I Round Robin Results: CeO_2

Group effort all nanotoxicity projects

II Project: ESH Emerging Nanoparticles Semiconductor Manufacturing

UA,UW project (Tasks 425.023 and 425.024)

Cytotoxicity of Nanoscale CeO_2: Summary of Round Robin Findings

PIs:

- JA Field, S. Boitano, R. Sierra-Alvarez, Univ. of Arizona
- J. Posner & TJ Thornton, Arizona State University
- Y. Chen, Georgia Institute of Technology
- R. Mumper, A. Tropsha, Univ. of North Carolina/Chapel Hill
- R. Draper, S. Nielsen, P. Pantano, Univ. of Texas/Dallas
- B. Ratner, Univ. of Washington

Objectives

Instructions Round Robin: Compare physical chemical properties and cytoxicity of the same CeO_2 sample in different laboratories

Sigma-Aldrich, P/N 643009 10 wt. % in pH 4.6 H_2O Size = <25 nm

1) Measure particle size distribution (PSD) and zeta potential (ZP) of CeO_2 suspension at acidic pH.

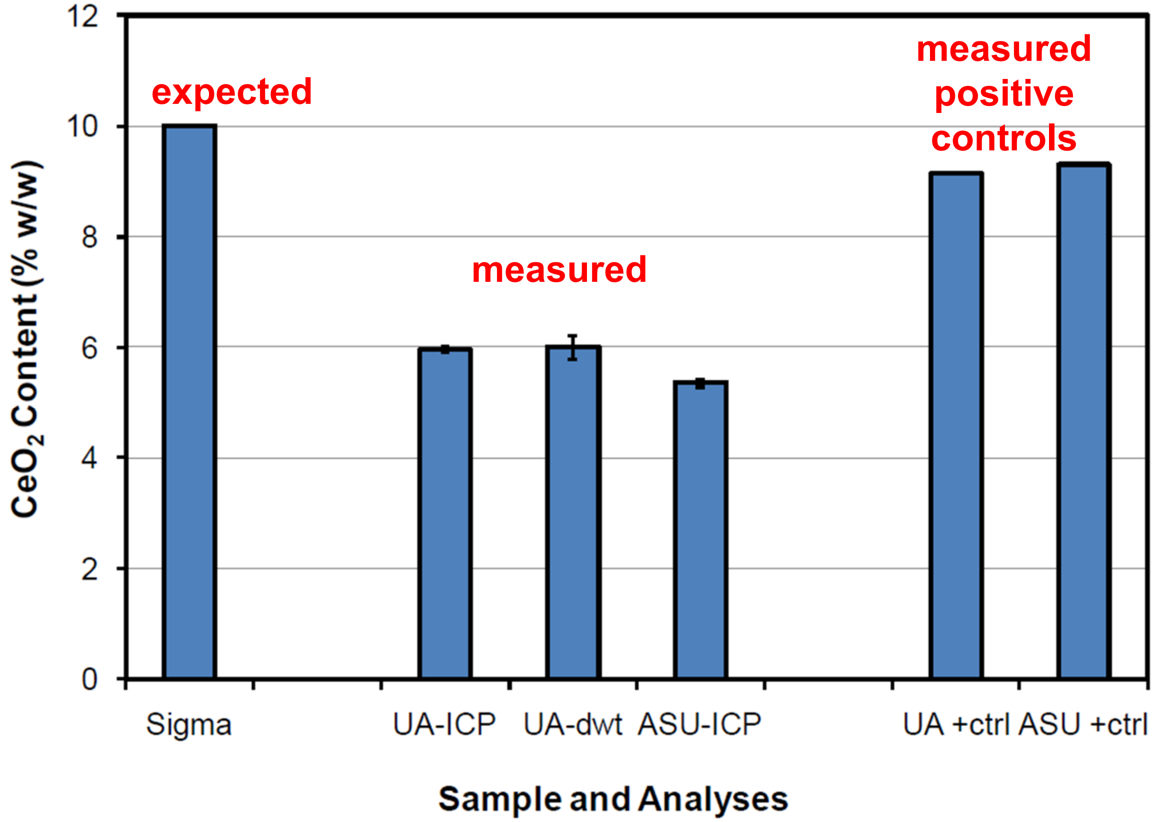
2) Measure PSD and ZP of CeO_2 suspension at pH 7 in water, phosphate buffer (PB) and biological medium

3) Measure change in PSD, ZP and CeO_2 concentration after 24 h

4) Measure cytoxicity up to a maximum concentration of 1,500 mg/L of CeO_2.

Results

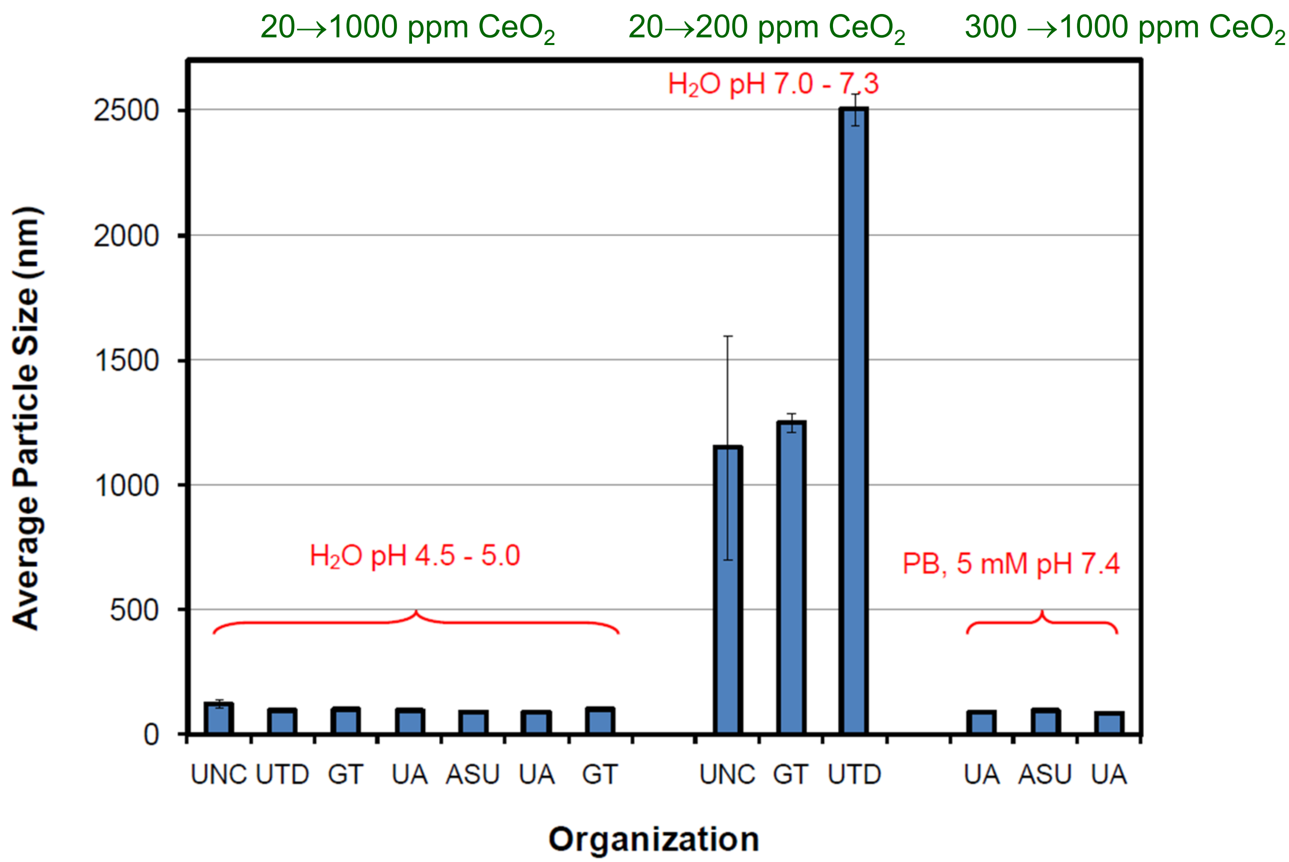
How Much CeO_2 was in Sigma 10% w/w Sample?



Conclusion: Based on ICP, the sample contained approx. 57% of the expected CeO_2 concentration. Purity could also be rapidly estimated with a simple dry weight measurement.

Results

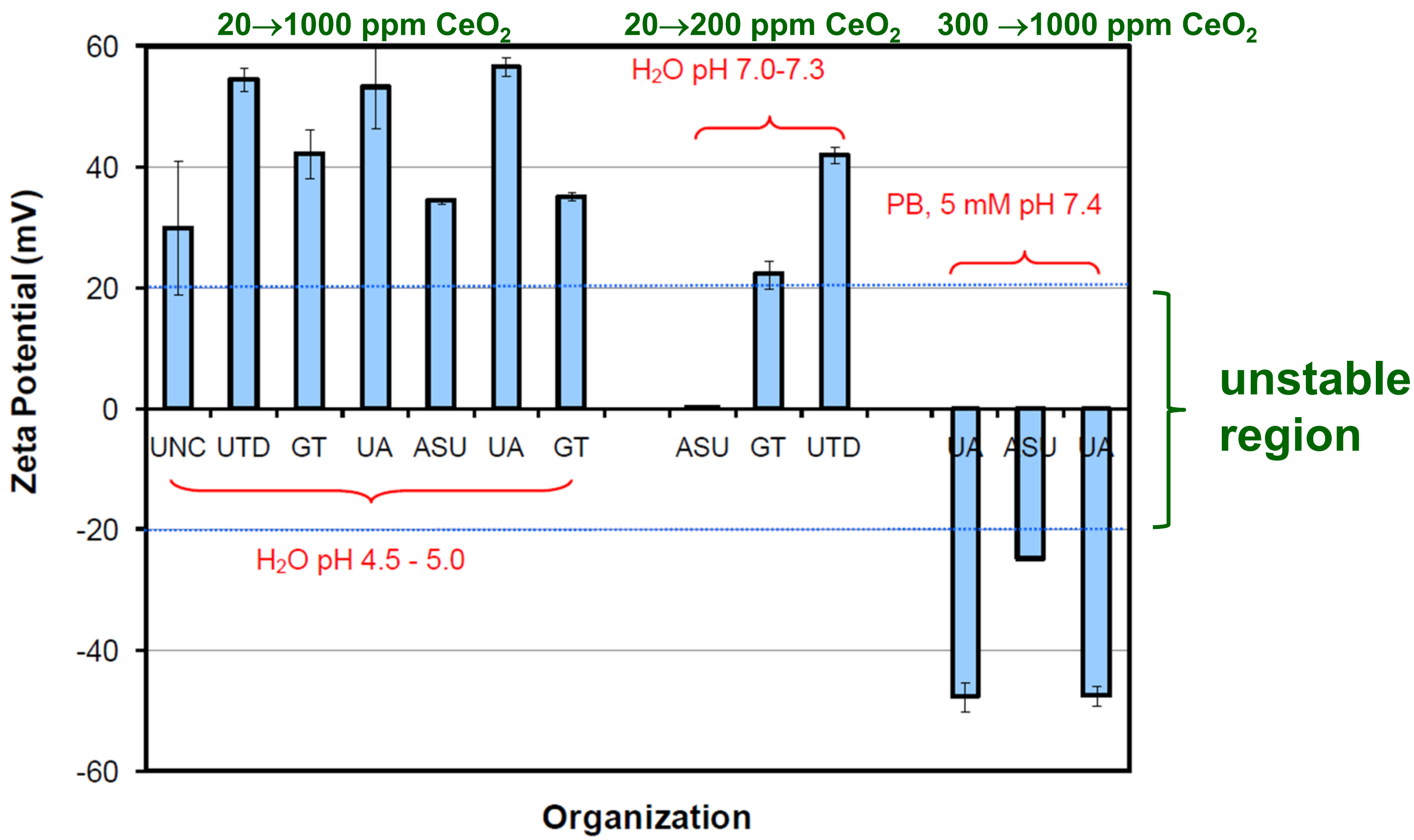
Intensity Averaged Particle Size in Water and Phosphate Buffer (PB)



Conclusion: Excellent dispersion of CeO_2 NP in water at pH 4.5 and PB pH 7.4. Dispersion could be repeated from lab to lab. Unstable dispersion of CeO_2 NP in neutral water, variability within and between labs.

Results

Zeta Potential in Water and Phosphate Buffer (PB)

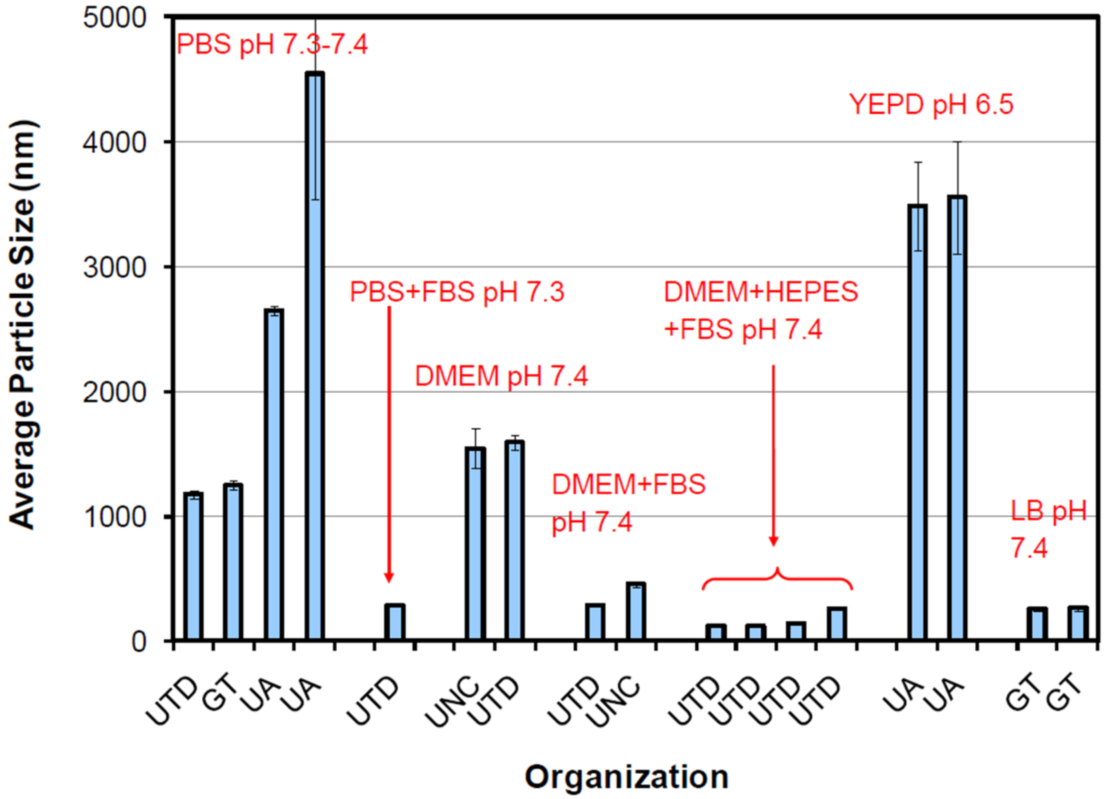


Conclusion: High absolute values of ZP in water at pH 4.5 and PB pH 7.4 to keep NP dispersion stable. ZP values could be repeated from lab to lab.

Unstable and highly variable values of ZP in neutral water.

Results

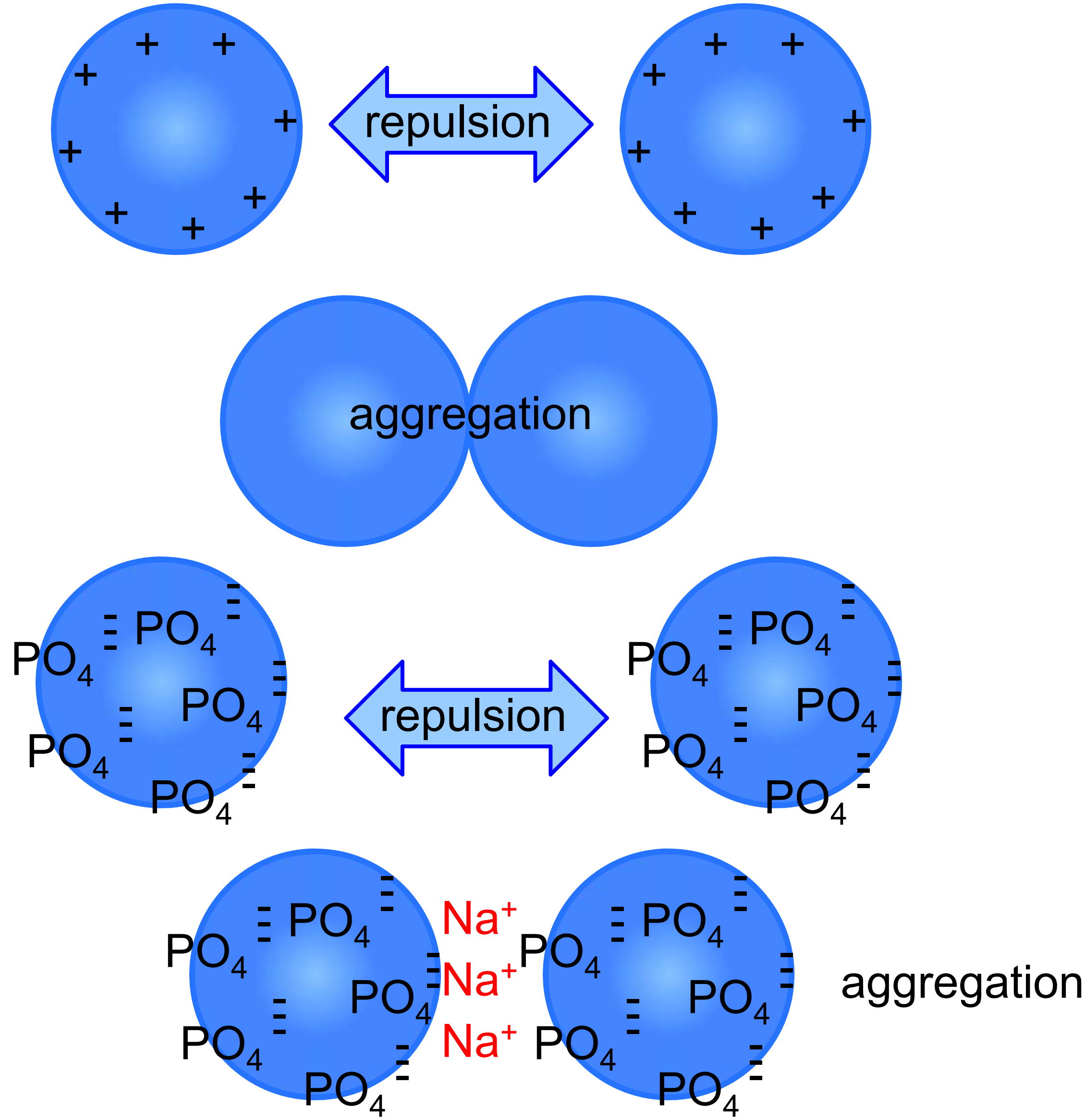
Light Intensity Averaged Particle Size in Biological Media



Conclusion: Many of the media types cause moderate to severe agglomeration of CeO_2 NPs. FBS and HEPES decrease agglomeration, both together are very effective in dispersing CeO_2.

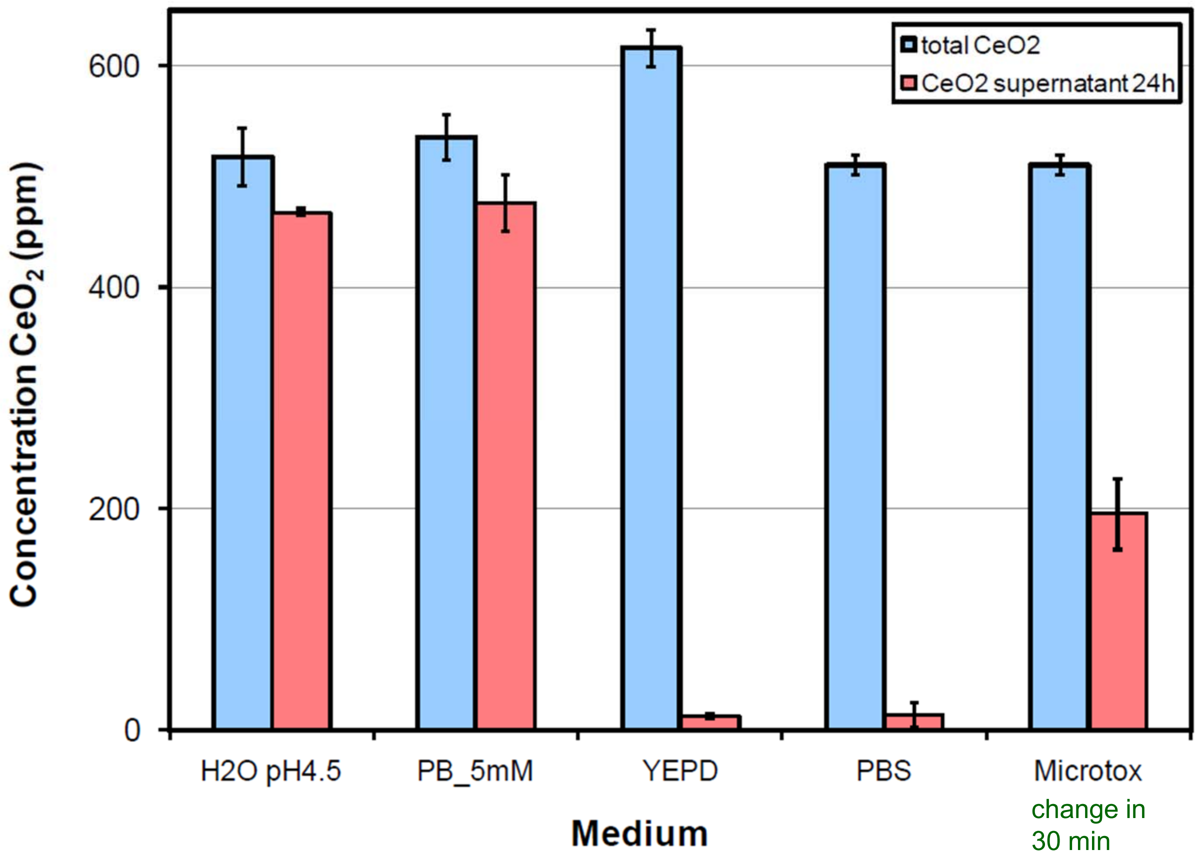
Results

Medium	**ZP**
H_2O, pH 4.5	+40 mV
H_2O, pH 7	≅ 0 mV
PB, pH 7	-40 mV
PBS, pH 7	



Results

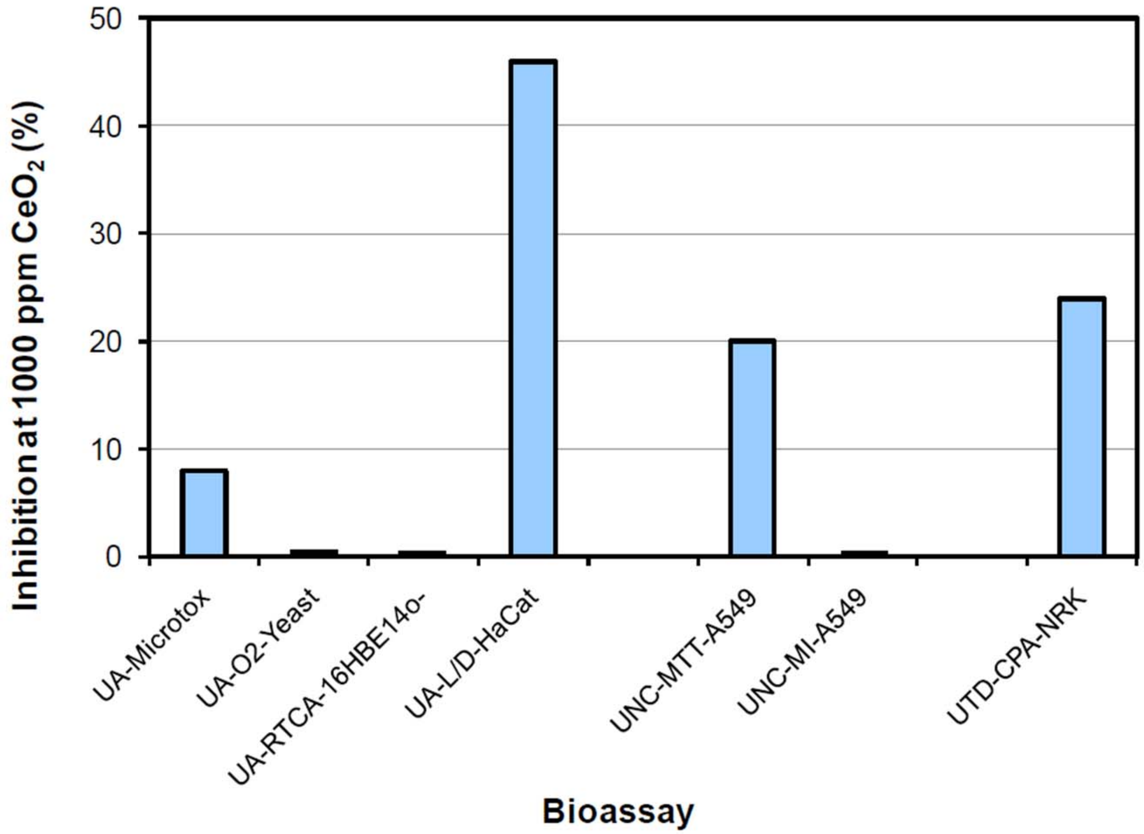
Change in CeO_2 Concentration in 24 h (only tested by UA)



Conclusion: In bioassay media, CeO_2 NP agglomerated and settled such that the concentration in suspension decreased by more than 90% in 24 h.

Results

Cytotoxicity of CeO_2



Conclusion: In most assays CeO_2 is either non-toxic or displays low toxicity. A moderate toxicity was observed with HaCat cells tested with the Live/Dead assay using PBS. (Note real conc. was approx. 600 mg/L)

Conclusions

- Manufacturer reported concentration of $CeO_2 \cong$ 2-fold off
- Acid water & 5 mM phosphate buffer (pH 7.4) provide stable CeO_2 NP dispersions
- Neutral water and most assay media cause instability and agglomeration of CeO_2 NP.
- A few media types (e.g. those including FBS, HEPES & Dispex) provide stability of CeO_2 NP dispersions in biological media.
- CeO_2 caused no to low inhibition in most of the assays. Moderate inhibition was only observed with HaCat cells assayed in PBS.

Environmental Safety and Health (ESH) Impacts of Emerging Nanoparticles and Byproducts from Semiconductor Manufacturing

Tasks 425.023 and 425.024

Research Team

PIs:

- **Jim A Field,** Dept. Chemical and Environmental Engineering, UA
- **Scott Boitano,** Dept. of Physiology & Arizona Respiratory Center, UA
- **Buddy Ratner,** University of Washington Engineered Biomaterials Center, UWEB
- **Reyes Sierra,** Dept. Chemical and Environmental Engineering, UA
- **Farhang Shadman,** Dept. Chemical and Environmental Engineering, UA

Graduate Students:

- **Isabel Barbero:** PhD candidate, Chemical and Environmental Engineering, UA
- **Lila Otero**, PhD candidate, Chemical and Environmental Engineering, UA
- **Jorge Gonzalez**, PhD candidate, Chemical and Environmental Engineering, UA
- **Mia McCorkel**, PhD candidate, Dept. of Physiology, UA
- **Hao Wang:** PhD candidate, Chemical and Environmental Engineering, UA
- **Jeff Rottman**: PhD candidate, Chemical and Environmental Engineering, UA
- **Rosa Daneshvar**: PhD candidate, Chemical Engineering, UW

Other Researchers:

- **Antonia Luna,** Postdoctoral Fellow, Chemical and Environmental Engineering, UA
- **Citlali Garcia,** Postdoctoral Fellow, , Chemical and Environmental Engineering, UA
- **Angel Cobo,** Exchange MS Student, Chemical and Environmental Engineering, UA
- **Jacky Yao,** Research Scientist, Chemical and Environmental Engineering, UA

Cost Shares

Cost Share (other than core ERC funding):

- **$80k** from UA Water Sustainability Program
- **$150k** to purchase real-time toxicity monitoring system (UA Water Sustainability Program)
- **Postdoctoral fellowship** to C. Garcia (Mexican Science Foundation, CONACyT)
- **Doctoral fellowshi**p to J Gonzalez (Mexican Science Foundation, CONACyT)
- **Doctoral fellowship** to M McCorkel (SRC graduate fellowship program)

Overall Objectives

- Characterize toxicity of current and emerging nanoparticles (NP) & NP byproducts
- Physicochemical characterization NPs
- Oxidative Stress as a Marker for Toxicity
- Develop new rapid methodologies for assessing and predicting toxicity

Task 1:
Physical Characterization and Preparation of Nanoparticles (NP)

Synthesis and Characterization of NP

- Characterizing and Improving NP Dispersion in Biological Medium
- Physicochemical Characterization
- Synthesis of NPs

Application for Abatement

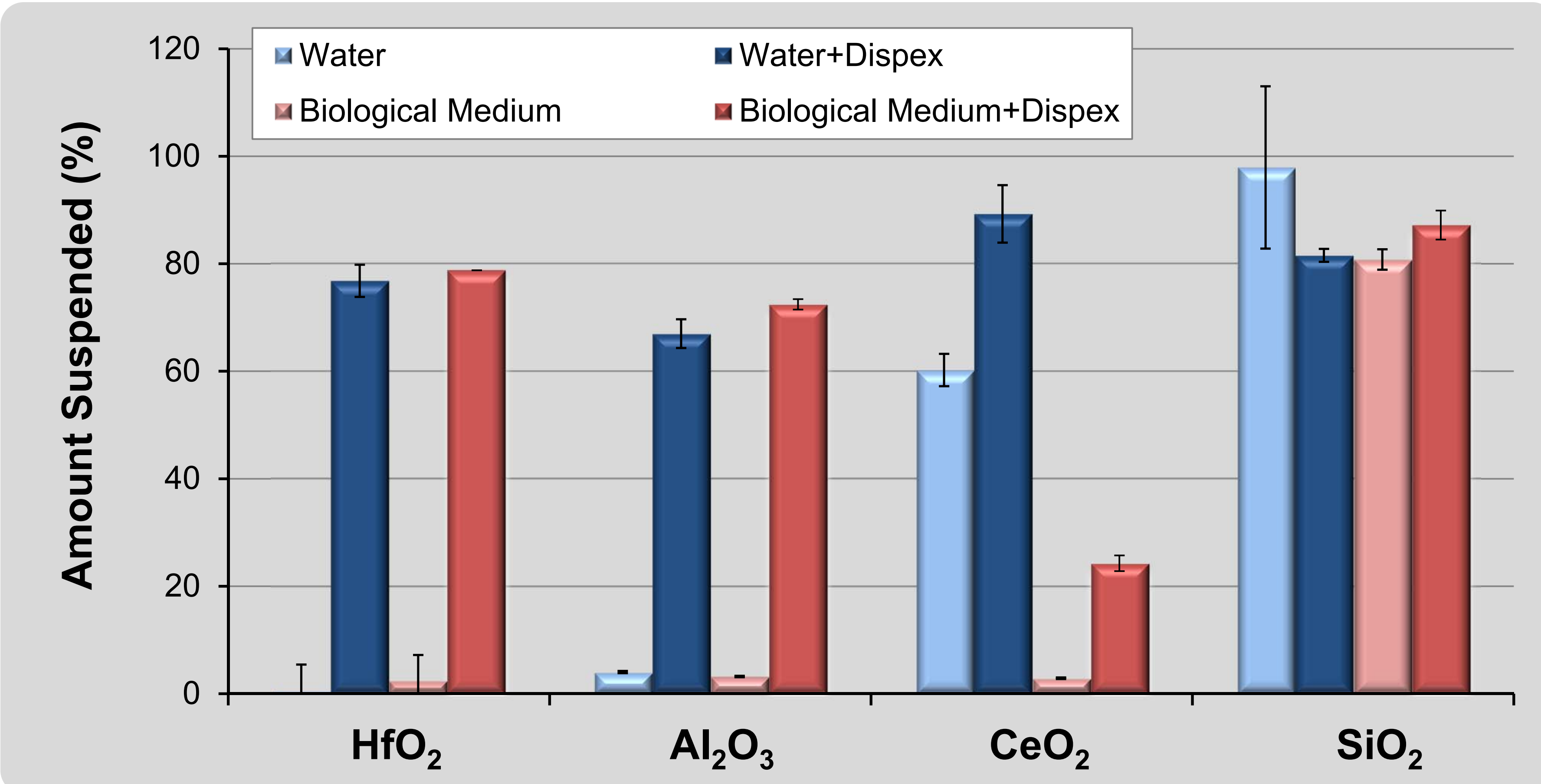
- NP Removal in Porous Media

PIs:
Reyes Sierra
Farhang Shadman

Graduate Students:
Jeff Rottman
Hao Wang
Isabel Barbero
Monica Rodriguez

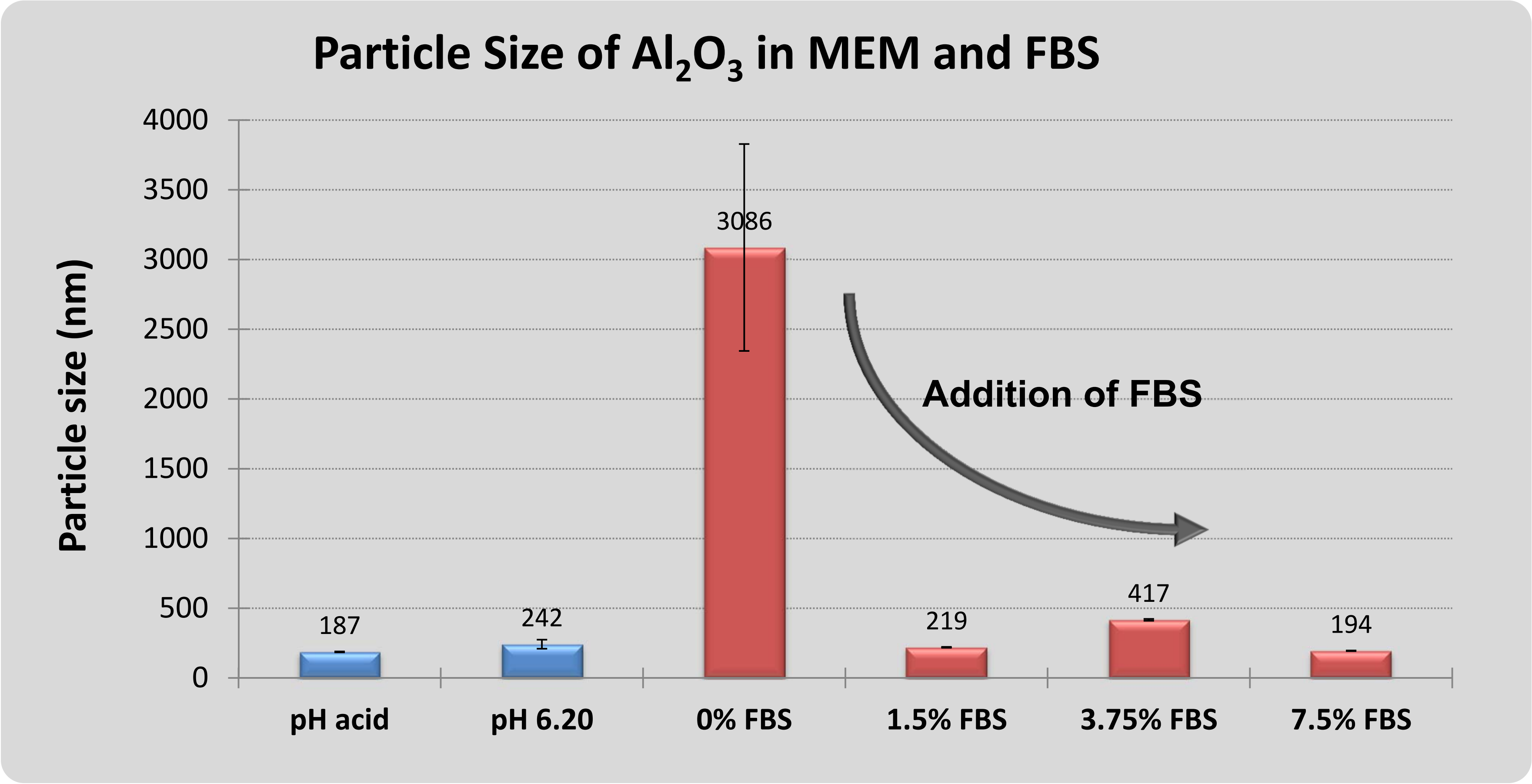
Other Researchers:
Antonia Luna
Jim A. Field

Non-toxic Polyacrylate Surfactants Enhances Dispersion



The polyacrylate dispersant, Dispex, enhanced NP dispersion in water and biological medium, yeast extract peptone dextrose (YEPD).

Effect of Protein on the Stability of NPs in Biological Media

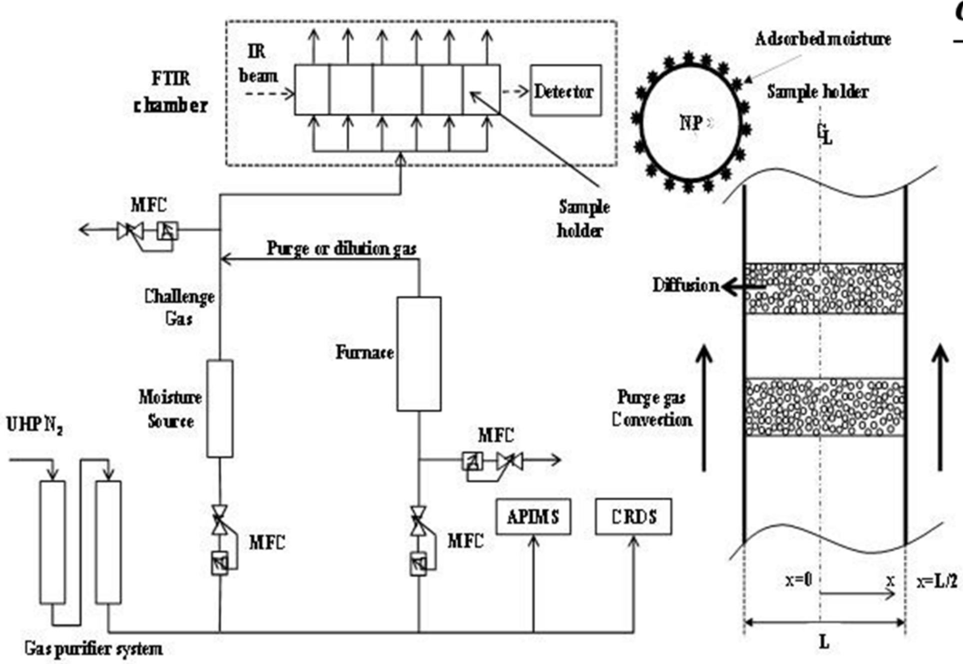


Fetal Bovine Serum (FBS) addition increases the stability of NP dispersions in biological medium, mineral essential medium (MEM).

Surface Characterization of Nanoparticles

Objective: Characterization of the surface sites on nanoparticles that contribute to concentration, retention, and enhanced transport of toxic chemicals.

Method approach: Surface hydroxylation (adsorption and desorption of contaminants).



Adsorbent concentration in the gas phase:

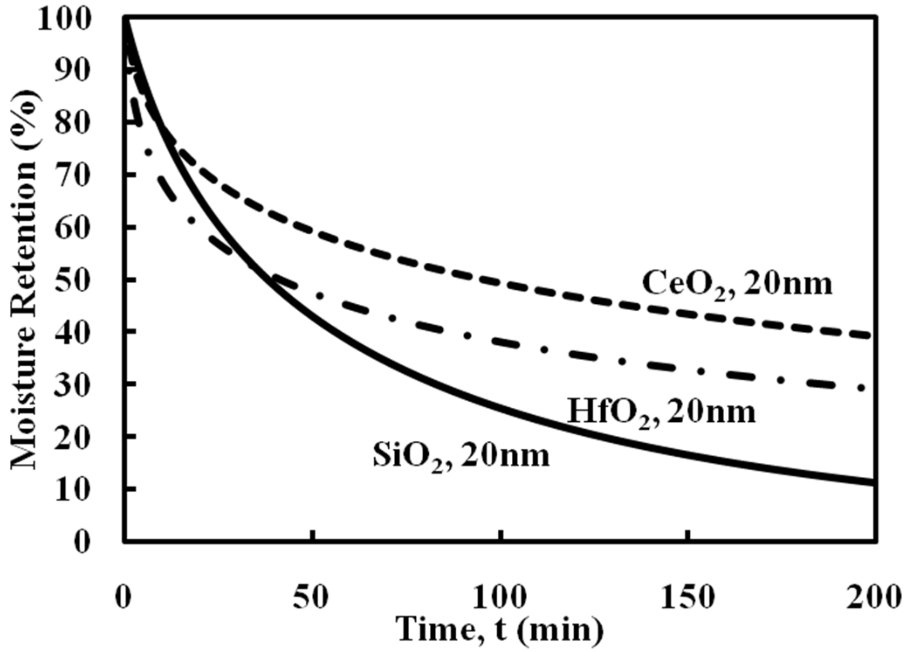
$$\frac{\partial C_g}{\partial t} = D_e \frac{\partial^2 C_g}{\partial x^2} + (1-\varepsilon)\frac{3}{r}[k_d C_s - k_a C_g (S_0 - C_s)]$$

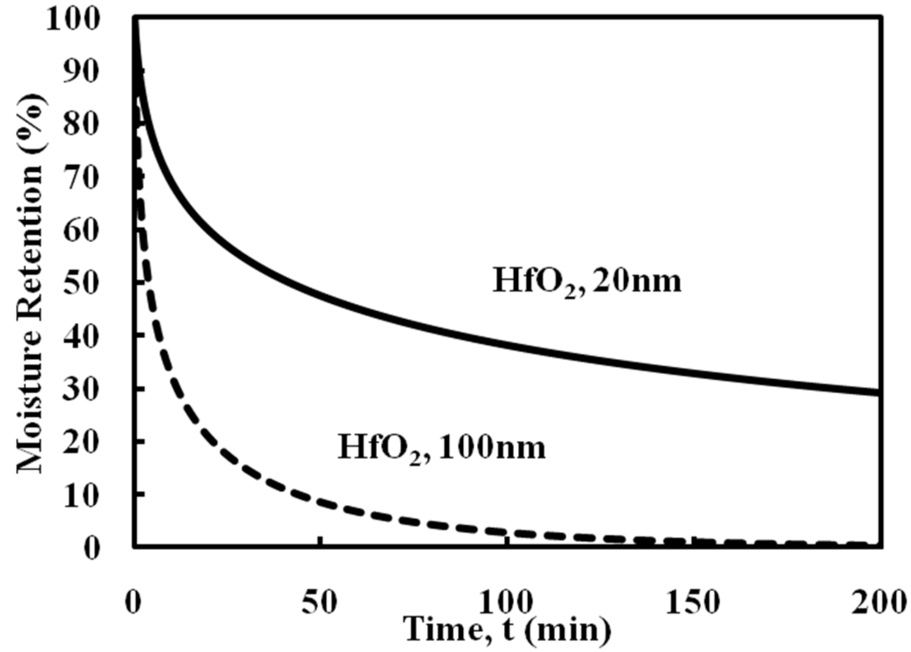
Adsorbent concentration on the surface:

$$\frac{\partial C_s}{\partial t} = k_a C_g (S_0 - C_s) - k_d C_s$$

C_g	concentration in the gas phase, $gmol \cdot m^{-3}$
C_s	concentration on the surface, $gmol \cdot m^{-2}$
k_a	adsorption rate coefficient, $m^3 \cdot gmol^{-1} \cdot s^{-1}$
k_d	desorption rate coefficient, s^{-1}
S_0	maximum capacity of the surface, $gmol \cdot m^{-2}$
ε	packing porosity
r	radius of nanoparticle, m
D_e	effective diffusivity, $m^2 \cdot s^{-1}$

Effect of NP Material and Size on Surface Retention



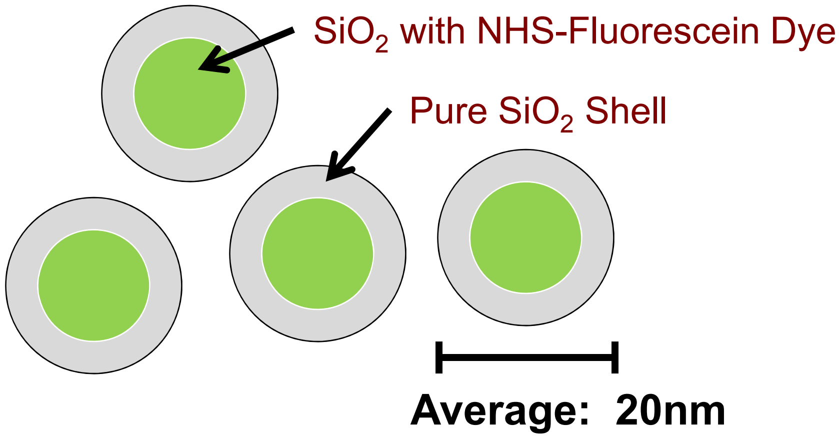


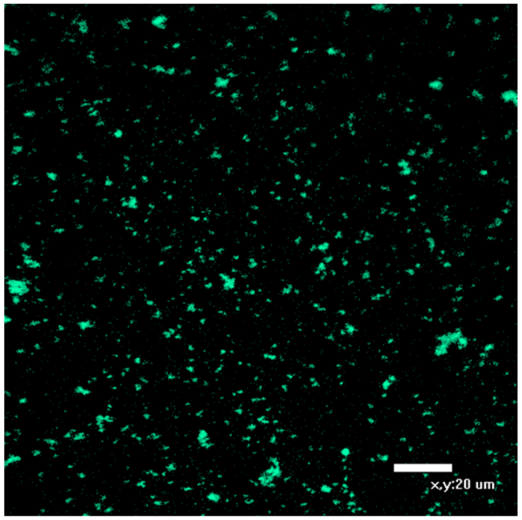
- **Surface retention depend on the material as well as on the particle size.**
- **The affinity of nanoparticles for adsorption and retention decreases in the order: CeO_2 > HfO_2 > SiO_2. The surface available sites under certain challenge concentrations decreases in the order: SiO_2 > HfO_2 > CeO_2.**

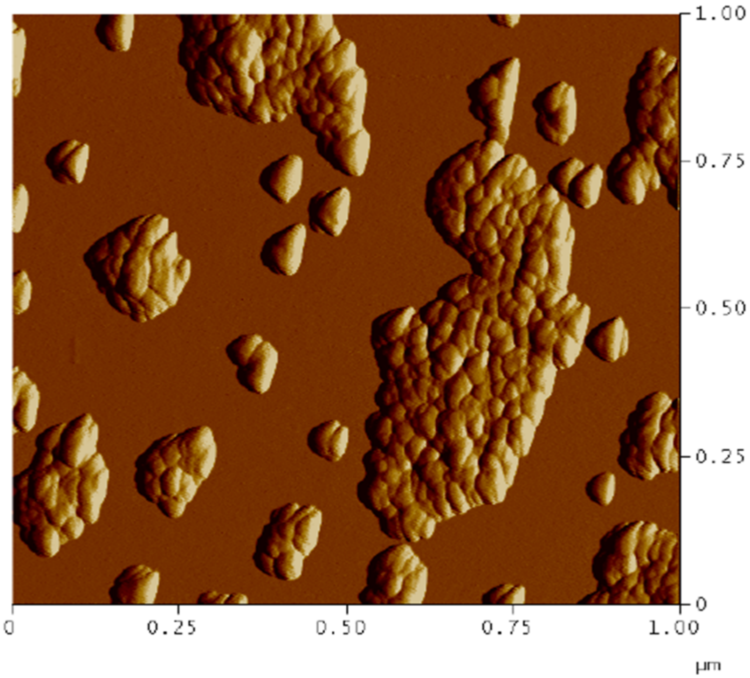
Synthesis of Fluorescent Silica Nanoparticles

Method

- Fluorescent core made with mixture of SiO_2 and NHS-Fluorescein
- Coat with pure SiO_2 shell







Advantages

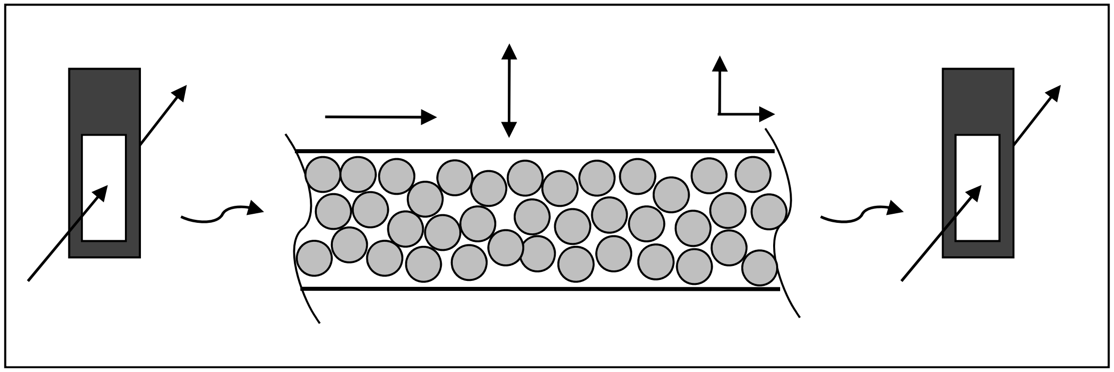
- Maintains surface chemistry of pure silica NPs
- Easy to monitor
- Low detection limit
- Final size can be adjusted

Fate of Nanoparticles in Porous Media

Objectives

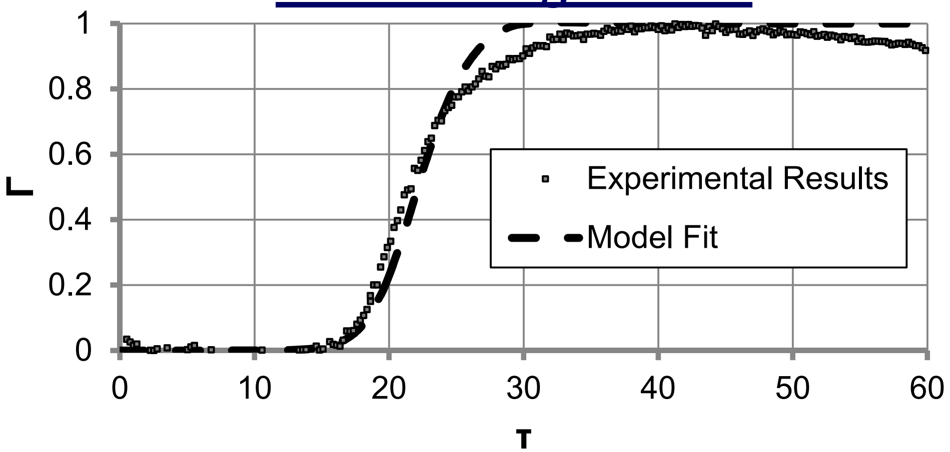
- Determine the fate of NPs in porous media.
- Model the transport of NPs in porous media.
- Establish techniques to enhance abatement.

Methodology



Rapid online measurement of nanoparticle retention utilizing UV-Vis or Fluorescence Spectroscopy

Breakthrough Curve



Model

$$\frac{\partial \Gamma}{\partial \tau} = \frac{1}{\mathrm{Pe}} \frac{\partial^2 \Gamma}{\partial x^2} - \frac{\partial \Gamma}{\partial x} - \alpha\left[K_a \Gamma(1-\theta) - K_d \theta\right]$$

$$\frac{\partial \theta}{\partial \tau} = K_a \Gamma(1-\theta) - K_d \theta$$

Conclusions

- **Dispex and FBS protein stabilize NP in biological media and are useful for toxicity testing.**
- **NP material and size affect active site density and energetics and therefore contaminant retention.**
- **A method was selected and tested for the synthesis of size controlled fluorescent silica NP**
- **A packed bed is a promising technique for the abatement of NPs in waste streams depending on bed conditions; a method was developed for selecting these parameters.**

Objectives: University of Washington Project

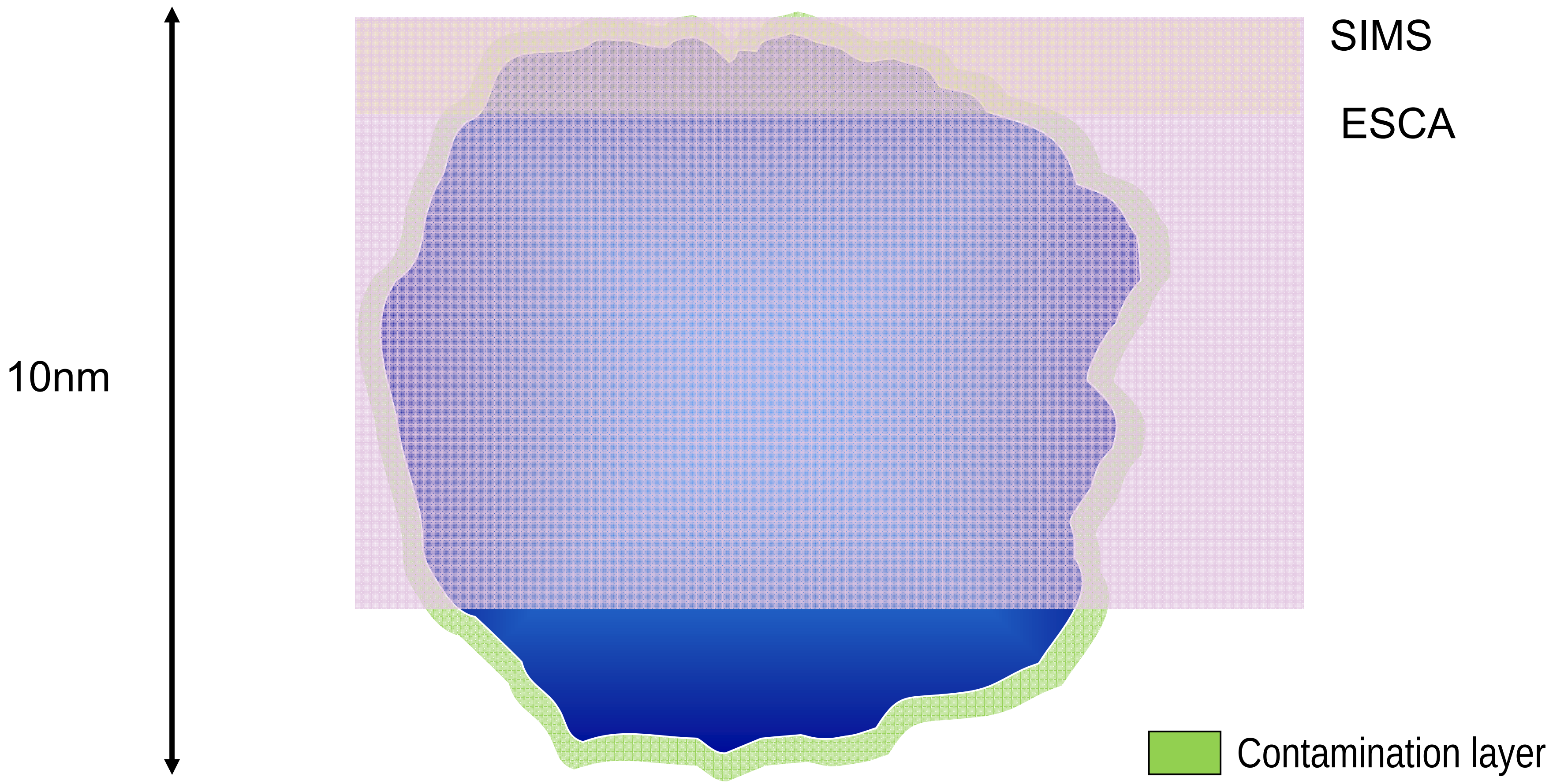
- Surface chemical characterization of CeO_2 nanoparticles from the "round robin" standardization experiment
  - ESCA (XPS)
  - SIMS (static ToF-SIMS)
  - SEM
  - TEM

- Nanoparticle toxicity assessed by a human foreskin organ culture model

Hypothesis: toxicity of nanoparticles may result from interactions of surface species coating these particles with biological organisms

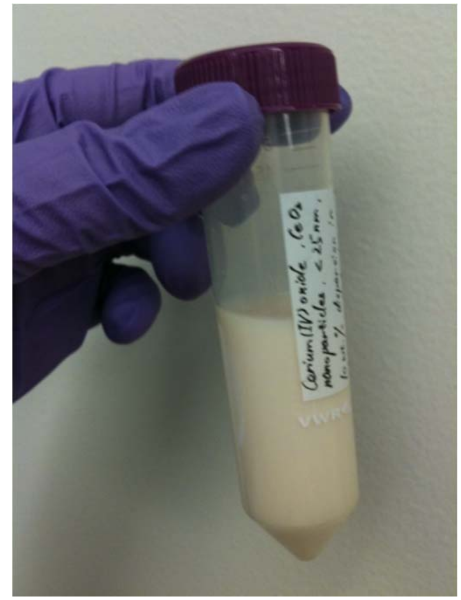
Sampling Depths

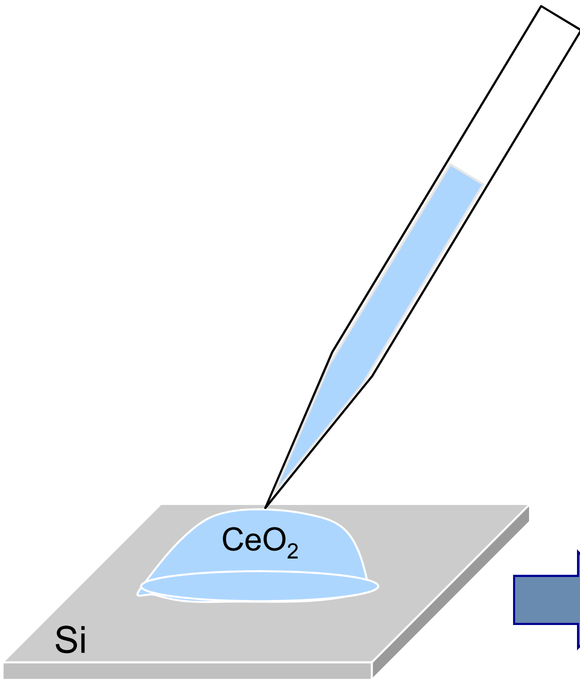
electron spectroscopy for chemical analysis (ESCA)
secondary ion mass spectrometry (SIMS) (static mode)



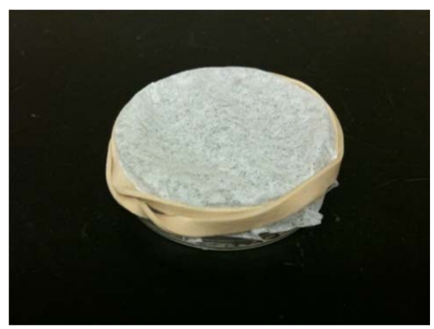
Sample preparation

$40\ \mu l$ 10 wt.% CeO_2 in water from Sigma-Aldrich (particle size label <25 nm)

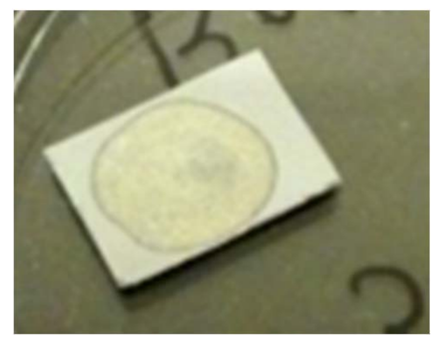




Drop of sample on Si wafer

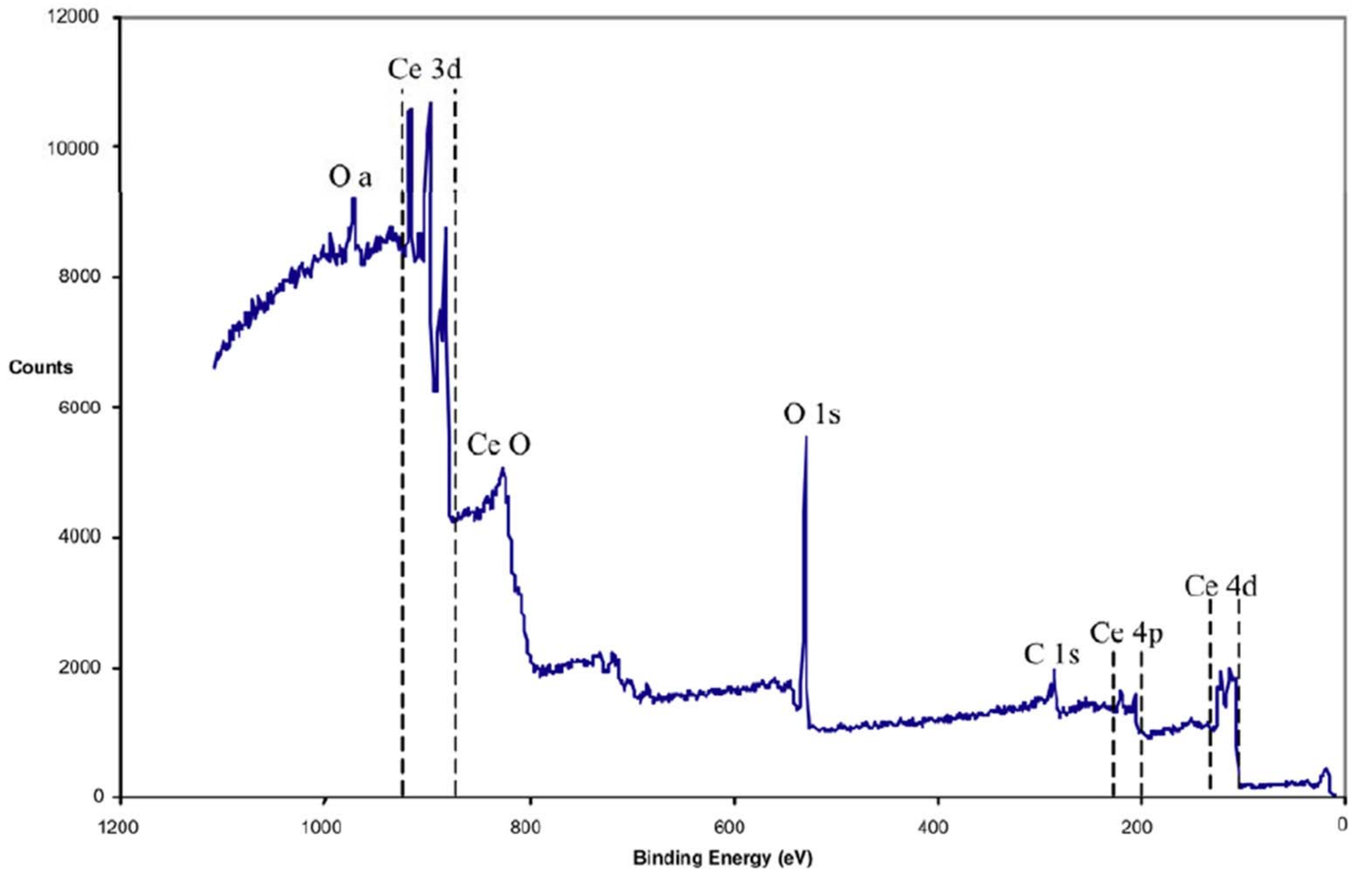


Sample covered and left in hood to dry



Dried sample

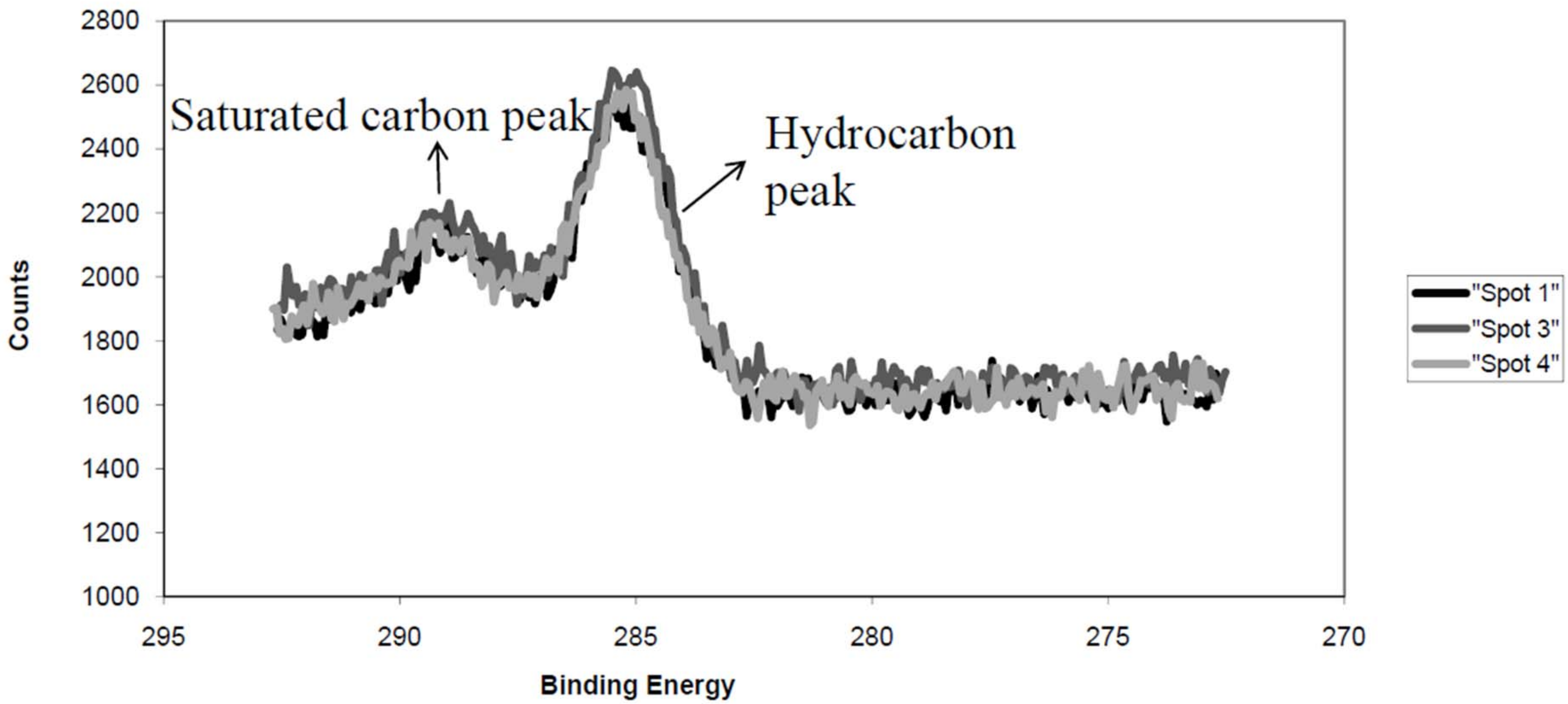
Survey scan



Survey scan of 10 wt. % CeO_2 in water, spot 2

Survey scan spectra shows that the elements present on the outermost 10 nm layer of nanoparticles are Ce, C, and O

High resolution C1s



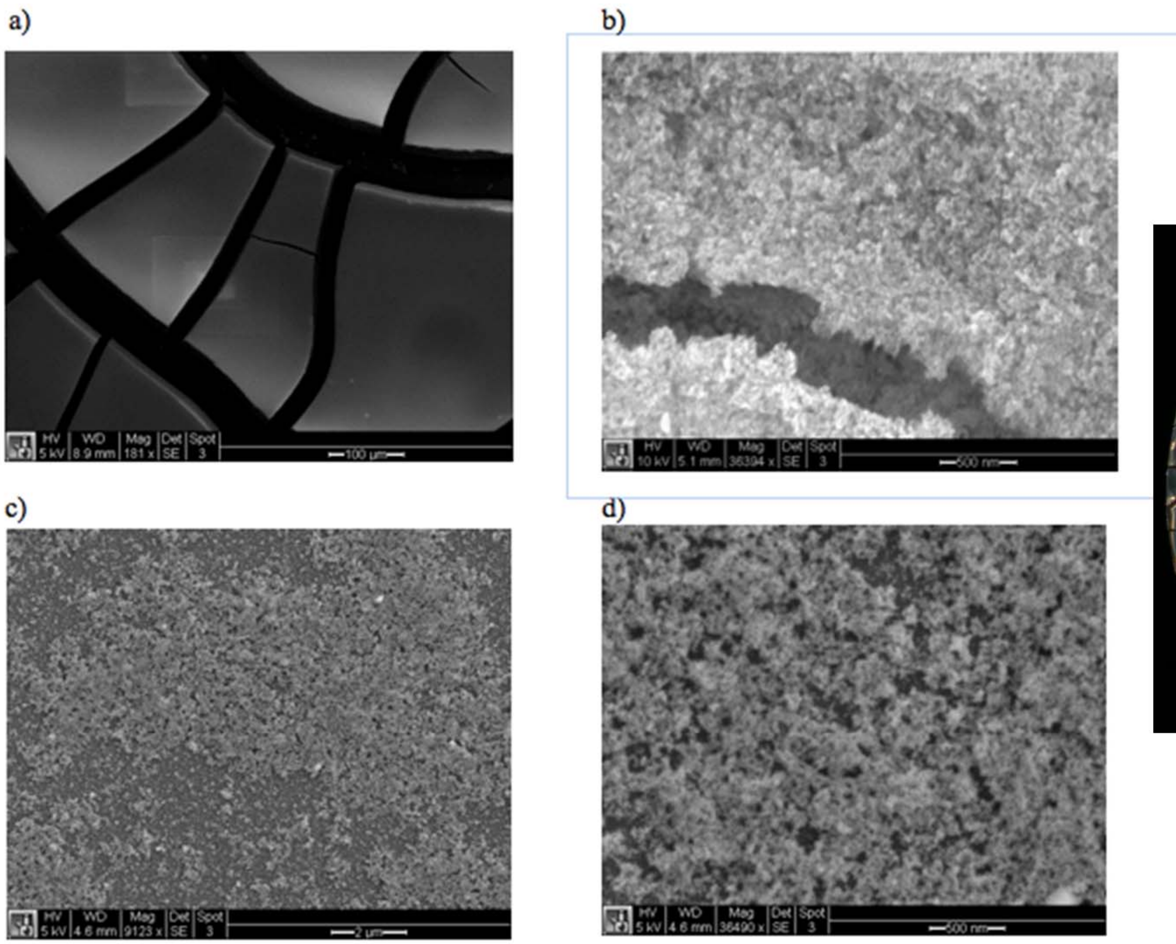
- High resolution C1s peak consists of hydrocarbon and unsaturated carbon peak
- Unsaturated C1s peak with a 4 eV shift from hydrocarbon peak could be associated with either carboxylate, or, less likely, carbonate

Surface elemental ratio

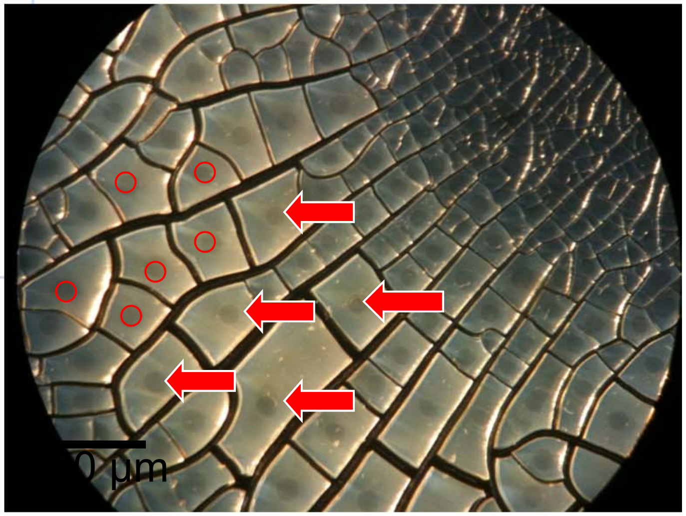
- Hydrocarbon and unsaturated carbon contents are calculated from the ratio of their respective area under the detailed scan peaks

	Ce %	O%	Total C%	Unsaturated Carbon%	Hydrocarbon %
Spot 2	19.3	60.2	20.5	4.7	15.8
Spot 5	17.1	54.4	28.5	9.1	19.4

SEM characterization of CeO_2 sample

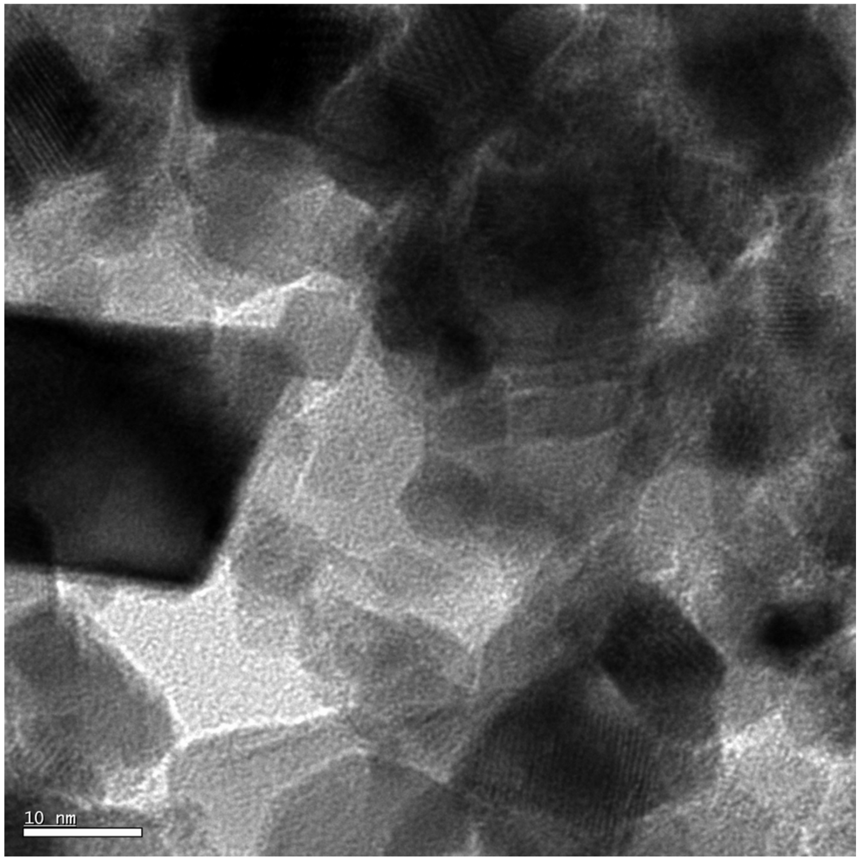


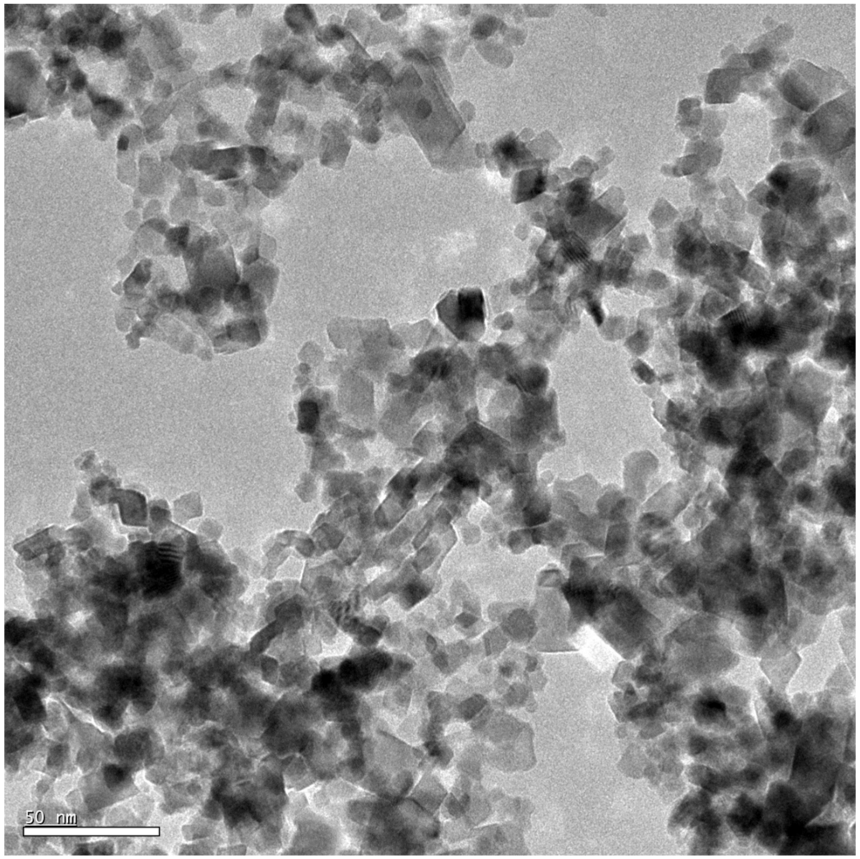
SEM micrographs of CeO_2 nanoparticles. a. 10 wt.% CeO_2 (the original sample concentration) b. Surface between cracks shown in a. c,d. Diluted sample (0.5 wt. %)



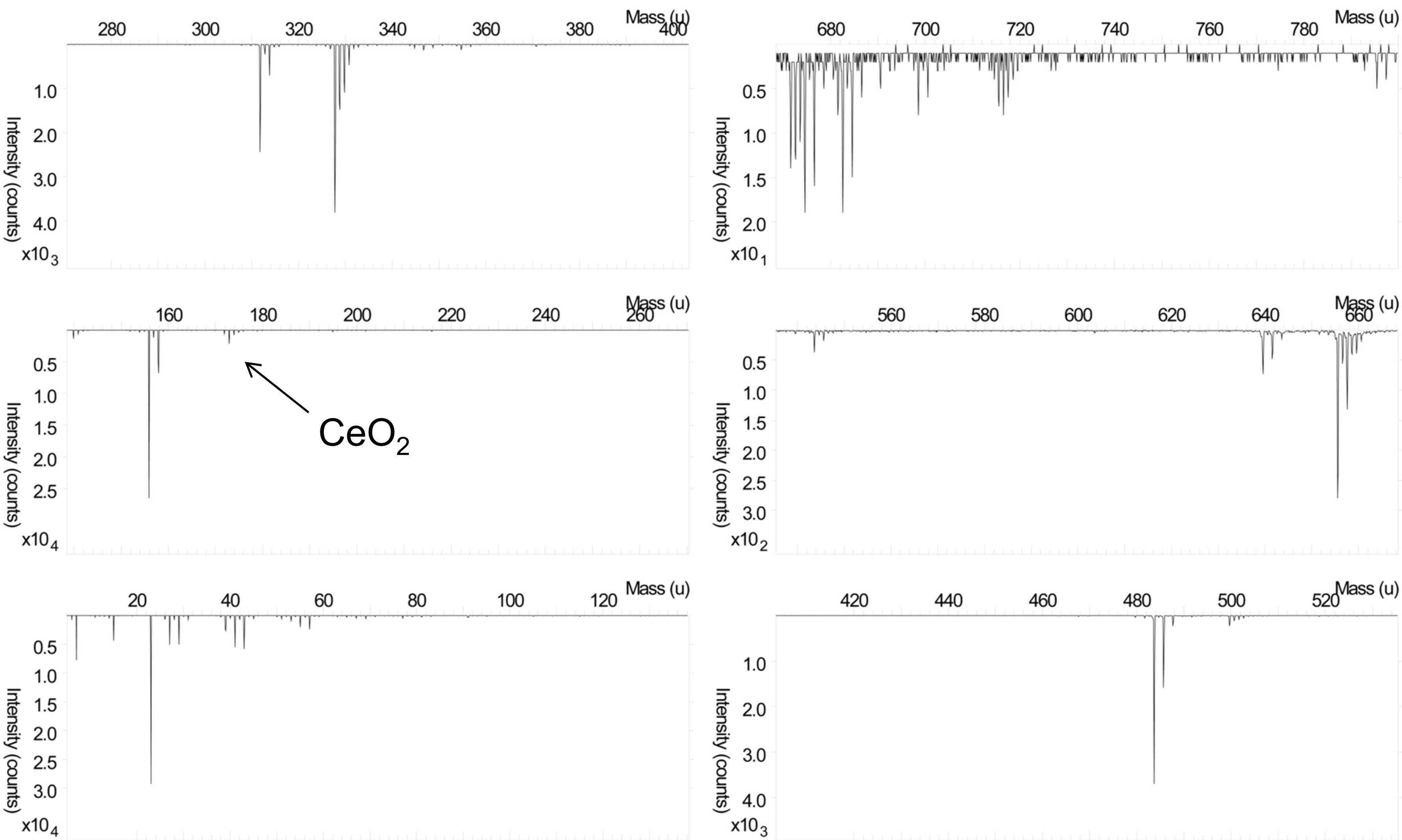
Circular features noted

Transmission Electron Microscopic Images

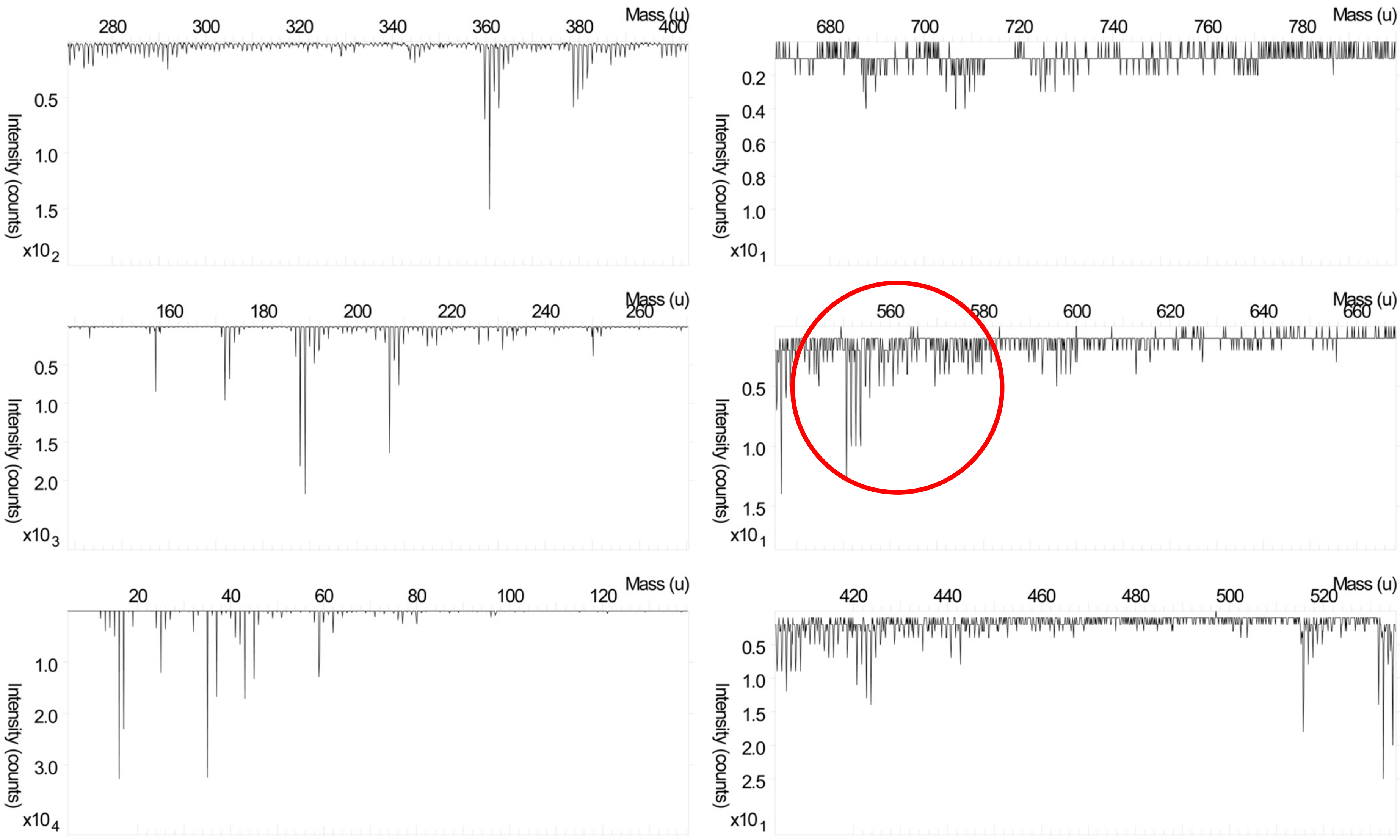




Static ToF-SIMS – CeO_2 2.5wt% (+) spectrum

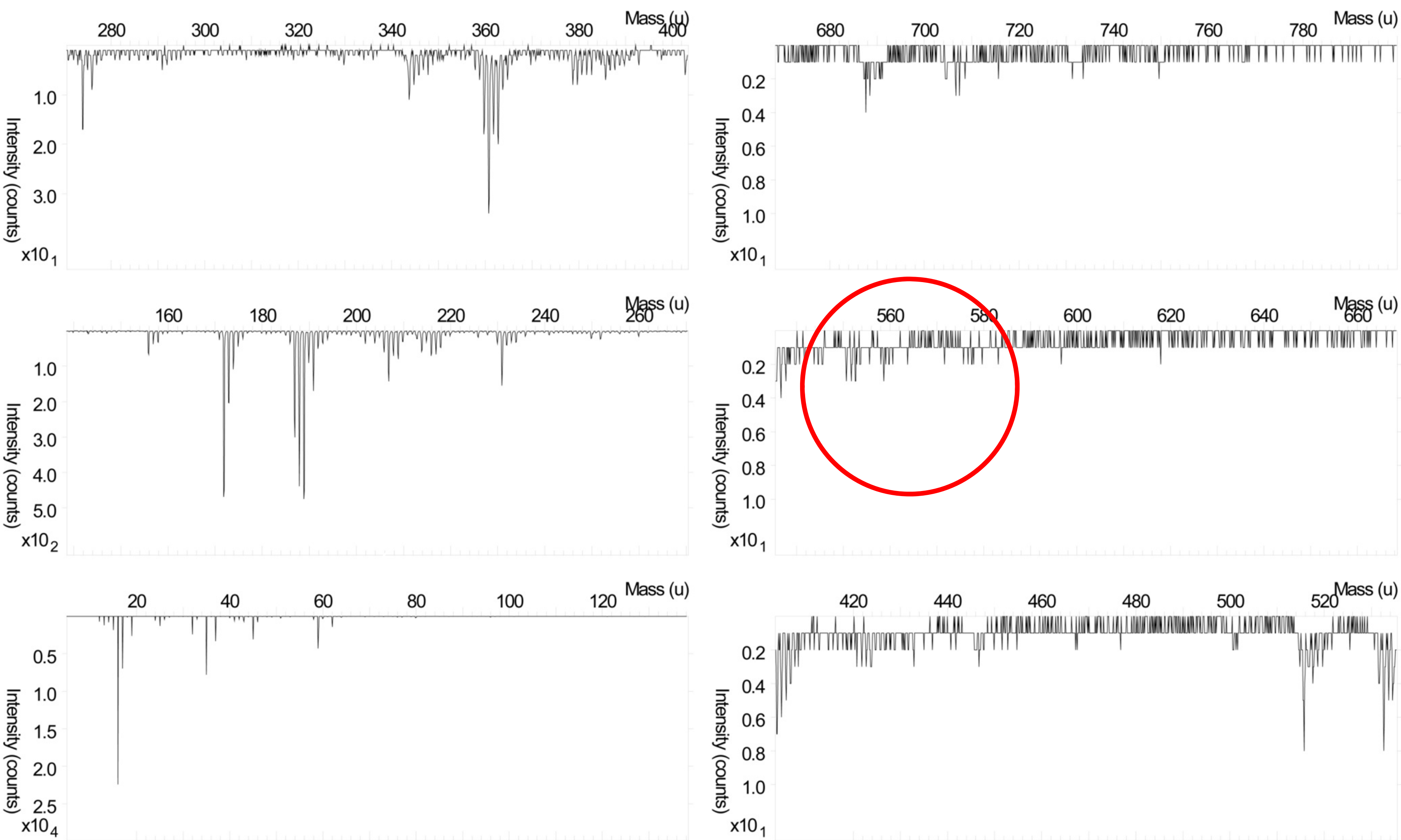


Static ToF-SIMS – CeO_2 2.5wt% (-) spectrum



C = circular feature

Static ToF-SIMS – CeO_2 2.5wt% (-) spectrum – C



Summary

- Nanoparticle surface chemical structure was characterized by XPS and surface were homogenous with respect to elemental species and oxidation state of Ce^{4+}

- Carboxylate species probably present on nanoparticle surface

- SIMS show inhomogeneity and will permit us to identify specific species

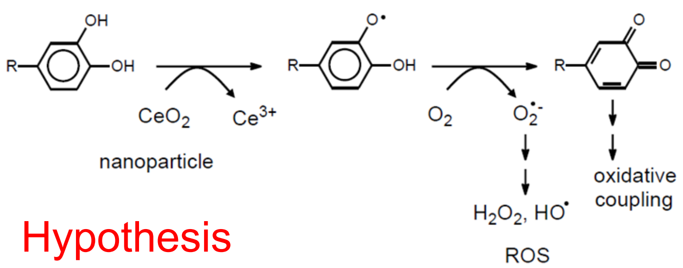
Toxicity Experiments Past Year

Tasks 425.024

- Completed study on chemical ROS production.
- Completed study on yeast O_2 uptake assay.
- Evaluated flow-cytometry for yeast membrane integrity assay.
- Impedance-based Real Time Cell Analysis (RTCA) for high throughput screening.

Experiments: Chemical ROS - 1

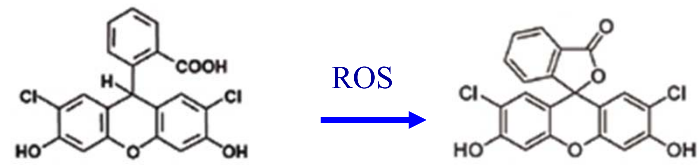
Monitor chemical ROS production caused NP oxidation of L-dopa



Hypothesis

fluorescent

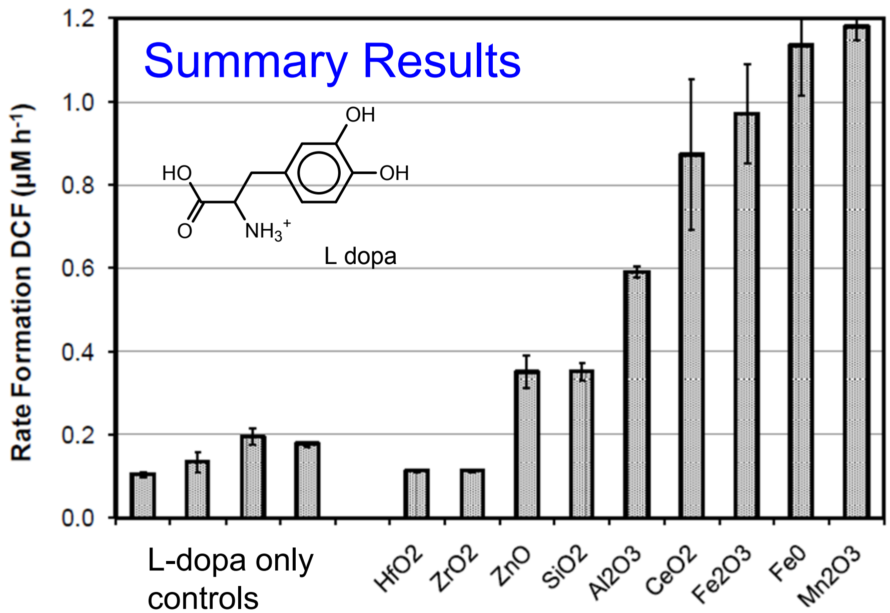
Fluorescence spectrometer



2′,7′-dichlorodihydrofluorescein (DCFH)

2′,7′-dichlorofluorescin (DCF)

Measurement



New findings since last year

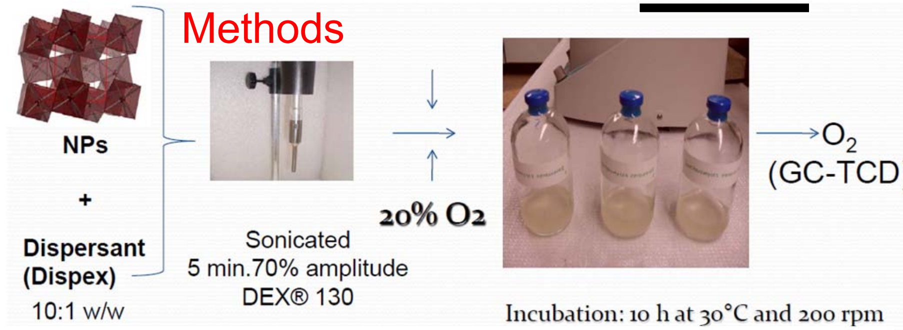
- Mn_2O_3 directly oxidizes DCFH (O_2 not required)
- Mn_2O_3 caused large effects in ppm range
- Completed screening

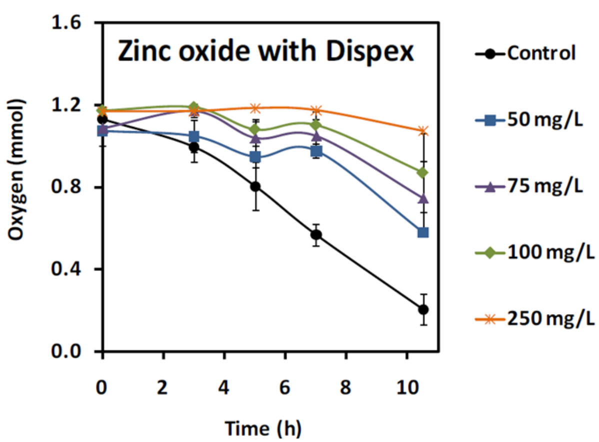
Conclusions

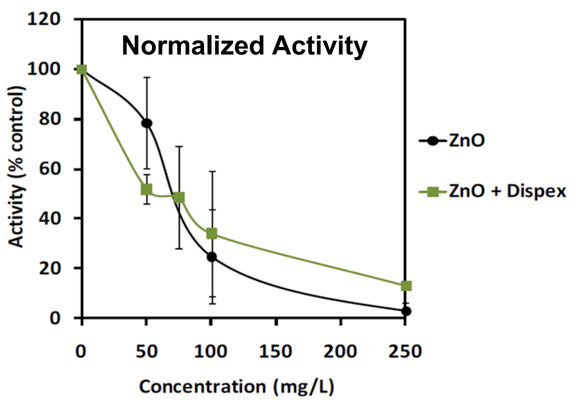
- Mn_2O_3, most reactive and directly oxidizes DCFH
- CeO_2, Fe_2O_3 and Fe^0 react with L-dopa and O_2 to greatly enhance ROS formation
- ZnO, SiO_2 and Al_2O_3 react with L-dopa and O_2 to enhance ROS formation to a lesser extent
- HfO_2, ZrO_2 do not enhance ROS production (inert)

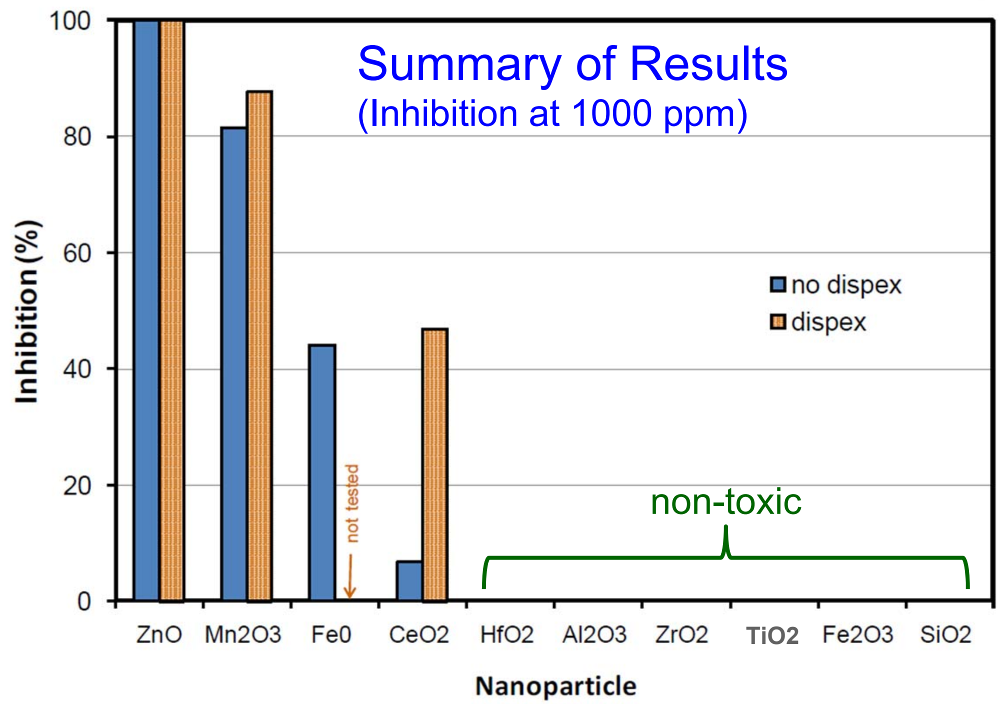
Experiments: Yeast O_2 uptake

Monitor O_2 uptake by yeast *S. cerevisiae* in pH 6.5 Yeast Extract Peptone Dextrose (YEPD) medium (effect dispersant, Dispex)









Conclusions:

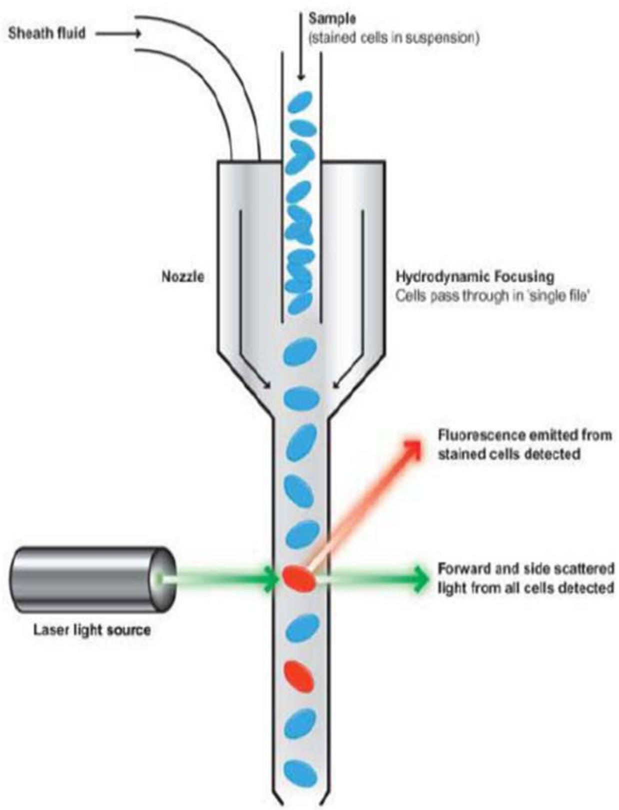
ZnO most toxic, due to solubilization of Zn^{+2}

Mn_2O_3, Fe^0 & CeO_2 toxic, due to oxidative stress

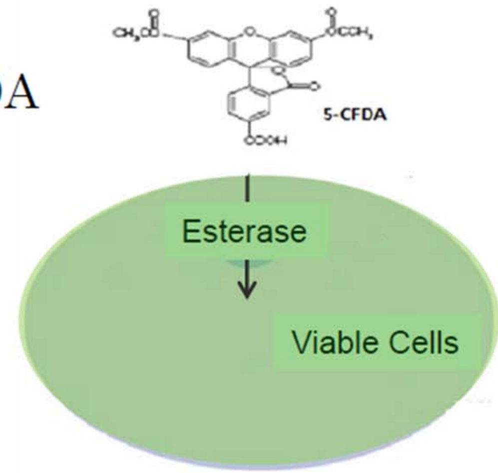
CeO_2 toxicity increased by better dispersion

Experiments: Yeast Flow Cytometry - 1

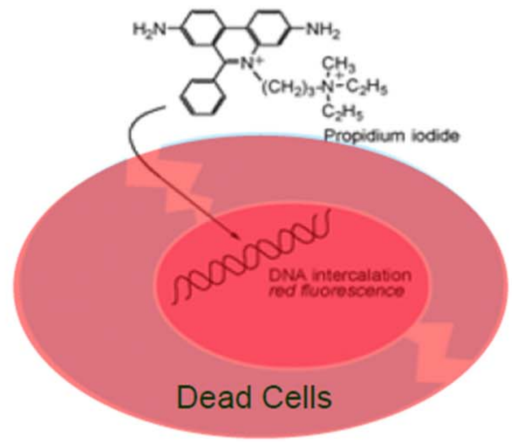
Flow cytometry for assaying membrane integrity of yeast *S. cerevisiae* in pH 6.5 Yeast Extract Peptone Dextrose (YEPD) medium exposed to NP dispersed in Dispex



- CFDA

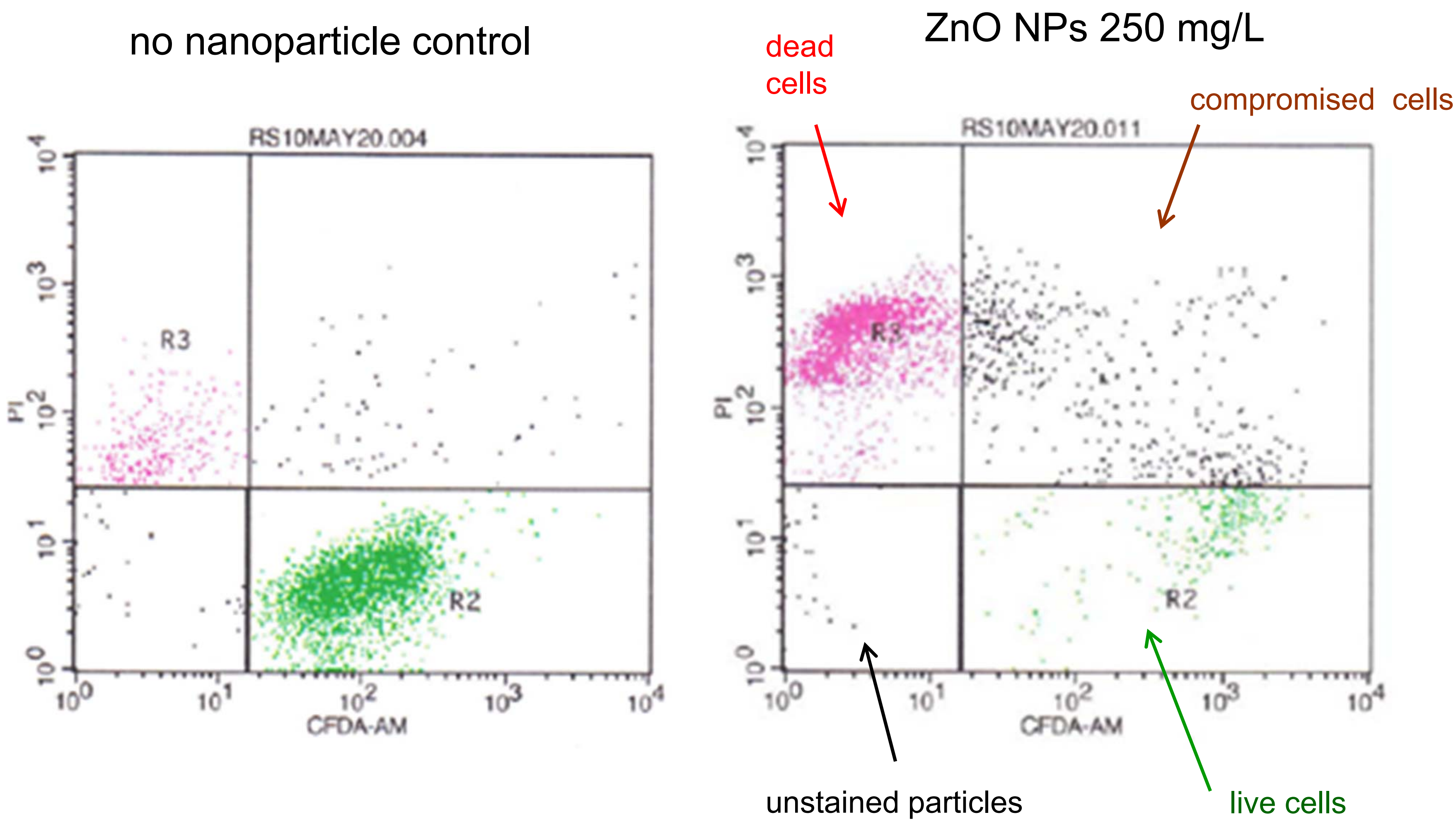


- PI

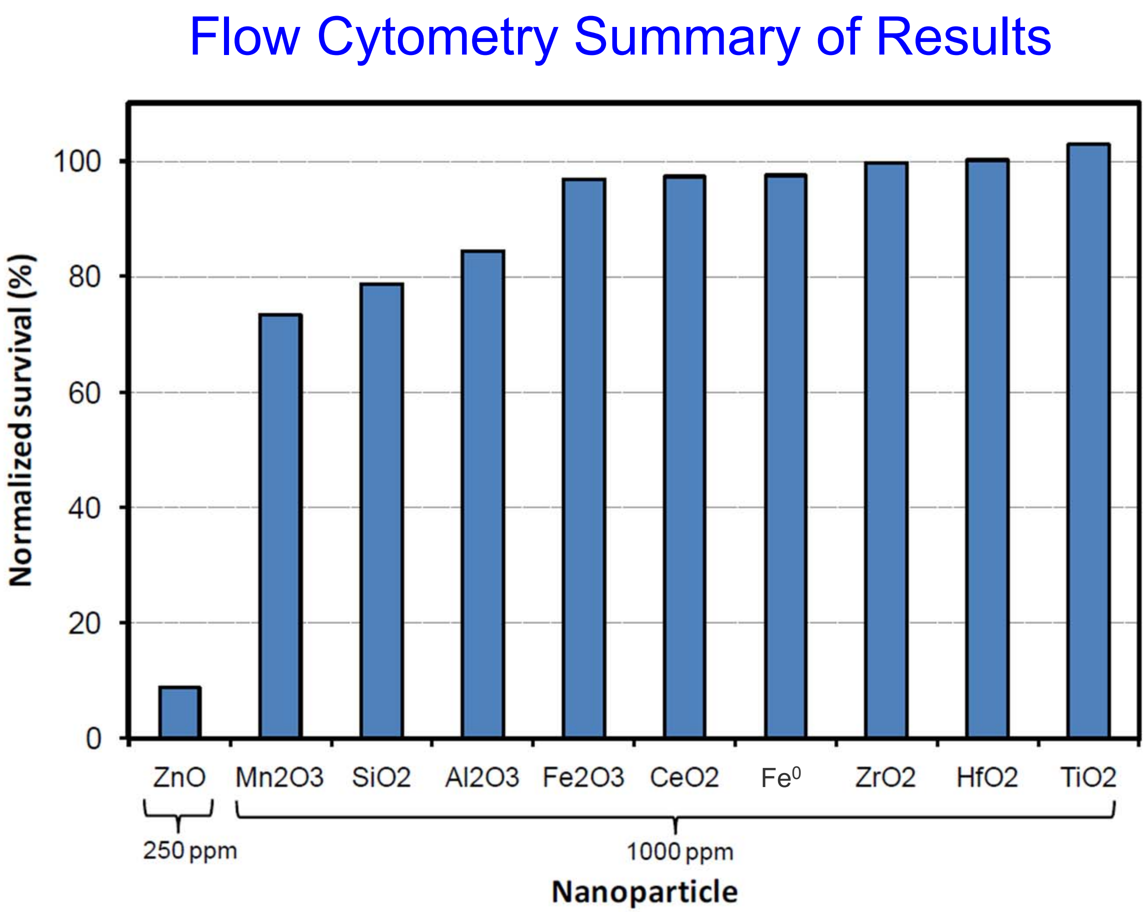


Experiments: Yeast Flow Cytometry - 2

Flow cytometry example plots (right plot with explanation of quadrants)



Experiments: Yeast Flow Cytometry - 3



Conclusions:

- ZnO most toxic, due to solubilization of toxic Zn^{2+} salt
- Mn_2O_3, SiO_2 and Al_2O_3 significant but low toxicity at 1000 ppm

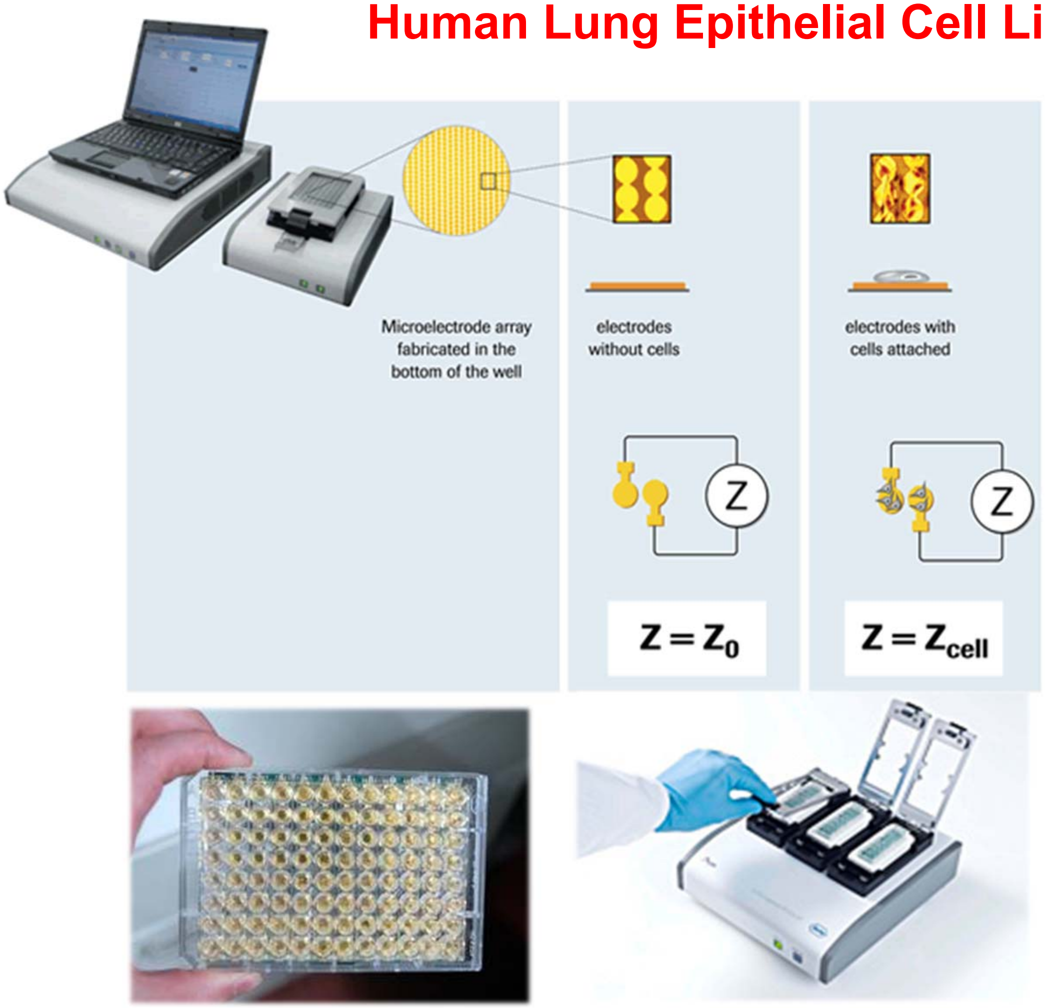
} membrane damage

- All other NPs did not disrupt membrane

Experiments: xCELLigence - 1

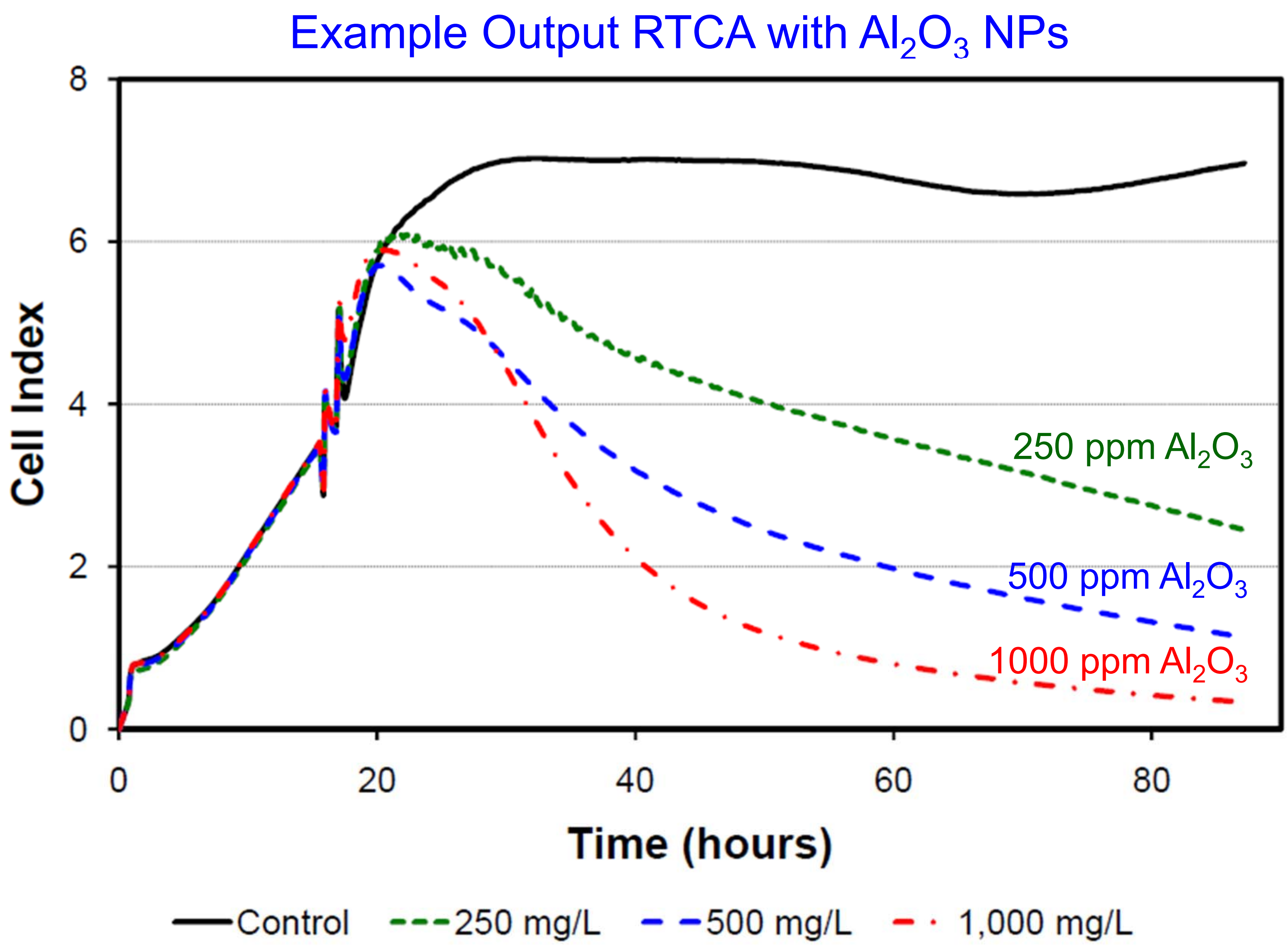
Monitor Impedance Based Real Time Cell Assay (RTCA) with xCELLigence (Roche)

Human Lung Epithelial Cell Line, 16HBE14o-



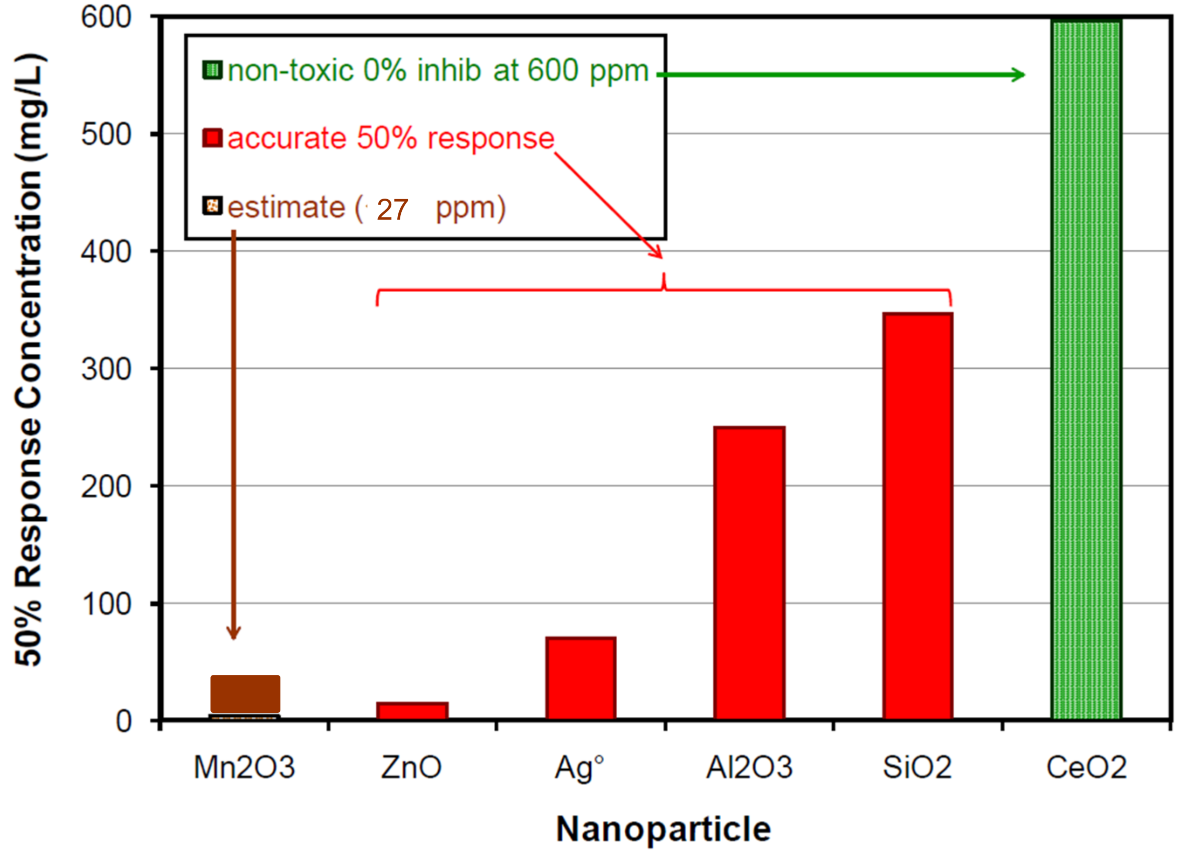
- The xCELLigence System measures electrical impedance across interdigitated micro-electrodes integrated on the bottom of tissue culture E-Plates.
- The impedance provides information about the biological status of the cells.
- The xCELLigence system does not need fluorescent labels.

Experiments: xCELLigence - 3



Experiments: xCELLigence 4

50% Response Concentrations from all RTCA experiments with NPs



Conclusions:

Mn_2O_3 most toxic (27 ppm, 50% response)

ZnO and Ag^0 also highly toxic

Al_2O_3 and SiO_2 moderate toxicity

oxidative

solubilization Zn^{+2} and Ag^+

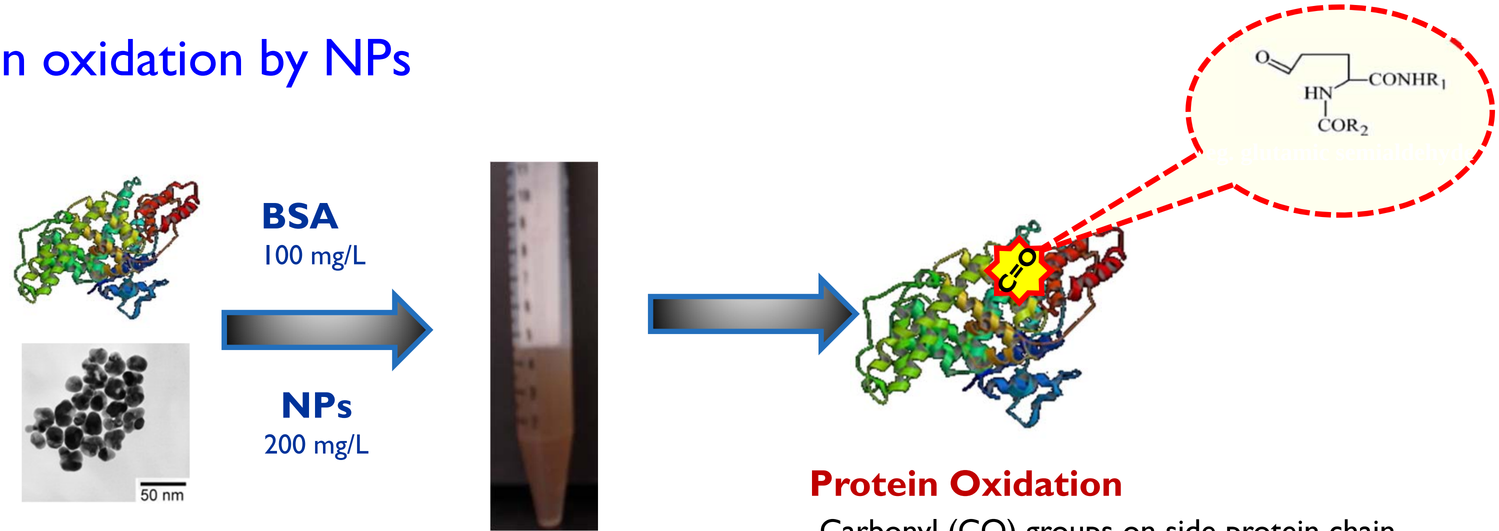
stability of NP suspensions

Experiments: Conclusions

- Most toxic NPs: ZnO, Ag^0 and Mn_2O_3
  - ZnO and Ag^0 NPs solubilize during the assays and are almost equivalent in toxicity to Zn^{+2} and Ag^+ salts.
  - Mn_2O_3 is oxidative (directly oxidizes ROS-dye, can also form ROS, and had a detectable impact in yeast membrane integrity test).
- Consistently moderately toxic NPs: Al_2O_3 and SiO_2
  - Al_2O_3 and SiO_2 had good NP stability in assay media utilized.
  - Al_2O_3 and SiO_2 also have moderate to low chemical ROS production.
- Sometimes moderately toxic NPs: CeO_2 and Fe^0
  - CeO_2 and Fe^0 strongly enhance chemical ROS production.
- Consistently non-toxic NPs: ZrO_2 and HfO_2
  - inert

New Experiments 1: Oxidation Macro Molecules

BSA protein oxidation by NPs

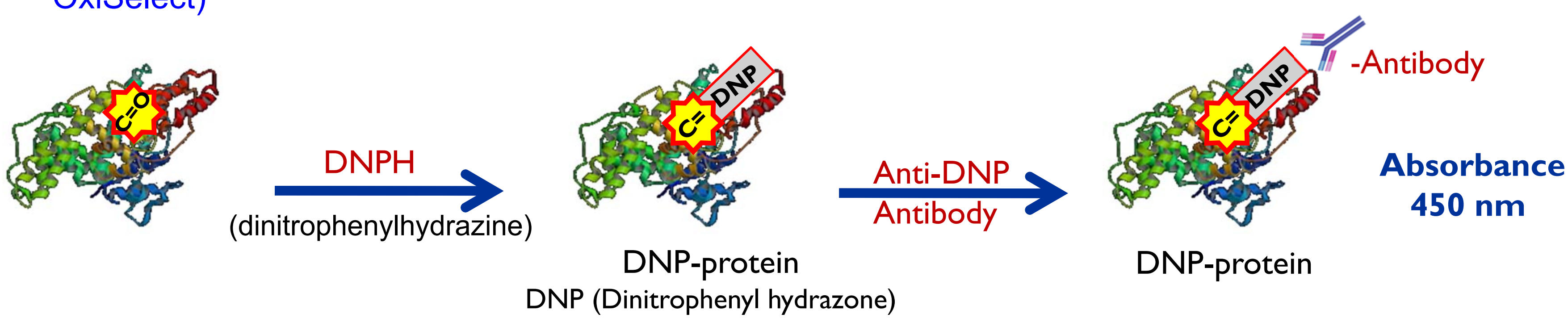


Protein Oxidation

Carbonyl (CO) groups on side protein chain mainly from: Pro, Arg, Lys, and Thr

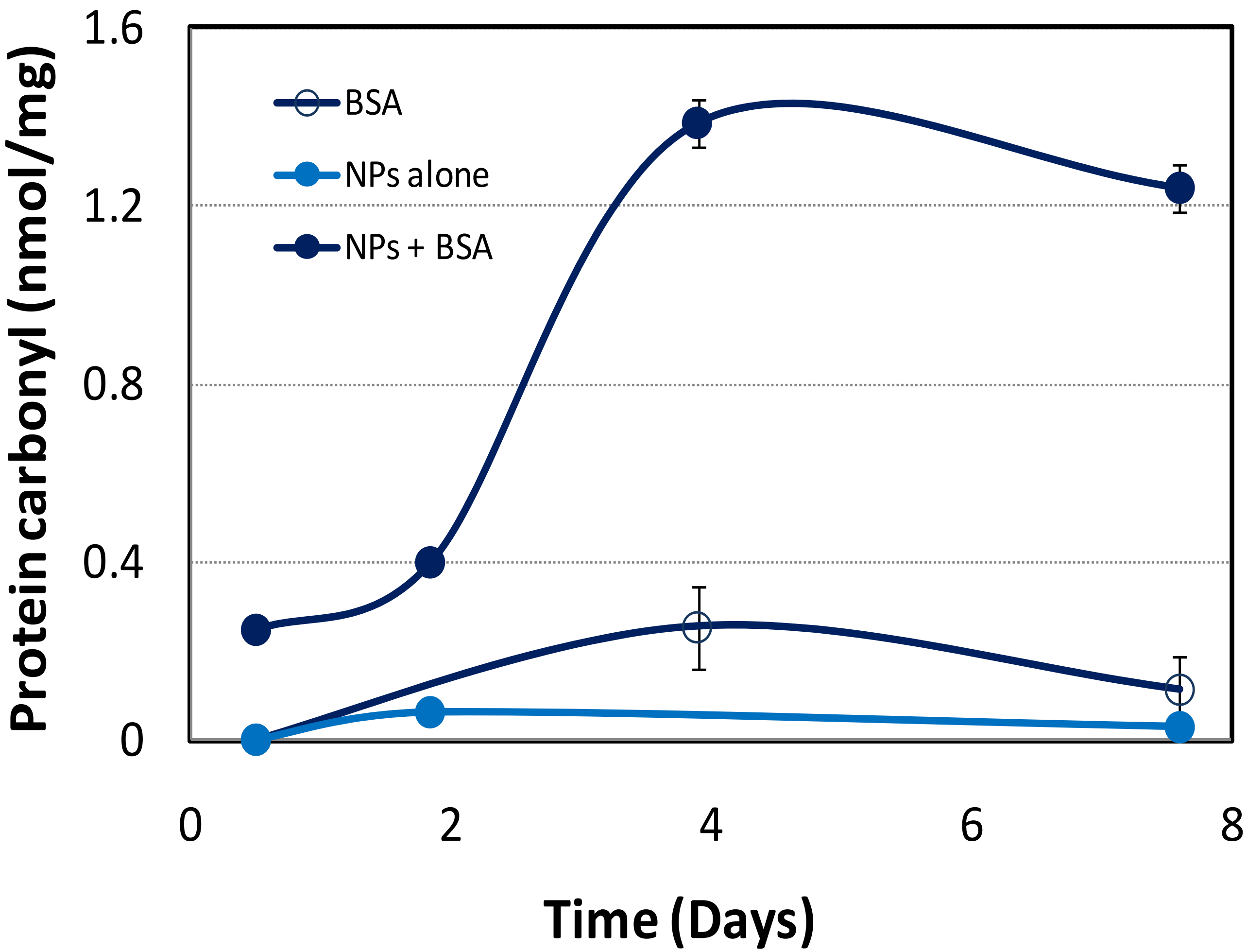
Protein carbonyls measurement by ELISA test

Rapid detection/quantification as an index of oxidized proteins (Kit OxiSelect)



New Experiments 2: Oxidation Macromolecules

Preliminary Result → BSA protein oxidation by Mn_2O_3 NPs



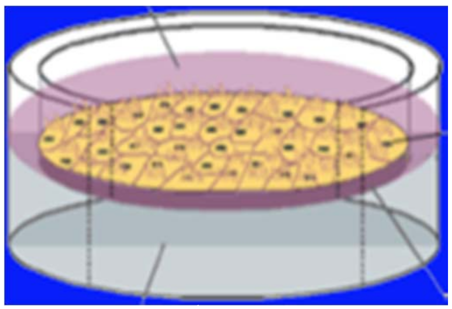
Oxidized standard BSA:
7.5 nmol protein carbonyl/mg protein (= 100% oxidized BSA)

Incubation: PBS at 37°C, Mn_2O_3 NPs (200 mg L^{-1}), BSA (100 mg L^{-1})

New Experiments – 3: Organ Cultures

UA: Development of Well-Differentiated Human Airway Epithelia

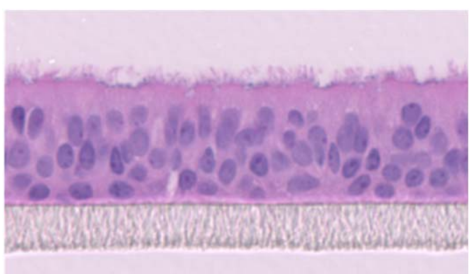
Air-Liquid Interface



Apical Airway Epithelium

Filter Support

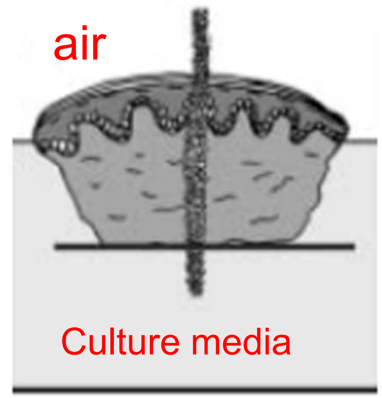
Basally-supplied Medium

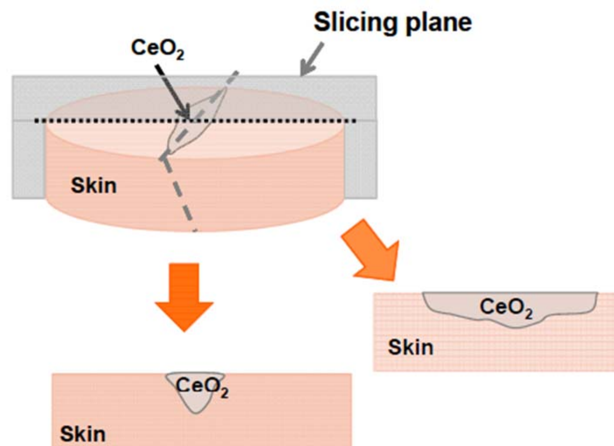


Differentiated Cells in Culture: Pseudostratified, ciliated epithelium

Epithelia develop trans-epithelial resistance (TER) > 500 Ω*cm[2]
Cell differentiation occurs

UW: Skin organ culture model





Skin punch sizes:
Circles with in 8 mm diameter and about 3mm thickness

Future Plans

UA

- NP oxidation of large biomolecules (proteins, *etc*)
- Correlation multiple parameters to measured toxicity
- NP impact on oxidative stress at cellular level
- NP impact on cell signaling (*e.g.* ATP signaling)
- NP toxicity to well-differentiated human airway epithelia, including impact on Trans-Epithelial Resistance (TER) barrier level
- Validation RTCA

UW

- Analyze SIMS spectra – perform principal components analysis to clarify differences
- Begin experiments with better defined CeO_2 from the Central Florida University and gold NPs
- Test samples for cytotoxicity in the human foreskin rafted organ culture model (data analysis by light microcopy and TEM)

Publications & Presentations

Journal Publications from Project

1. Luna-Velasco A, Field JA, Cobo-Curiel A, Sierra-Alvarez R. 2011. Inorganic nanoparticles enhance the production of reactive oxygen species (ROS) during the autoxidation of L-3,4-dihydroxyphenylalanine (L-Dopa). J. Haz. Mat. (*Submitted*)

2. Garcia-Saucedo C, Field JA, Otero L, Sierra-Alvarez R. 2011. Toxicity of HfO_2, SiO_2, Al_2O_3 and CeO_2 nanoparticles to the yeast, *Saccharomyces cerevisiae*. J. Haz. Mat. (*Submitted*)

3. Field JA, Luna-Velasco A, Boitano SA, Shadman F, Ratner BD, Barnes C, Sierra-Alvarez R. 2011. Cytotoxicity and physicochemical properties of hafnium oxide nanoparticles. Chemosphere (*Submitted*)

4. Gomez-Rivera F, Field JA, Brown D, Sierra-Alvarez R. 2011. Fate of cerium dioxide (CeO_2) nanoparticles in municipal wastewater during activated sludge treatment Bioresource Technol. (*Submitted*)

5. Wang H, Yao J., Shadman F. 2011. Characterization of the surface properties of nanoparticles used in semiconductor manufacturing. (*Submitted*)

Conference Papers Project

6. Rottman J, Shadman S, Sierra-Alvarez R. 2010. Interactions of CMP nanoparticles and sewage sludge. *SESHA Journal*, Summer 2010. pp. 8

7. Gomez-Rivera P, Brown D, Field JA, Shadman F, Sierra-Alvarez, R. 2010. Fate of CeO_2 nanoparticles during laboratory-scale activated sludge treatment. *SESHA Journal*, Summer 2010. pp. 10.

Publications & Presentations

Conference Presentations

- Field JA, Luna-Velasco A, Garcia C, Otero L, Sierra-Alvarez R. 2010. Toxicity and environmental fate of nanoparticles. 2010 Nano Monterrey Forum: Nanotechnology Industrial Applications. 2010. Nov. 18-19, Monterrey, Mexico. [ORAL]
- Rottman J, Barbero I, Rodriguez M, Sierra-Alvarez R, Shadman F. 2010. ate of CMP nanoparticles in municipal wastewater treatment. TECHCON Conference: Technology and Talent for the 21st Century. Austin, TX. Sept. 13-14. Prize for best presentation in the Environmental session. [ORAL]
- Gomez-Rivera, P., Brown, D. , Field JA, Shadman F, Sierra-Alvarez, R. 2010. Fate of CeO_2 Nanoparticles During Laboratory-Scale Activated Sludge Treatment. 32nd Semiconductor Environmental, Safety & Health Association (SESHA) Annual Int. High Technology ESH Symp. Exhibition, Scottsdale, AZ, April 26-29. Prize for 3rd best student presentation in the Environmental session. [ORAL]
- Rottman J, Barbero I, Rodriguez M, Shadman F, Sierra Alvarez R. 2010. Fate of CMP nanoparticles during municipal wastewater treatment. 32nd SESHA Annual Int. High Technology ESH Symp. Exhibition, Scottsdale, AZ, April 26-29, 2010. Prize for 2nd best student presentation [ORAL]
- Rodriguez M, Barbero I, Luna A, Shadman F, Field JA, Sierra-Alvarez R. 2010. Impact of Wastewater Components on the Aggregation Behavior of CMP Nanoparticles 32nd SESHA Annual Int. High Technology ESH Symp. Exhibition, Scottsdale, AZ, April 26-29, 2010. [ORAL]
- Field JA, Gomez-Rivera F, Barbero I, Rottman J, Rodríguez M, Luna A, Shadman F, Sierra-Alvarez R. 2010. Fate of Inorganic Oxide Nanoparticles in Semiconductor Manufacturing Effluents during Activated Sludge Treatment. 10th American Inst. Chemical Engineers (AIChE) Annual Meeting, Salt Lake City, UT, Nov. 7-12, 2010 [ORAL]
- Rottman J, Barbero I, Rodríguez M, Shadman F, Sierra-Alvarez R. 2010. Fate of metal oxide nanoparticles in municipal wastewater treatment. WSP Water Forum: Our Water Future. Nov. 22, 2010, Tucson, AZ. [Poster]

Publications & Presentations

Conferences Presentations (continued)

- Gomez-Rivera F, Barbero I, Rodríguez M, Luna-Velasco A, Shadman F, Field JA, Sierra-Alvarez R. 2010. Interactions Between Inorganic Oxide Nanoparticles and Municipal Wastewater Constituents: Implications for Nanoparticle Removal during Biological Wastewater Treatment. Proc. Leading Edge Technology 2010, Phoenix (AZ), June 2-4. p. 55 [Poster]
- Sierra-Alvarez R, I. Barbero, J. Rottman, M. Rodríguez, A. Luna-Velasco, F. Shadman, JA Field. Removal of CeO_2 and Al_2O_3 Nanoparticles in Semiconductor Manufacturing Effluents during Activated Sludge Treatment. Proc. Leading Edge Technology 2010, Phoenix (AZ), USA, 2-4 June 2010. p. 48. [Poster]
- Boitano S, M. McCorkel, I. Barbero, JA Field, R. Sierra-Alvarez. 2010. Nanoparticle Toxicity: Chemical Adsorbents Increase Cytotoxicity. TECHCON Conf.:Technology & Talent for the 21st Century. Austin, TX. Sept. 13-14. Pub. ID: P056590. [Poster]
- Sierra-Alvarez R, Gomez F, Barbero I, Rottman J, Rodríguez M, Shadman F, Field JA. 2011. Removal of Inorganic Oxide Nanoparticles in Semiconductor Manufacturing Effluents during Activated Sludge Treatment. 2nd International Congress on Sustainability Science & Engineering (ICOSSE '11). Jan. 9-14, Tucson, AZ. [Poster]
- Boitano S, Sherwood CL, Flynn AN, McCorkel M, Field JA, Sierra-Alvarez R. 2010. Use of xCELLigence RTCA to assay cellular signaling and nanocytoxicity responses in an adherent human bronchial epithelial cell line. Mountain 28th Annual Regional Chapter Meeting of the Mountain West Society of Toxicology, Tucson, AZ, Sept. 9 –10, 2010. [Poster].
- McCorkel M, Boitano S. 2011. Nanoparticle toxicity on airway epithelial cells. Society of Toxicology, Washington, D.C. March 6-10. [Poster].

Publications & Presentations

Seminars

- Field JA, Sierra-Alvarez R. 2010. Brownbag presentation: Nanoparticle Interaction with Biological Wastewater Treatment Processes, Water Sustainability Program, Phoenix, Arizona. Jan . 2010 at Arizona Cooperative Extension.
- Garcia-Saucedo C, Otero L, Field JA, Sierra-Alvarez R. 2010. Developing a Yeast Cell Assay for Measuring the Toxicity of Inorganic Oxide Nanoparticles. Teleseminar series of Semiconductor Research Corporation/Sematech Eng. Research Center for Environ. Benign Semiconductor Manuf. May 6th, 2010, Tucson, AZ.
- Otero, L., Garcia-Saucedo, C., Field JA, Sierra-Alvarez, R. 2010. Comparison of Nanoparticle Toxicity to Yeast Cells and Human Lung Epithelial Cells. ERC Teleseminar series. Dec. 2, 2010, Tucson, AZ>
- Boitano, S. 2009. Measuring cytotoxicity of nanoparticles in human cells. ERC Teleseminar Series. Sept. 17, Tucson, AZ.
- Sierra-Alvarez, R. 2009. Toxicity characterization of HfO_2 nanoparticles. ERC Teleseminar Series, Aug. 6, 2009. Tucson, AZ.