Sixth Sustainable Nanotechnology Organization Conference 2017
Sunday, Nov. 5 – Tuesday, Nov. 7
Los Angeles, California

Tribute to Pedro Alvarez

Challenges of Environmental Nanotechnology

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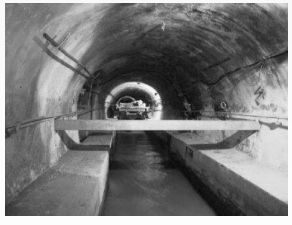
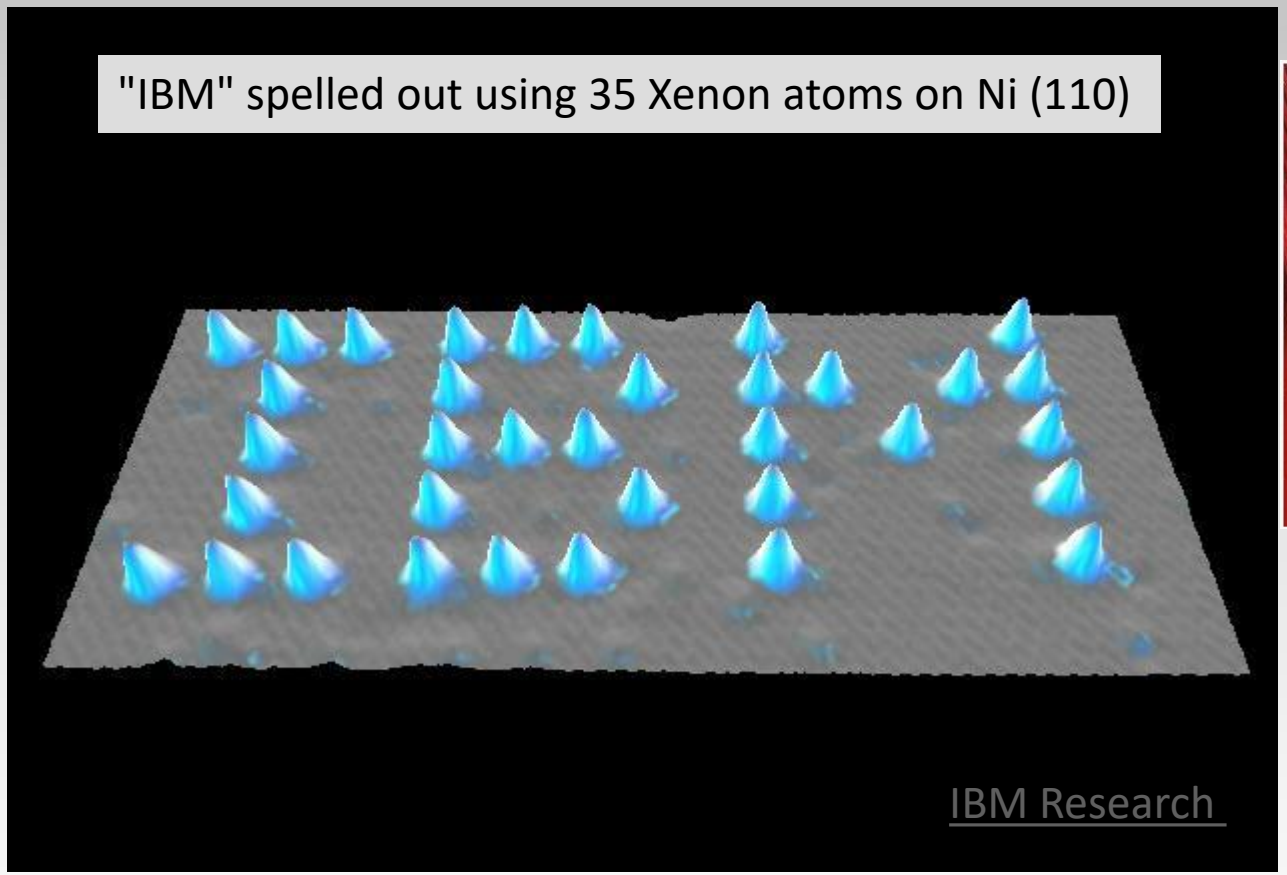





Hans-Max Gamper
Joan Gamper.

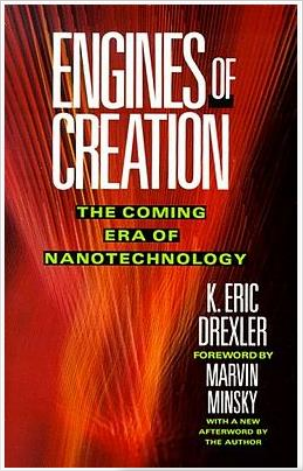
Brief (subjective) historical overview on the development of environmental NT

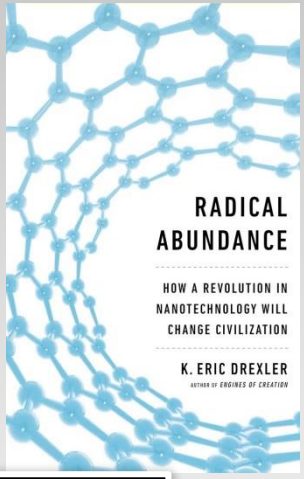
"IBM" spelled out using 35 Xenon atoms on Ni (110)



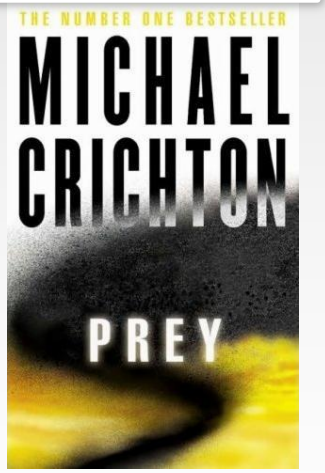
D.M. Eigler, E.K. Schweizer. **Positioning single atoms with a scanning tunneling microscope.** *Nature 344, 524-526 (1990).*

High hopes





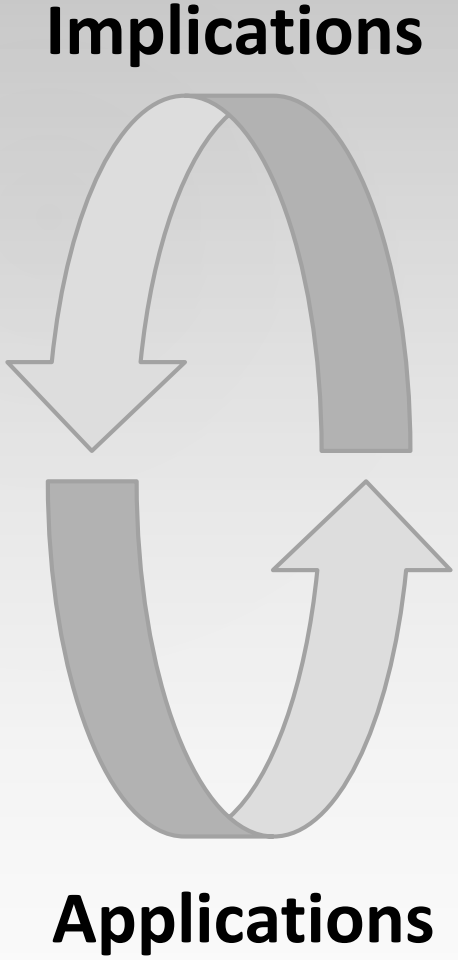
raising concerns



The Implication – Application Wheel

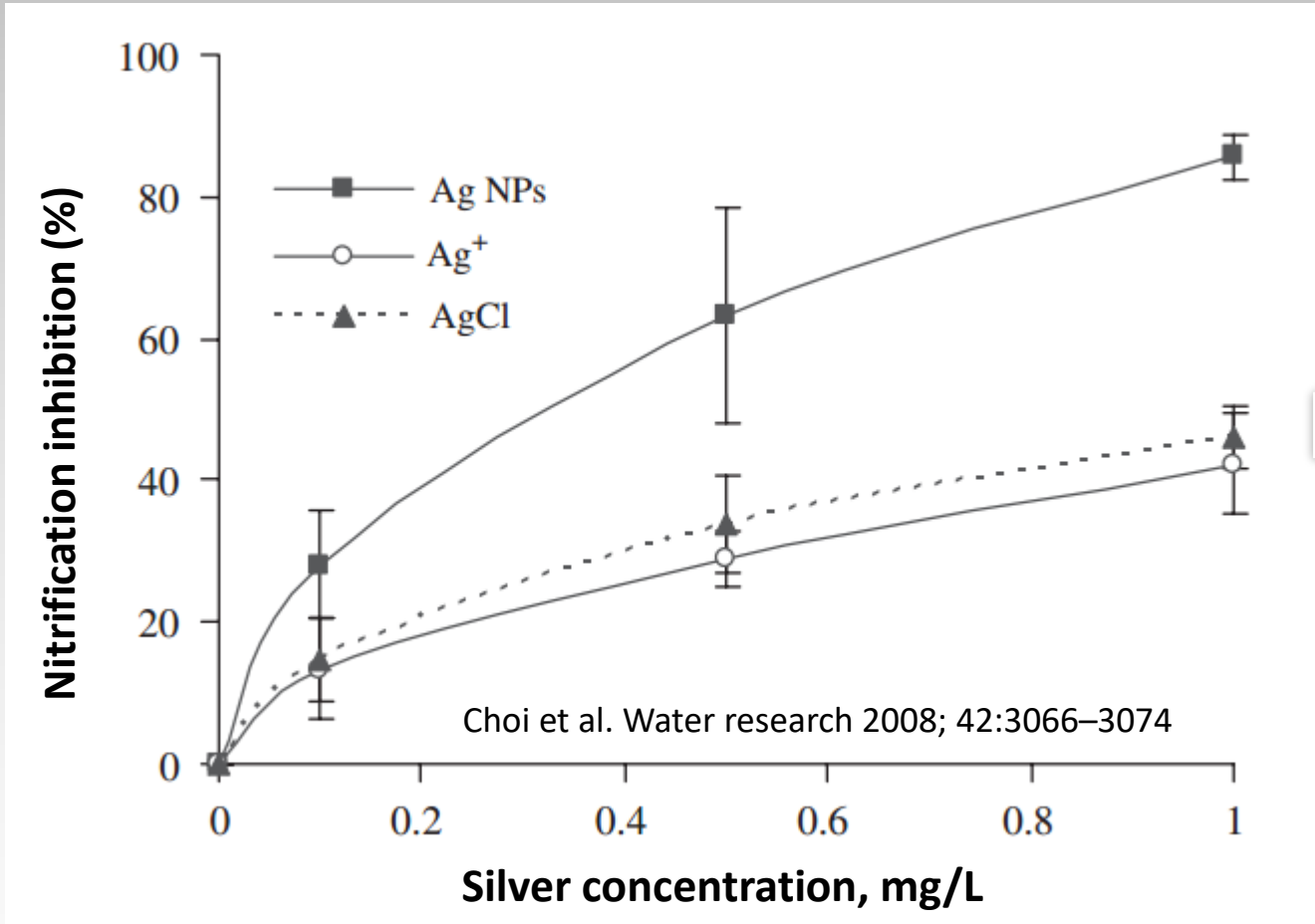
nanoECO: Nanoparticles in the Environment:
Implications and Applications
March 2-7, 2008

IWA Specialist Conference on Applications of
Nanotechnology in the Water Sector (Nano and Water 2011)
May 15-18, 2011



eawag
aquatic research

Pristine nanomaterials: A dark future…



WWTP

Results are valid, but may not be extrapolated to field-scale systems.

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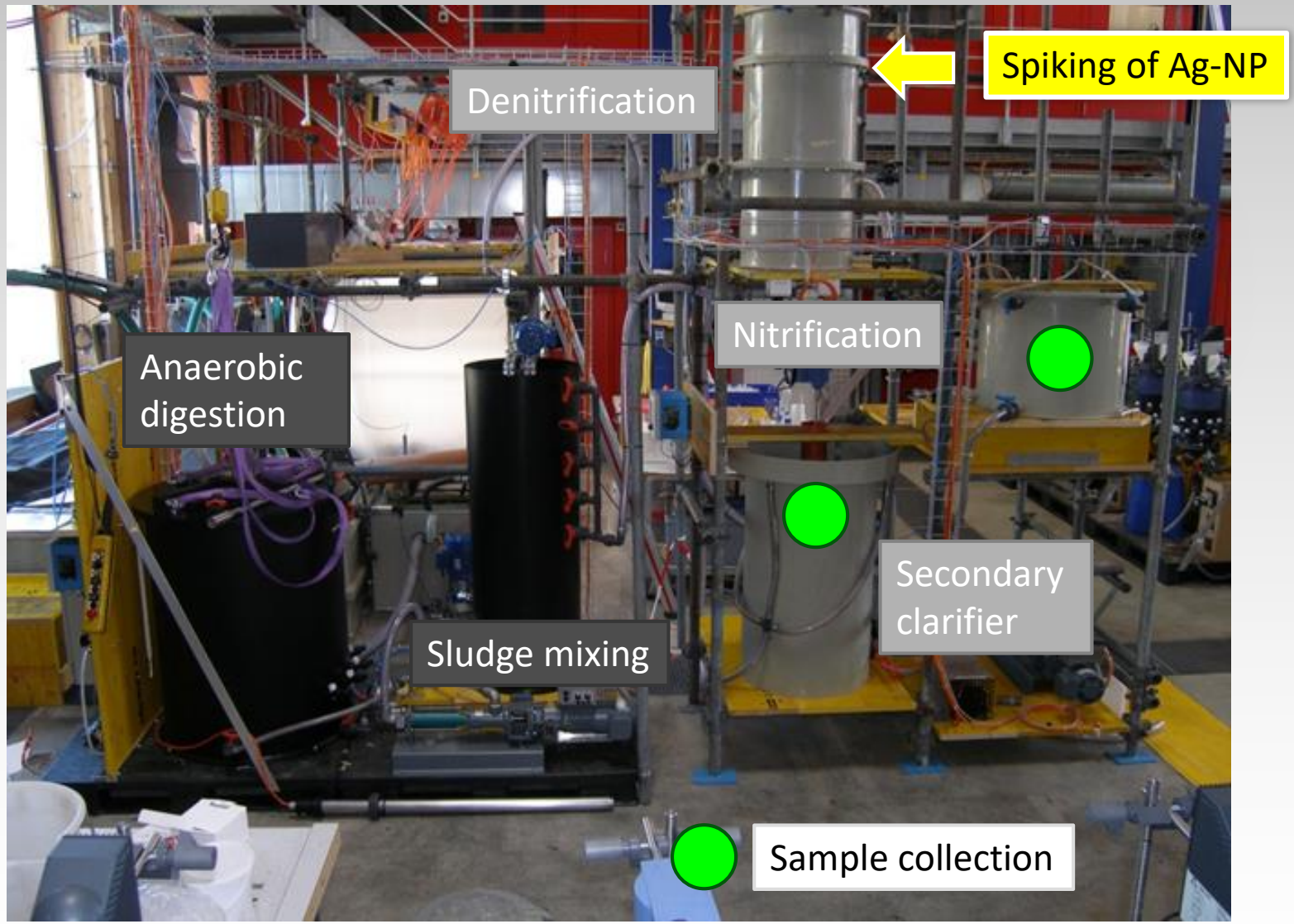
aquatic research

From lab scale to engineered systems (WWTP)



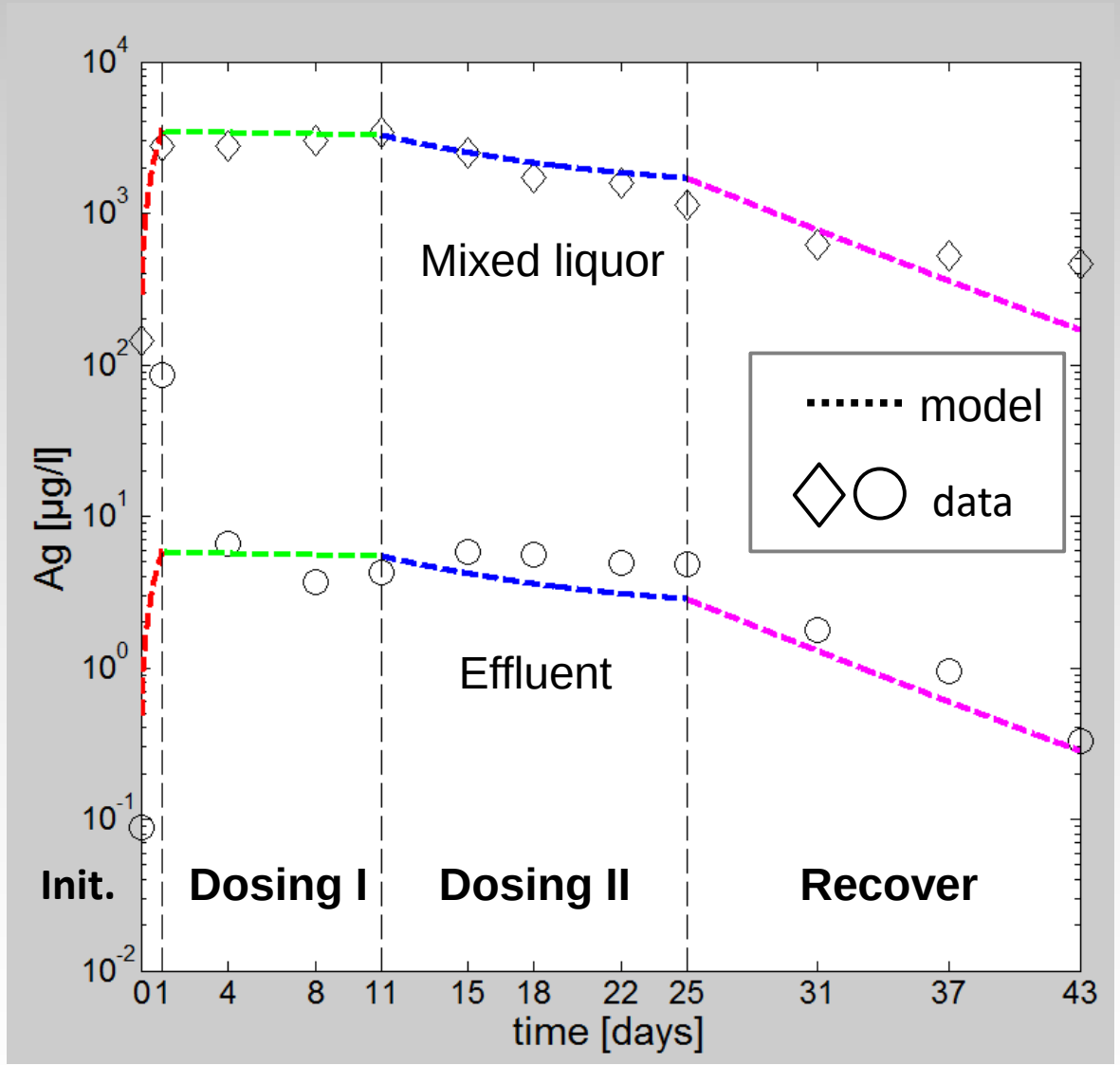
Ag-NP in a WWTP

Initial spike
(1day, 2400µg/l)

Dosing I
10days, 130µg/l, 1m3/d

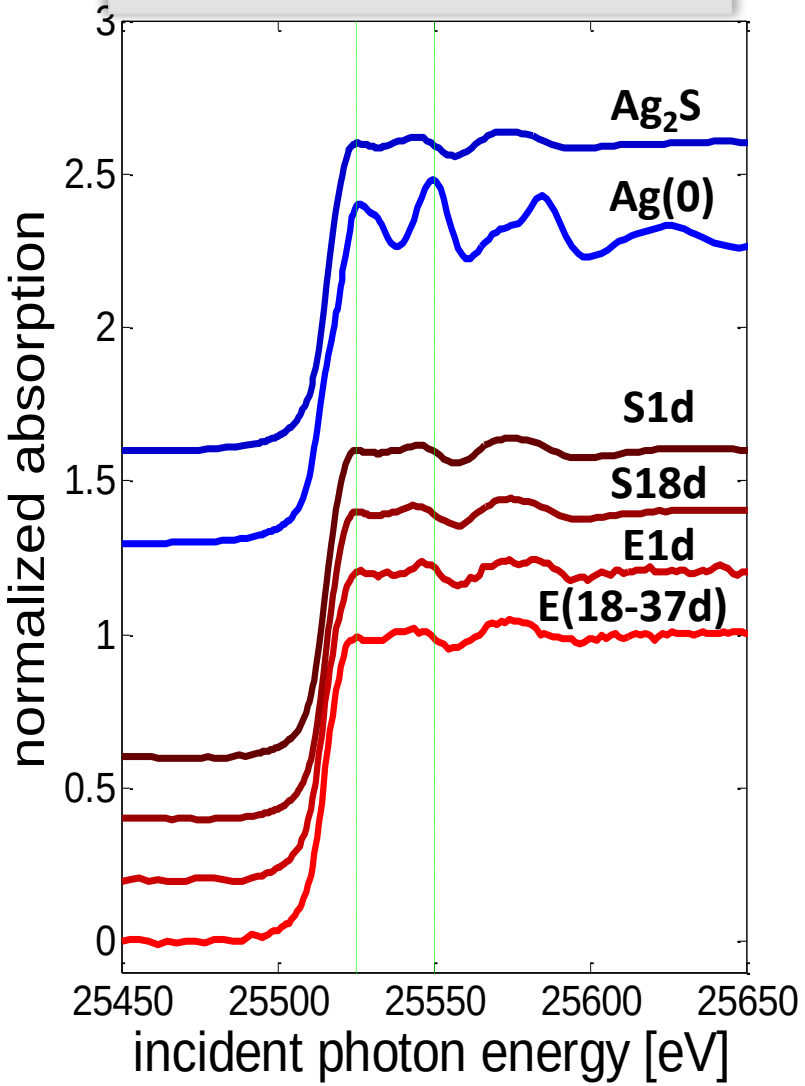
Dosing II
10days, 130µg/l, 2.2m3/d

Recover
24days, no Ag added



From lab scale to engineered systems (WWTP)

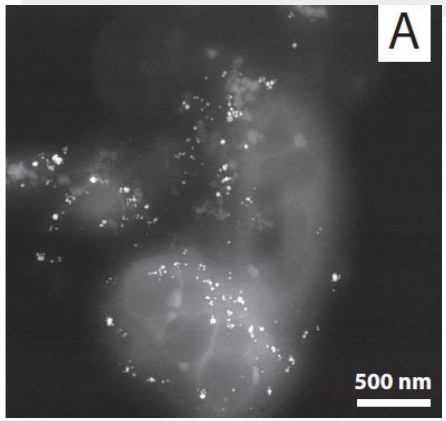
Synchrotron Spectroscopy

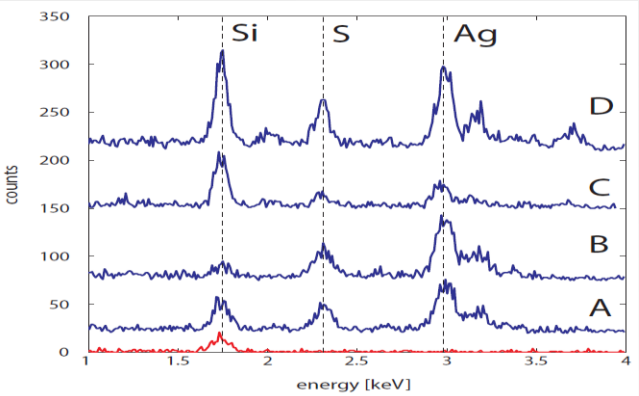


Linear combination fits (%)

Pilot WWTP	Ag(0)	Ag_2S
Sludge(1d)	2	99
Sludge(18d)	3	98
Effluent (1d)	0	100
Effluent (18-37d)	15	86

Electron microscopy





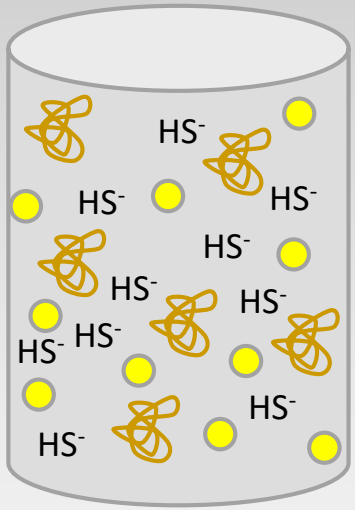
Kaegi et al., EST 2011;45:3902–3908.

Sulfidation of Ag-NP in the presence of HS- and humic acid

Experimental setup

Ag-NP

Humic acid



Liquid N_2

Synchrotron

TEM grid

TEM

Ag NP (100ppm, 0.93 mM)

- 20, 40, 100, 200 nm

Humic acid

- 0, 50, 250 or 1000 mg_{HA} L^{-1}

Bisulfide (HS^-, 2.5 mM)

50 mM, HEPES, **pH 7.5**

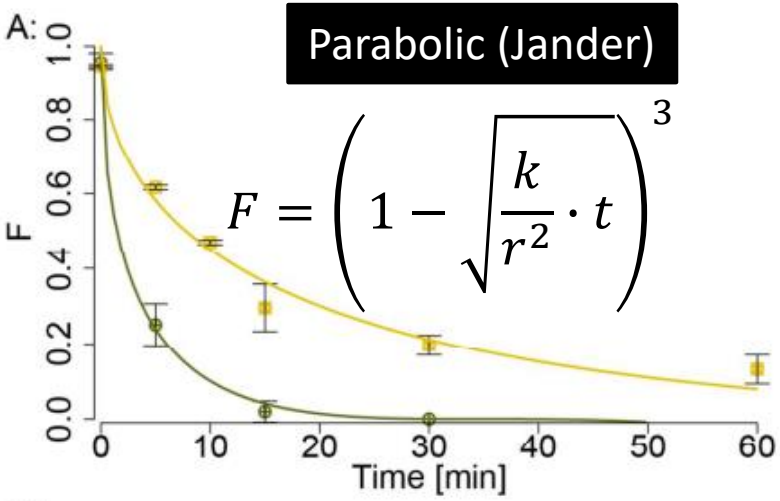
Reaction time **up to 60 mins**

Four different reaction models

A:

Parabolic (Jander)

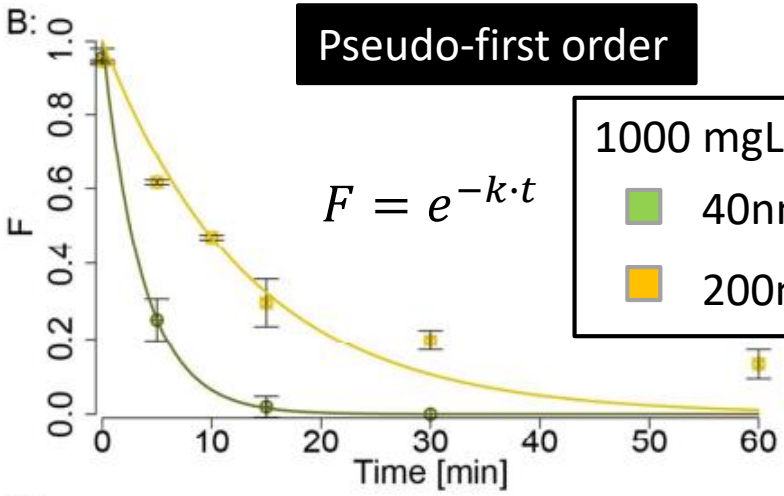
$$F = \left(1 - \sqrt{\frac{k}{r^2} \cdot t}\right)^3$$



B:

Pseudo-first order

$$F = e^{-k \cdot t}$$

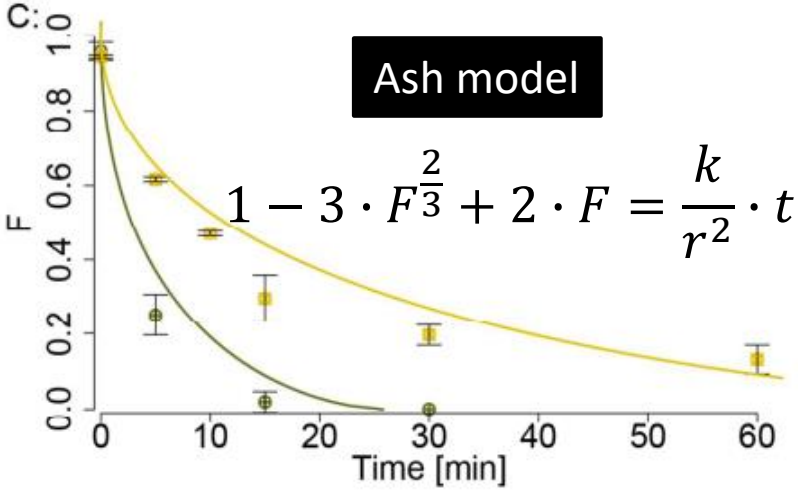


1000 mgL^{-1} HA
- 40nm
- 200nm

C:

Ash model

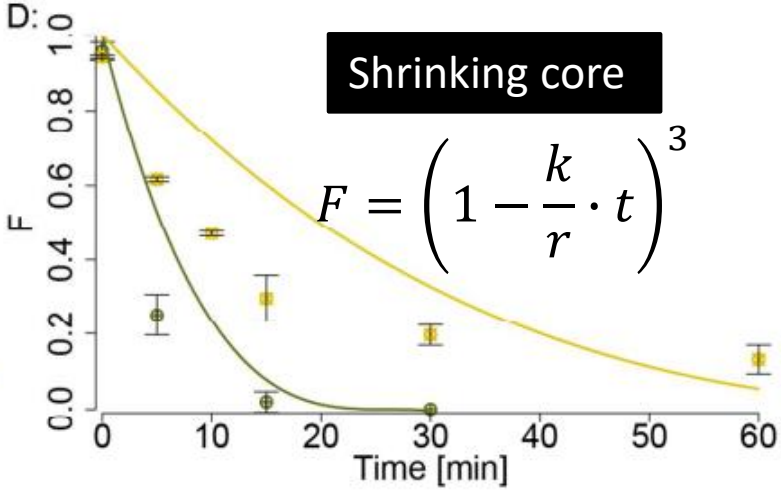
$$1 - 3 \cdot F^{\frac{2}{3}} + 2 \cdot F = \frac{k}{r^2} \cdot t$$



D:

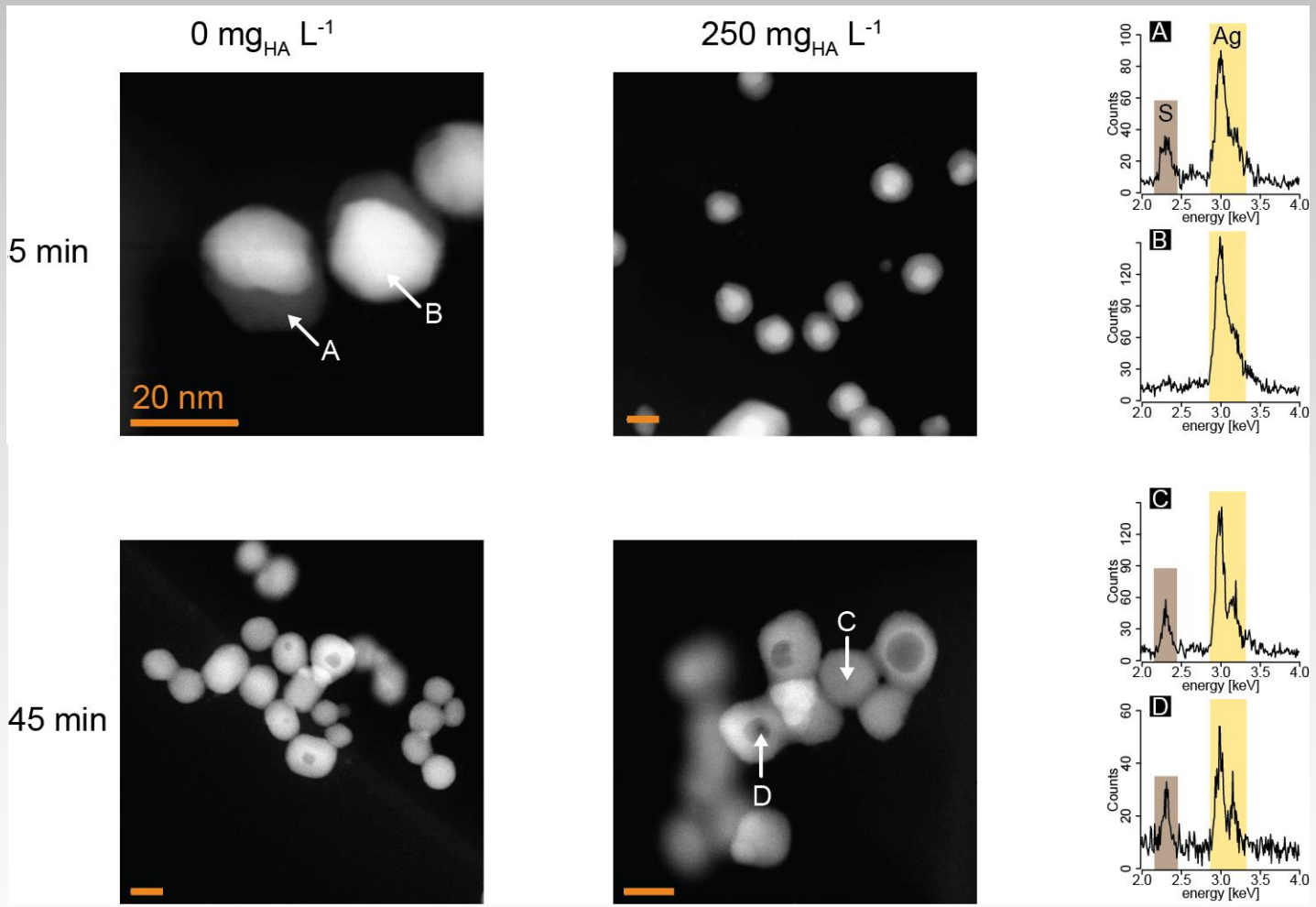
Shrinking core

$$F = \left(1 - \frac{k}{r} \cdot t\right)^3$$

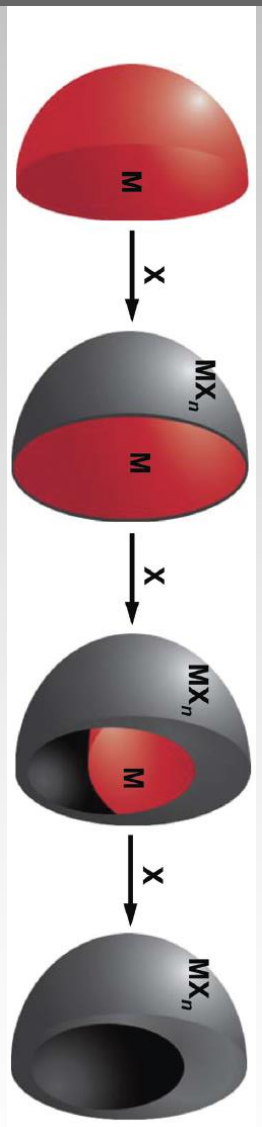


Half-life times ($t_{½}$) are in the order of a few tens of minutes ($t_{½}$ << average hydraulic residence time).

From complex systems to mechanistic insight



Thalmann et *al.* 2016, ES Nano, DOI: 10.1039/c5en00209e



The formation of Kirkendall voids explains the strongly reduced toxicity of only partly sulfidized Ag-NP

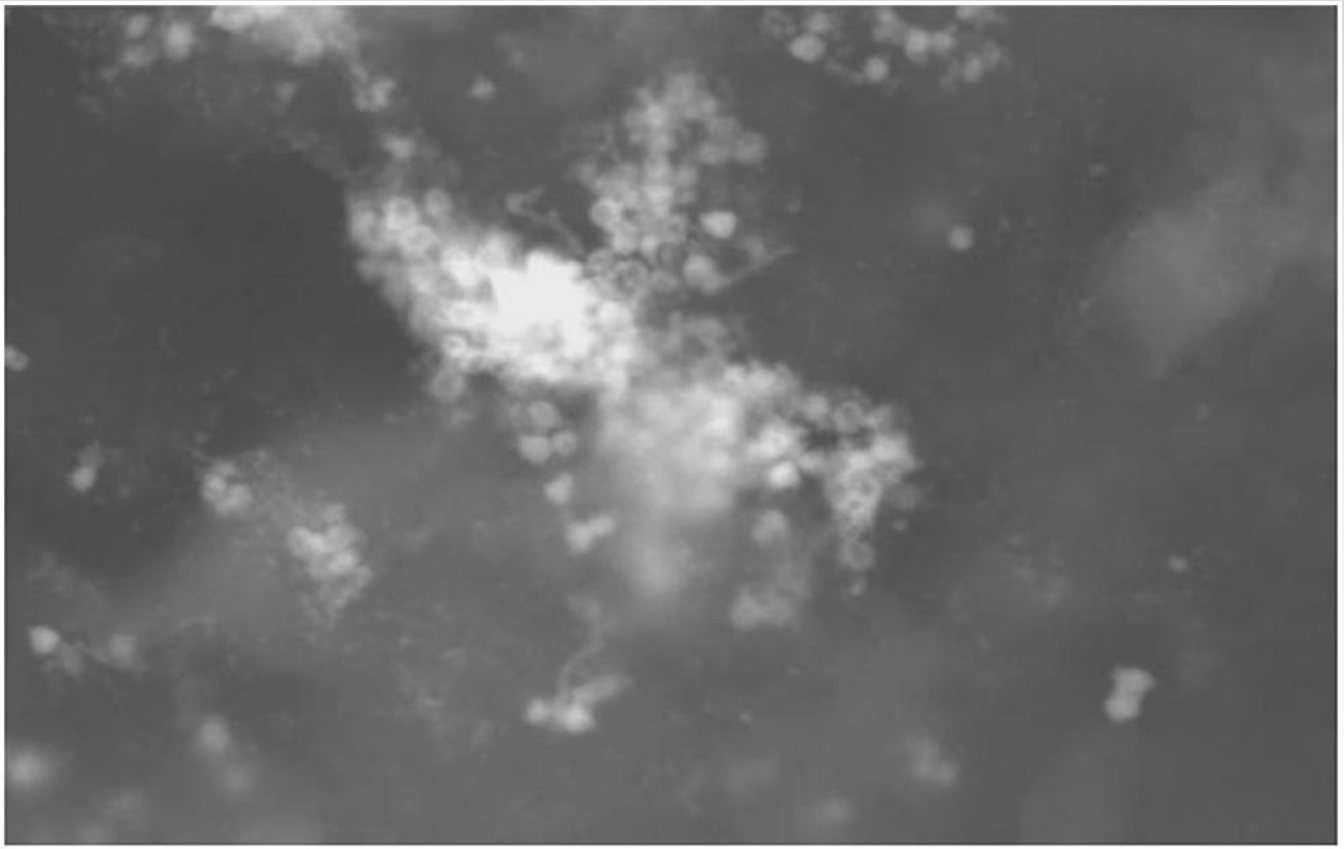
(Reinsch et al., 2012,ES&T, 46, 13, pp 6992-7000)

Anderson and Tracy, 2014, Nanoscale, 6,21, pp 12195-12216

‘Hollow’ spheres in natural systems

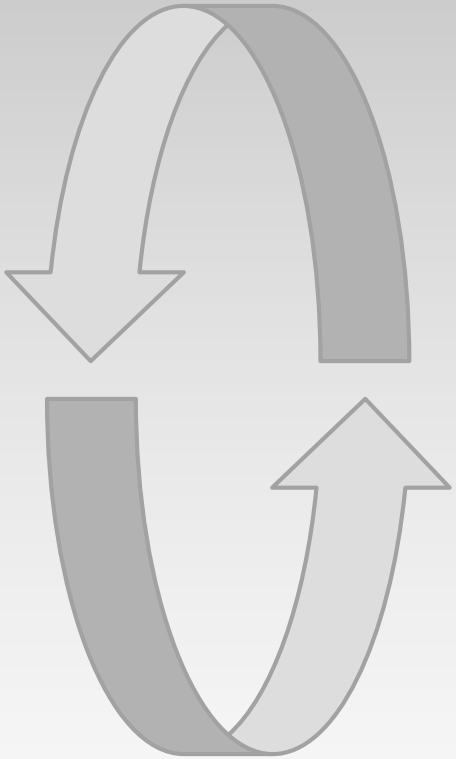
Transformation of silver nanoparticles in fresh, aged, and incinerated biosolids

Christopher A. Impellitteri [a,], Stephen Harmon [a], R. Gune Silva [b], Bradley W. Miller [c], Kirk G. Scheckel [a], Todd P. Luxton [a], Donald Schupp [b], Srinivas Panguluri [b]*



Outlook

Implications



high exposure	controlled exposure	limited exposure
high yield (high release)	moderate yield (coating)	high yield (smart coating)

Applications

Towards safe NT applications

Sound assessment of implications

eawag aquatic research