# Vault Nanoparticles for Water Treatment: Educational and Experimental Approaches

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2017 SNO CONFERENCE

UCLA ENGINEERING
Civil and Environmental Engineering

UCLA David Geffen School of Medicine | Shaping the Future

# Nanotechnology – Complex topic

**Synthesis** → **Characterization** → **Application** → **Implication**

**Synthesis**
- Bottom up
  - Deposition
  - Condensation
  - Self-assembly
- Top-down
  - Milling
  - Attrition

**Characterization**
- TEM
- SEM
- DLS
- Zeta-potential
- AFM
- Cryo-EM
- XRD

**Application**
- Environmental
  - Water treatment
  - Air treatment
  - Soil treatment
  - Disinfection
  - Monitor
  - Energy
- Medical
- Chemical
- Construction

**Implication**
- Exposure
- Toxicity

# ENG 103 Environmental Nanotechnology

- UCLA Engineering School-wide undergraduate “minor” in nanotechnology
- Course Topics:
  - Synthesis and characterization of nanoparticles
  - Transport and transformations in natural environments and engineered systems
  - Nanomaterials applied to civil engineering, biosensors, water treatment, contaminant remediation, energy production and storage
  - Nanoparticle-biological interactions
  - Environmental toxicity and risk

# ENG 103 Environmental Nanotechnology

- Mini-Lectures by Student Groups
  - 3-4 students per group
  - 45min – 1 hr mini-lecture
  - Introduce a nanoparticle that is environmentally-relevant
    - General description
    - Synthesis
    - Characterization: morphology, size, zeta-potential, etc..
    - Environmental application
    - Potential risk
  - Graded by other students
    - Strength
    - Things to improve

# Lessons from Student Lectures

1. Every group included four main topics in nanotechnology

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2014-2016

# What applications are students interested in?

2014


2015


2016

# Lessons from Student Lectures

1. Every group talked about potential risk

2. What applications are students interested in?

3. What nanomaterials are students interested in?

# Lessons from Student Lectures

1. Every group included four main topics in nanotechnology

2. What applications are students interested in?

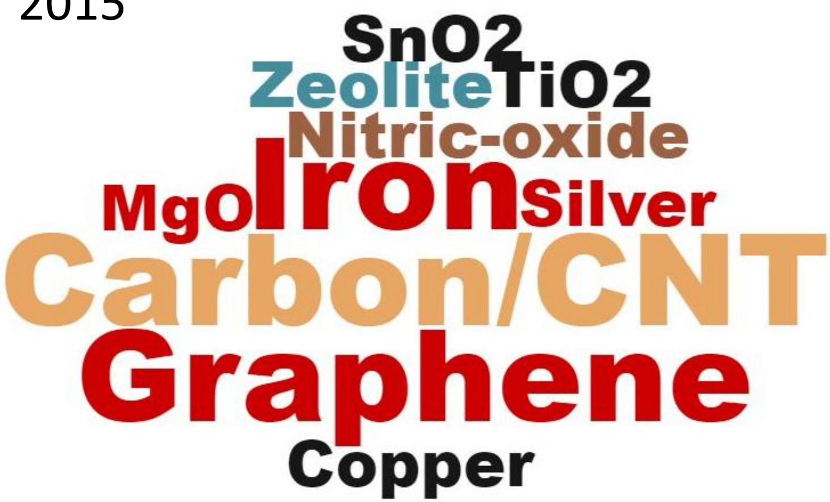
3. What nanomaterials are students interested in?


2014-2016

# What nanomaterials are students interested in?

2014


2015

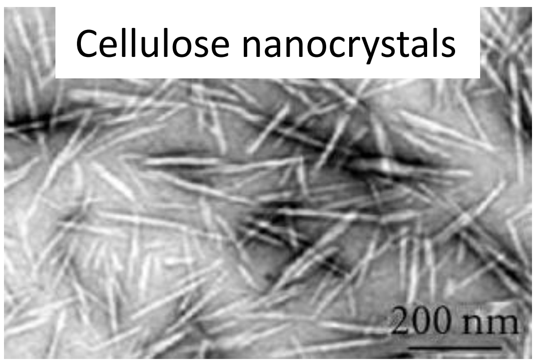



2016

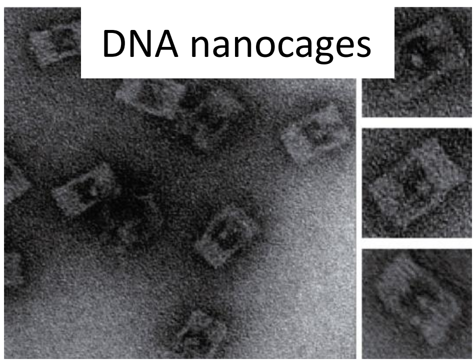
# Bio-Nanomaterial

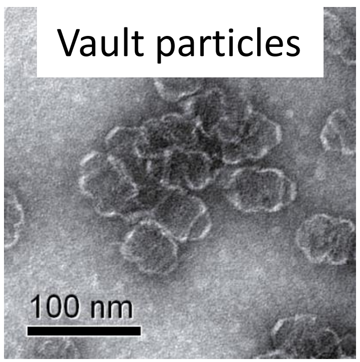
- Assembled/Synthesized from organic molecules
  - Carbohydrate
  - Nucleic acid
  - Peptide/protein
  - Viruses

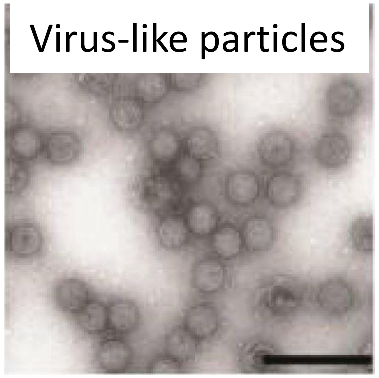
(Kalia et al., 2011)



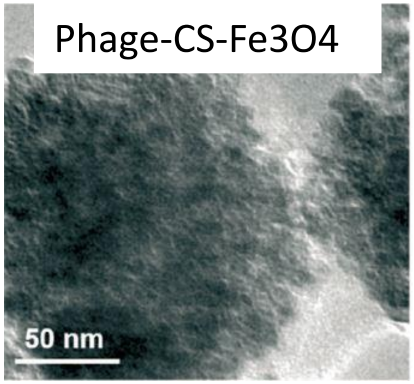

(Zhao et al., 2016)




(Patterson et al., 2012)



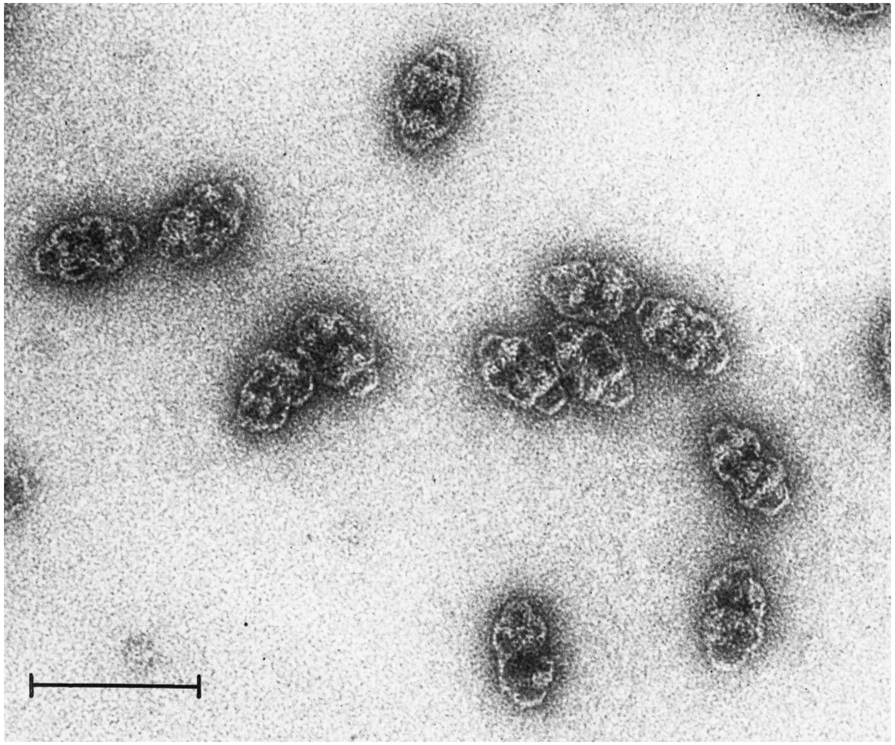

(Li et al., 2017)

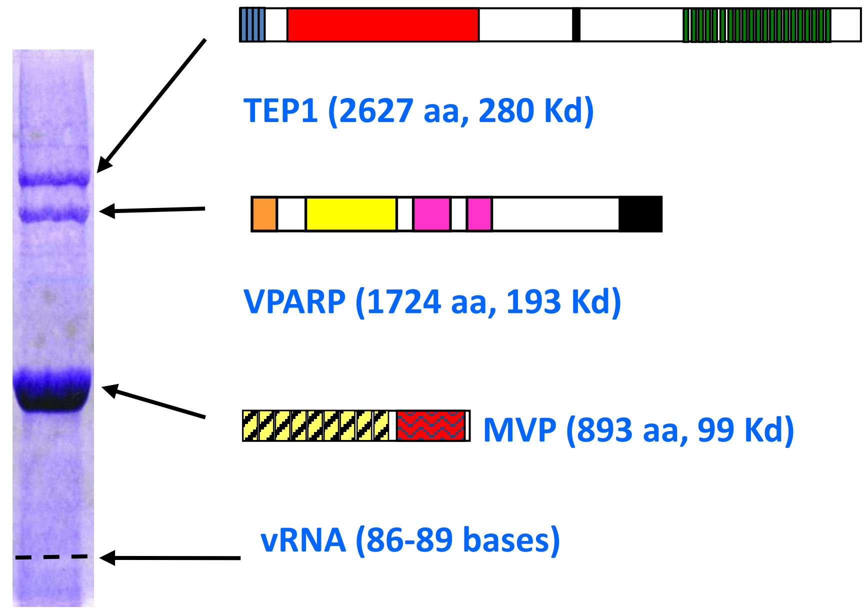
# Bio-Nanomaterial

- Compare with inorganic nanomaterial

| | **Bio-Nanomaterial** | **Inorganic Nanomaterial** |
|---|---|---|
| Synthesis | • Biosynthesis<br>• Physiological condition<br>• Less hazardous waste | • Chemical synthesis<br>• Harsh condition (extreme pH, organic solvent, etc..)<br>• Hazardous waste generation |
| Disposal | • Biocompatible<br>• Degradable<br>• No toxicity – Low toxicity | • Recalcitrant<br>• Pose risk for human or ecosystem |
| Application | • Medical: Drug delivery; antibacterial drug; tissue regeneration, etc.. | • Medical<br>• Environmental<br>• Chemical<br>• Energy<br>• Construction |

# The Vault Particle



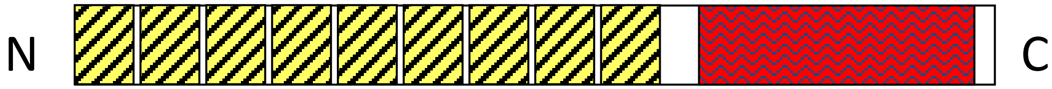



With a mass of 13 MD, vaults are the largest naturally-occurring cell particle

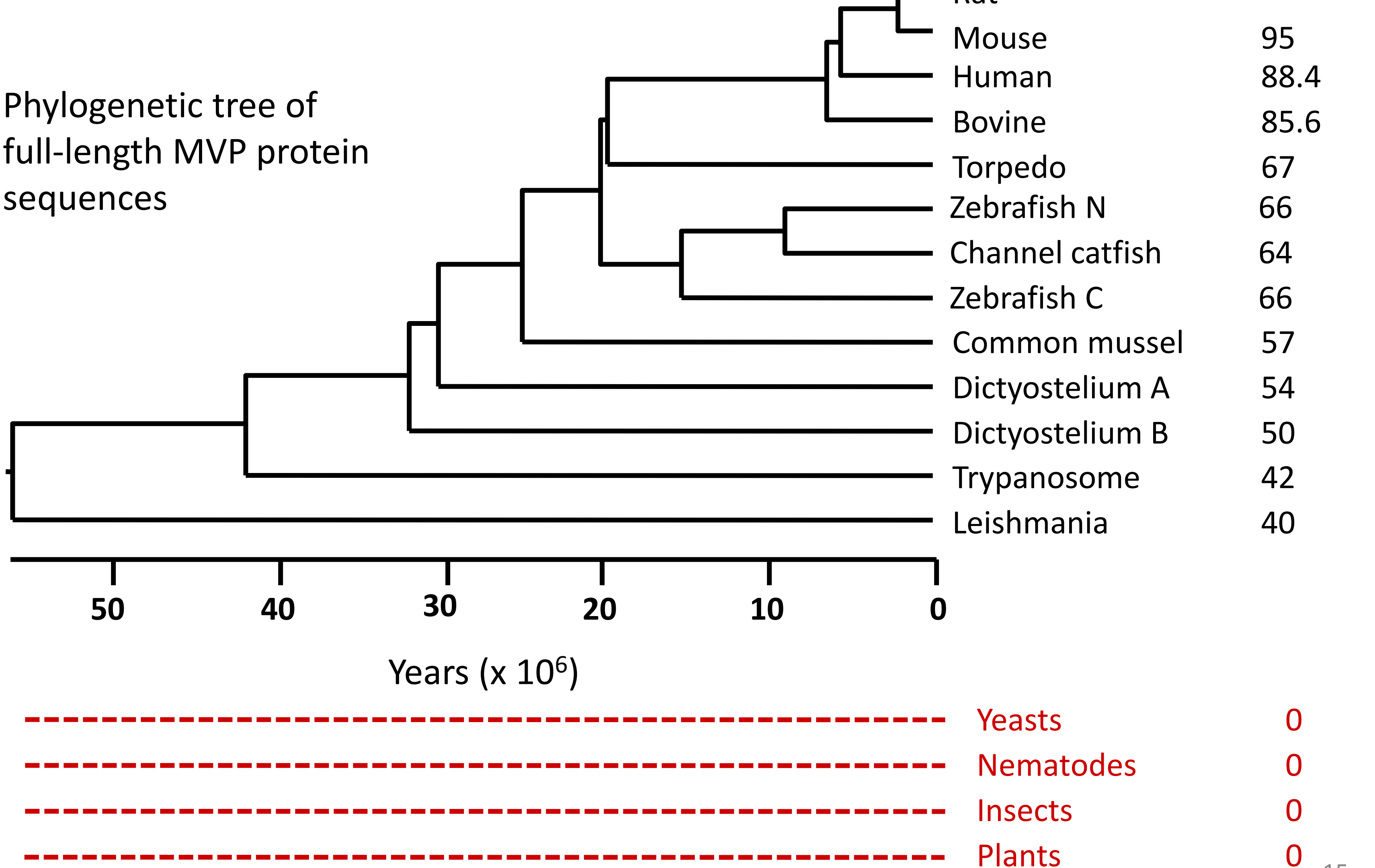
Yet they are composed of just three proteins and a small untranslated RNA

*Kedersha, N.L. and Rome, L.H.. J. Cell Biol. 103: 699 709 (1986).*
*Kedersha, N.L., et al., J. Cell Biol. 110: 895-901 (1990) and J. Cell Biol. 112: 225-235 (1991).*
*Kickhoefer, V.A. and Rome, L.H., Gene 151:257-260 (1994).*
*Kickhoefer, V.A.,et al., J. Cell Biol. 146:917-28 (1999) and J. Biol. Chem. 274: 32712-32718 (1999).*

# MVP's are highly conserved

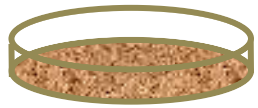



Phylogenetic tree of full-length MVP protein sequences

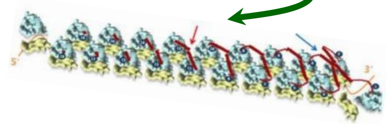


# Engineering Vaults

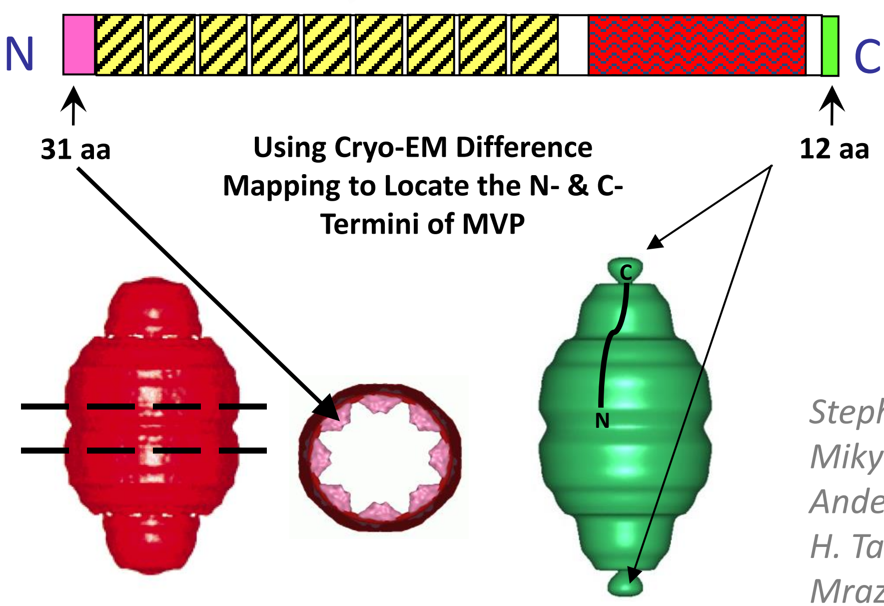
- Insert MVP gene in an infectious piece of DNA (Bacmid)
- Insert the gene into Sf9 insect cells
- MVPs assemble into vaults

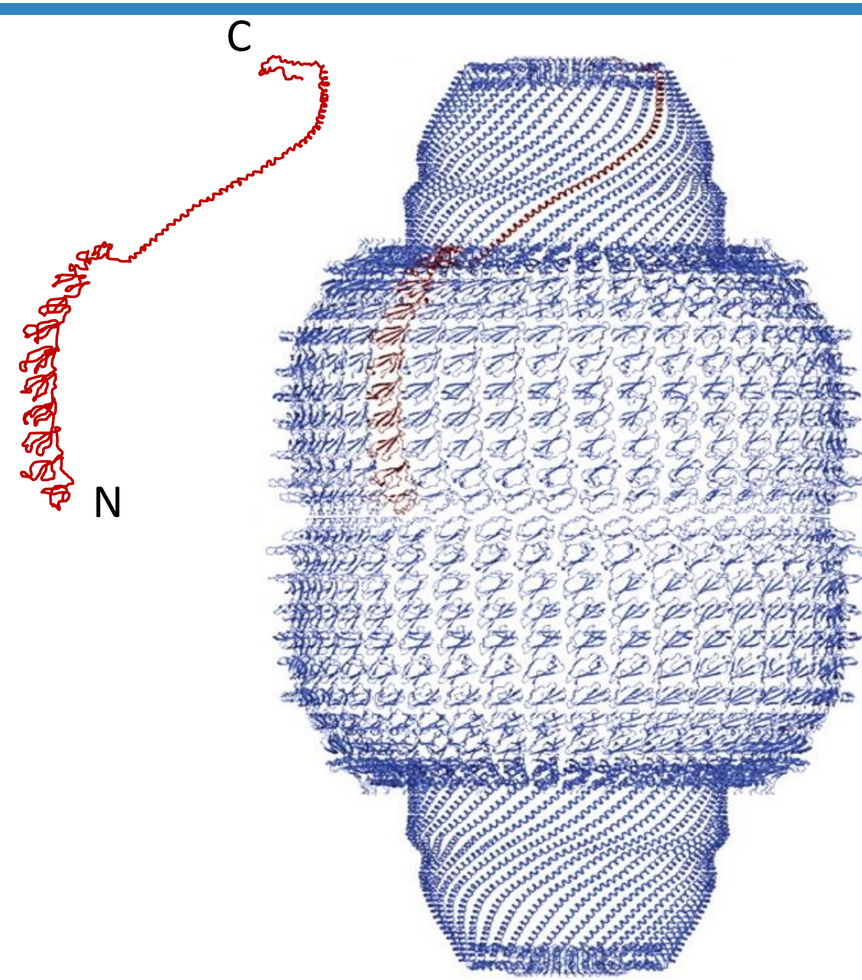


**Insect cells**



**MVP on polyribosome**



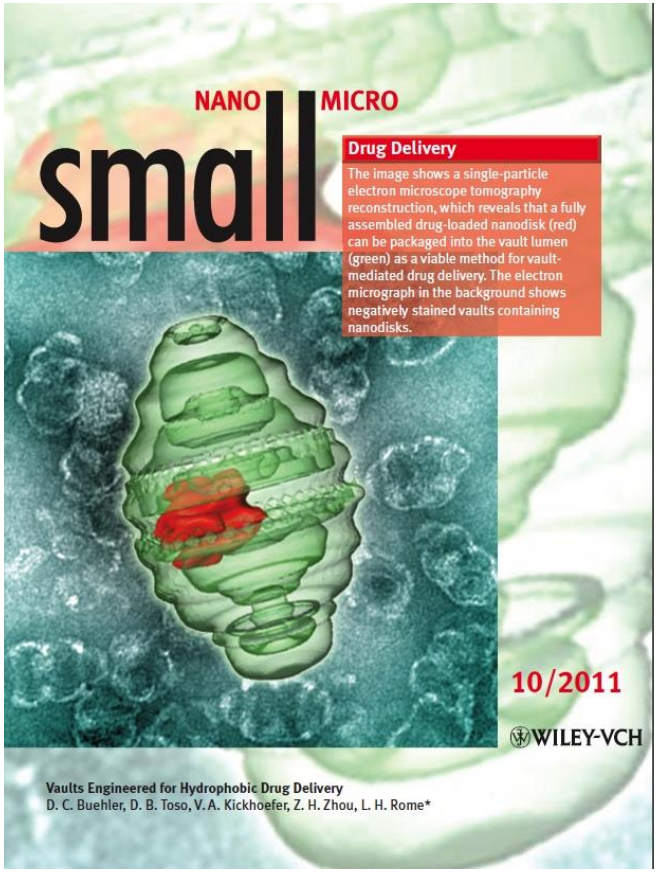





*Stephen, A.G. et al., J. Biol. Chem. 276: 23217-23220 (2001).*
*Mikyas,Y., et al., J. Mol. Biol. 344: 91-105 (2004).*
*Anderson D.H., et al.. PLoS Biology, 11:2661-70 (2007).*
*H. Tanaka, et al. Science 323, 384 (2009).*
*Mrazek, J. et al., ACS Nano 8, 11552–11559 (2014).*

# Vault Applications

- Targeted delivery of therapeutics
  - Proteins (enzymes, growth factors, chemokines)
  - DNA, RNA (RNAi)
  - Drugs
- Vaccines
  - “Smart” adjuvants for pathogen vaccines
  - Anti-cancer vaccines
- *In vitro* (delivery to cells)
  - Proteins
  - DNA, RNA (RNAi)
  - Drugs
- Environmental Remediation
- Other
  - Controlled release
  - Protein/Enzyme stabilization
  - Sequestration (toxins, proteins etc..)



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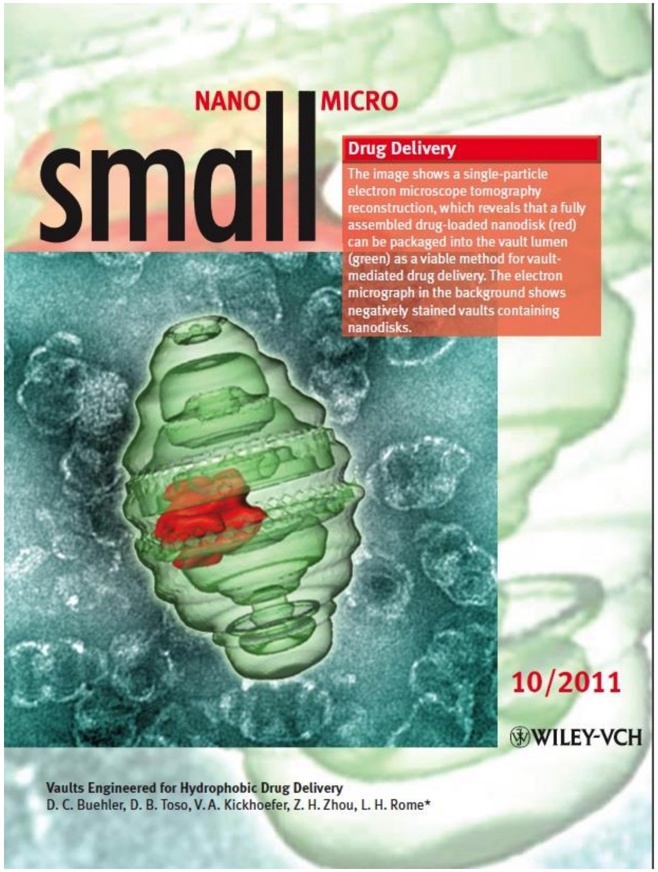
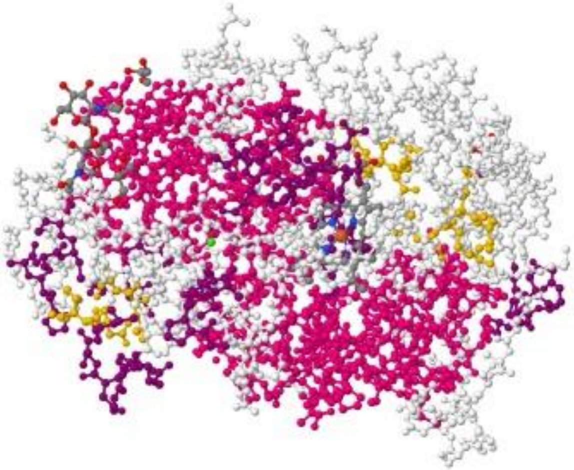


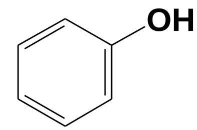
# Applying Vaults in Water Treatment

Manganese peroxidase (MnP)

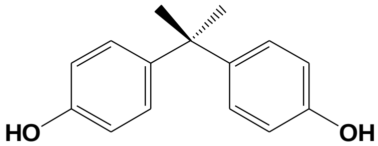


(http://www.rcsb.org)

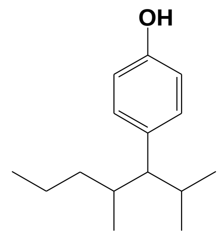
Phenol



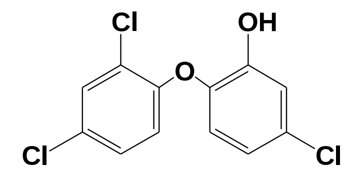

Bisphenol A (BPA)

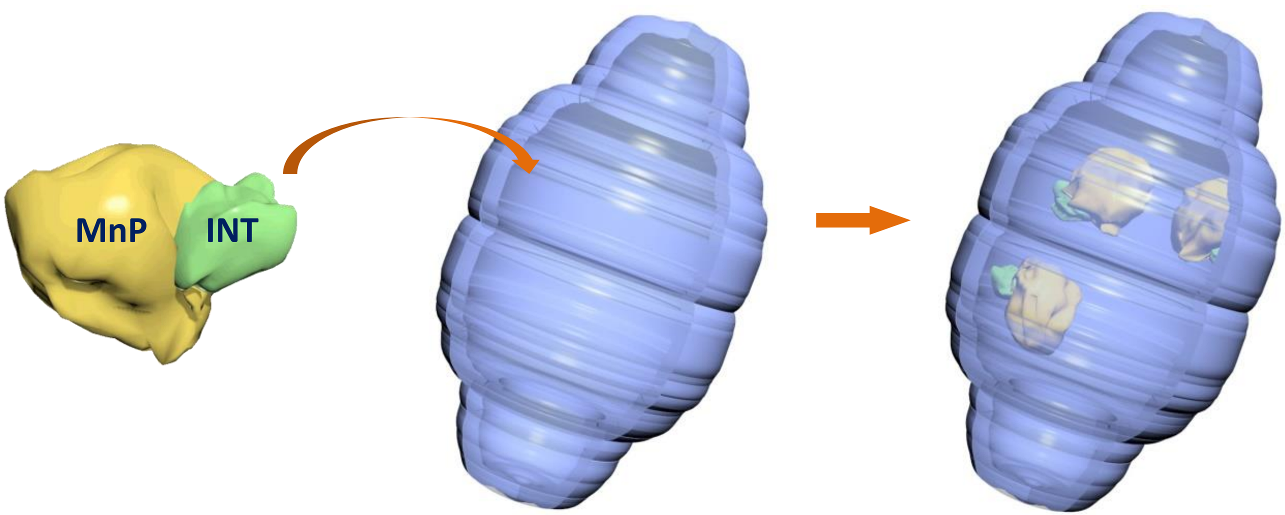



Nonylphenol

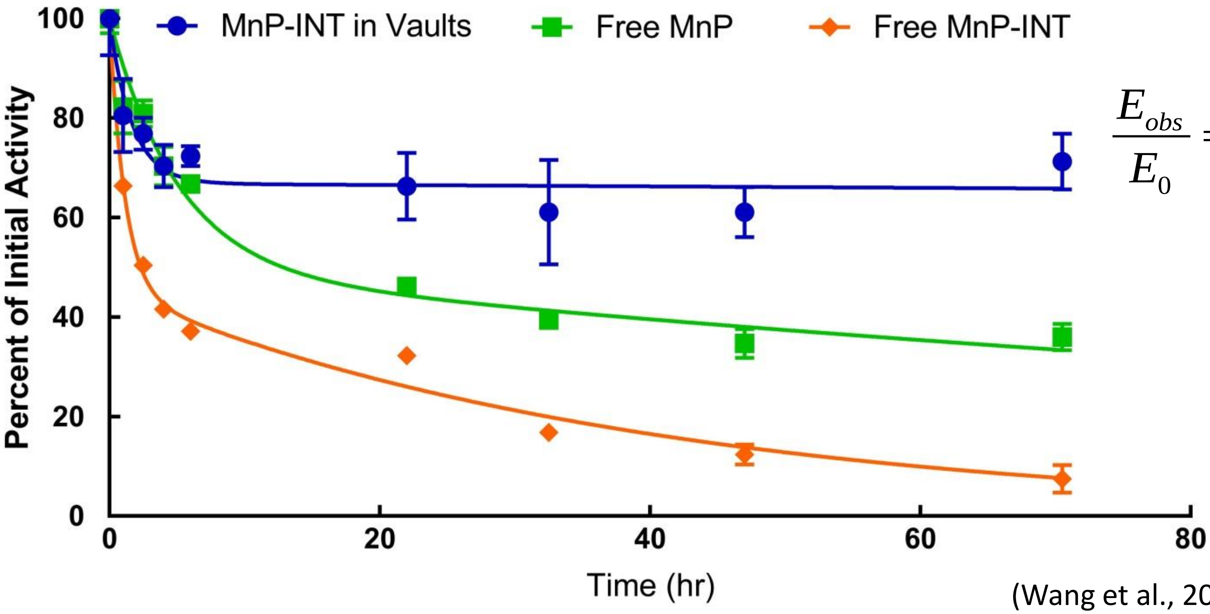



Triclosan



# Vault Packaging Enhanced Enzymatic Stability




(Wang et al., 2015)

$$E_0 \xrightarrow{k_1} E_1 \xrightarrow{k_2} E_D$$

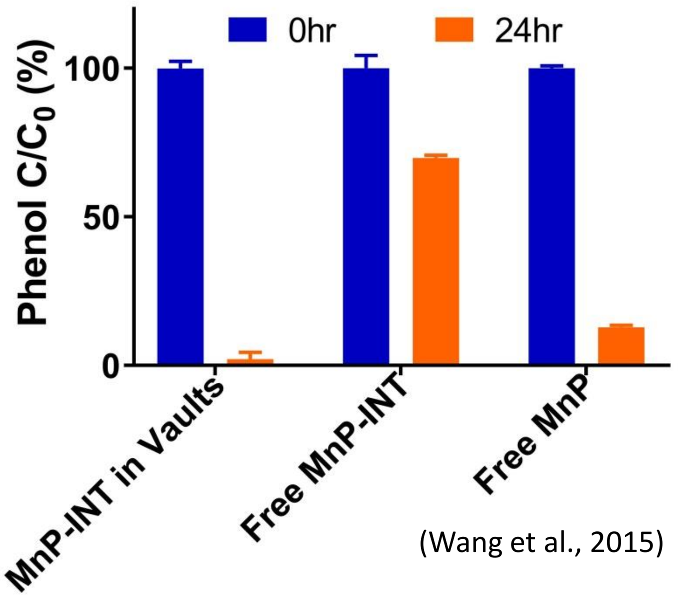
$$\frac{E_{obs}}{E_0} = a = \left[1 + \frac{\alpha k_1}{k_2 - k_1}\right] e^{-k_1 t} - \frac{\alpha k_1}{k_2 - k_1} e^{-k_2 t}$$

(Henley and Sadana, 1985)

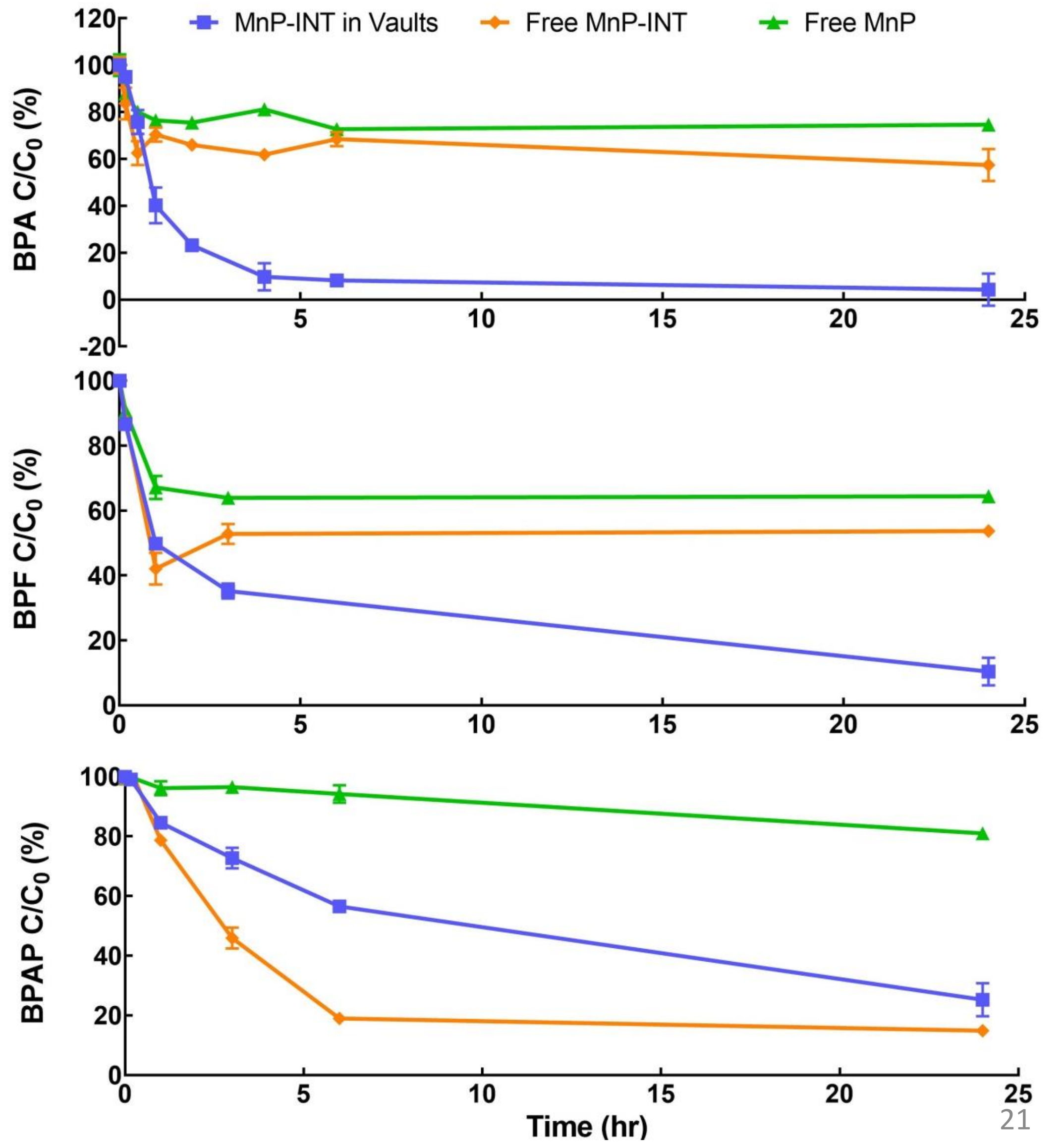
| | $k_1$ ($hr^{-1}$) | $k_2$ ($hr^{-1}$) | α |
|---|---|---|---|
| **MnP-INT in vaults** | 0.6 | 0.00021 | 0.67 |
| **Free MnP-INT** | 0.86 | 0.043 | 0.45 |
| **Free MnP** | 0.20 | 0.0056 | 0.48 |

(Wang et al., 2015)

# Vault Packaging Enhanced Biodegradation




(Wang et al., 2015)

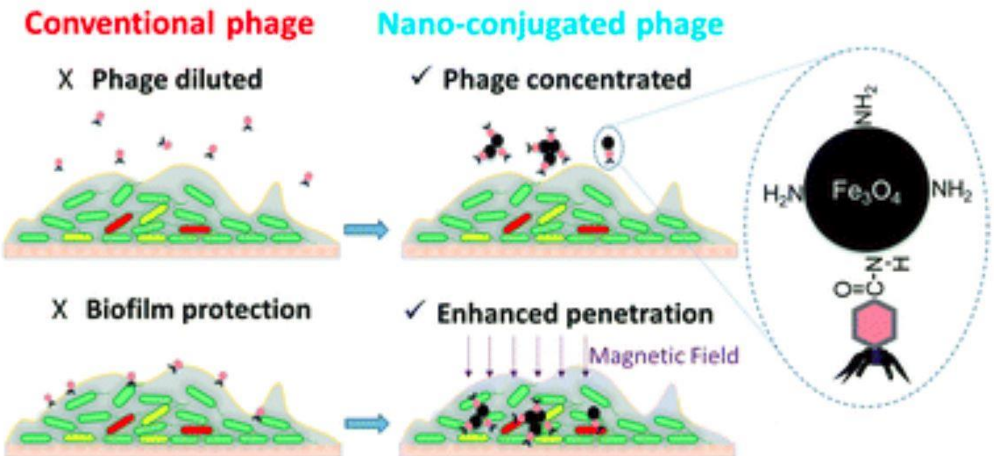




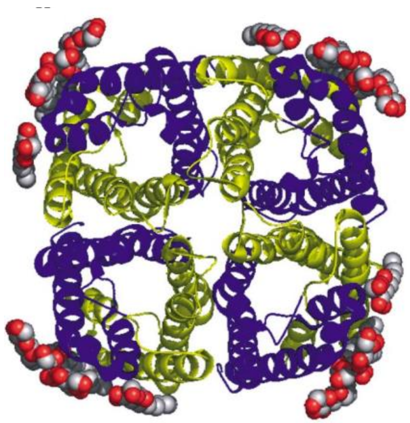

(Wang et al., In prep)

# Other Bio-Nanomaterial

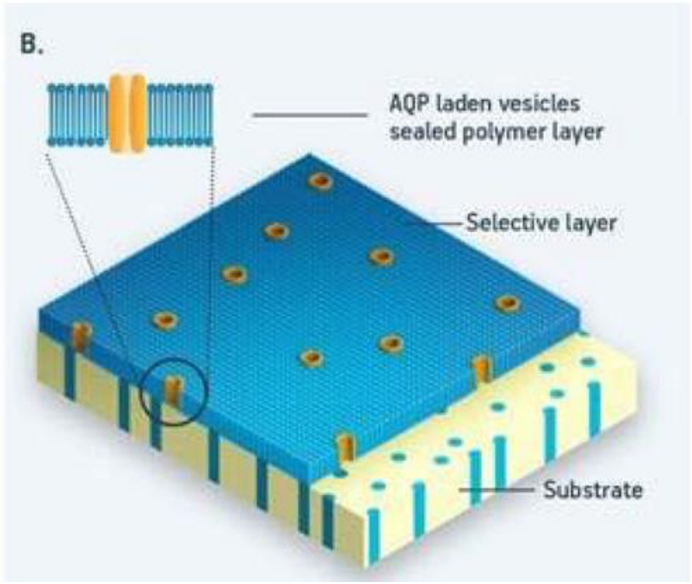
(Li et al., 2017)




Bacterial Phage in Biofilm Control



(Savage et al., 2003)




(Perry et al., 2015)

Aquaporin in Water Desalination

# Summary

- Preparing mini-lectures helped students get comprehensive understanding of the core knowledge nanotechnology.
- Water treatment was the most interesting application for students, but application of nanomaterial in energy was attracting increased attention.
- Carbon based nanoparticles were the most popular nanomaterials in students. But other materials, such bio-nanomaterial was getting students' interest.
- Research topics/ideas from student mini-lectures.

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Paul L. Busch Award

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