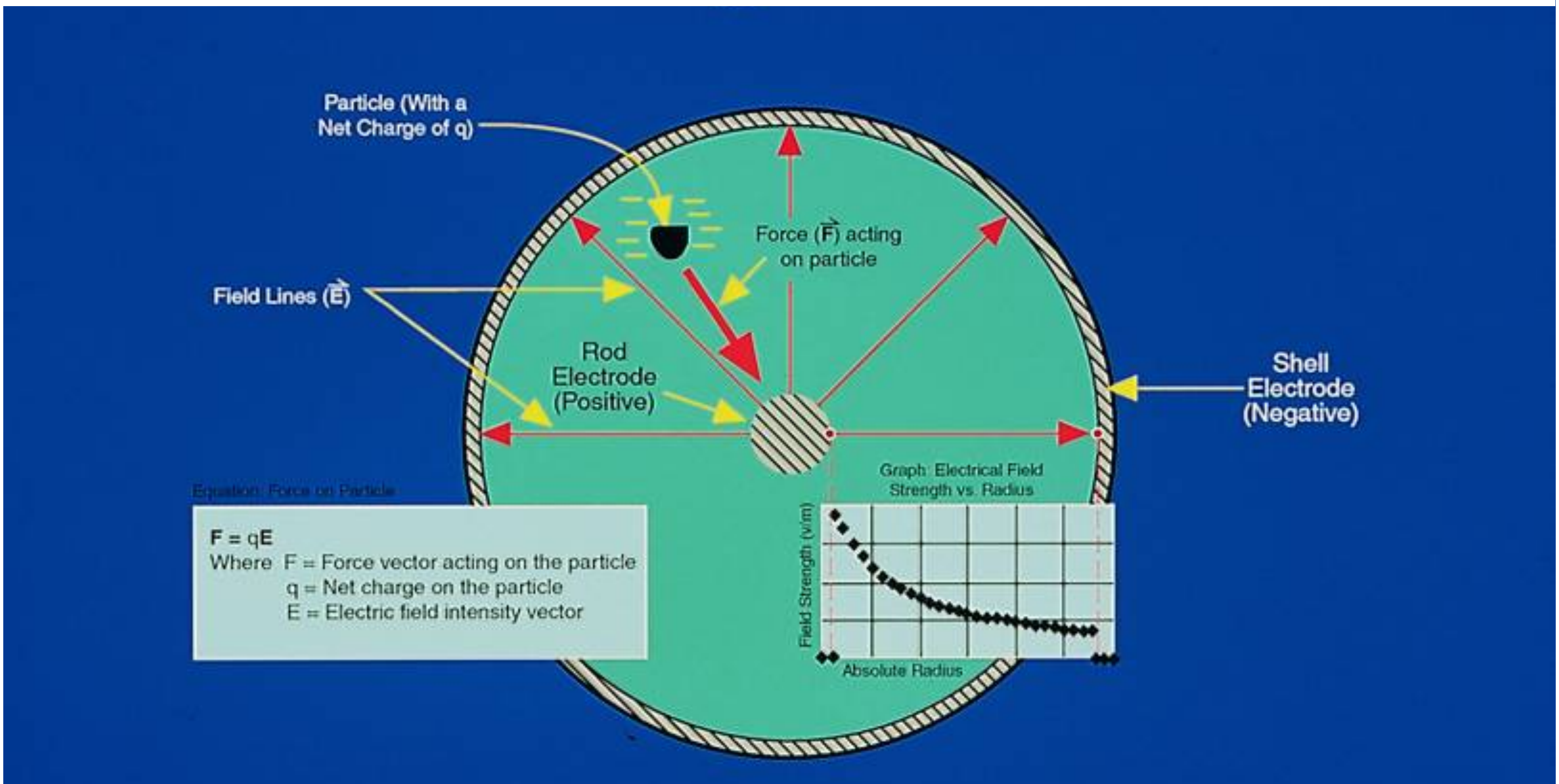


Membrane-Free Low Surface Area and Clean Design Provide Immediate Rinse-Up.

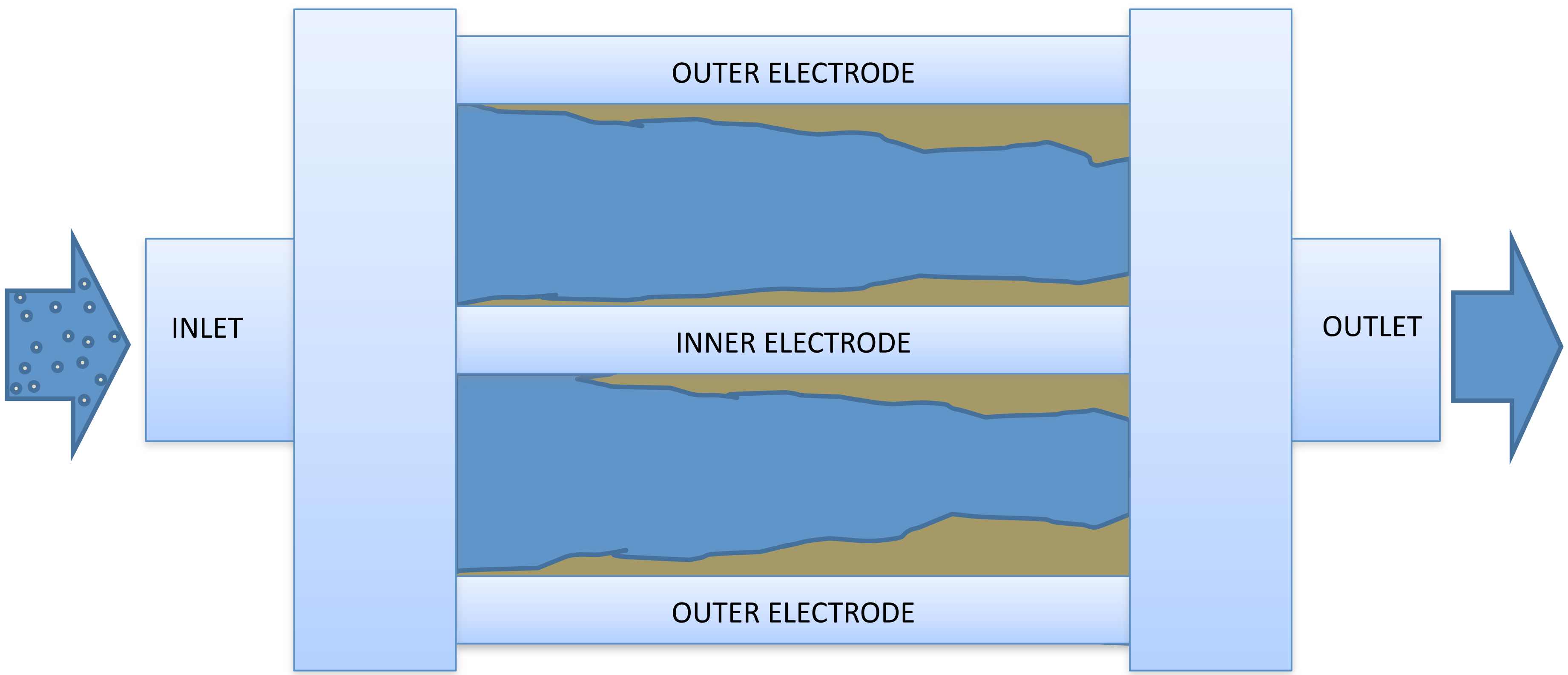
OPC Data from CT Associates



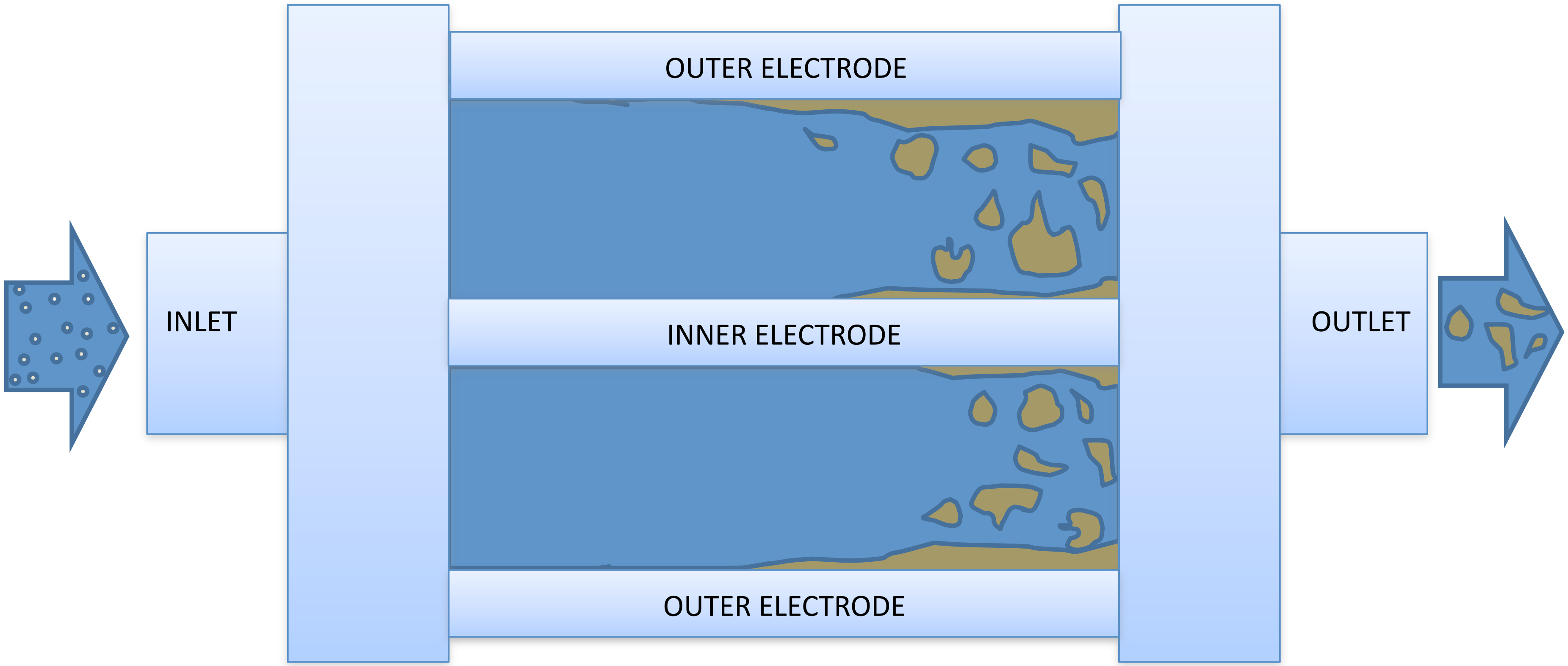
Cross-Section of Coaxial Chamber Illustrates the Removal of Particles from Ultrapure Water.



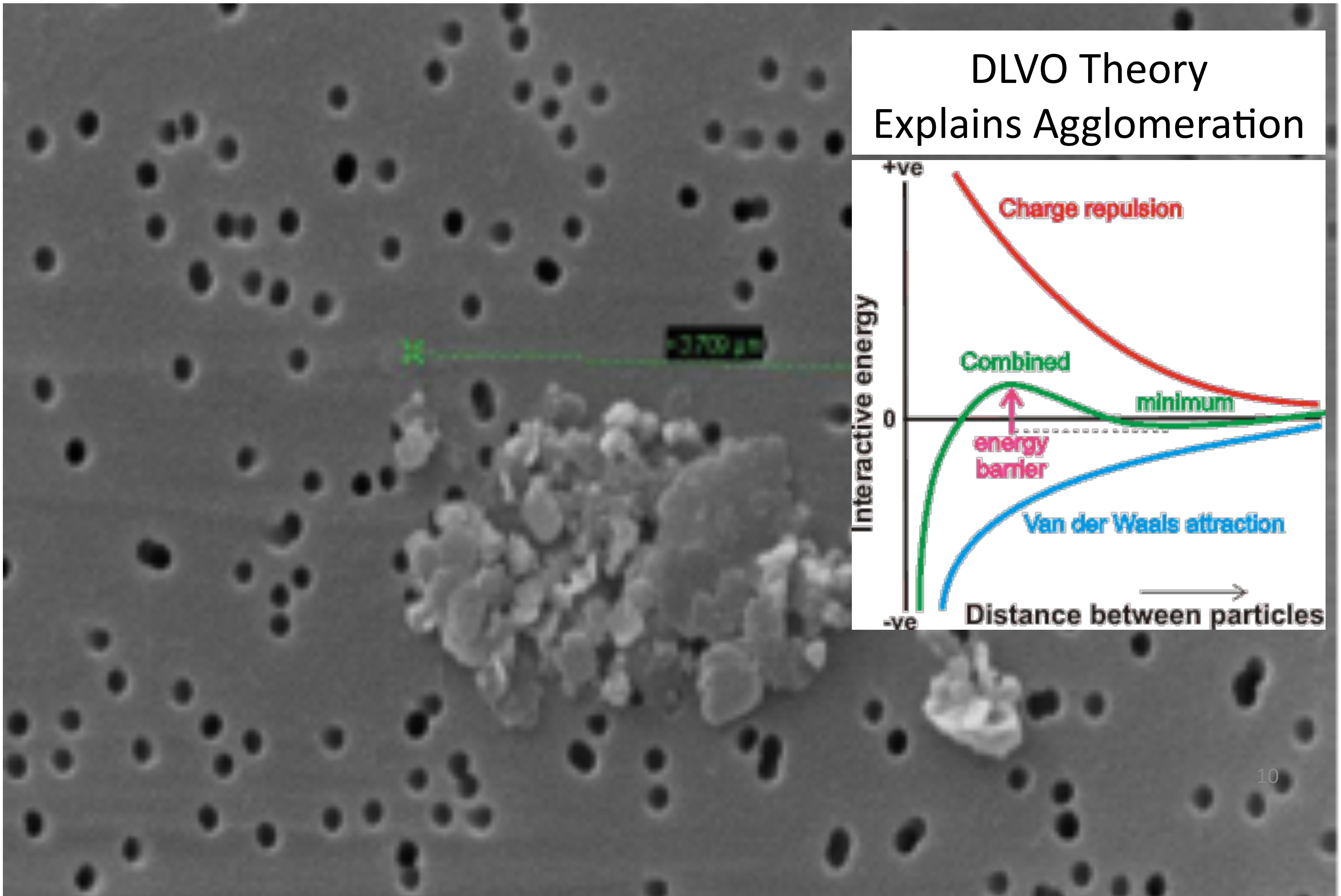
Capture Cycle Concentrates, Agglomerates, And Holds Particle Contamination on Electrodes.



Release Cycle Drives Agglomerated Particle Contamination Off the Electrodes.

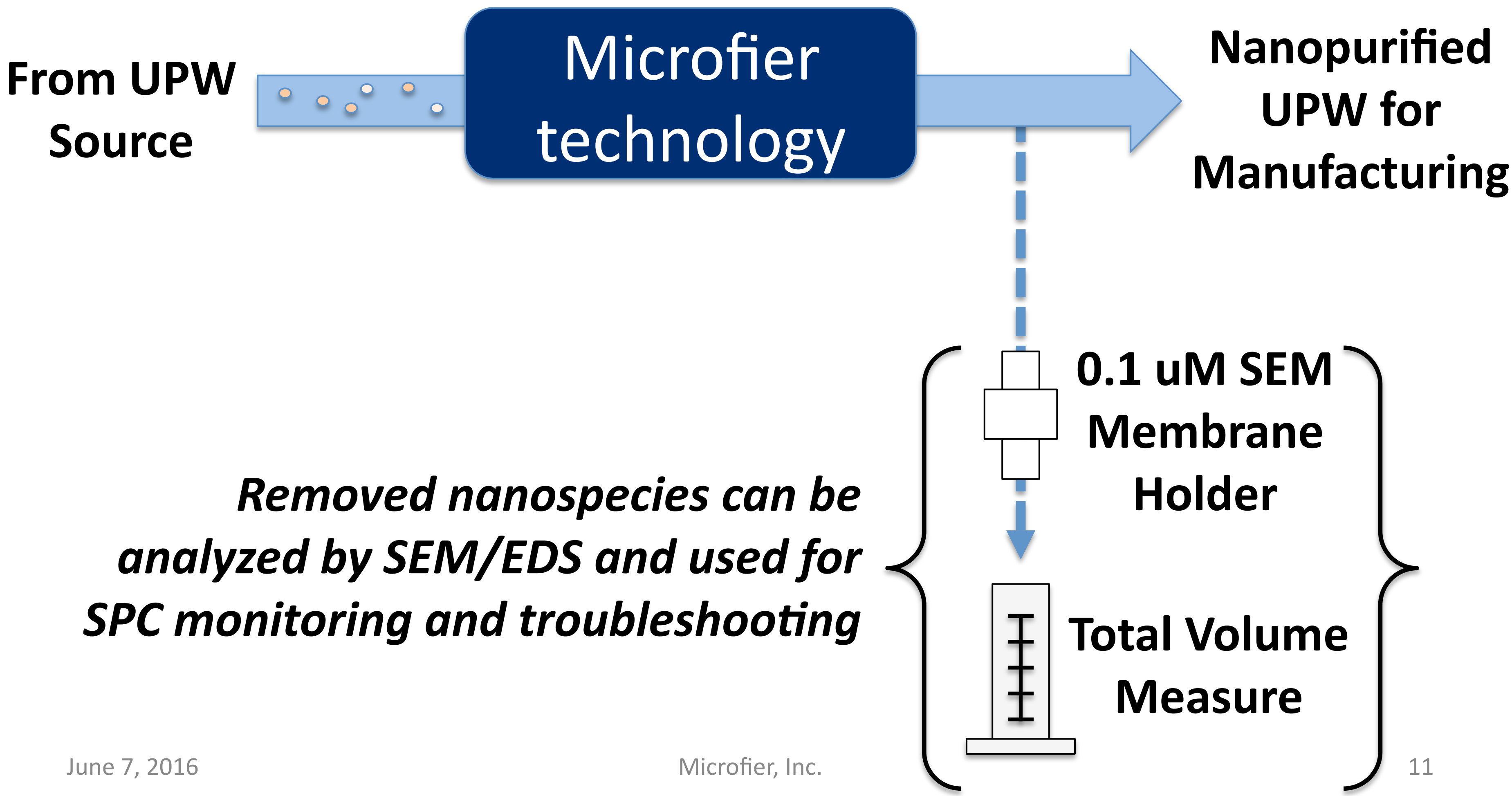


Technology Uses an Electric Field to Overcome the Energy Barrier, Forcing Nanoparticles to Agglomerate.



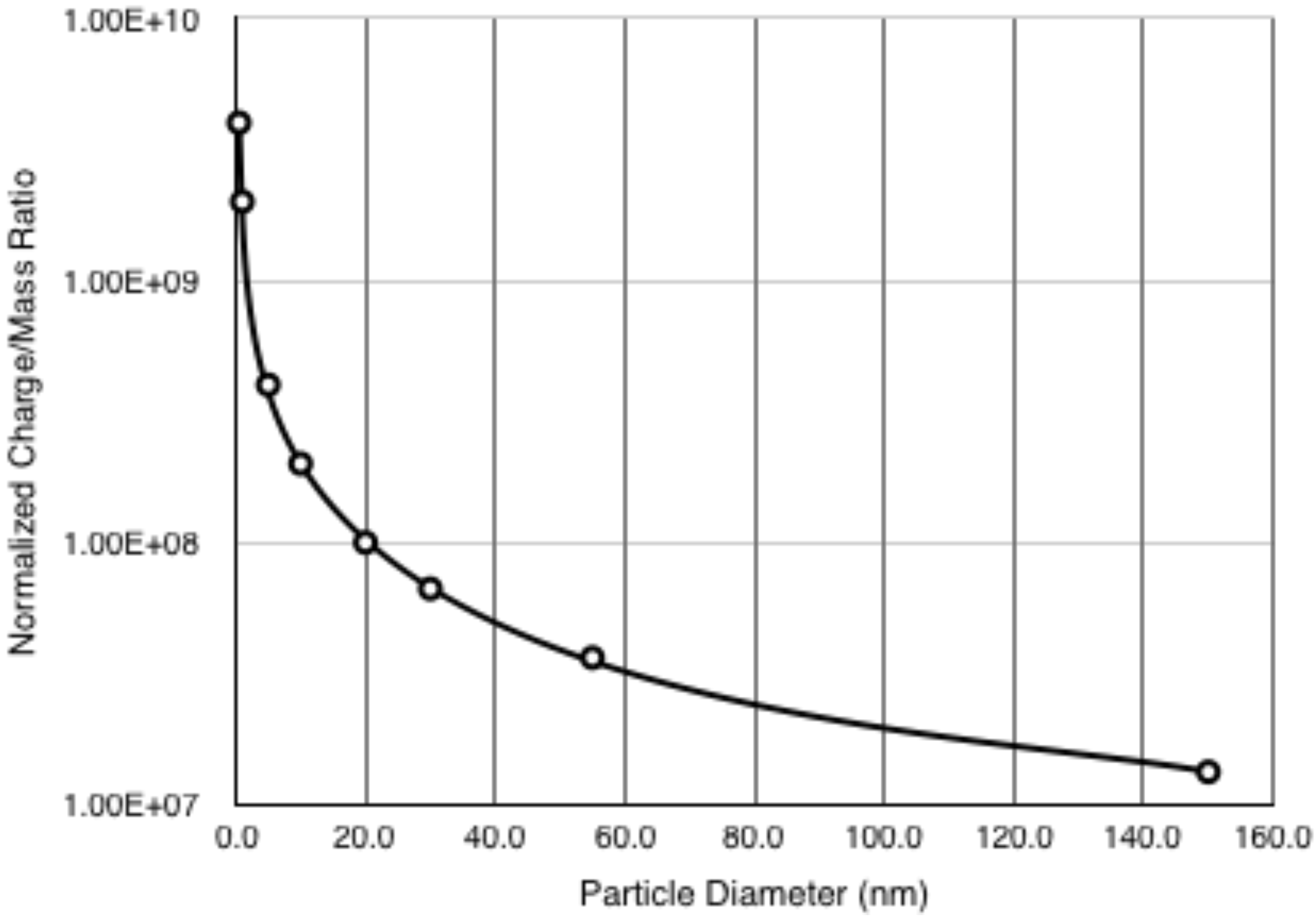
DLVO Theory
Explains Agglomeration

Microfier Technology Purifies UPW and Can be Used to Measure and Identify Particles During the Release Cycle.



Removed nanospecies can be analyzed by SEM/EDS and used for SPC monitoring and troubleshooting

As Particle Size Decreases, Charge/Mass Ratio Increases, Dramatically Improving Removal.



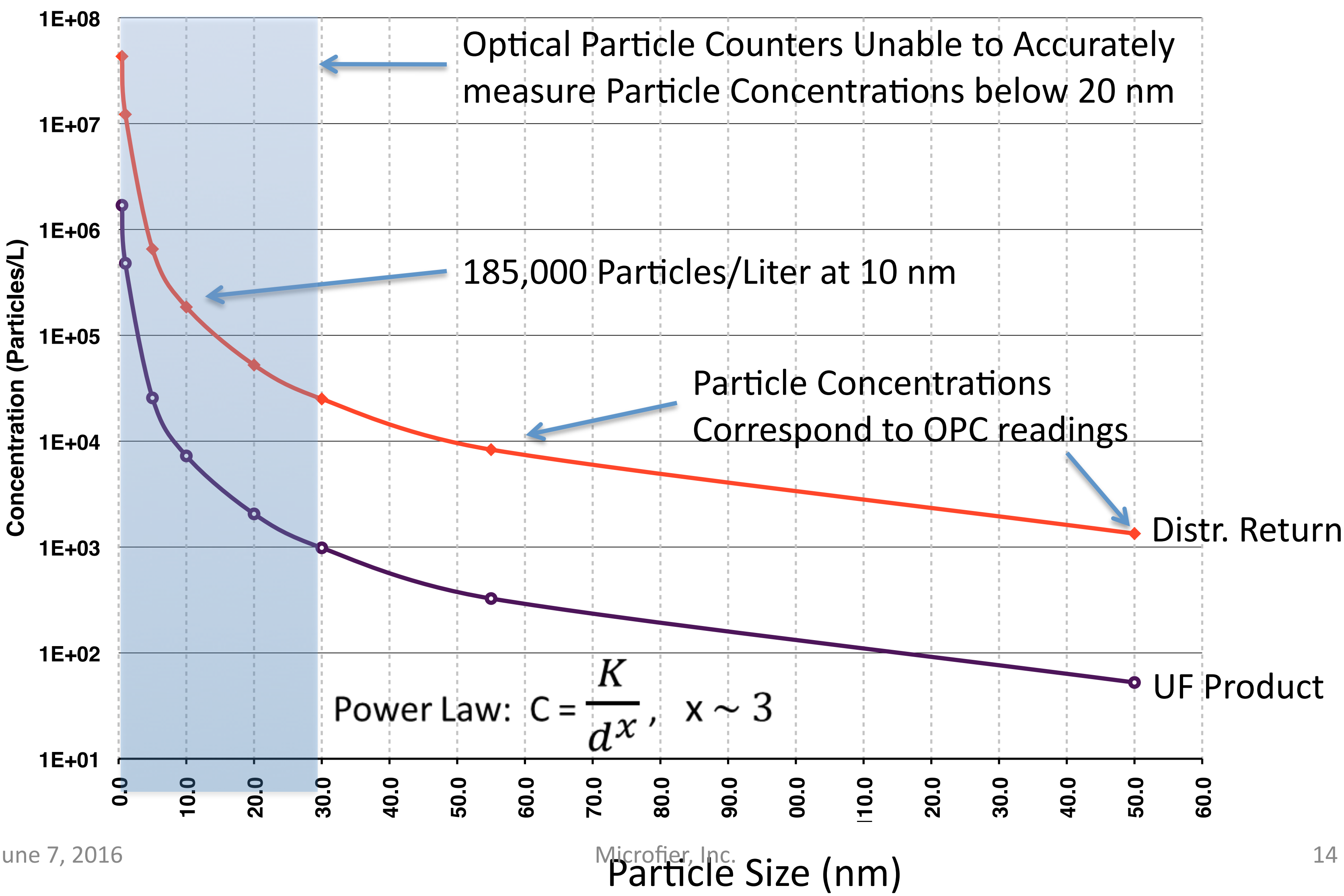
Volume (mass) decreases by the <u>cube</u> of the radius: [V = $\frac{4}{3}\pi r^3$]

Surface area (charge) only decreases by <u>square</u> of radius [A = $4\pi r^2$]

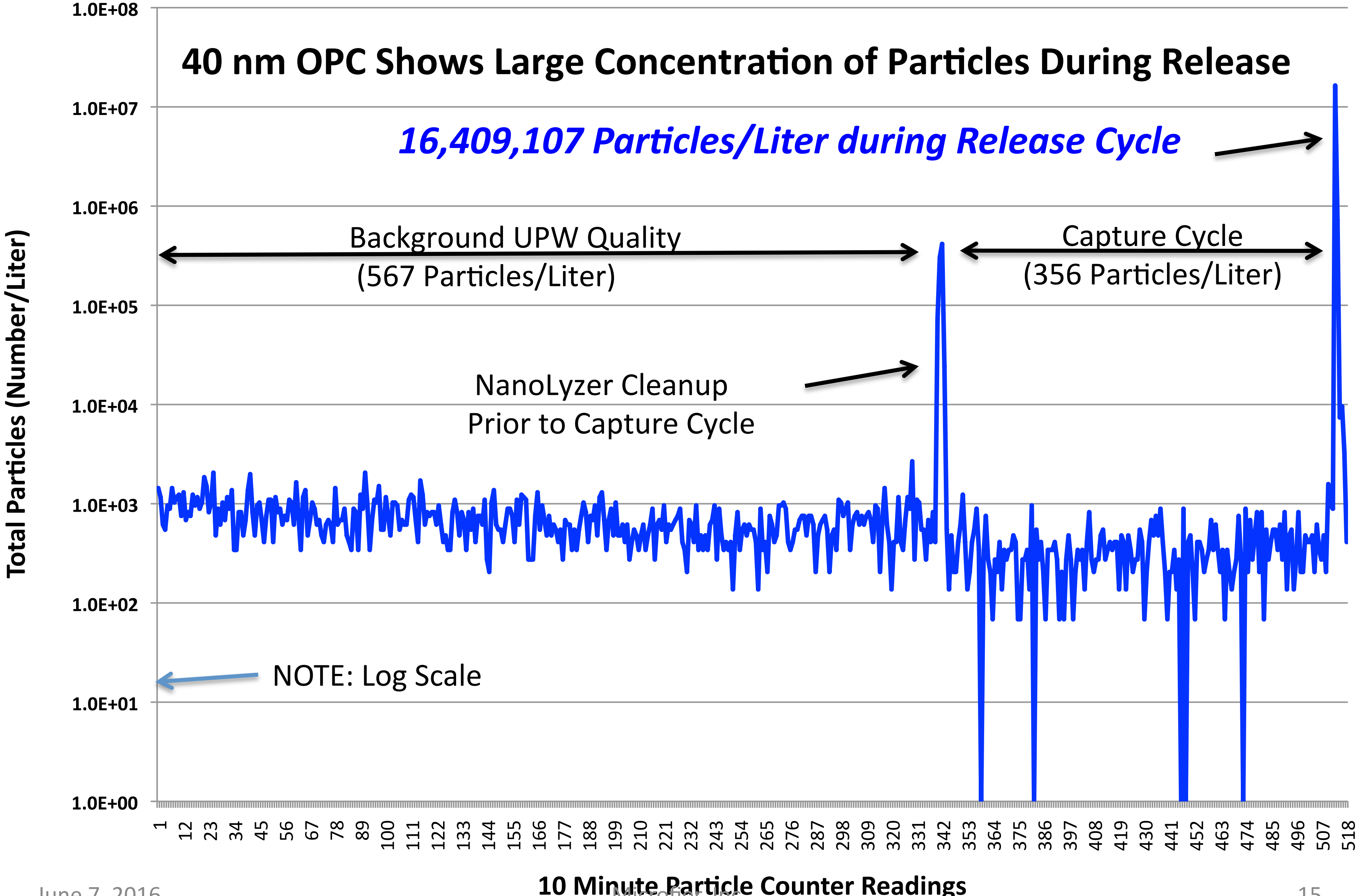
III. Removing Nanoparticles

Process and quality control managers see yield gains through lower particle levels.

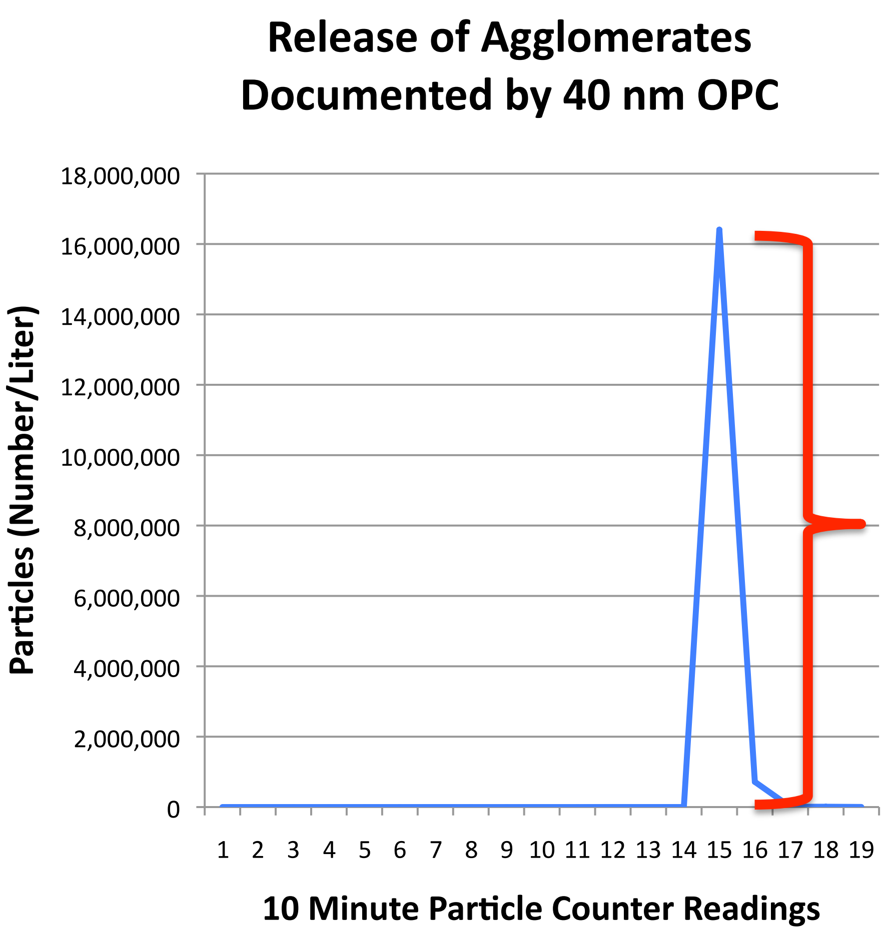
Power Law Expects Elevated Nanoparticle Levels below Current Removal and Detection Limits.



OPC Shows High Concentration of 40 nm Particles During Release Cycle.



Release Cycle Discharges Large Concentration of Agglomerated Nanoparticles



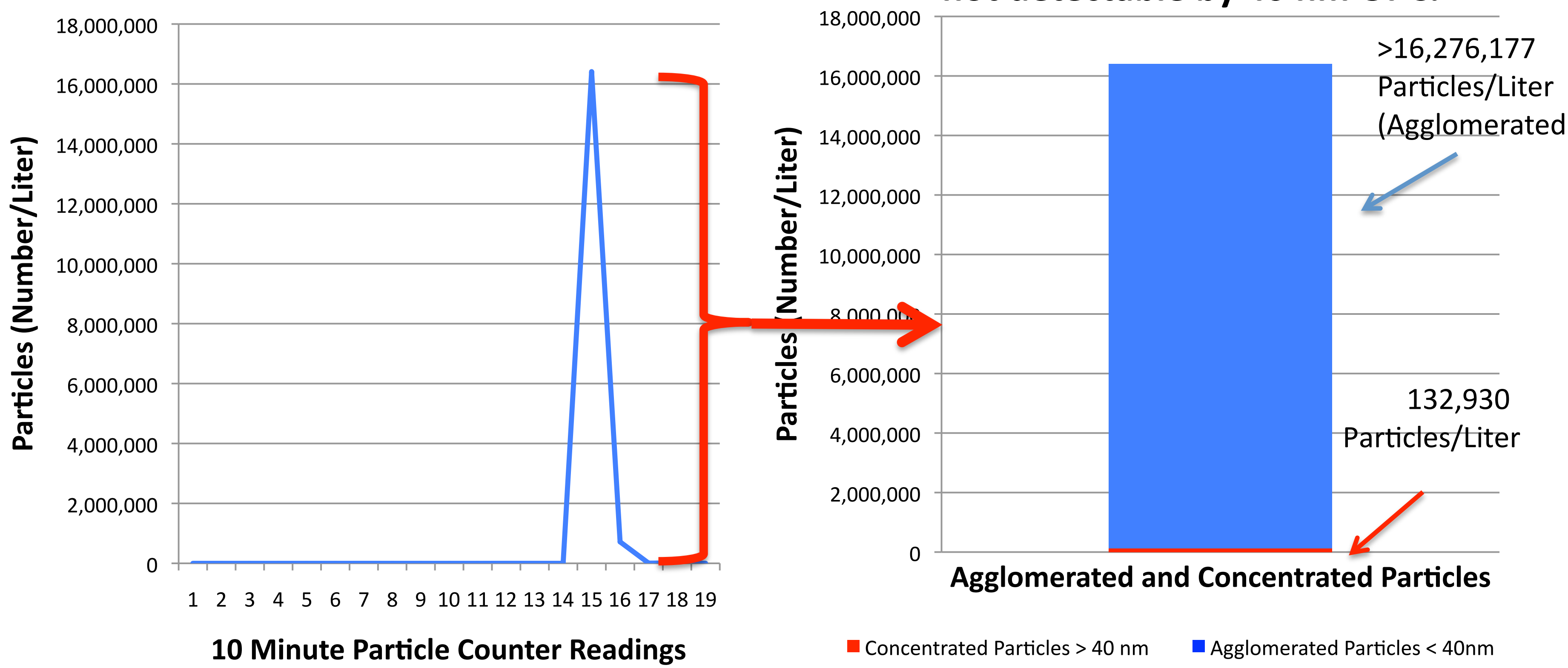
46,000X Increase in Particles Greater than 40 nm During Release Cycle

Greater Than 99% of Particles Measured During the Release Cycle Were Not Detectable by 40 nm OPC.

46,000X Increase in Particles Greater than 40 nm During Release Cycle

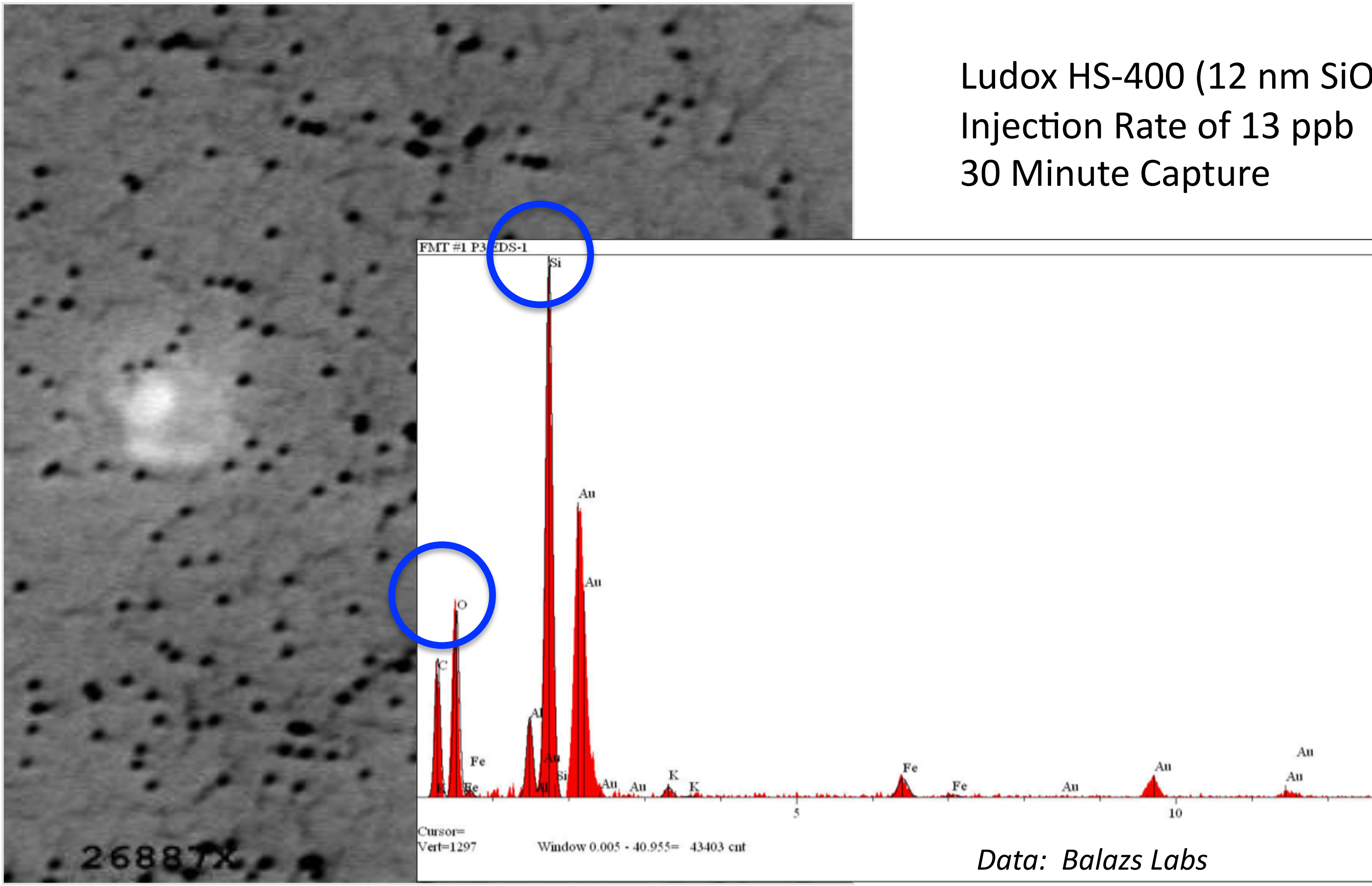
Release of Agglomerates Documented by 40 nm OPC

Over 99% of released agglomerates came from nanoparticles not detectable by 40 nm OPC.



SEM/EDS Results Prove Effectiveness of the Technology on 12 nm Silica Particles in UPW.

Ludox HS-400 (12 nm SiO_2)
Injection Rate of 13 ppb
30 Minute Capture

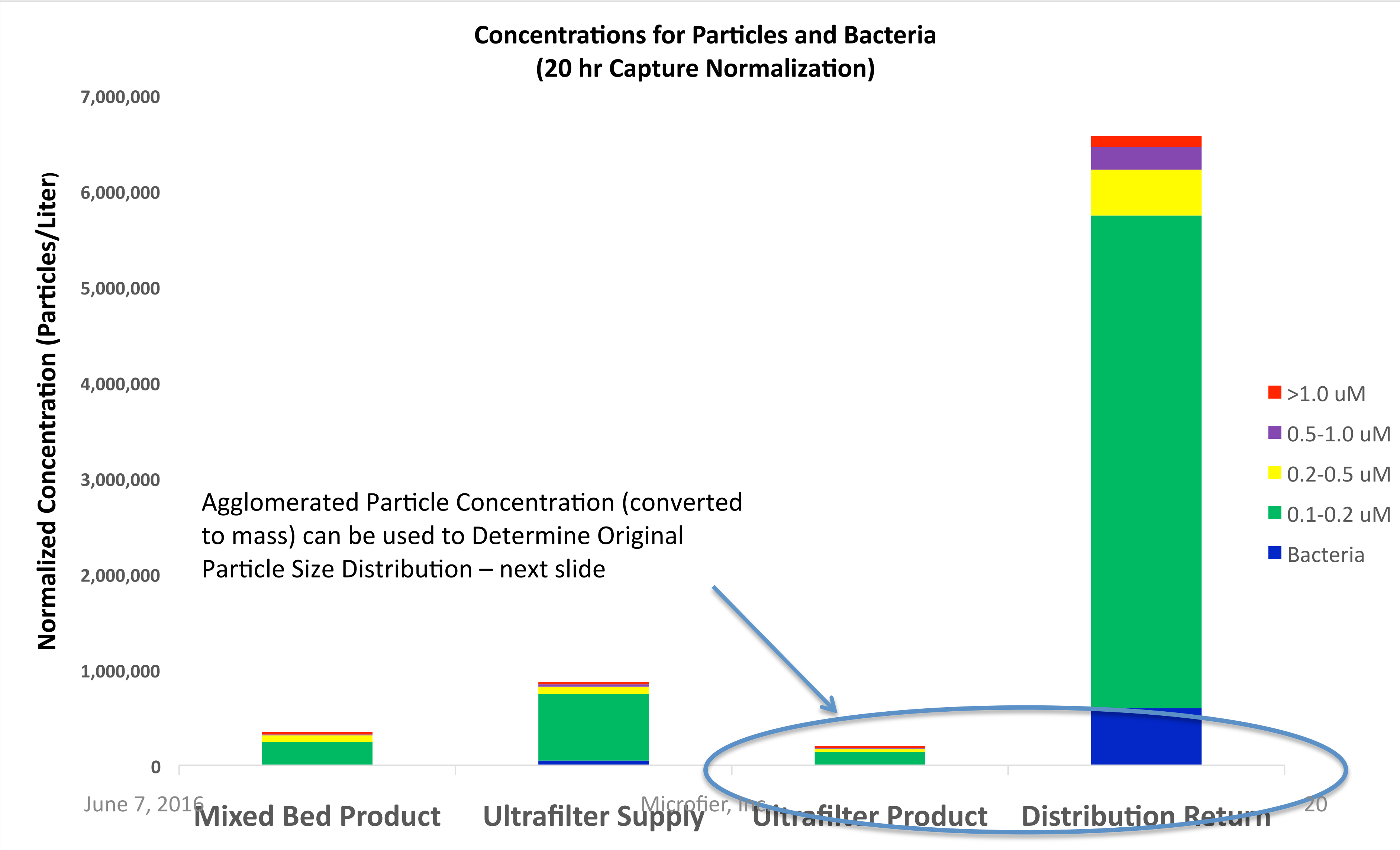


IV. Characterization and Quantification of Particles during Release Cycle

• Nanoparticle Concentration	Impacts Manufacturing Process Steps and Cleaning Efficiency
• Charge Characteristics	Determine Particle Affinity to Wafer and Device Surfaces
• Elemental Concentration	Affects Device Yields and Performance (Life-Time)
• Morphology	Improves Contamination Identification

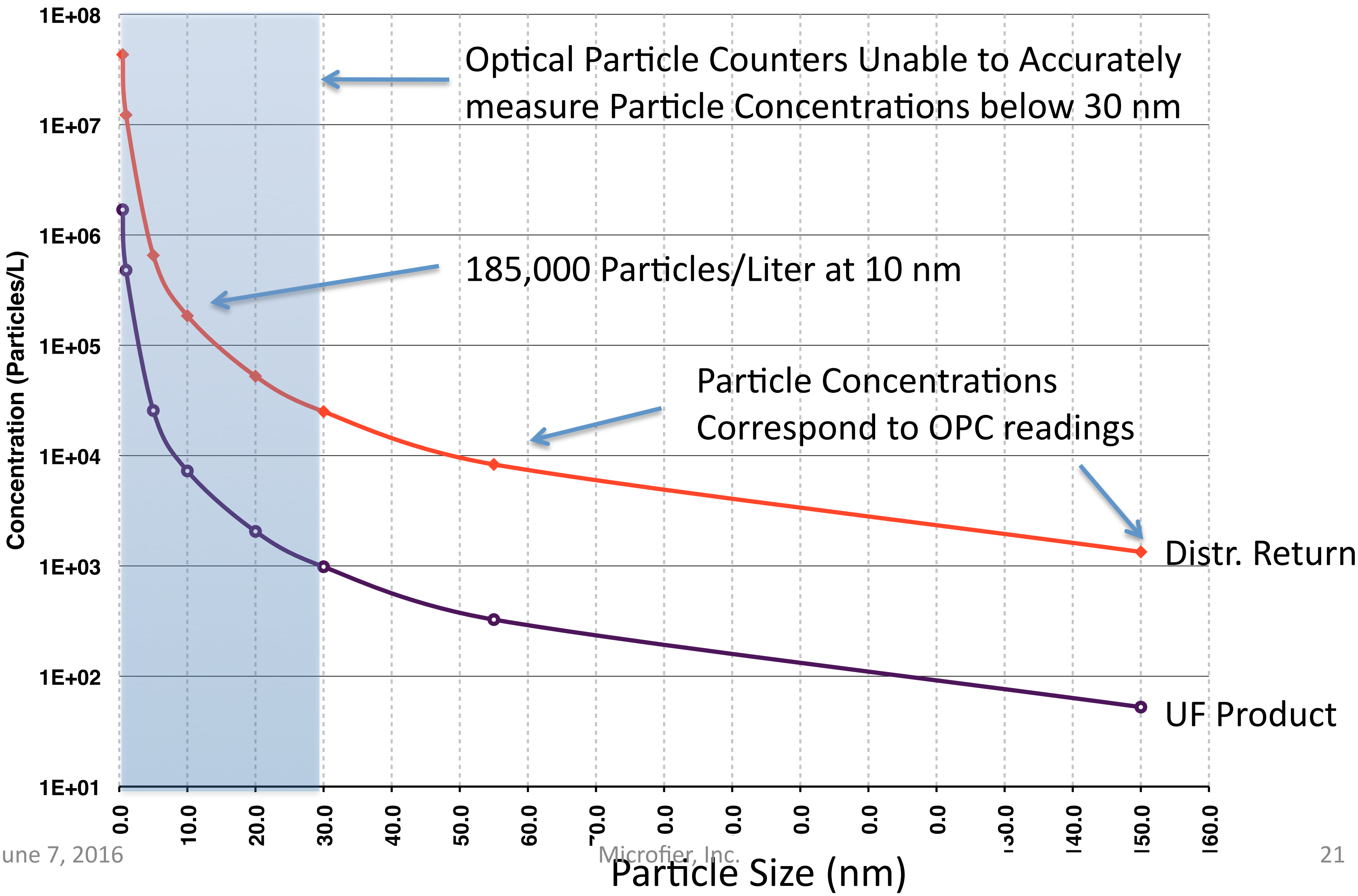
Nanoparticle Concentration

SEM Particle Analysis Profiles Agglomerated Particle Concentration and Size Throughout a System.



Nanoparticle Concentration

Mass Balance Using Power Law Determines Concentration of Nanoparticles.



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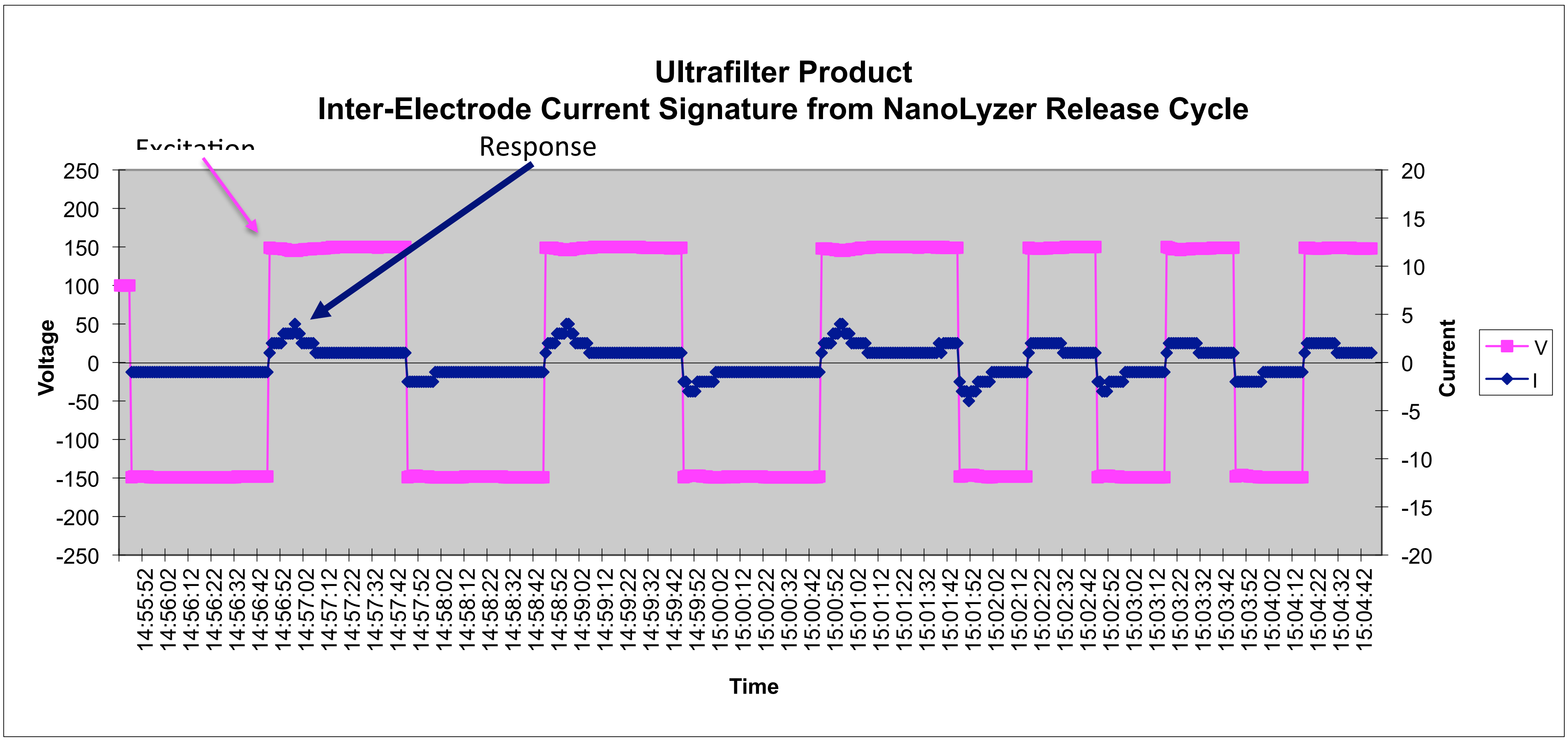
Charge Characteristics

Technology's Interelectrode Current Signature Describes Particle Charge Characteristics in Real Time.

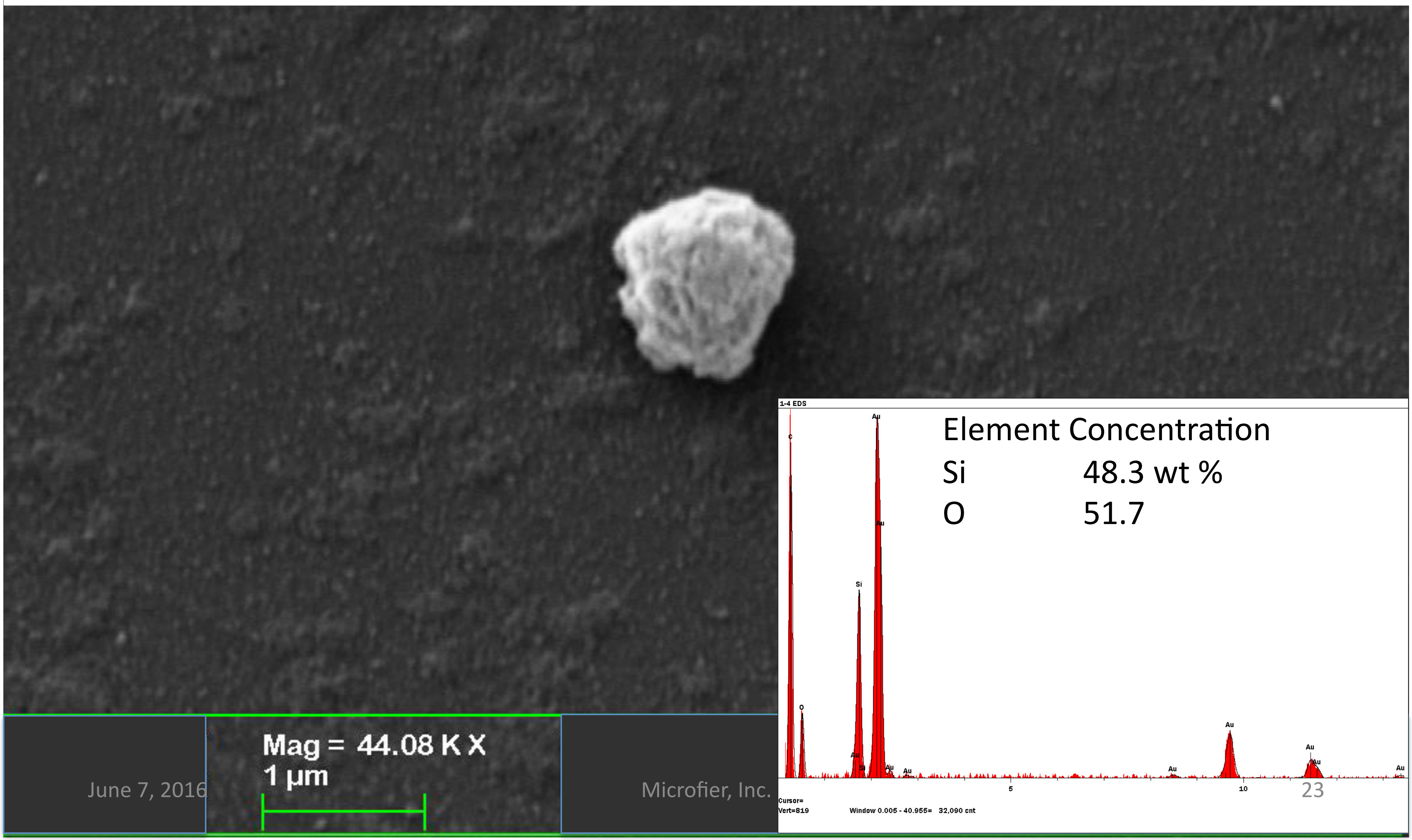
Response During Release Indicates Conductivity and Concentration of Charged Particles



Elemental Concentration

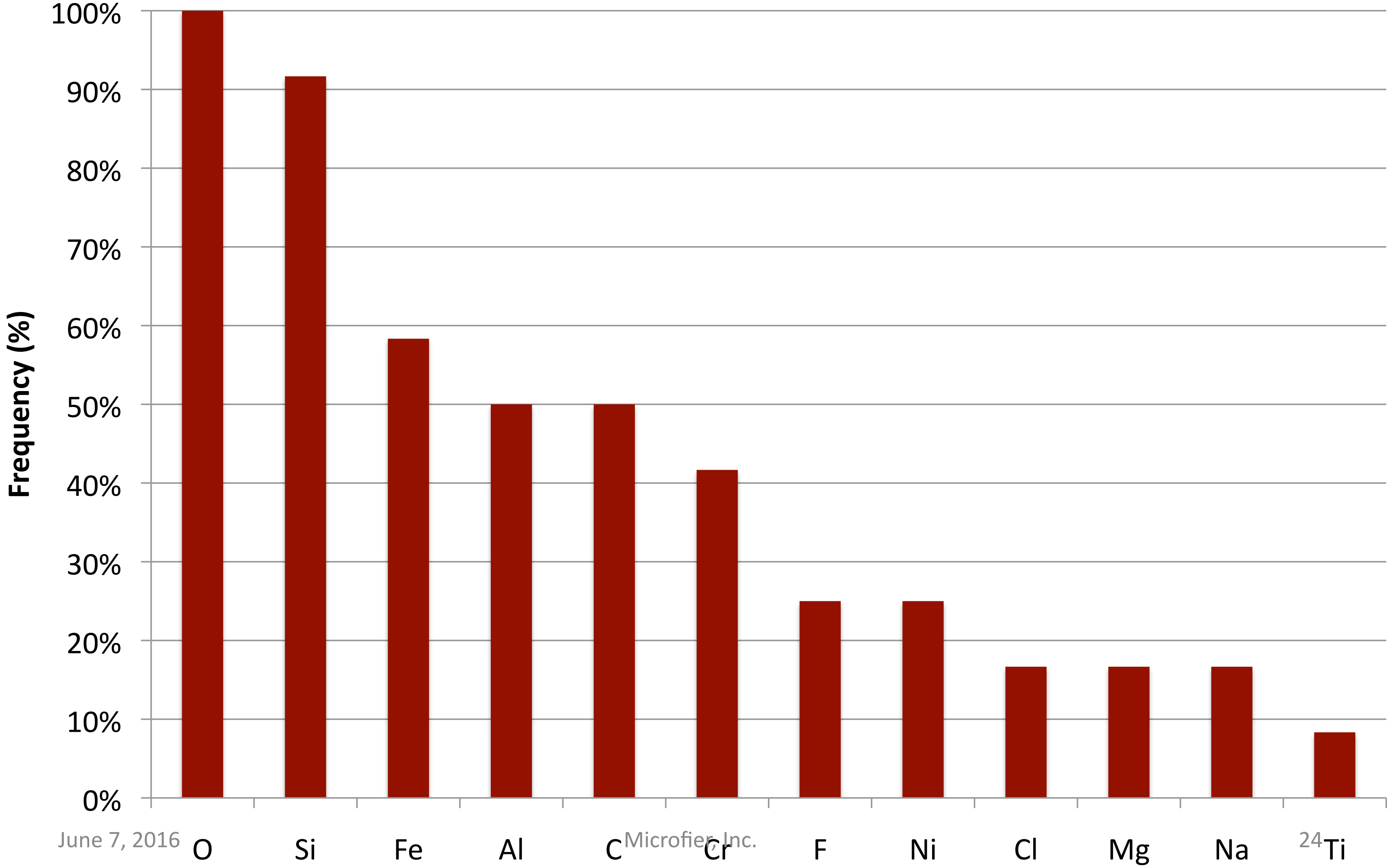
EDS Analysis Determines Elemental Concentration.

Silicon and Oxygen Peaks Identify Agglomerated Silica Colloids



Element	Concentration
Si	48.3 wt %
O	51.7

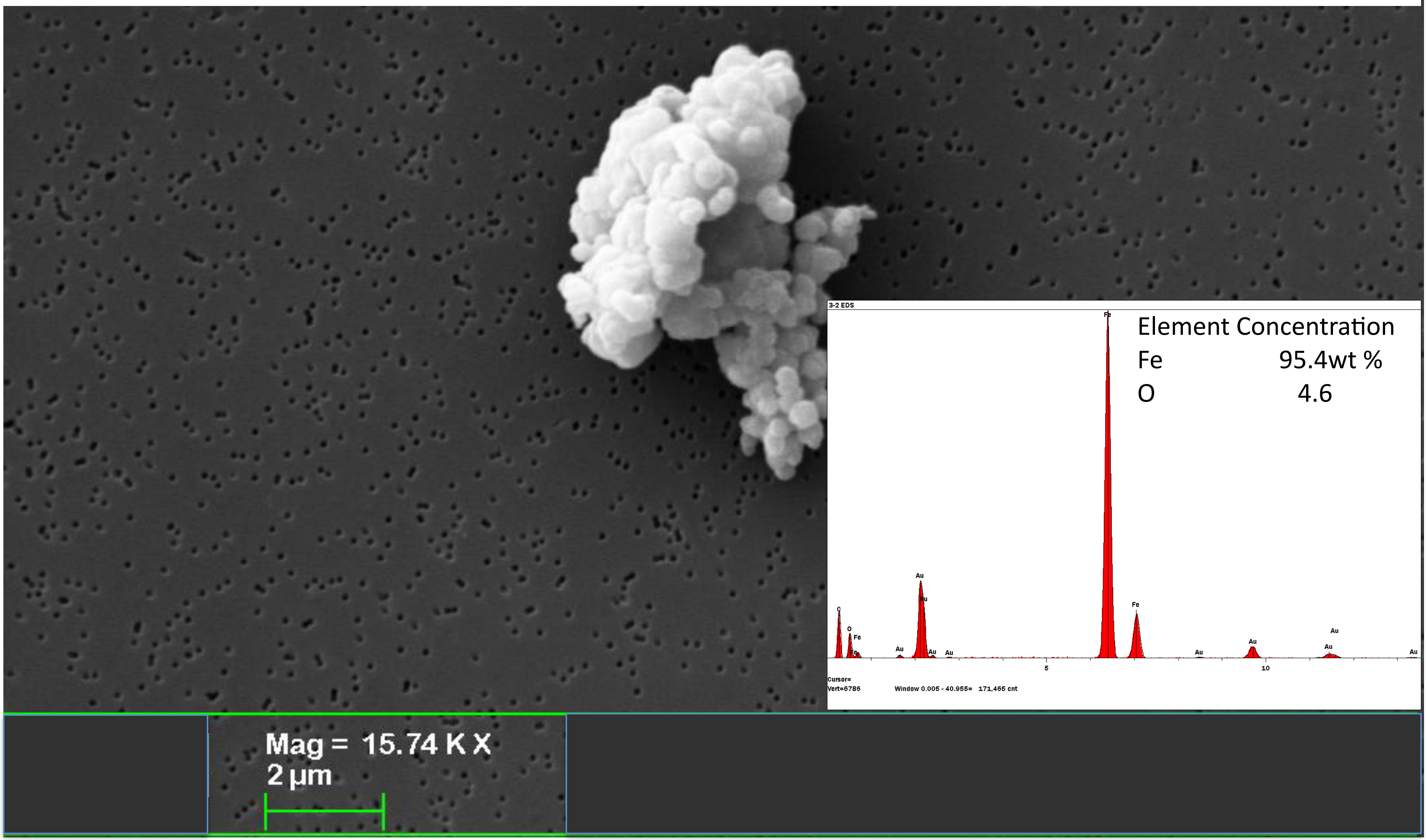
UF Product Data from 12 Different Systems Document Dominant Elements.



Morphology

Particle Morphology Is Unique to Contamination.

Agglomerated Iron Nanoparticles

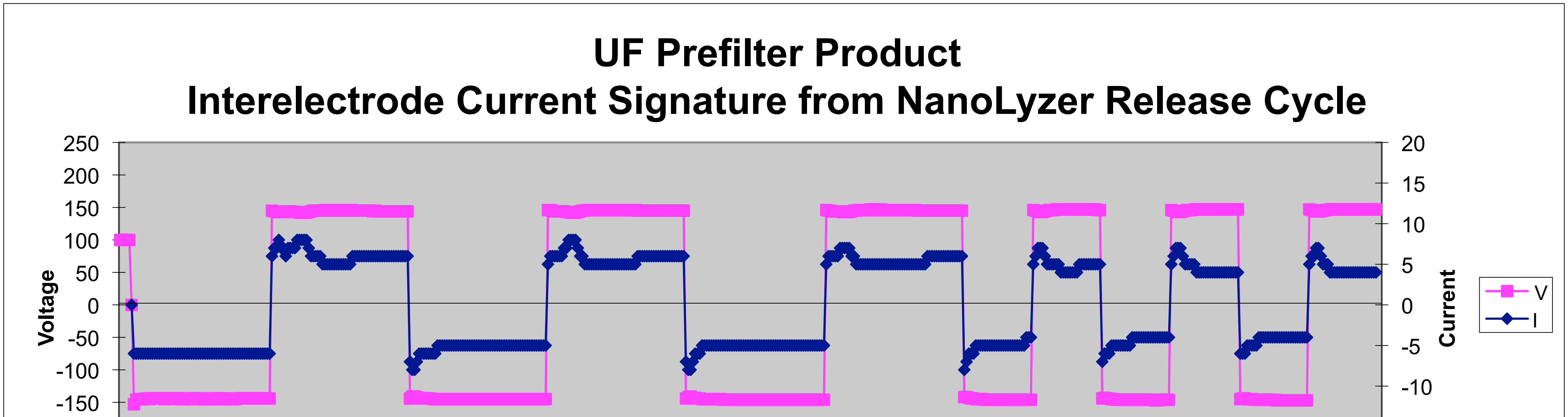


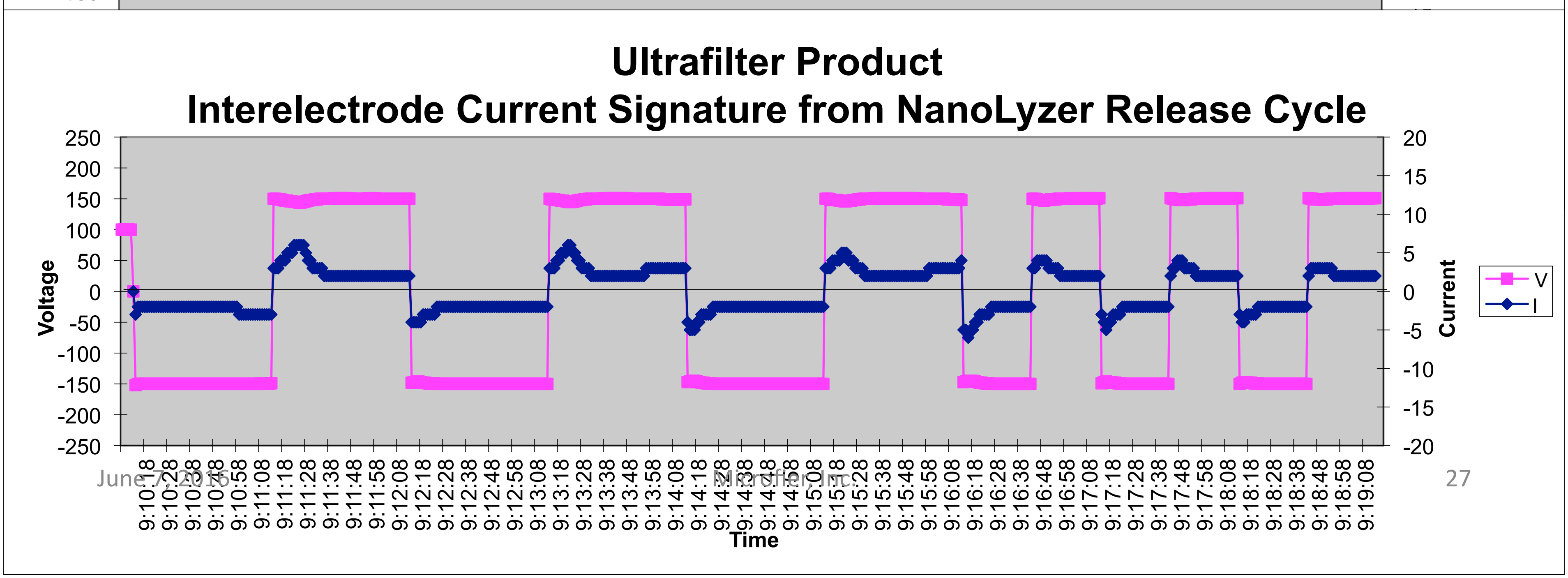
VI. Troubleshooting Case Study

How a 14 nm fab found unexpected contamination in their UPW system

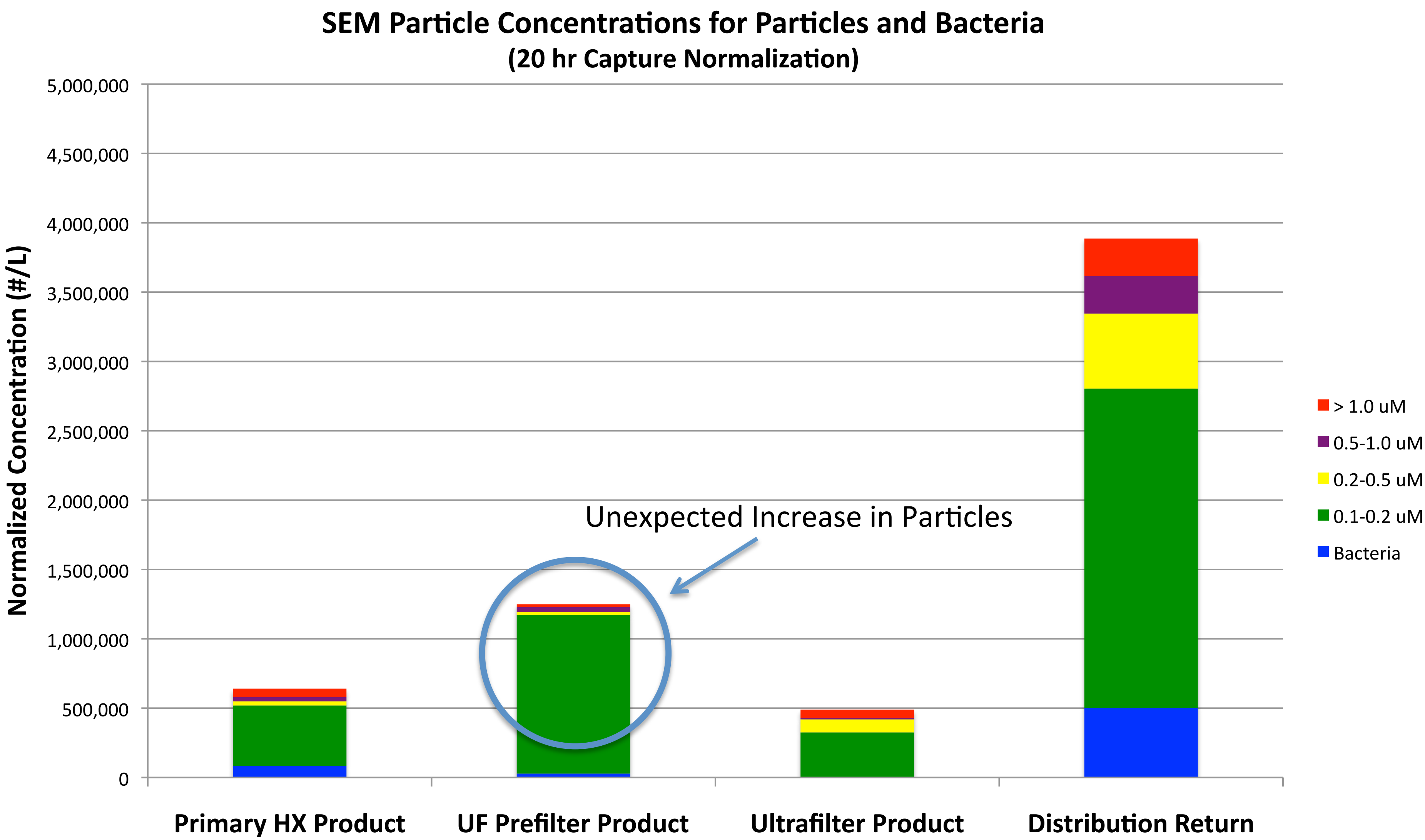
Real Time Data for the UF Prefilter Product Showed Higher Conductivity Compared to the UF Product.

Indicated Presence of Charged Particles in the UF Prefilter Product



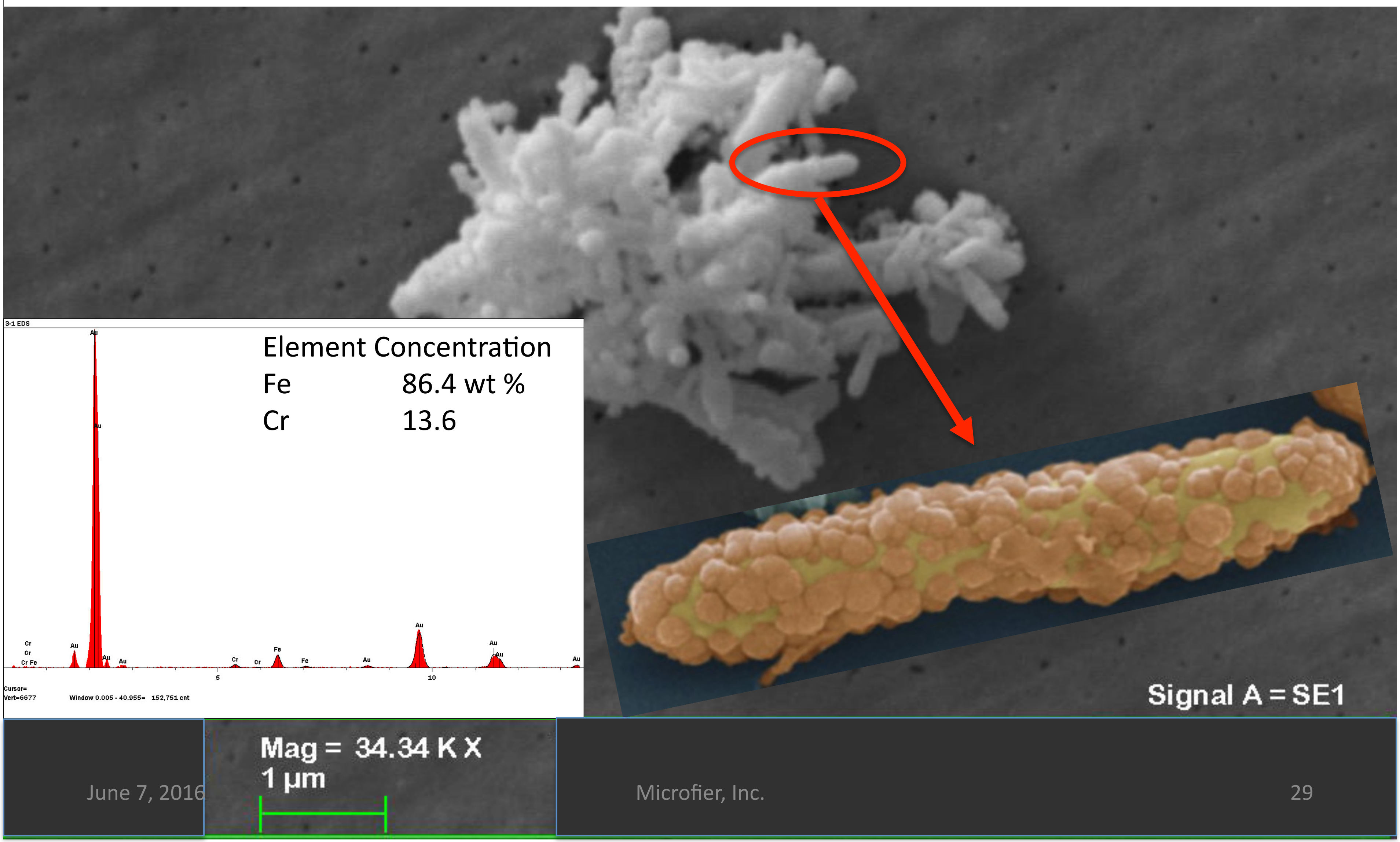


SEM Particle Concentration Data Detected an Increase in Particles Across UF Prefilter.



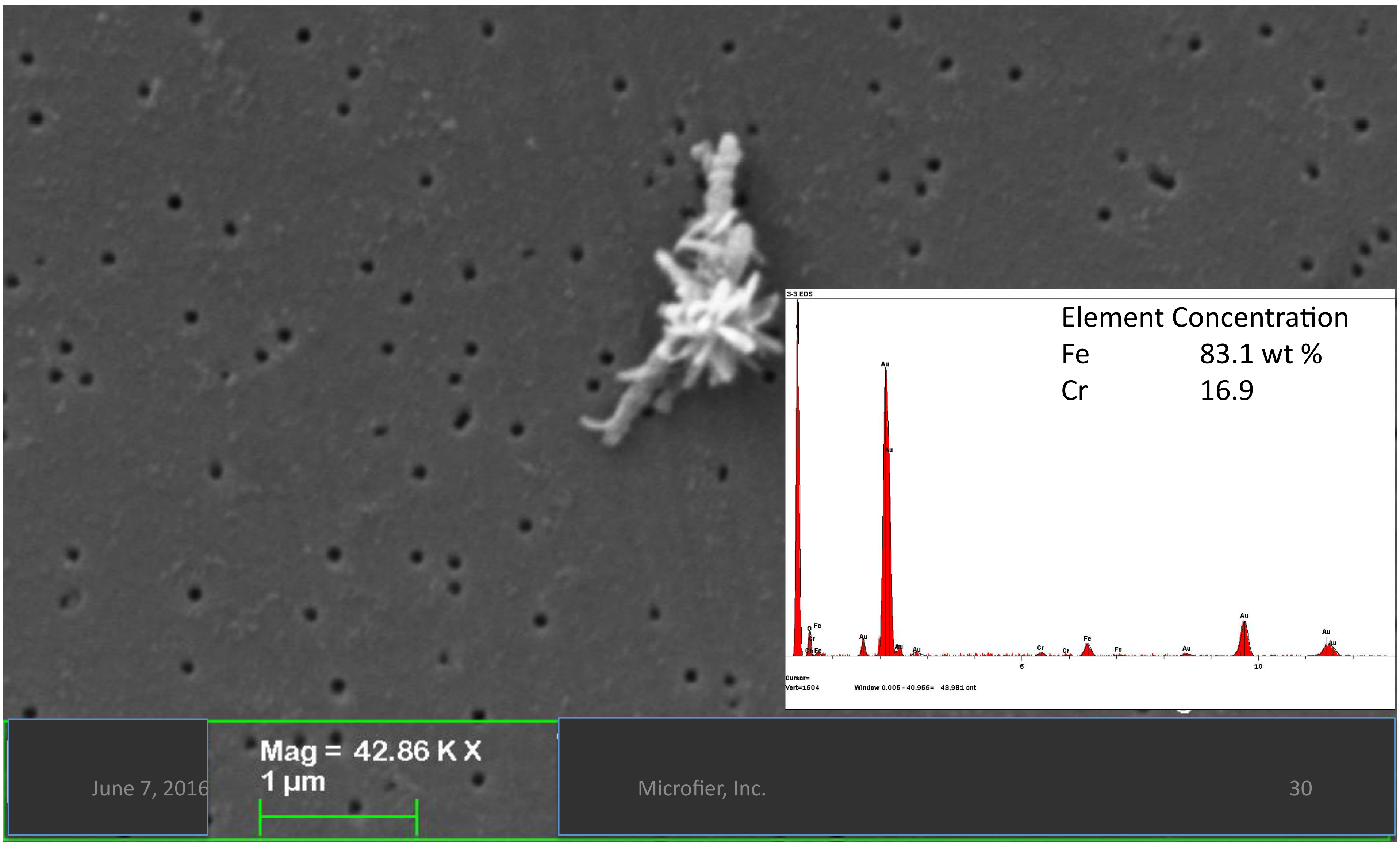
SEM/EDS Analysis Identified Iron Bacteria in UF Prefilter Product.

UF Prefilter Used an Electropolished Stainless Steel Housing



SEM/EDS Analysis Also Identified Iron Bacteria in Ultrafilter Product.

Indicates Prefilter Contamination is Penetrating UF Membrane



Case Study: Iron Bacterial Contamination from UF Prefilter

What did we learn?

Technology's capture and agglomeration identified the source (UF prefilter) and the specific contaminant (iron bacteria and iron nodules) using SEM/EDS, along with interelectrode current signature alert.

- Profiling the polishing loop using the technology can determine relative impact of each unit process and piping system on the concentration of nanoparticles.
- Unit processes (including membrane filtration) can contribute particles.
- There is a need to routinely monitor unit processes for nanoparticles.
- Nanoparticle contamination can penetrate UF systems.

The Technology Provides Several Advantages for Advanced Processes.

- Removes smaller nanoparticles than membrane filtration
- Unlike membrane filtration, the removal efficiency *improves* as particle size requirements tighten
- Rapid contaminant identification
- Products available for immersion lithography, single wafer rinse, and similar applications

Leading Edge Devices Require Leading Edge Technologies.

Increased Device Complexity Has Always Required Increased UPW Purity

- The only particle removal technology that also identifies and quantifies nanoparticles in UPW.
- Solving contamination problems in leading edge fabs *now*
- Positive nanoparticle removal and identification for tomorrow's processes.

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