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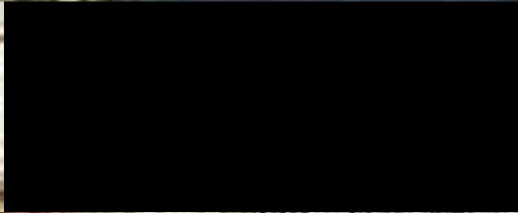
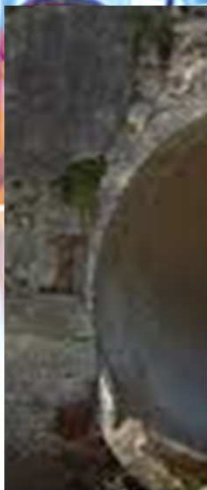
Carolina?





Klaine Lab





Quality, Protection and Peace of mind

Water

Quality

Emerging materials

Emerging chemicals

Mixtures

Microplastics



Institute of Environmental Toxicology

Biologists
Chemists
Engineers
Material Scientists
Physicists

Institute of Environmental Toxicology

Ecotoxicology

Immunology

Endocrine Disruption

Arsenic Toxicity

Biomarkers

Nanotechnology

Phytoremediation

Microbiology

Environmental Toxicology at Clemson University

- MS and Ph.D degree programs
- 20 affiliated faculty
 - Molecular to ecosystem effects
- 20 graduate students
- Exchange programs available
- Contact Dr. Steve Klaine if you want more information - sklaine@clemson.edu

The Janus Face of Nanotechnology: Promises, Products, and Potential Problems



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Institute of
Environmental Toxicology



The 24th
Jyväskylä Summer School
Jyväskylän yliopisto

What is Nano?

- Any particle that has
 - at least one dimension less than 100 nm
 - novel properties compared to their bulk counterparts

Specific Surface Area

“Nano” Effects



Fluorescence of Quantum dots
color = $f(\text{size})$



Catalytic Activity of Nanogold
activity = $f(\text{size})$



Tubes made out of carbon - the same element used in pencils - are stronger than steel.

There's Plenty of Room at the Bottom

- Richard P. Feynman's talk in 1959 at the annual meeting of the American Physical Society:
 - "I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, "What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical application."
 - What I want to talk about is the problem of manipulating and controlling things on a small scale
 - *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?*

Problem

Knowledge

Implications

Time



Problem

Knowledge

Applications

Implications

Time



Smallness

Strangeness

Sophistication

Smallness

A photograph of a city street scene. In the foreground, a dark grey Smart car is parked on the side of the road. To its right, a white van with a black roof rack is also parked. The Smart car's license plate is 'DL 51726'. In the background, there is a brick building with many windows, bare trees, and a traffic light with a red 'no parking' sign.

Gets you to new places

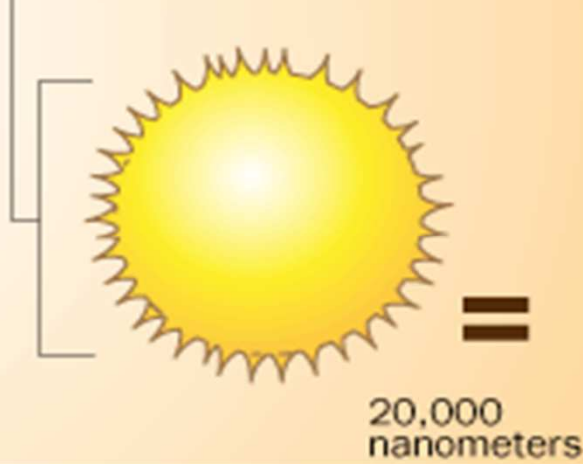
How Nanotechnology Works

©2007 HowStuffWorks

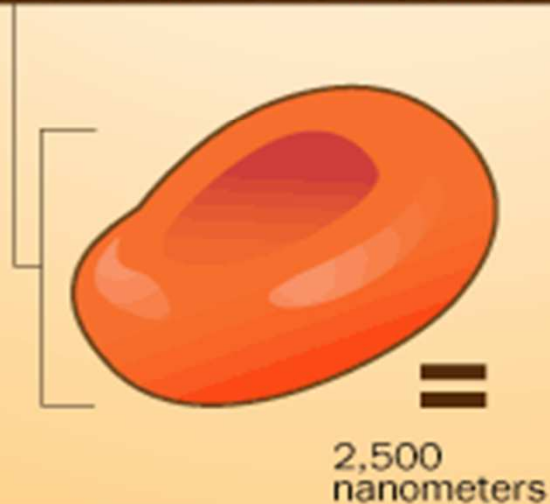
Head of a Pin is 1 millimeter



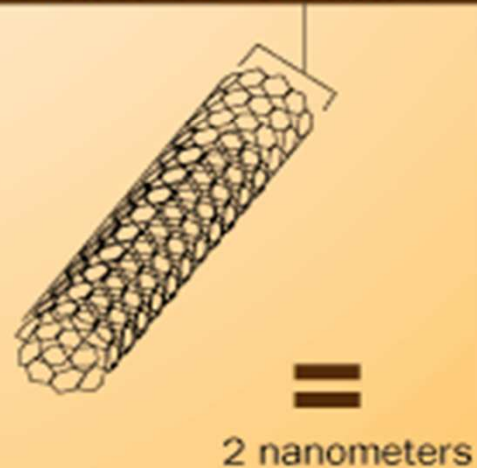
Ragweed pollen is 20 micrometers



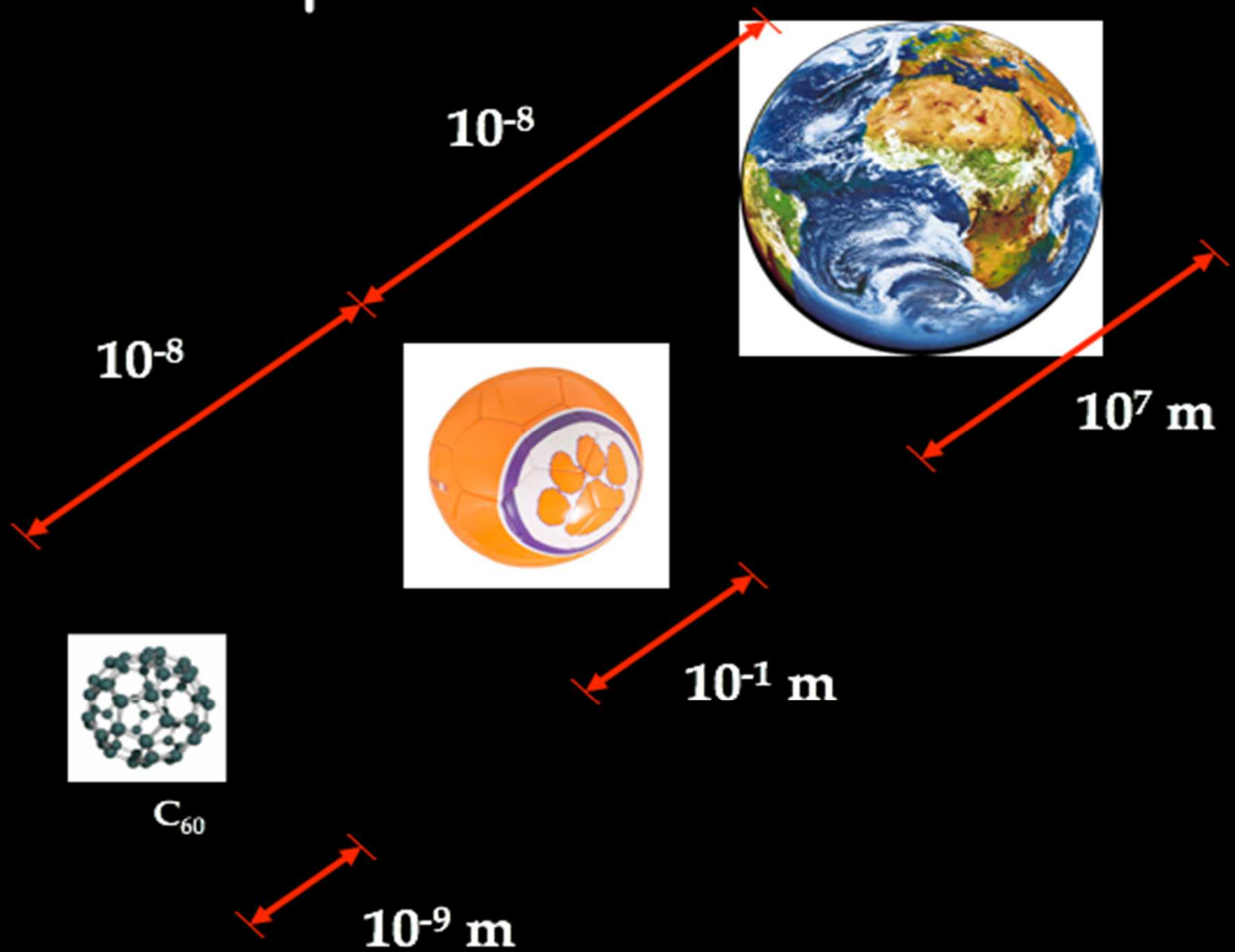
Red blood cell is 2.5 micrometers



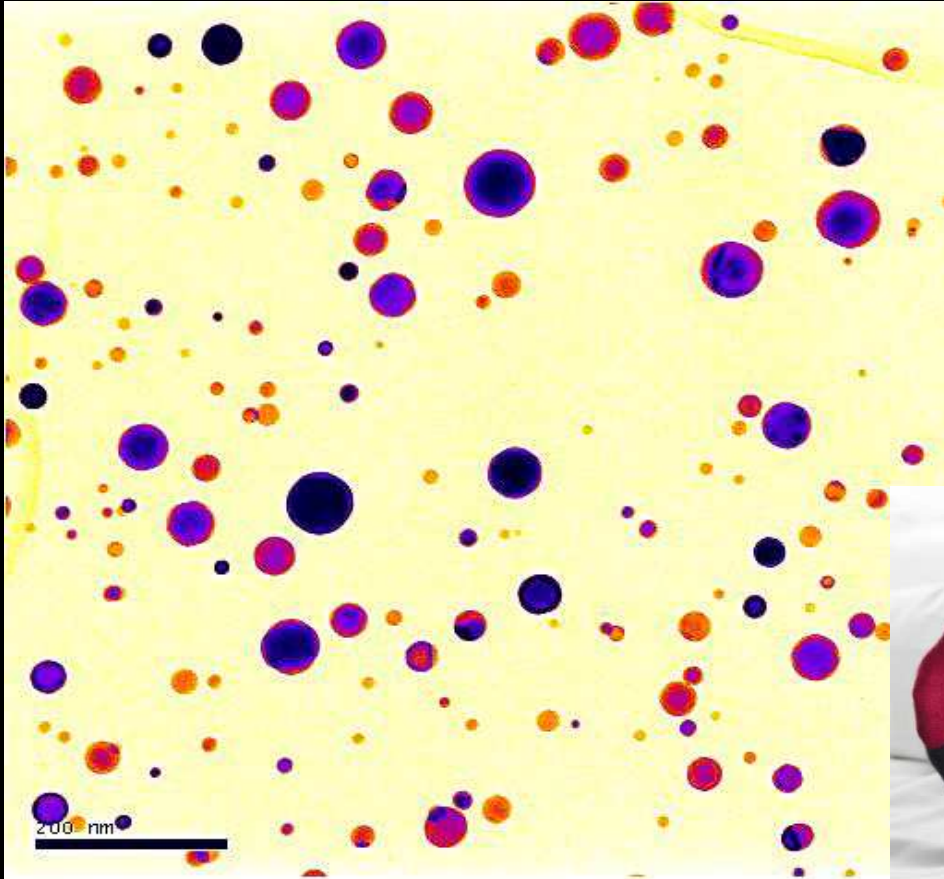
Carbon nanotube is 2 nanometers



A local Perspective....



Smallness



Silver

Small

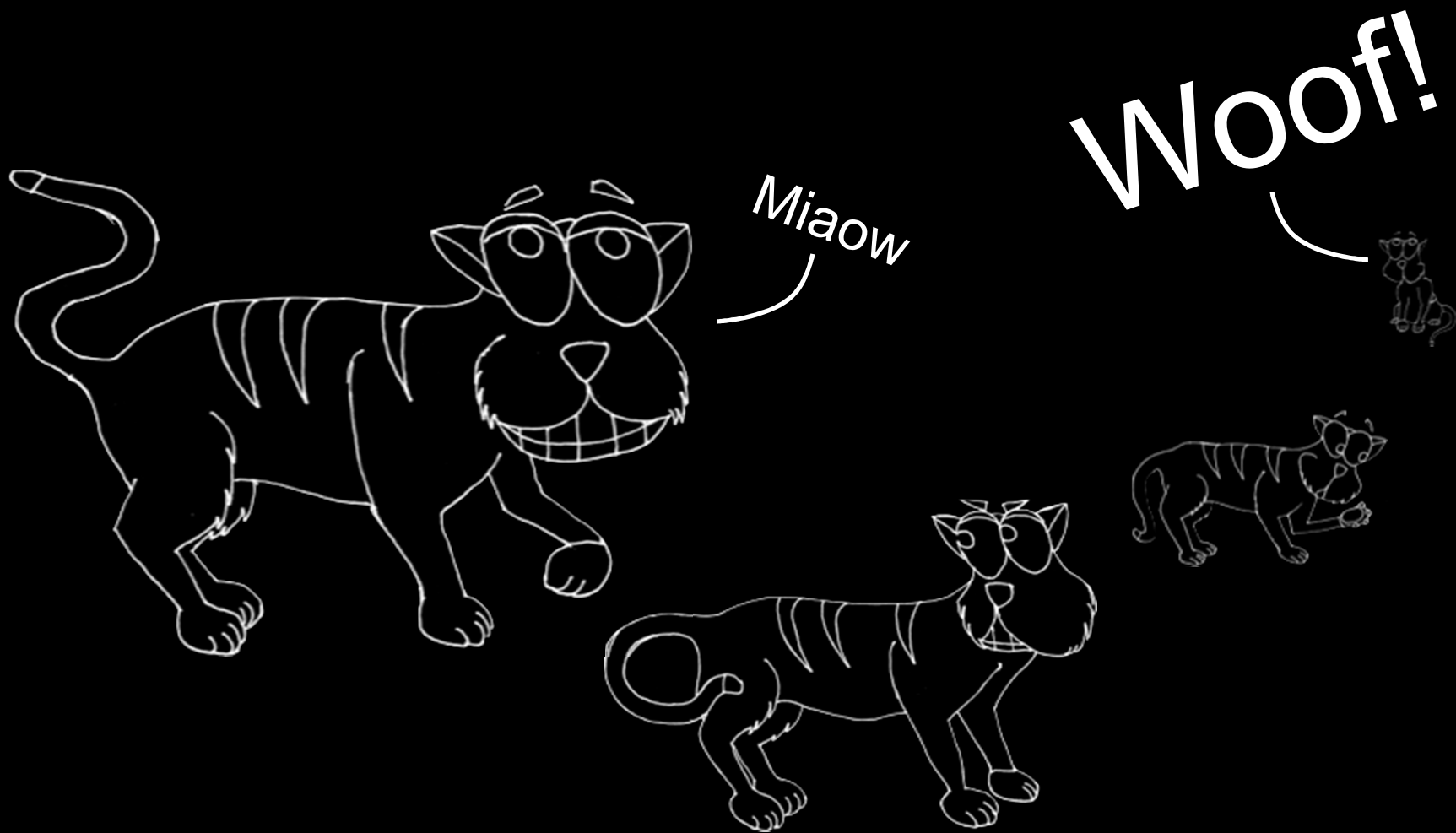
Suffocated bugs

Sweet feet



Gets you to new places

Strangeness



Behaves in unexpected ways

Strangeness

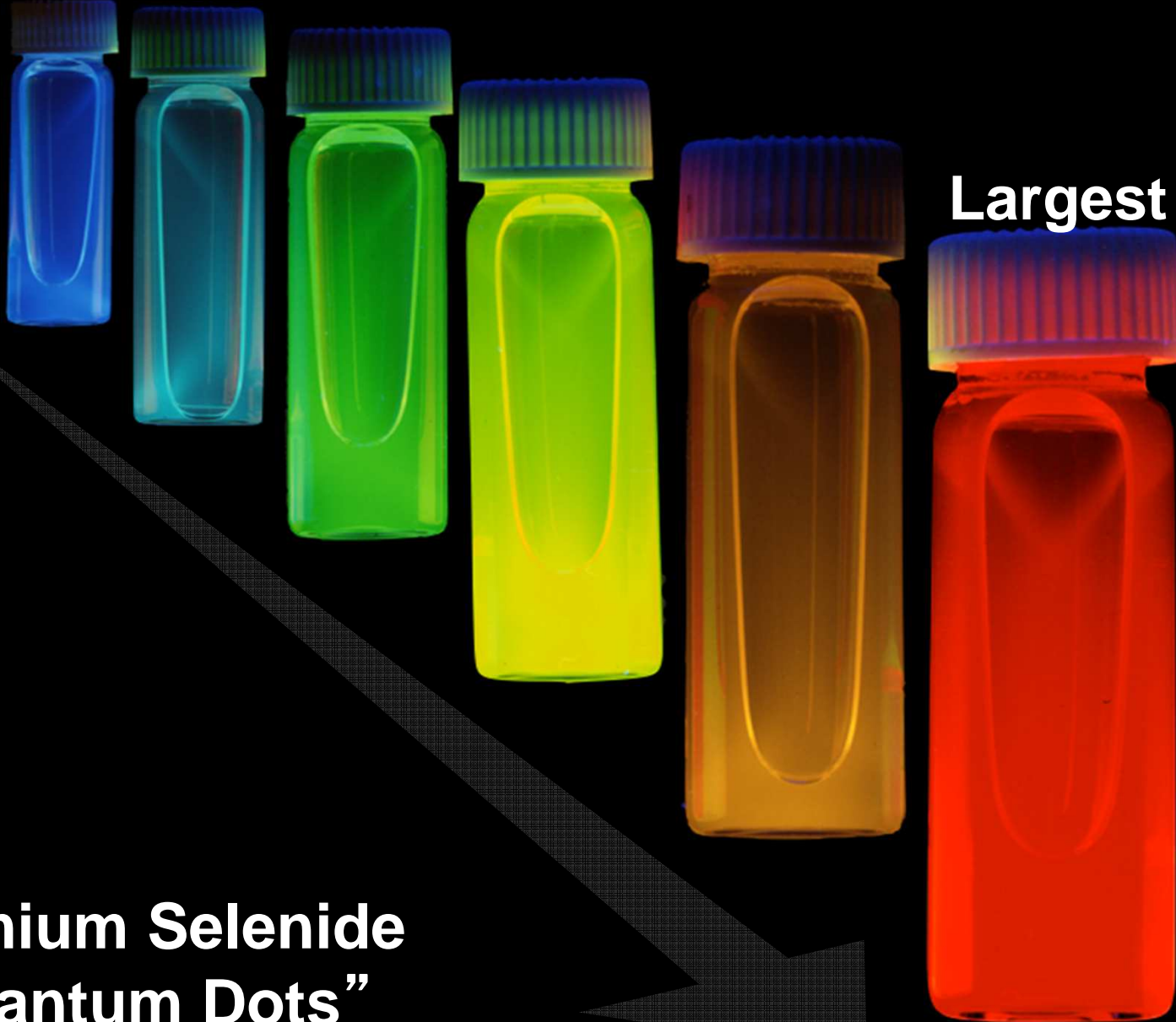


Lycurgus Cup



Behaves in unexpected ways

Smallest



Largest

Cadmium Selenide
“Quantum Dots”

©Felice Frankel

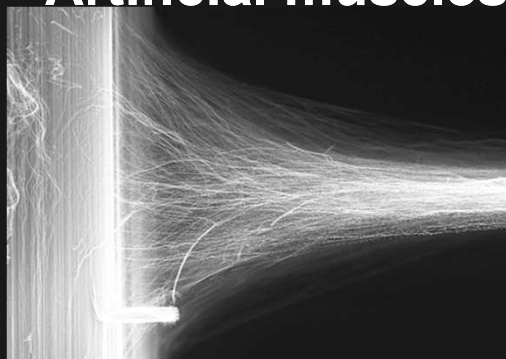
Electronics

© Beckman Institute



Artificial muscles

blog.wired.com



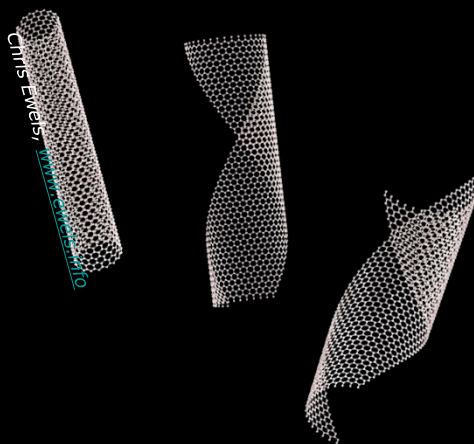
Spun textiles

© CSIRO



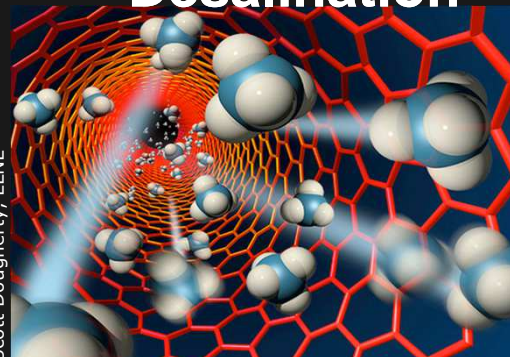
Medicine

JPL



Desalination

Scott Dougherty, LLNL



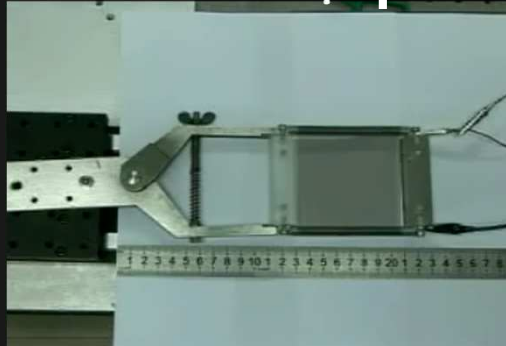
Strong materials

Easton



Flexible loudspeakers

Kaili Jiang, Tsinghua University



Space elevator

NASA



Sophistication

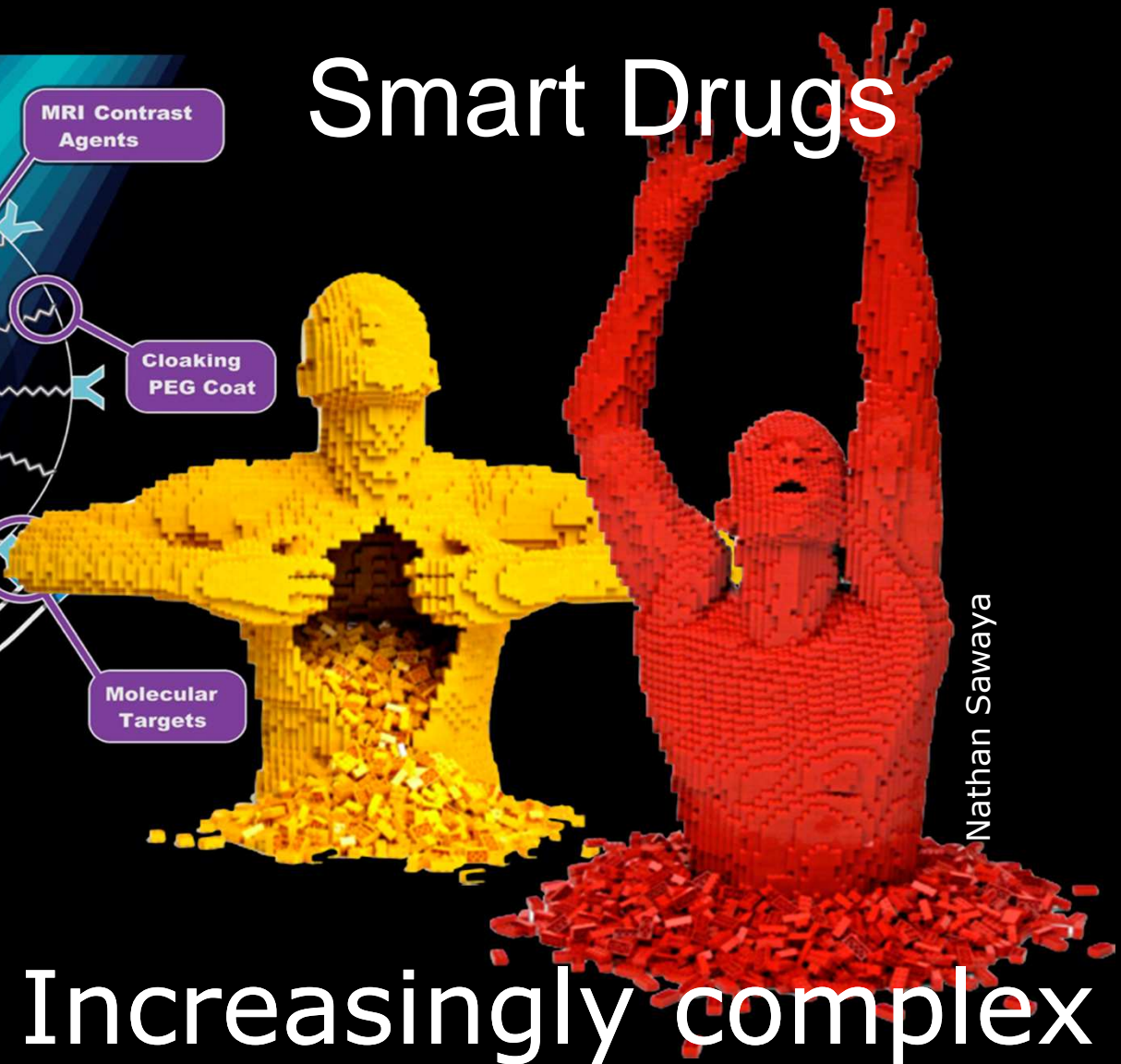
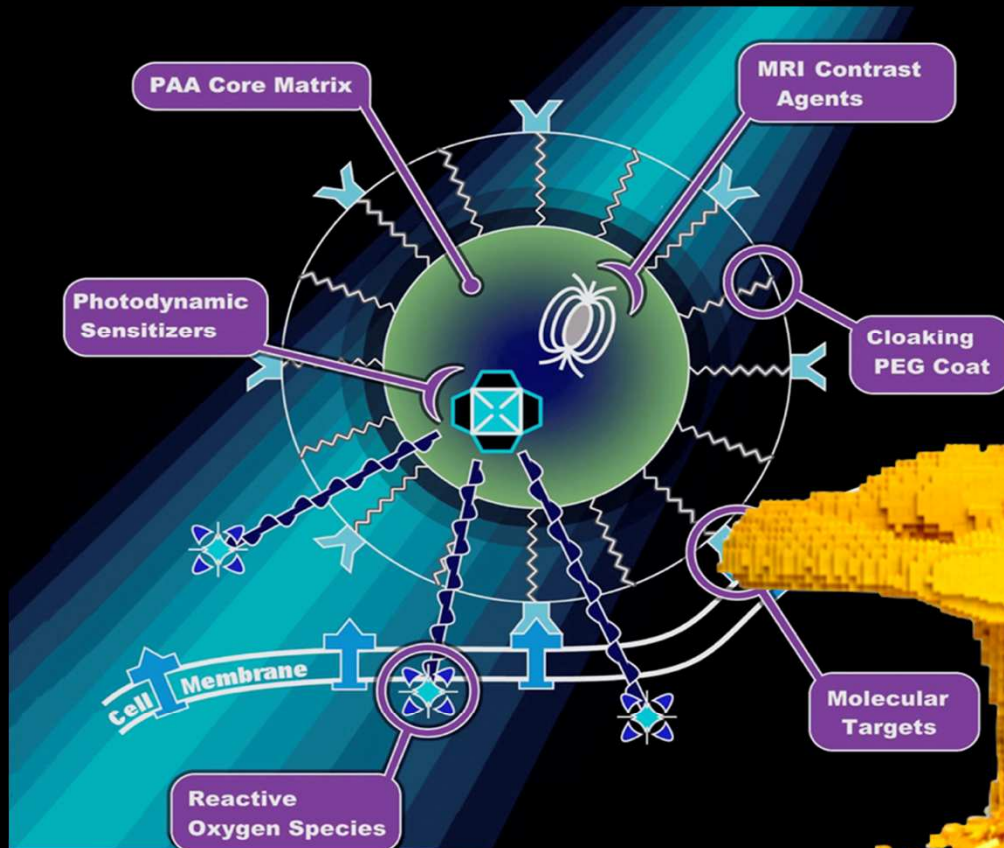


Nathan Sawaya

Increasingly complex

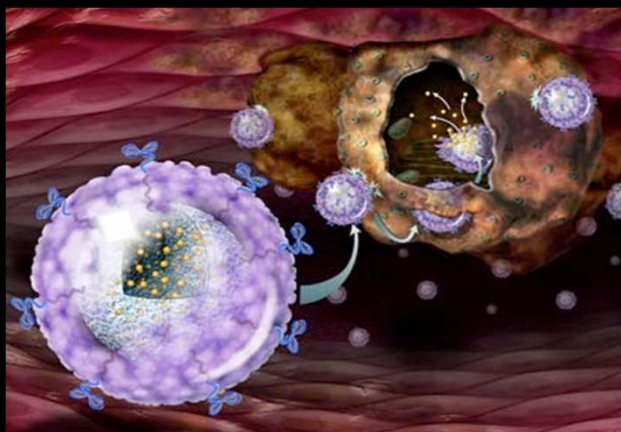
Sophistication

Smart Drugs

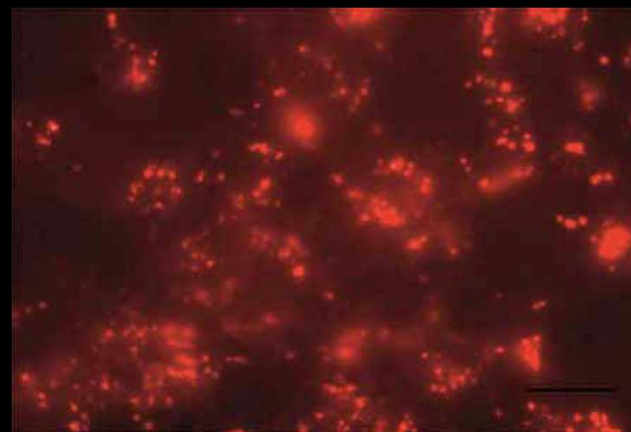


Nathan Sawaya

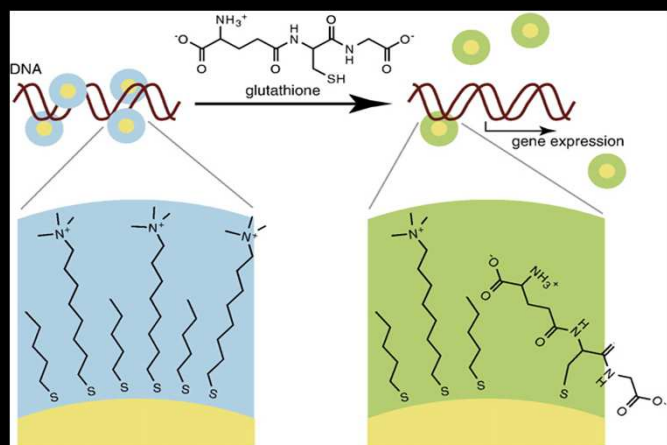
Increasingly complex



Pharmaceutical Delivery



Imaging



Gene Therapy

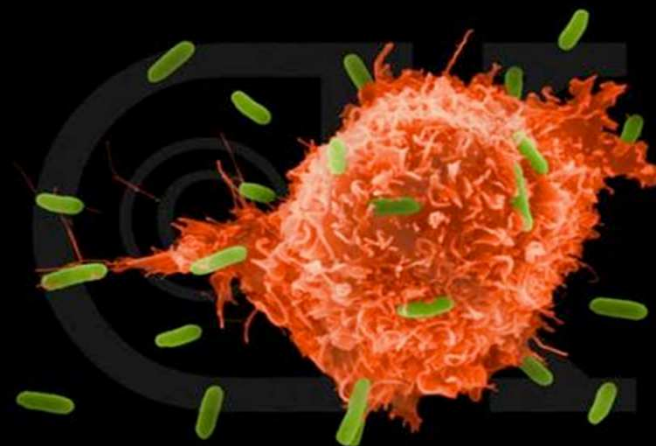
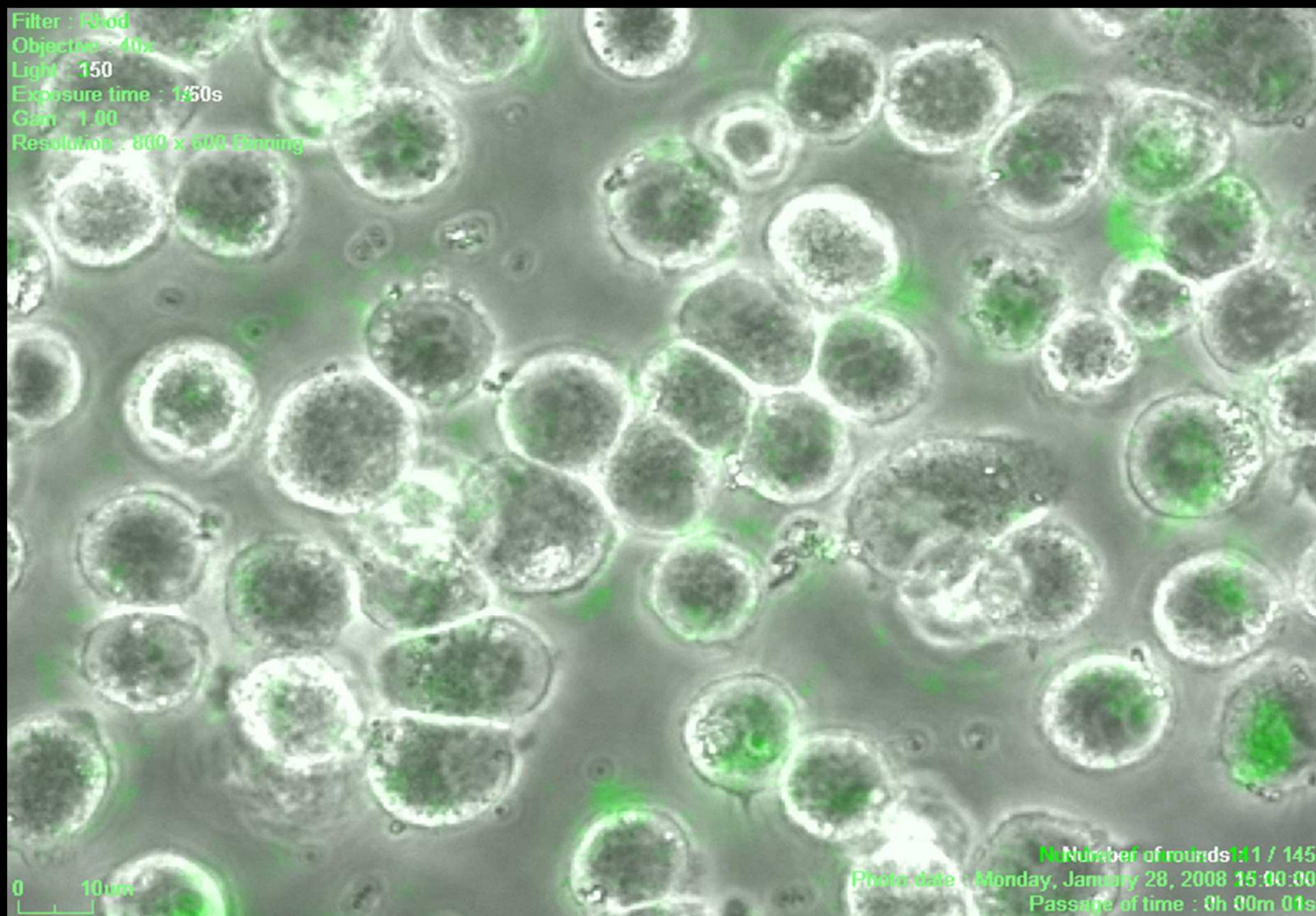


Photo-thermal Cancer Treatment

Filter : Rhod
Objective : 40x
Light : 150
Exposure time : 1/50s
Gain : 1.00
Resolution : 800 x 600 Binning



Number of rounds : 1 / 145

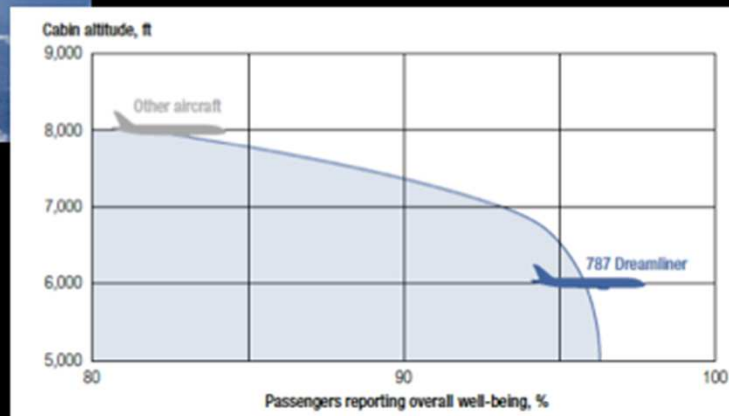
Photo date : Monday, January 28, 2008 15:00:00

Passage of time : 0h 00m 01s

Boeing Dreamliner



**Increases oxygen
carrying capacity by 8%
and composite materials
allow for higher humidity**



Smallness

Strangeness

Sophistication

Nanoscale control:

Adding value to products

I wish my sunscreen wasn't so unsightly



I wish my socks didn't smell so much!



I wish my tennis racquet was lighter and stronger



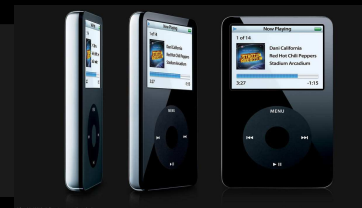
I wish I could keep leftovers for longer, before they go off



I wish spilt red wine would run off my pants without staining



I wish I could get more songs on my iPod



Over 800 listed manufacturer-identified nanotech consumer products:
www.nanotechproject.org/consumerproducts

Nanoscale control:

Adding value to products

I wish my sunscreen
wasn't so unsightly



Over 800 listed manufacturer-identified nanotech consumer products:
www.nanotechproject.org/consumerproducts



Solar Rx

SPF 30+ Nano-Zinc Oxide
Therapeutic
Sunblock

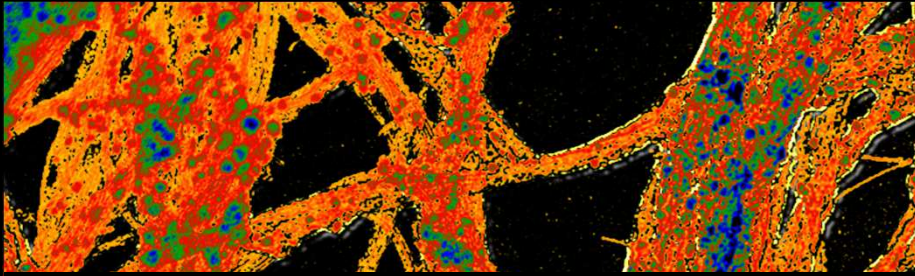
Chemical-Free
Skin Health

Net Contents 100 ml

Protect

Nanoscale control:

Solutions to problems



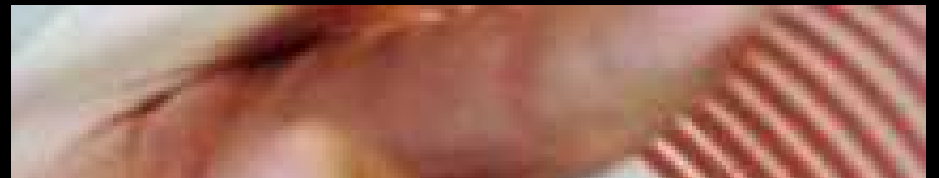
Materials



Medicine



Water

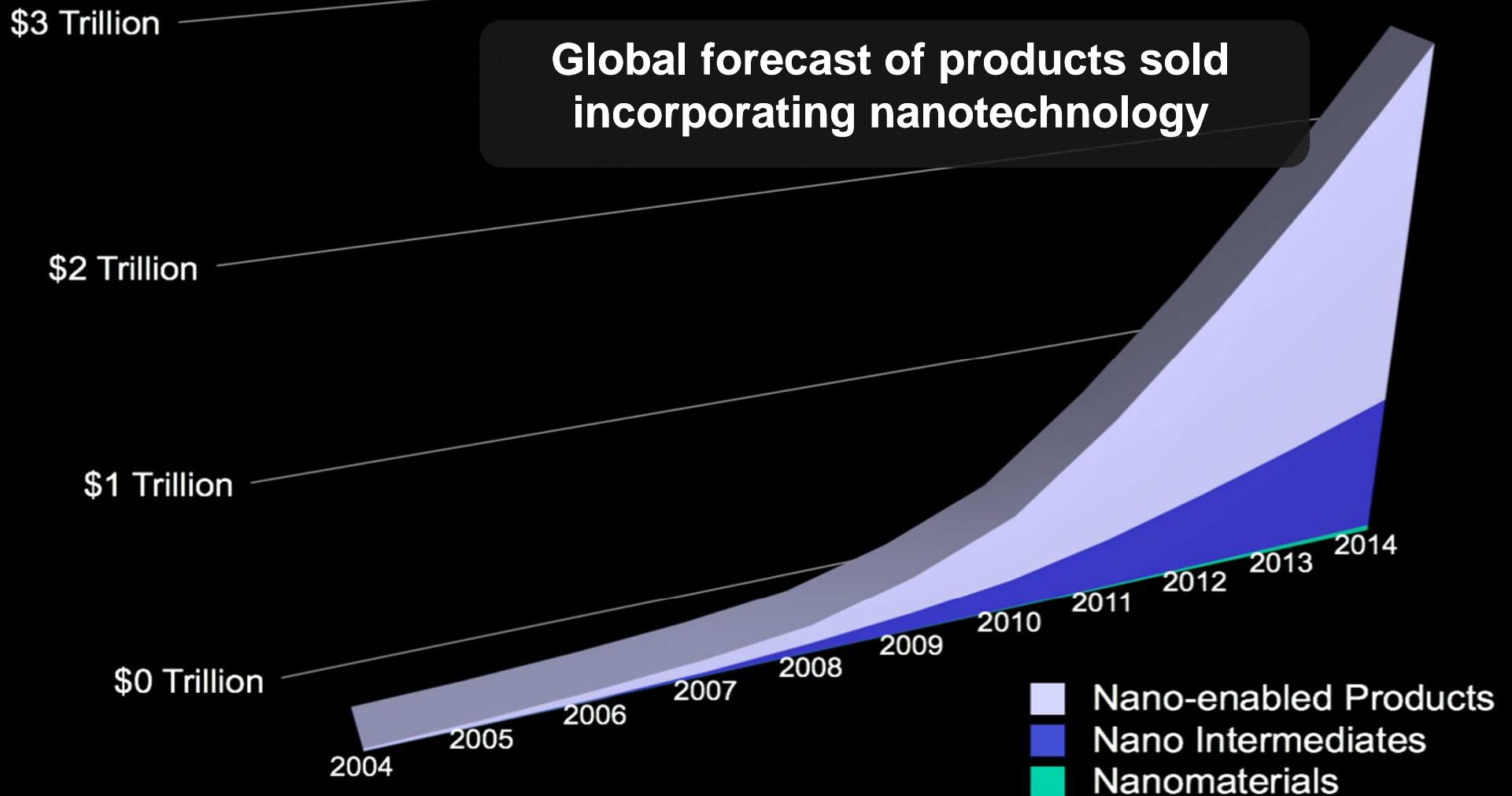


Energy

Nanoscale control:

Wealth Generation

Global forecast of products sold incorporating nanotechnology



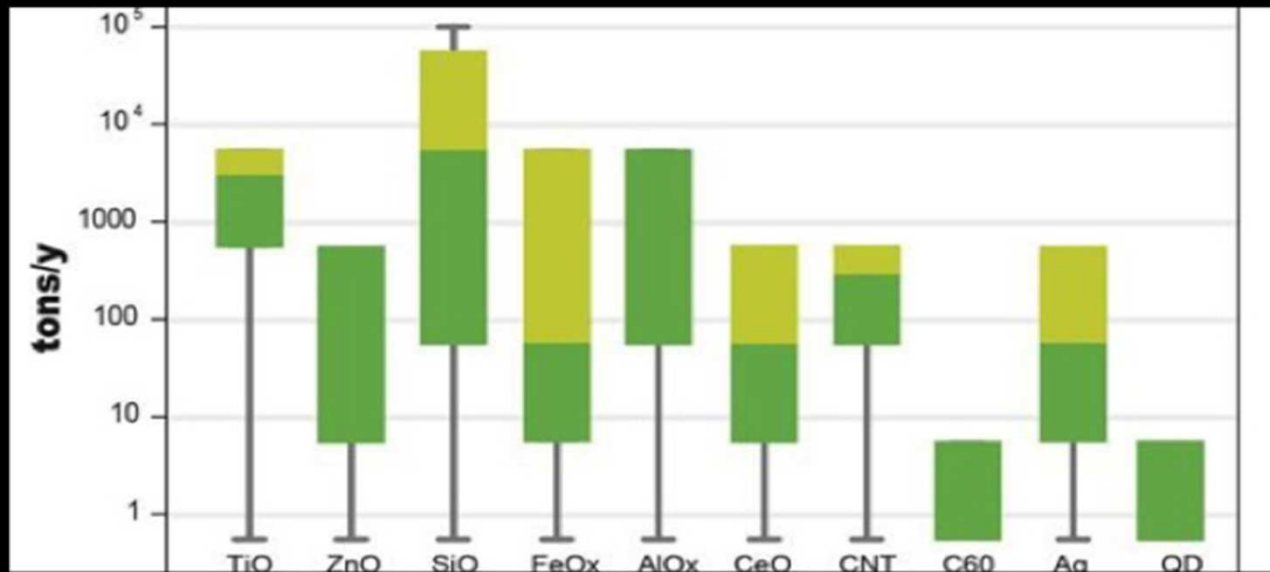
Source: 2004 Lux Research Report: "Sizing nanotechnology's value chain"

New Questions...

...but is nano
SAFE?

...New Answers

What do we know about Nano?



Estimated nanoparticle tonnage produced globally by core material (Piccinno et al 2012)

What do we know about Nano?

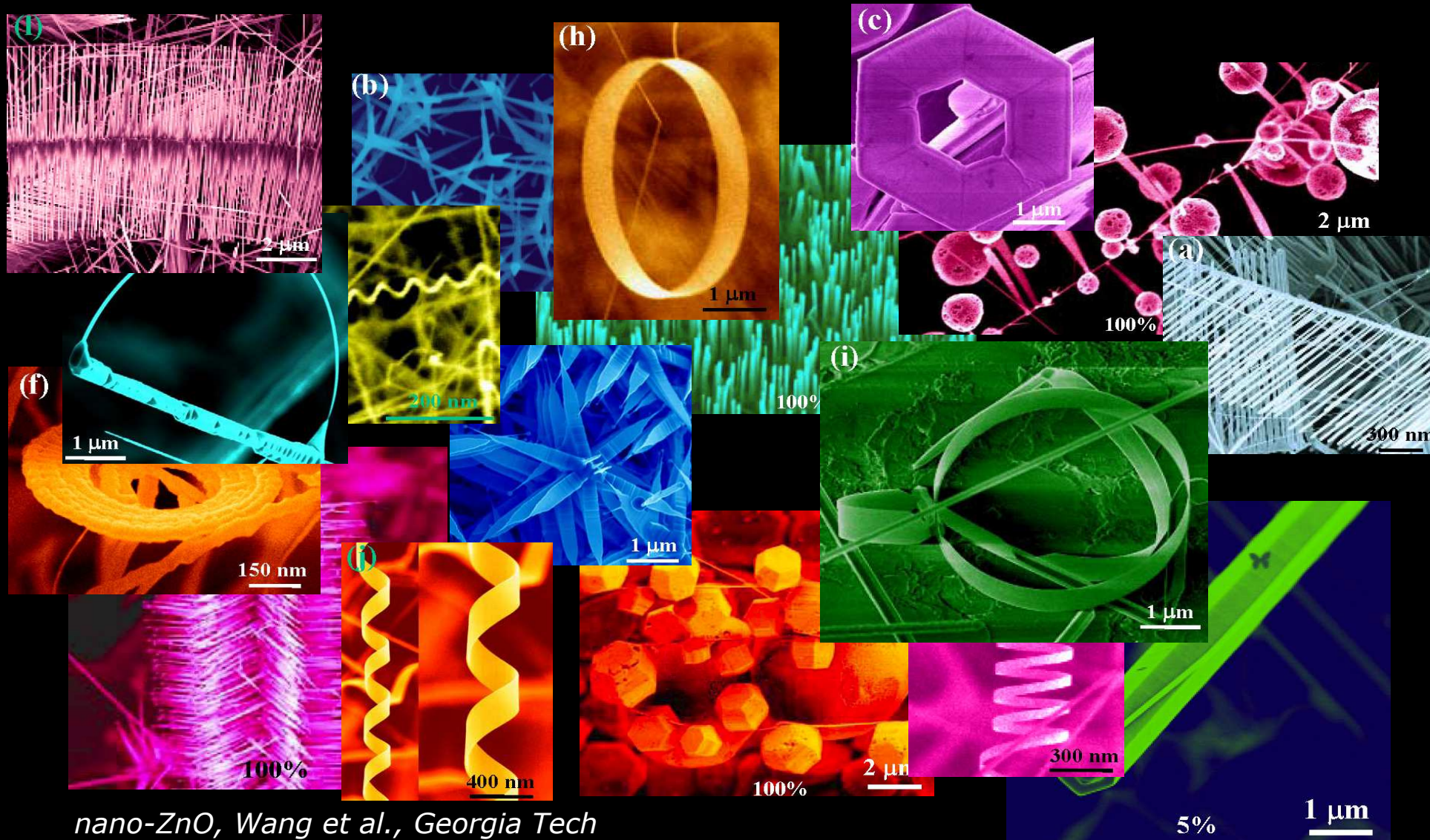
Nano-TiO₂ leaching from freshly painted surfaces was measured as high as 600 mg/L (Kaegi et al 2008)

Nano-TiO₂ was measured in STP effluents from 5 – 15 µg/L and up to 6 mg/g in biosolids (Kiser et al 2009)

Fullerenes were measured in STP effluents as high as 19 µg/L (Farre et al 2010)

Socks containing up to 1360 µg Ag per sock leached as much as 650 µg Ag in 500 mL distilled water (Benn et al 2008)

Similar Chemistry

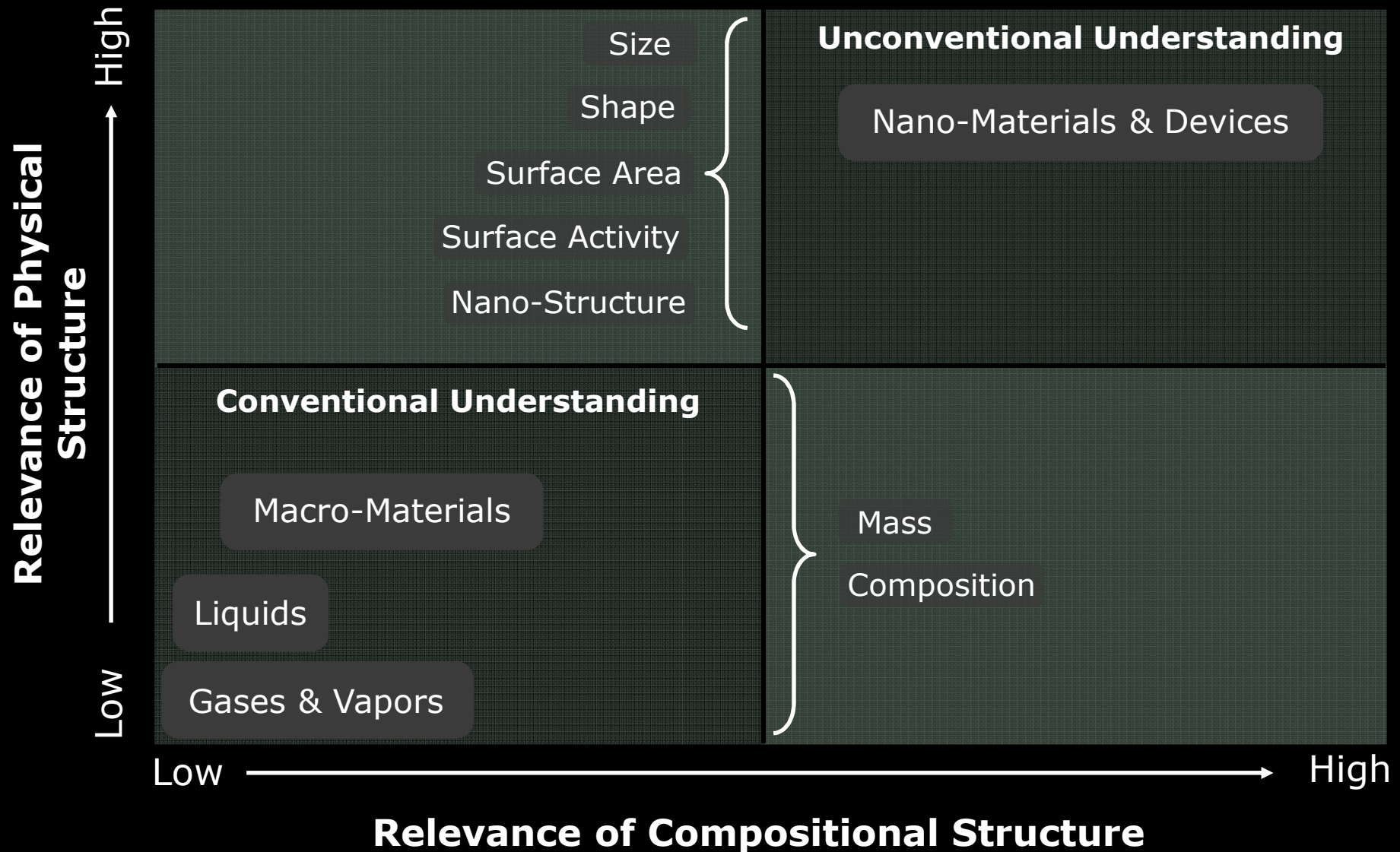


nano-ZnO, Wang et al., Georgia Tech

Potentially Different Risks

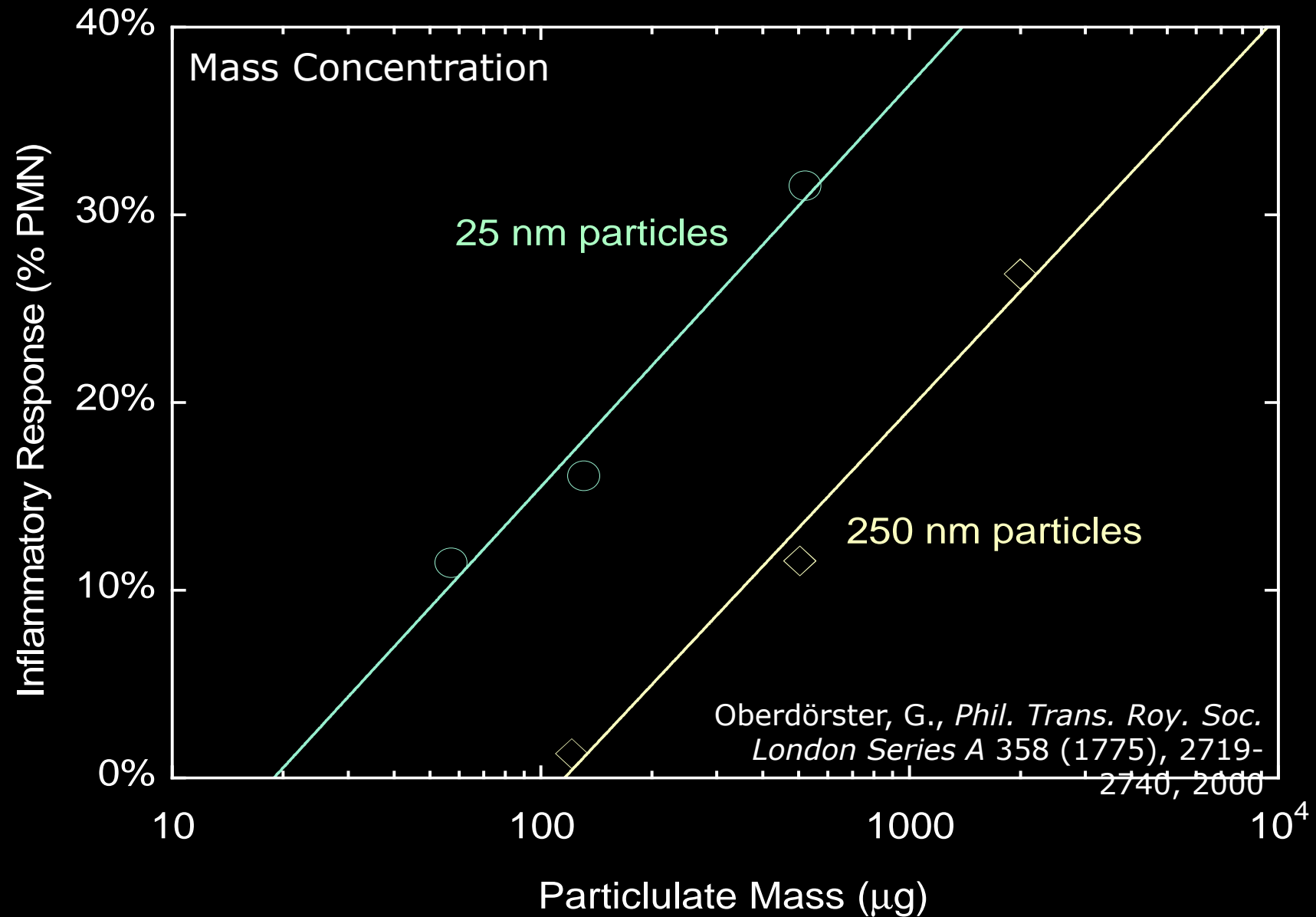
A thought experiment

The potential significance of structure on nanomaterial impact



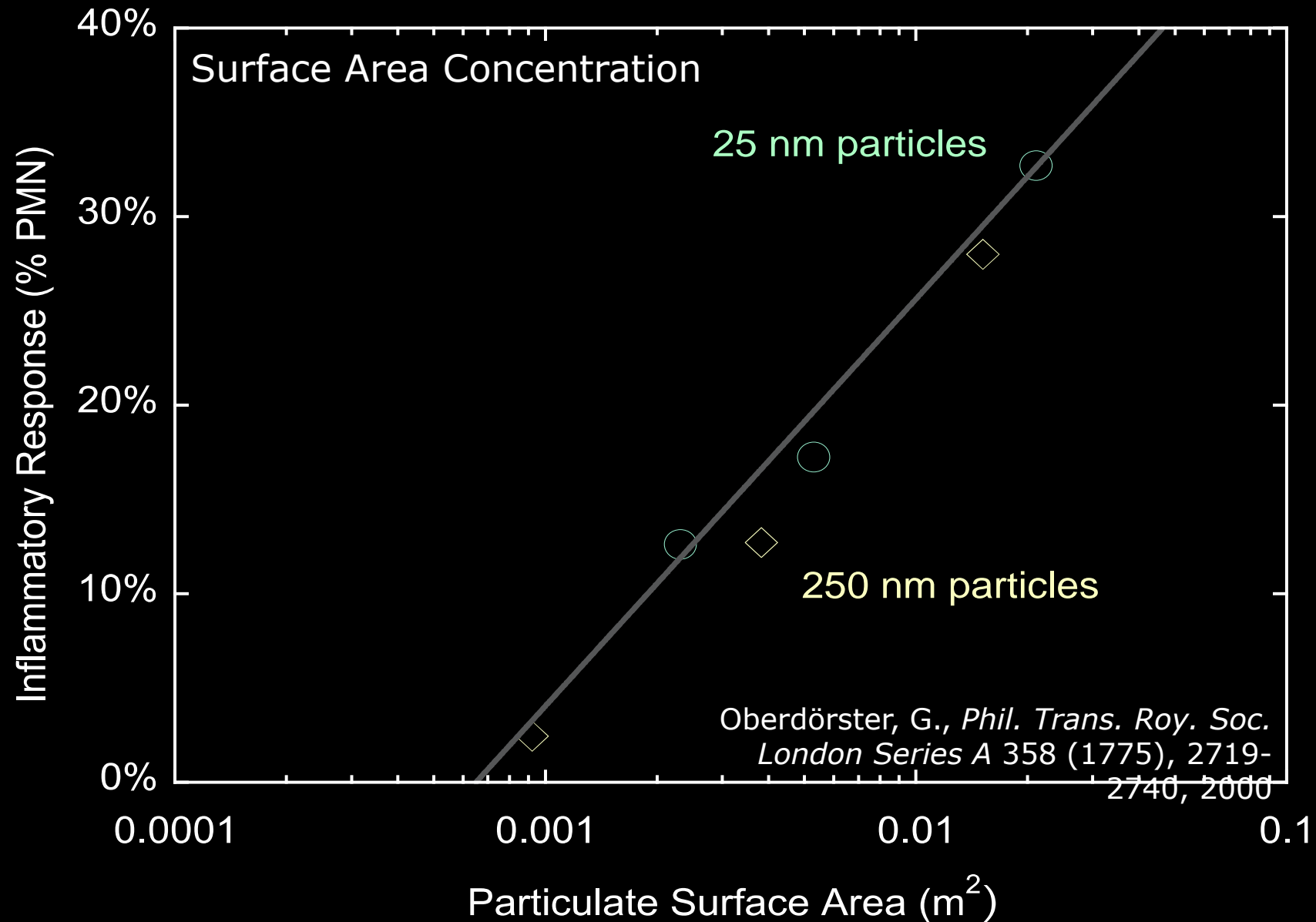
Scale-specific hazard: Particle Size

TiO₂ Instillation in Rats



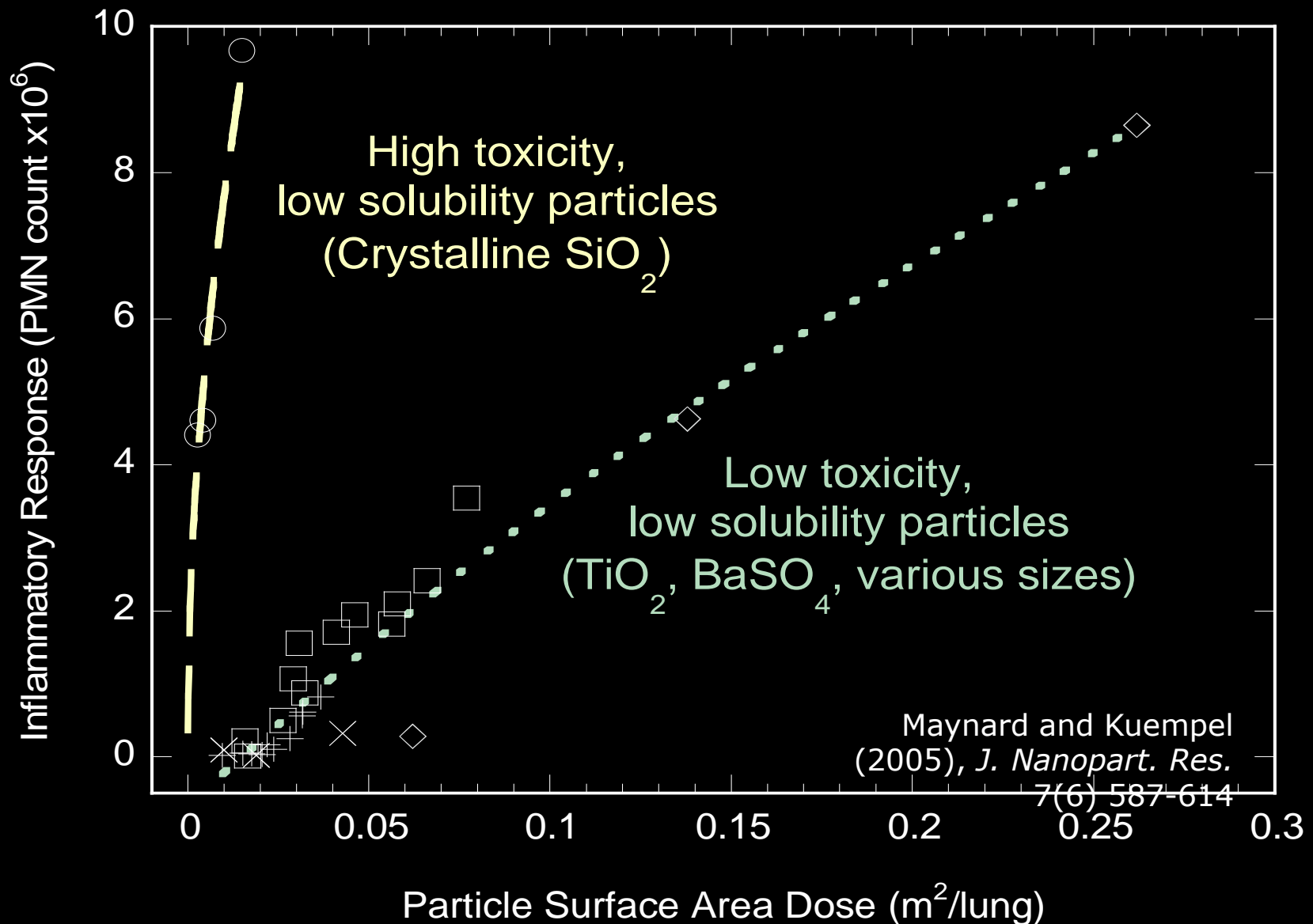
Scale-specific hazard: Particle Size

TiO₂ Instillation in Rats



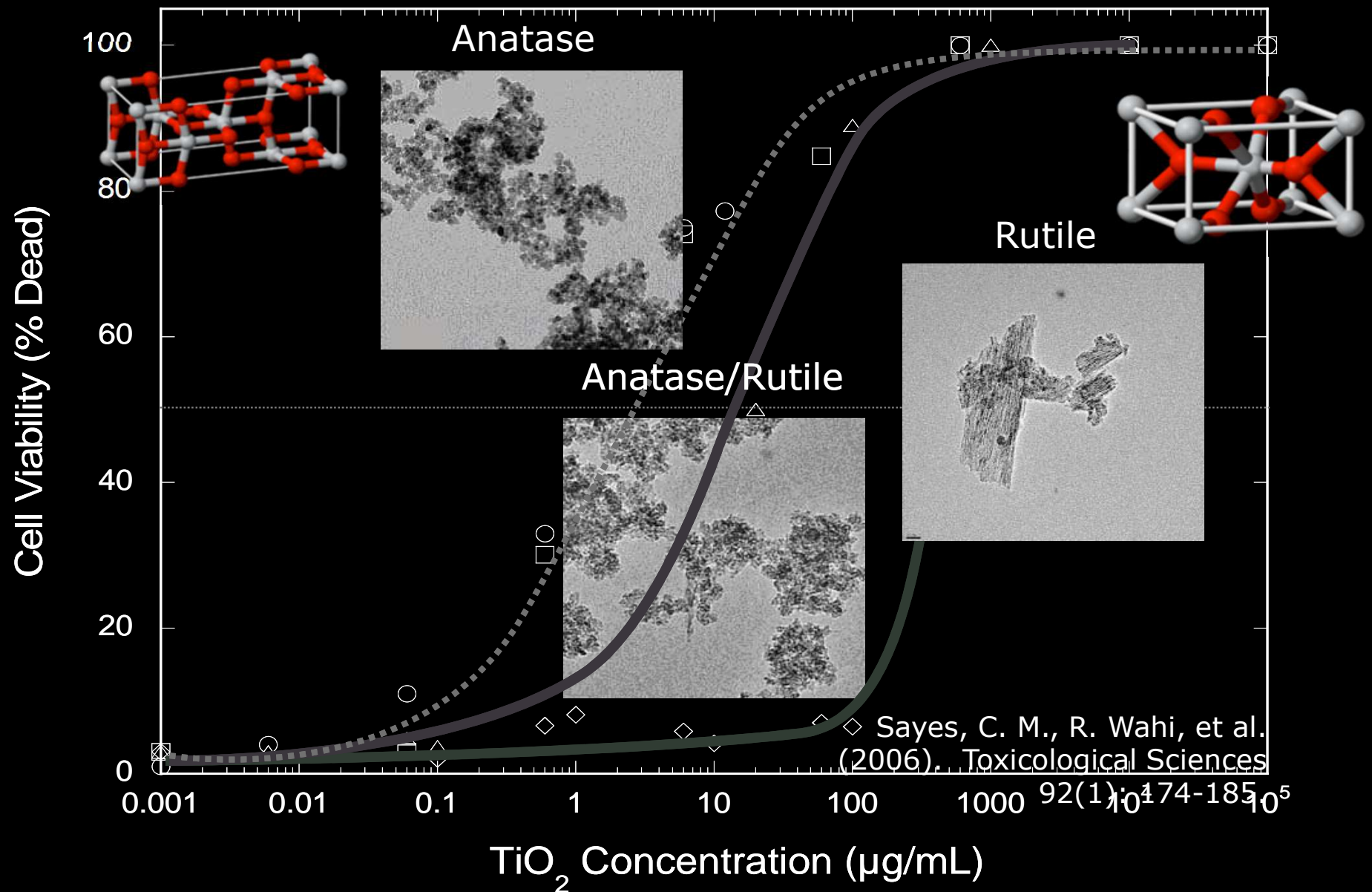
Scale-specific hazard: Particle Surface

TiO₂ Instillation in Rats



Structure-related hazard: Crystallinity

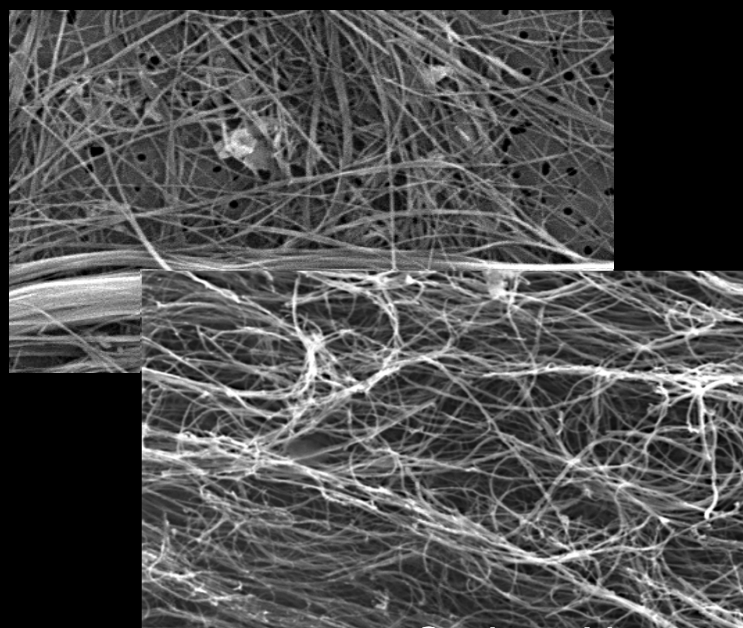
In vitro studies - Human Dermal Fibroblasts



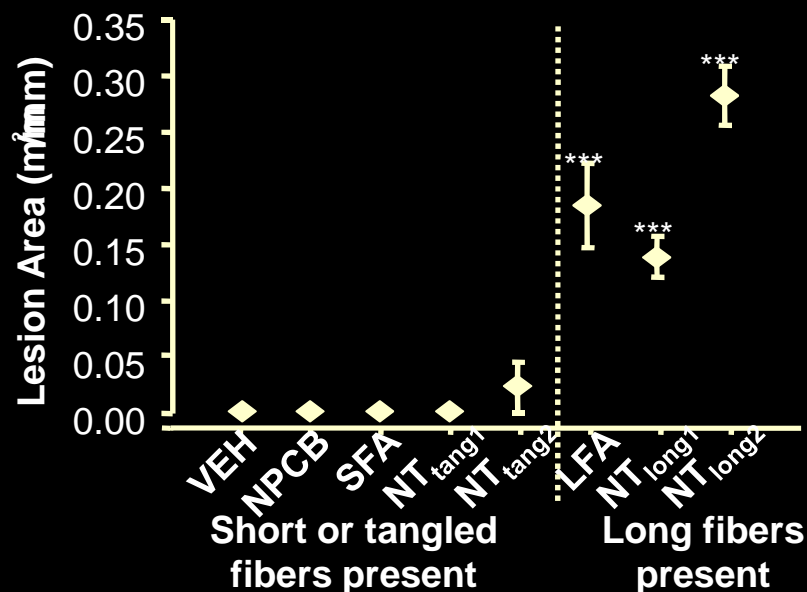
Structure-related hazard: Things we already know

Does the fiber paradigm hold for fiber-like nanomaterials?

Asbestos



Carbon Nanotubes



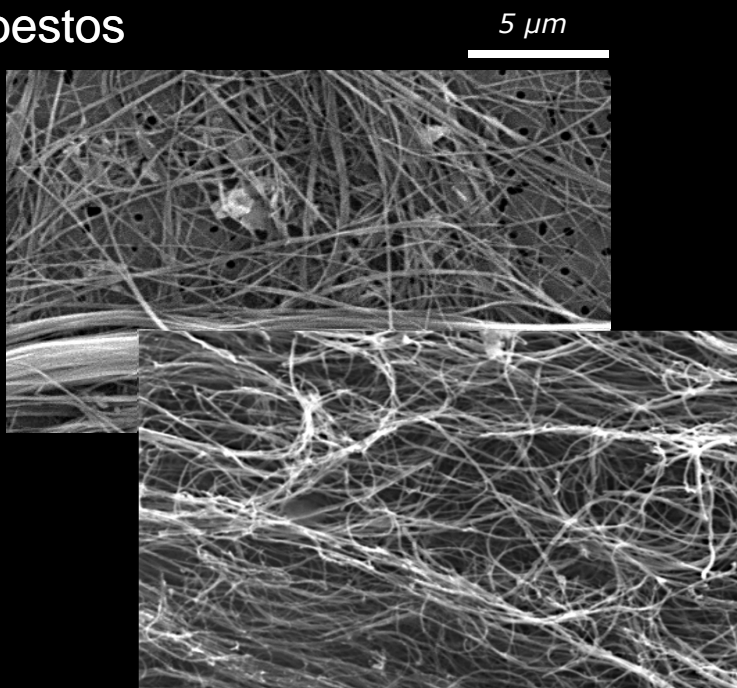
Carbon nanotubes that look like harmful asbestos fibers, behave like harmful asbestos fibers

Poland, C. A., R. Duffin, I. Kinloch, A. Maynard, W. A. H. Wallace, A. Seaton, V. Stone, S. Brown, W. MacNee and K. Donaldson (2008). "Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study." *Nature Nanotechnology* doi:10.1038/nnano.2008.111.

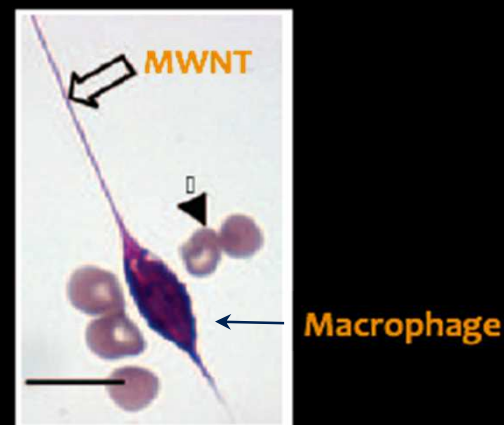
Structure-related hazard: Things we already know

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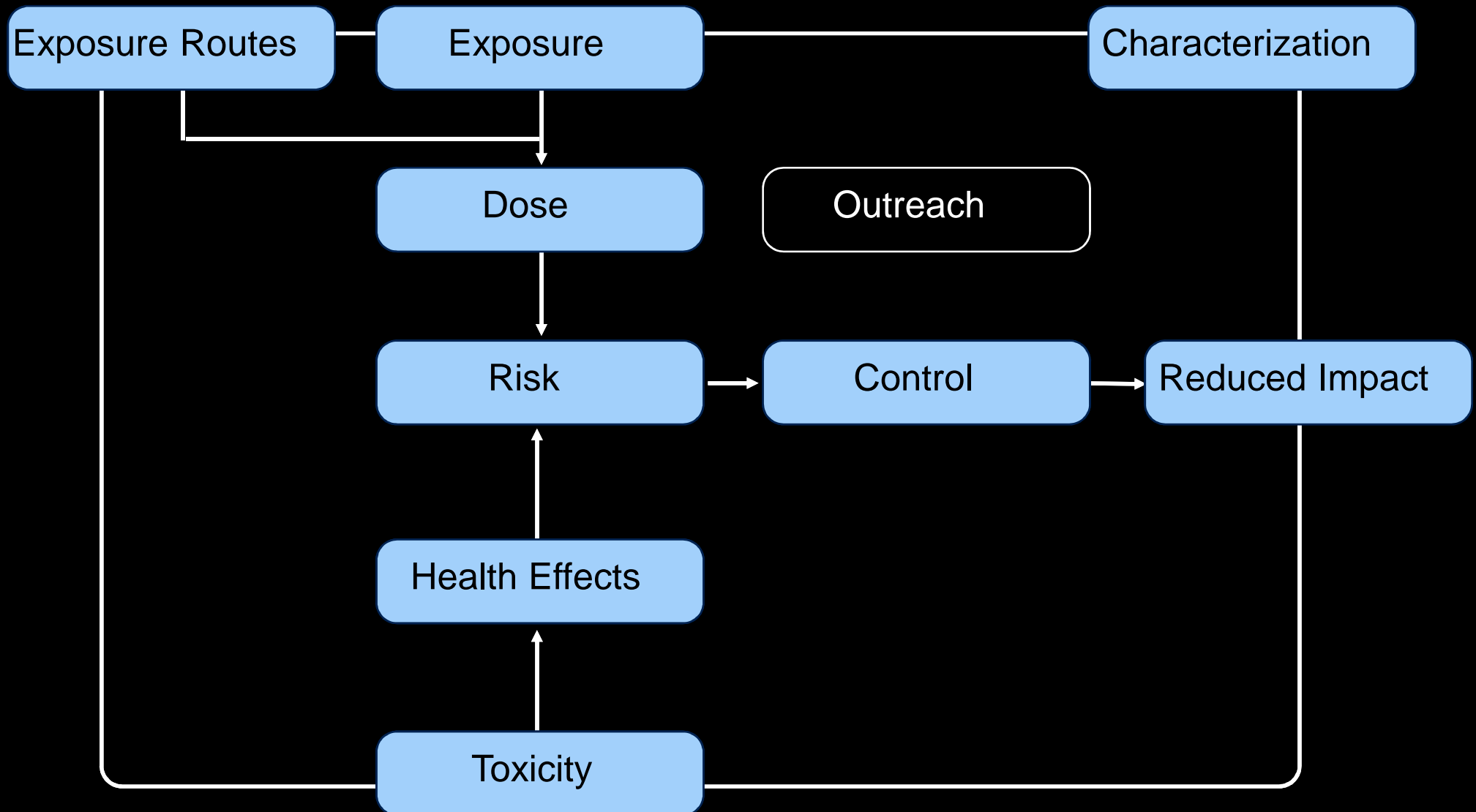


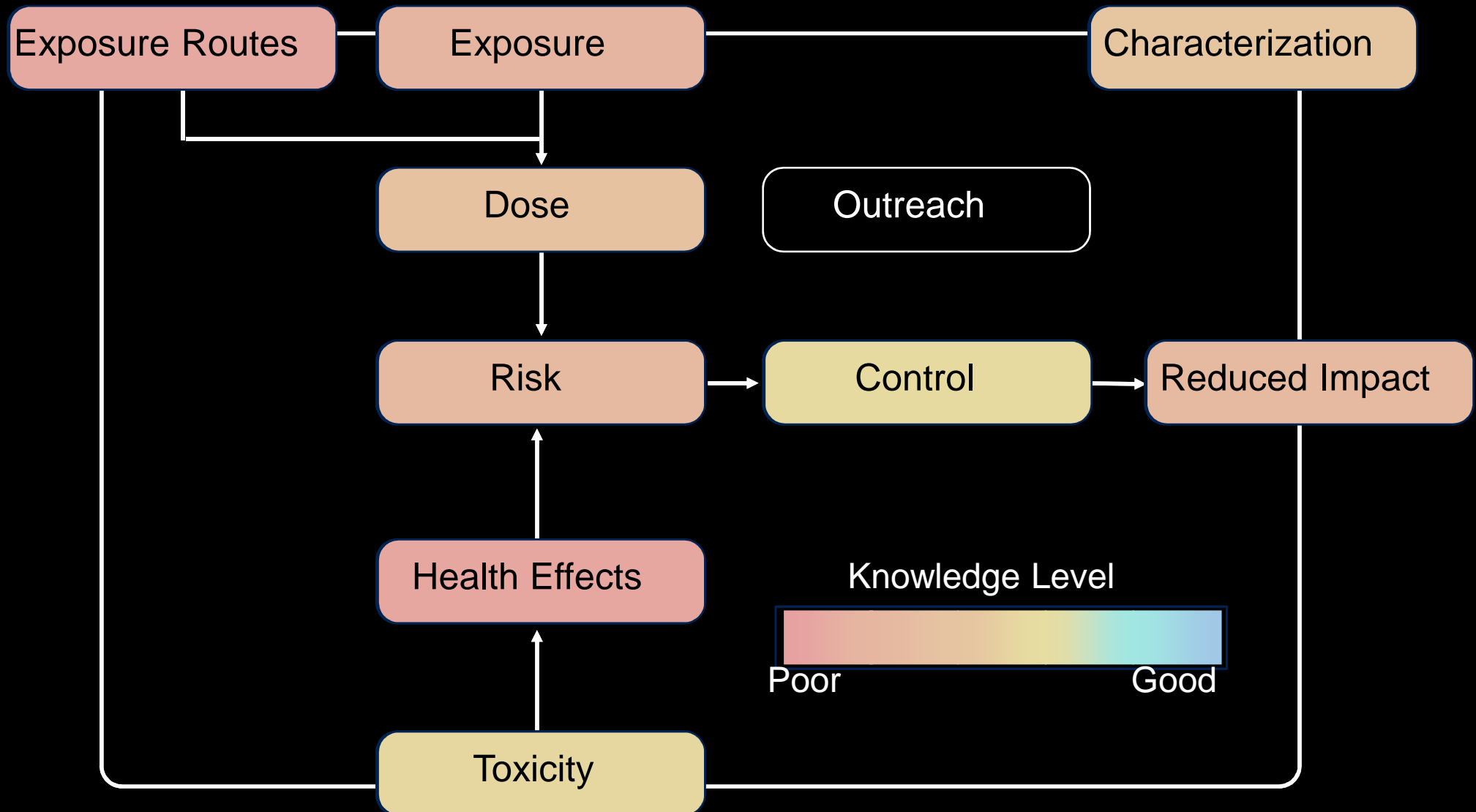
Frustrated Phagocytosis



Carbon nanotubes that look like harmful asbestos fibers, behave like harmful asbestos fibers

Poland, C. A., R. Duffin, I. Kinloch, A. Maynard, W. A. H. Wallace, A. Seaton, V. Stone, S. Brown, W. MacNee and K. Donaldson (2008). "Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study." *Nature Nanotechnology* 3:423-428





Novel Risks (*potential*): **Engineered Nanomaterials**

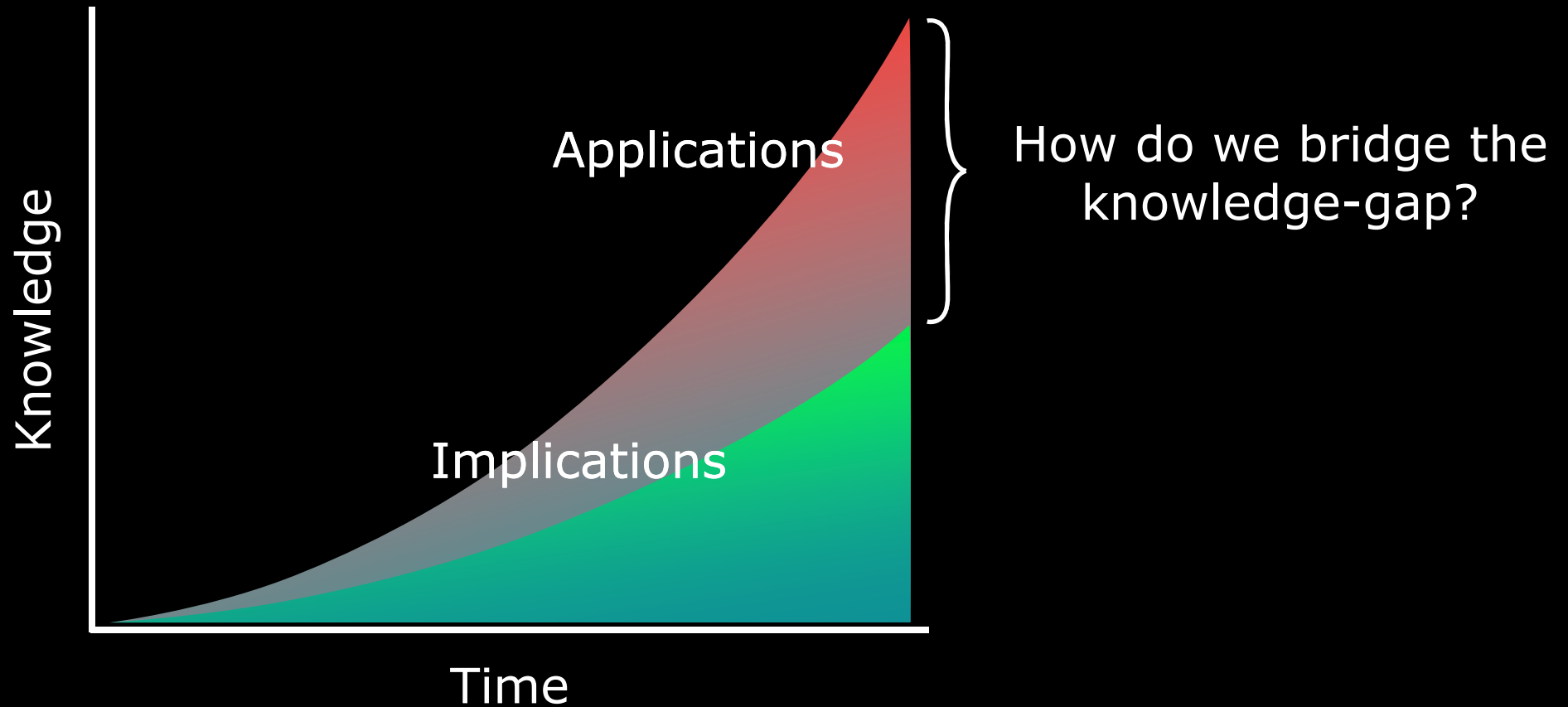
Concerns:

- ⌈ Might get to normally inaccessible places
- ⌈ Might cause harm in unusual ways
- ⌈ Harm might not be predictable from chemistry alone

Cautions

- ⌈ Few generic principles of behavior
- ⌈ Not all nanomaterials will present novel risks
- ⌈ Existing risk management approaches *may* work

REGULATION Challenge
KNOWLEDGE



A Call to Research

**Policy in the absence of Knowledge is
a recipe for disaster**

Research -> Data -> Knowledge

A Call to Research

**In the absence of defensible data the
public will draw their own
conclusions....**

Research -> Data -> Knowledge



Graffiti protesting the establishment of nanotechnology laboratories, on the Bastille fortress in Grenoble, France

© 2006 David Monniaux

Nanotechnology & Sunscreens



a consumer guide for avoiding nano-sunscreens

August 2007

A Call to Research

**Objective, hypothesis-driven research
is needed to quantify nanomaterial
exposures and effects.**

Data -> Knowledge -> Wisdom

**The result of this process is a quantitative
assessment of risk that
facilitates risk management.**

Risk Management

Can we develop strategies
by which society can benefit from
nanotechnology without incurring
unacceptable (and unforeseen) problems?

The more we know about the risks
the better able we are to minimize them.

Any Questions?

