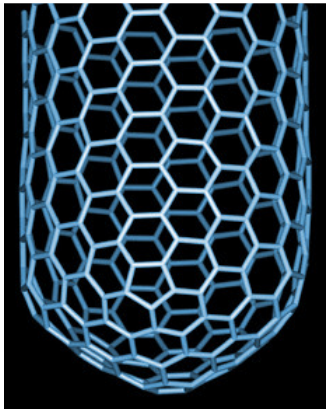


# Carbon Nanotubes as a Novel Filter Media

Seoktae Kang<sup>1)</sup>, Anna S. Stirgwolt<sup>2)</sup>,  
Menachem Elimelech<sup>2)</sup>



<sup>1)</sup>Department of Civil and Environmental Engineering,  
University of Alberta

<sup>2)</sup> Environmental Engineering Program, Yale University

# Outline

## ▶ Background

- Carbon nanotubes
- Novel antimicrobial properties of CNTs

## ▶ Novel CNT Filters for Water Treatment

- Point-of-Use application
- Novel application for organic removal

## ▶ Conclusion

# Nanotechnology?

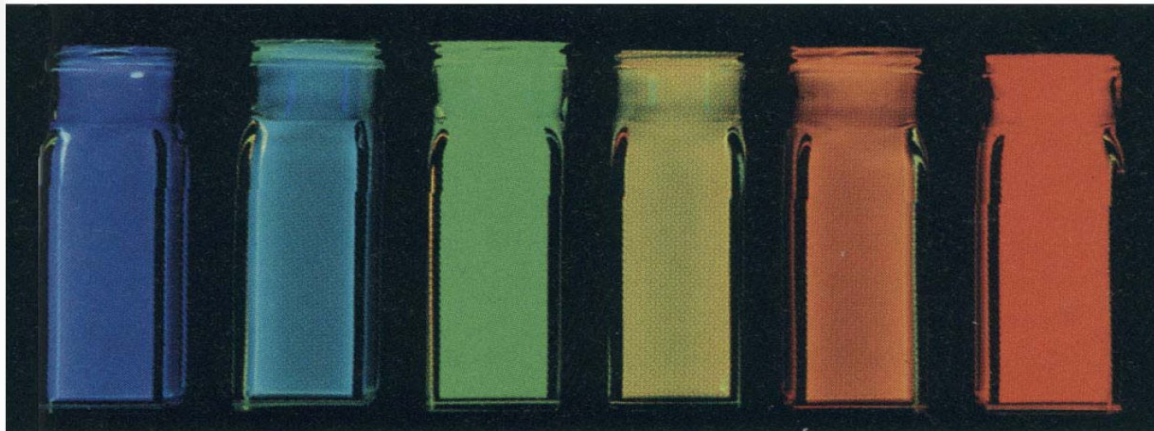
## National Nanotechnology Initiative (NNI)

.....Research and technology to **control** or **develop** at the atomic, molecular or macromolecular levels, in the length scale of **1 - 100 nanometer** range.....

# Nanotechnology?

**RECHARD FEYNMANN (1959)**

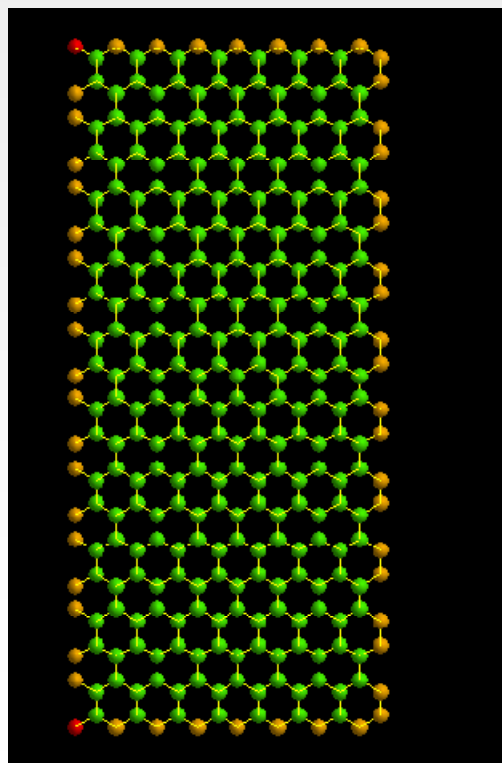
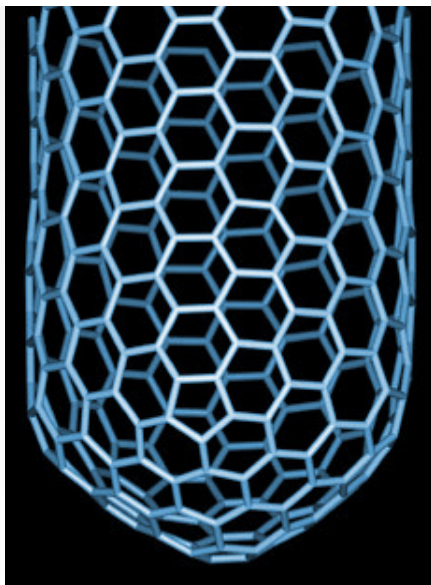
There is plenty of room at the bottom.....  
All things will not simply scale down in proportion.



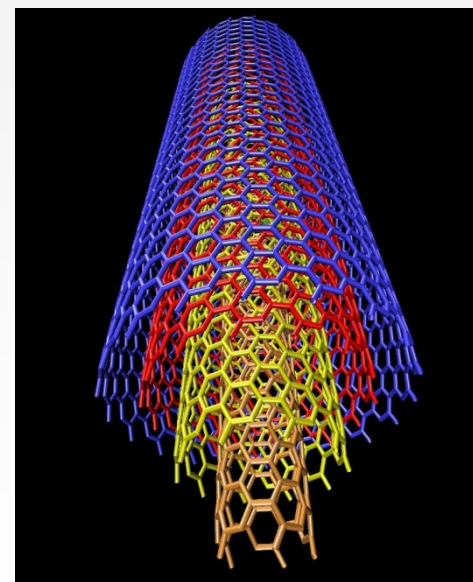
**Nanosized gold particle at different diameters**

# Carbon Nanotubes (CNTs)?

**SWNT**



**MWNT**



<http://www.photon.t.u-tokyo.ac.jp/~maruyama/agallery/nanotubes/>

# Why Carbon Nanotubes?

## **UNIQUE PROPERTIES:**

- Exceptional strengths
- High thermal stabilities
- Large surface areas
- Electrical properties (semi-conducting, metallic)

## **IMPORTANT APPLICATIONS:**

- High-strength, light-weight fibers
- Nano-electronics and sensors
- Novel displays (FED)
- Fuel cells, energy storage applications
- Nanocomposite materials



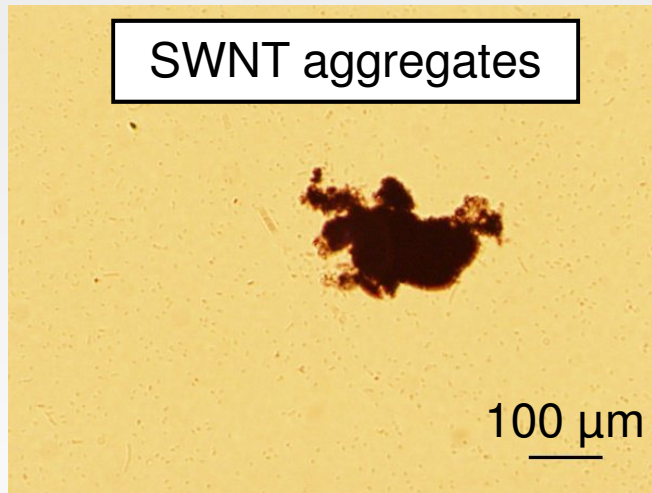
# Why Carbon Nanotubes?

We recently found novel  
antimicrobial properties of  
CNTs

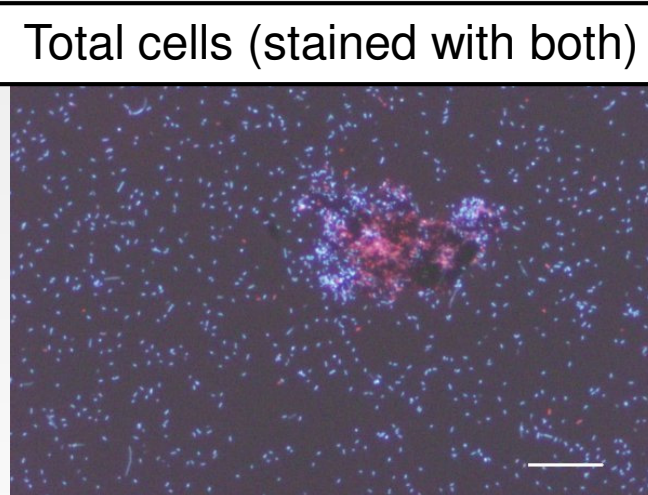


# Antimicrobial property of CNTs

SWNT aggregates



Total cells (stained with both)



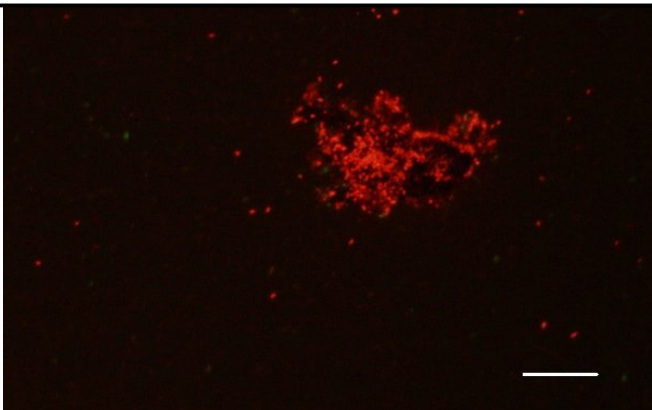
*E. coli* cells

0.9% (154 mM) NaCl solution

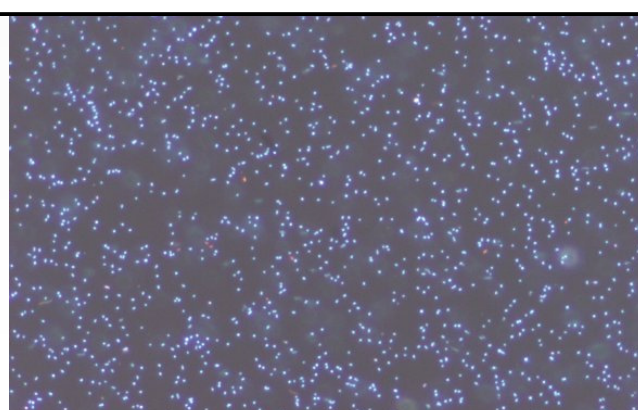
pH=5.6±0.3

Incubated at 37°C

Damaged cells (PI stained)



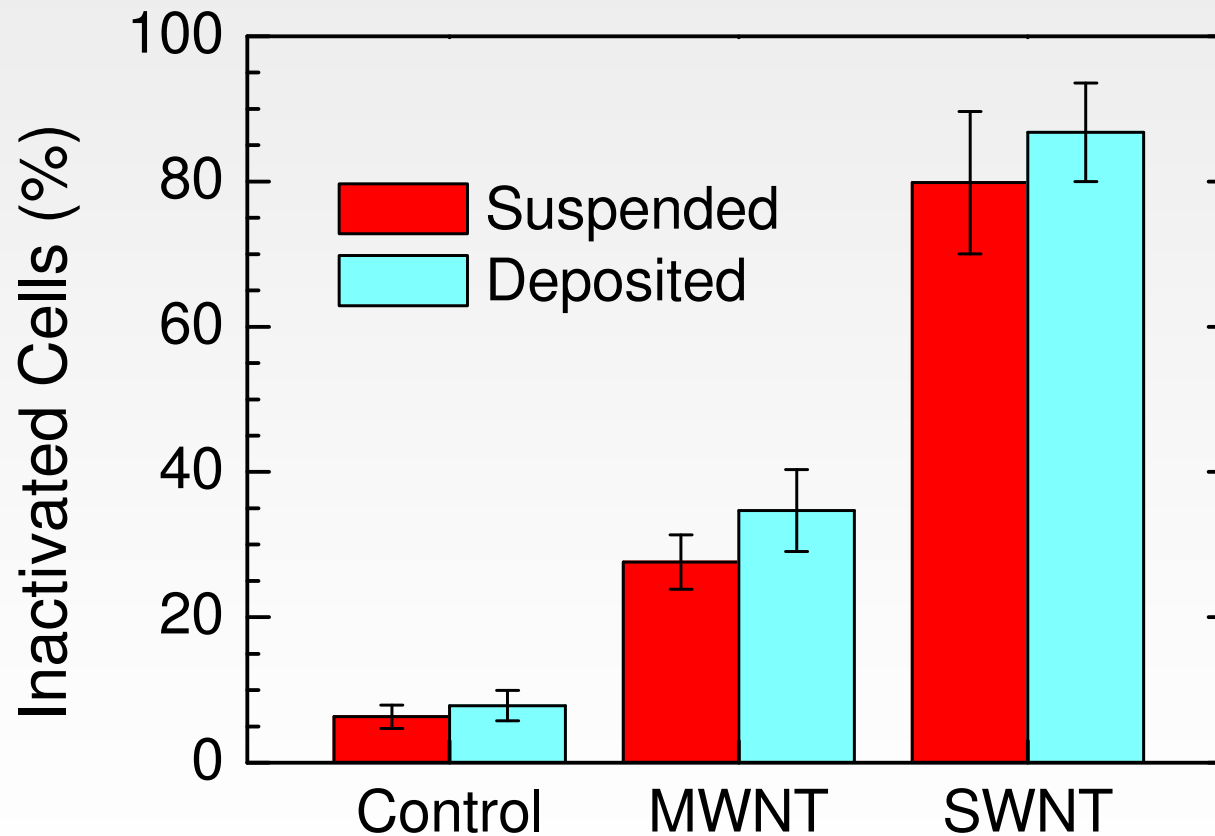
Free swimming cells



UNIVERSITY OF  
ALBERTA

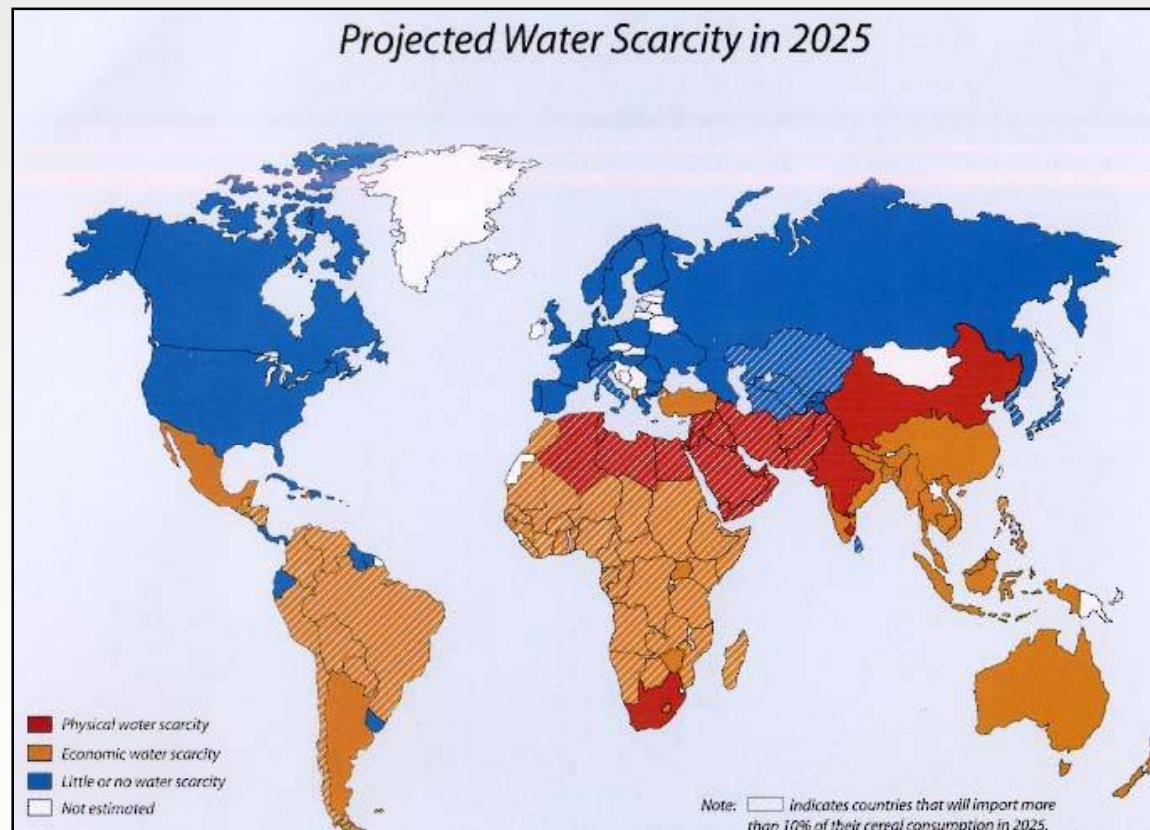


# Antimicrobial property of CNTs



Kang et al., *Langmuir*, 2007

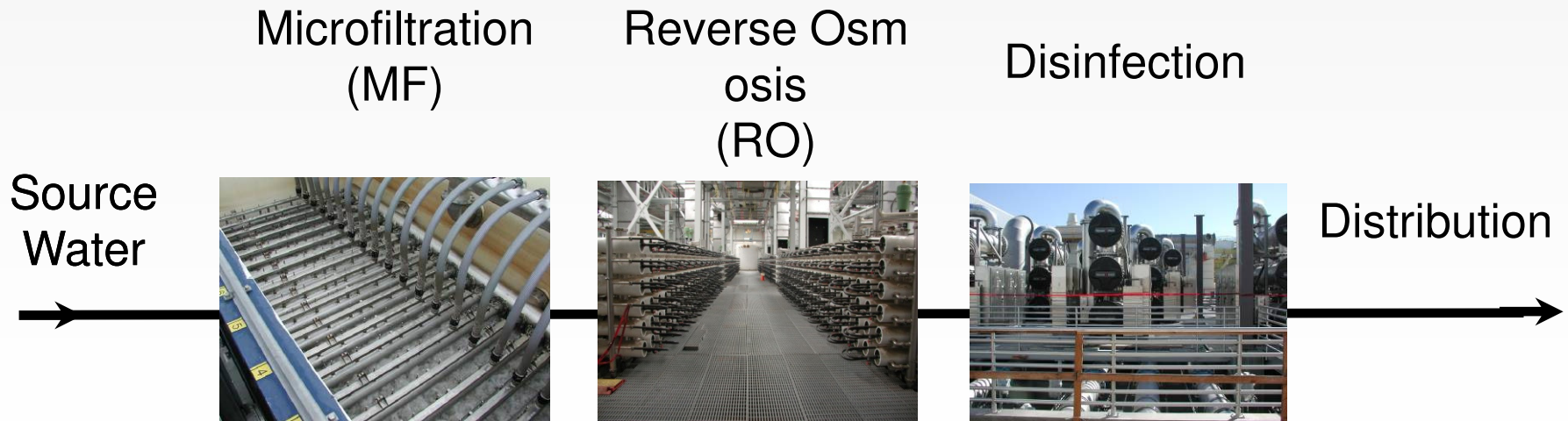
# Environmental Application of CNTs: Global Water Challenges



- ▶ 1.1 Billion people lack access to improved water globally.
- ▶ 1.6 million children under age 5 die annually from waterborne illnesses.  
(WHO & Unicef, 2006)

# How do we increase the amount of water in developing countries?

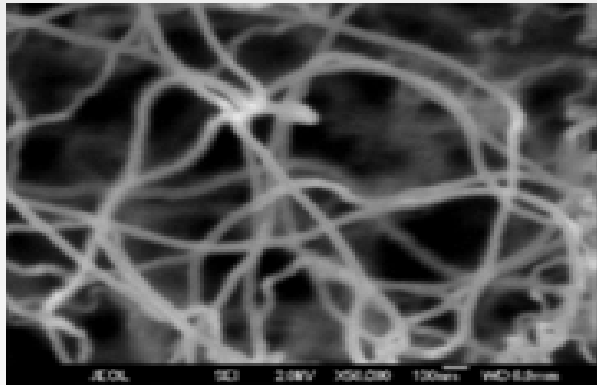
- Build water and wastewater treatment plant to increase drinking water supplies
- Afford simple, on site technology to remove emerging **contaminants** from all types of water sources



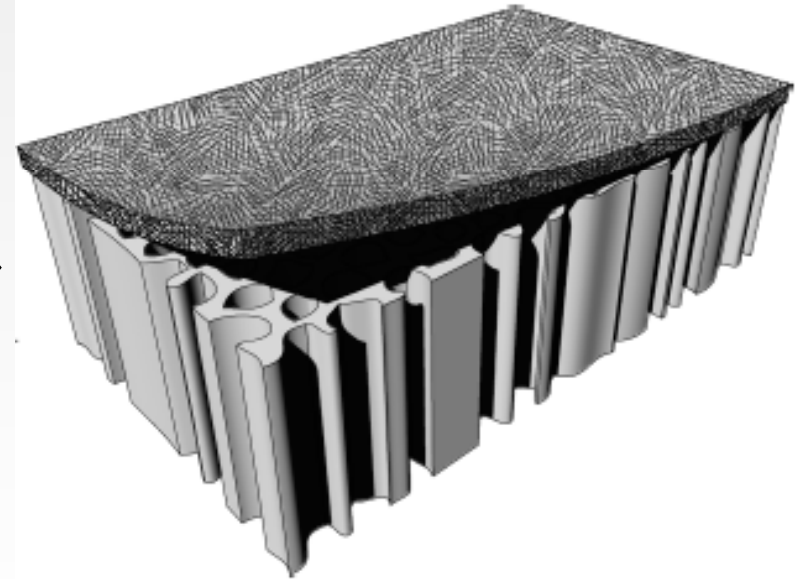
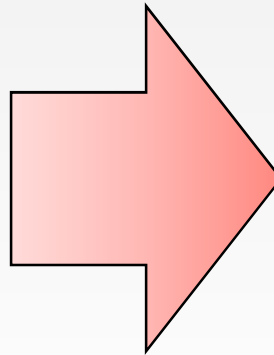
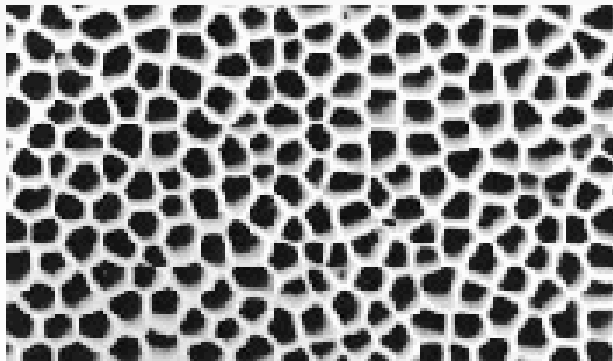
# Point-of-Use Treatment Needs List

- ▶ Low-cost of materials and production
- ▶ Low energy or gravity-driven operation
- ▶ Removal of bacteria
- ▶ Removal of viruses
- ▶ Portability
- ▶ Inhibition of biofilm formation
- ▶ Simple regeneration techniques for reuse

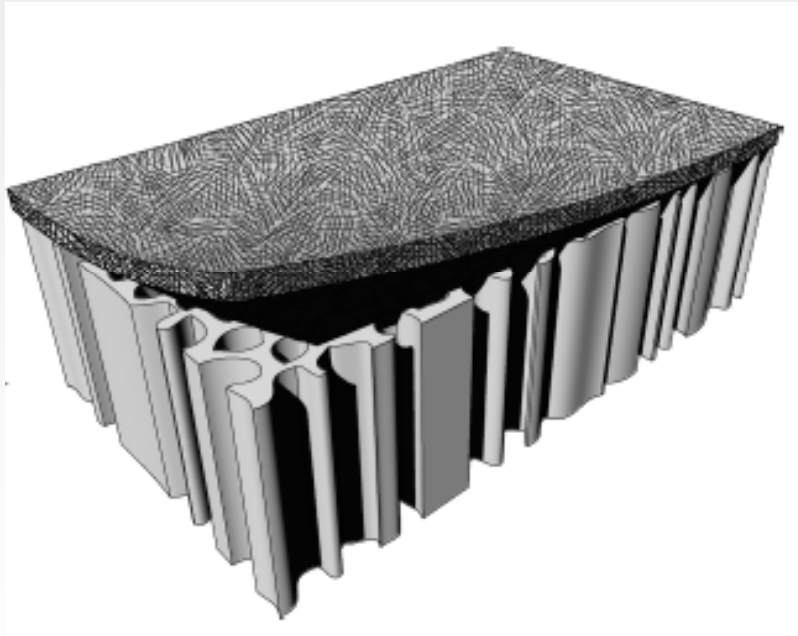
# Concept of CNT Hybrid Filter



+



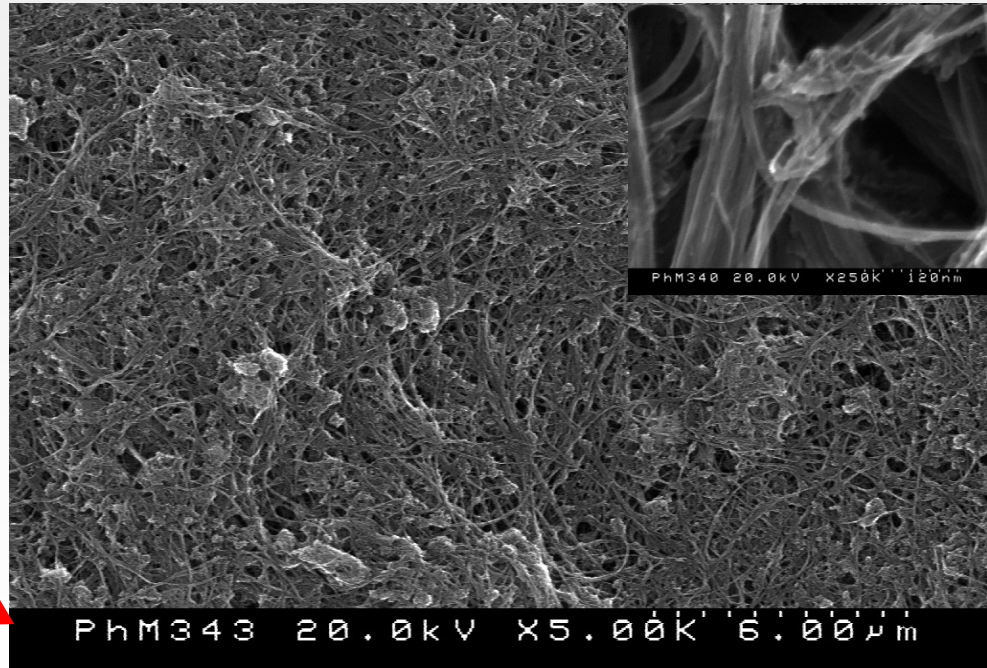
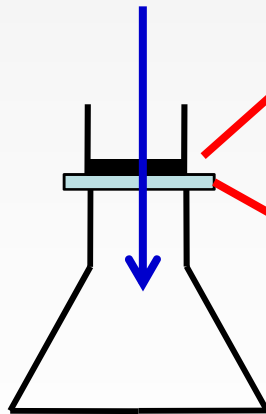
# Concept of CNT Hybrid Filter



- ▶ **Antimicrobial**
- ▶ **High permeability**
- ▶ **Very high surface area (adsorption, filtration)**
- ▶ **Can be regenerated at high temperatures/harsh conditions**
- ▶ **Compact and portable**

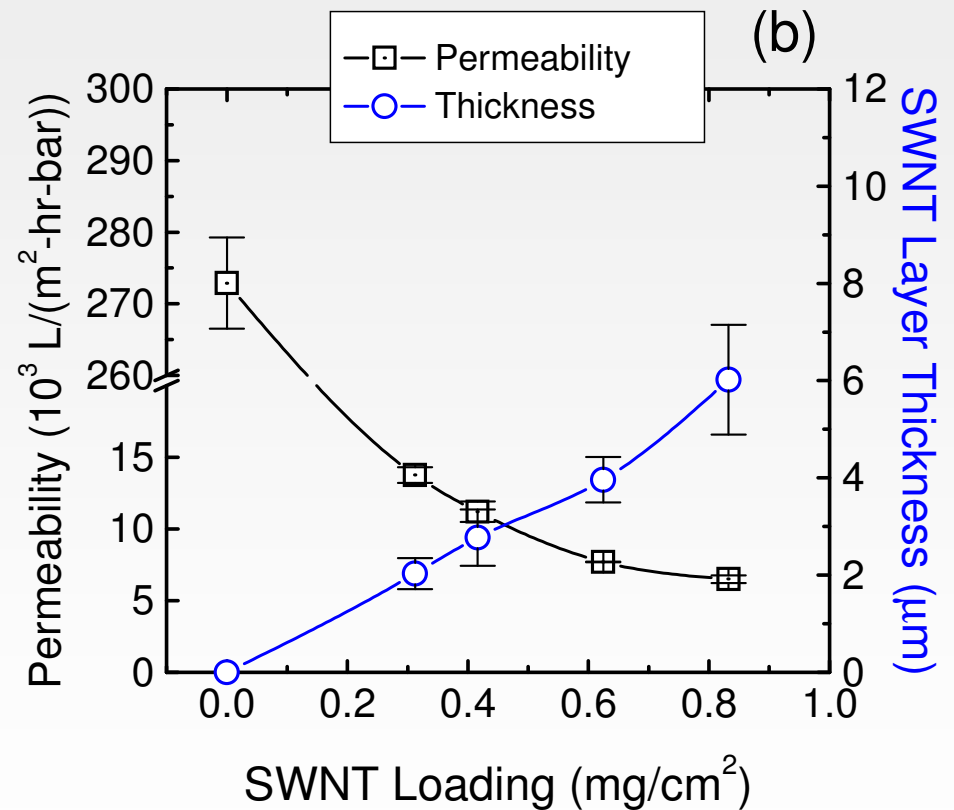
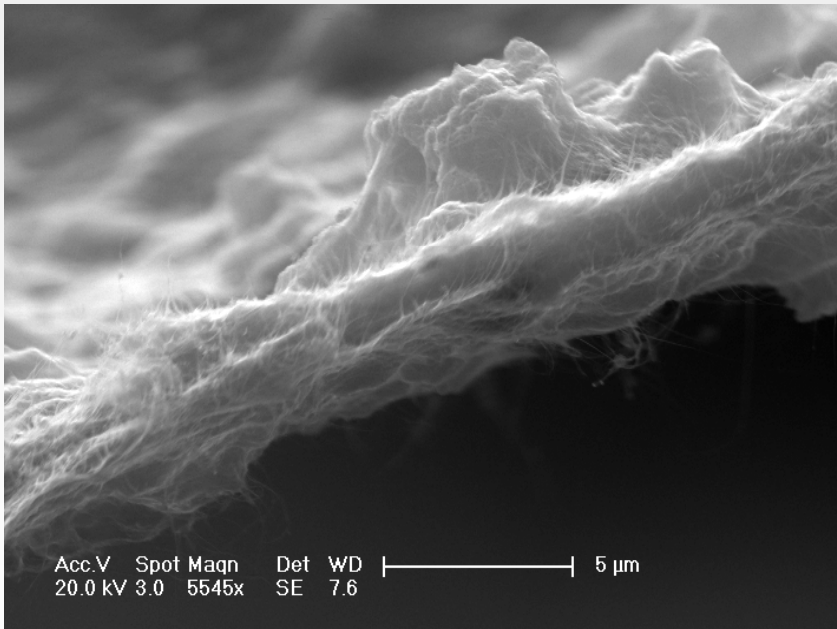
# Preparation of CNT Filter

Vacuum filtration of  
CNT dispersion  
in DMSO

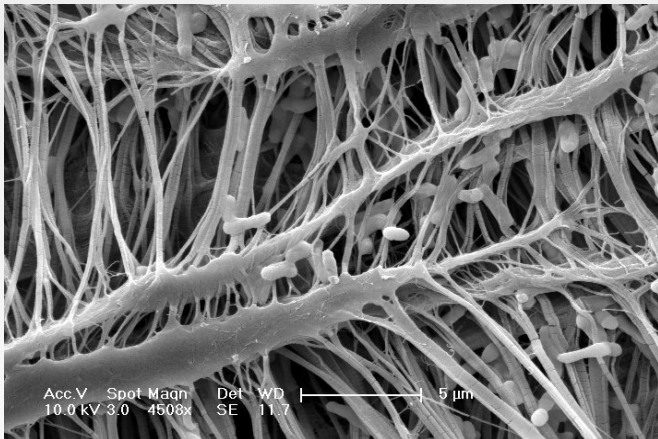




# Low Pressure Operation

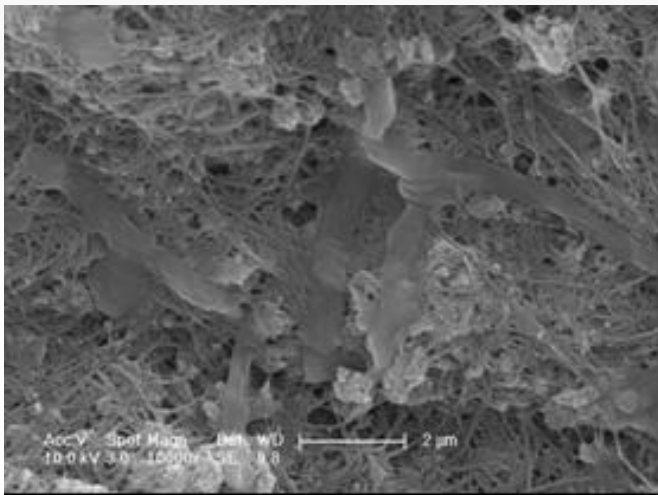


# Complete Retention and High Inactivation of Bacteria



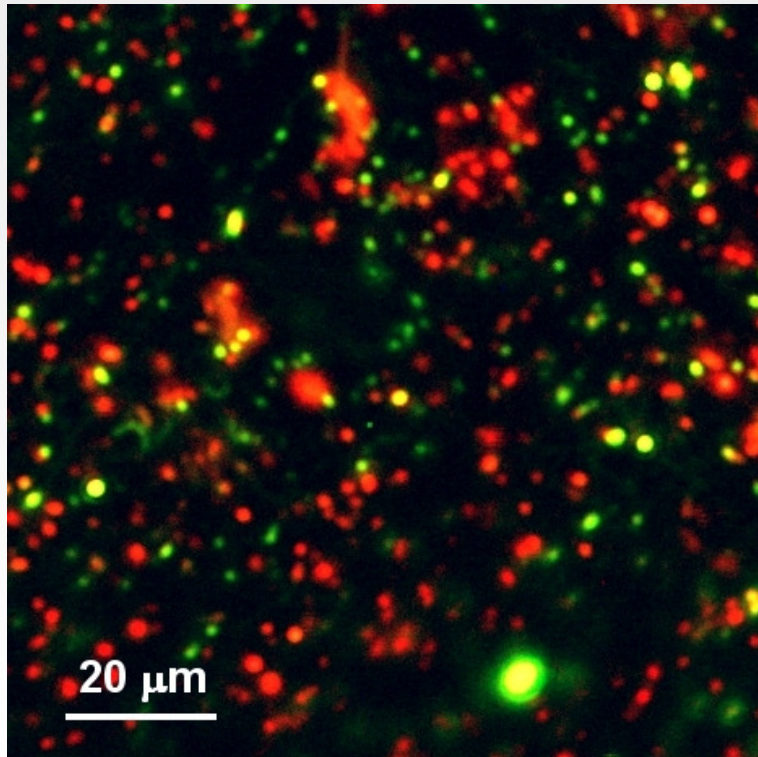
Base filter  
(PVDF)

- *E. coli* K12
- $N_0 \approx 5 \times 10^5$  cells
- pH 5.7
- 0.9 % NaCl
- 22 °C
- Flow rate, 125 LMH

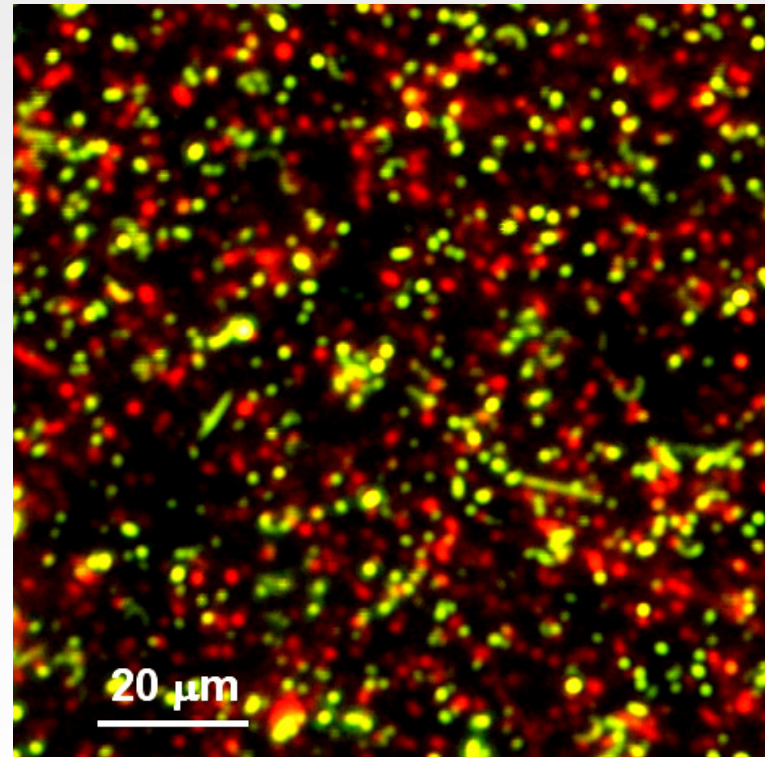


Hybrid  
(SWNT layer)

# Impacts on Microorganisms from Natural and Engineered Aquatic Systems

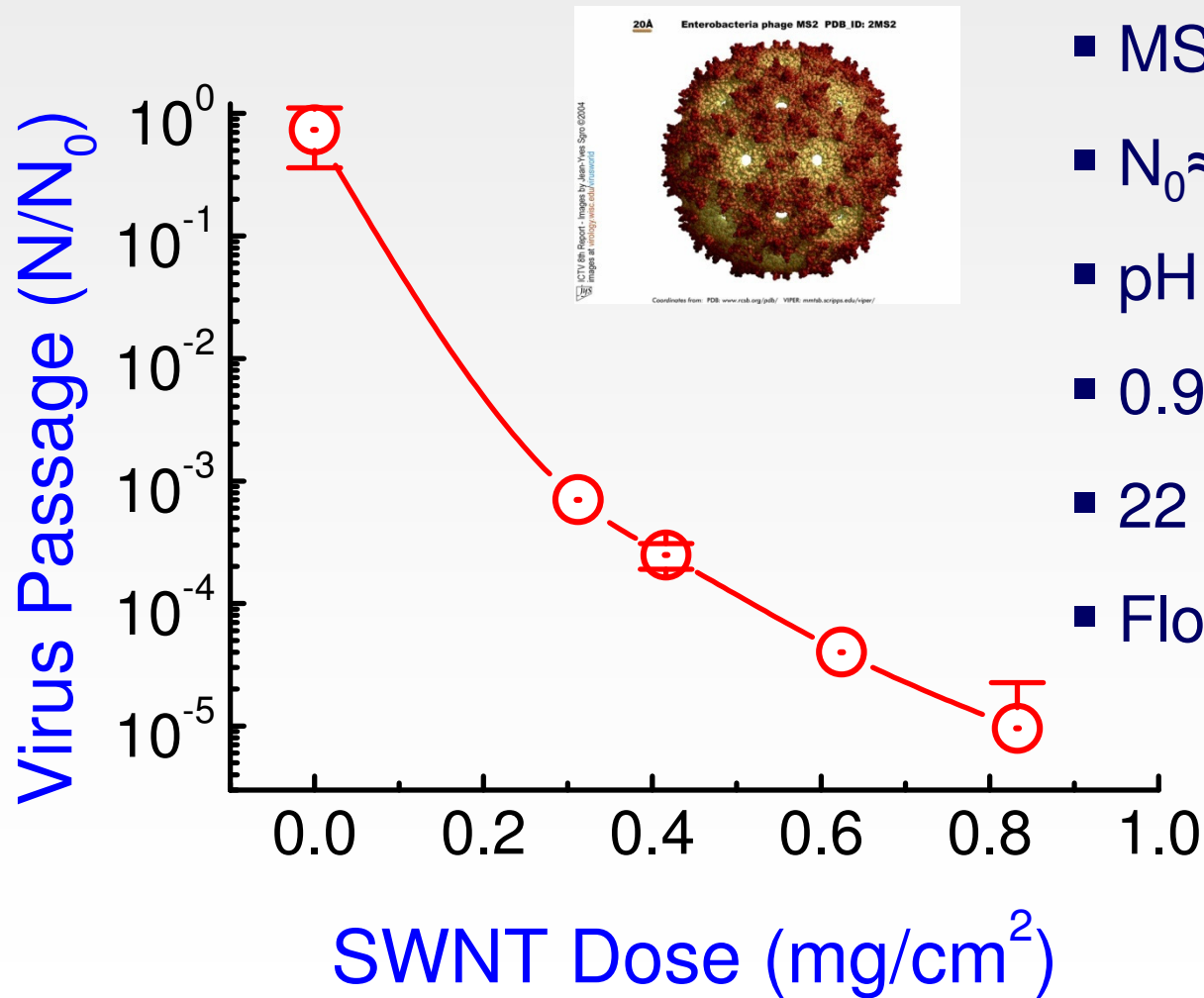


**River Water**



**WWTP Effluent (1/5X)**

# CNT Filter for Viral Removal

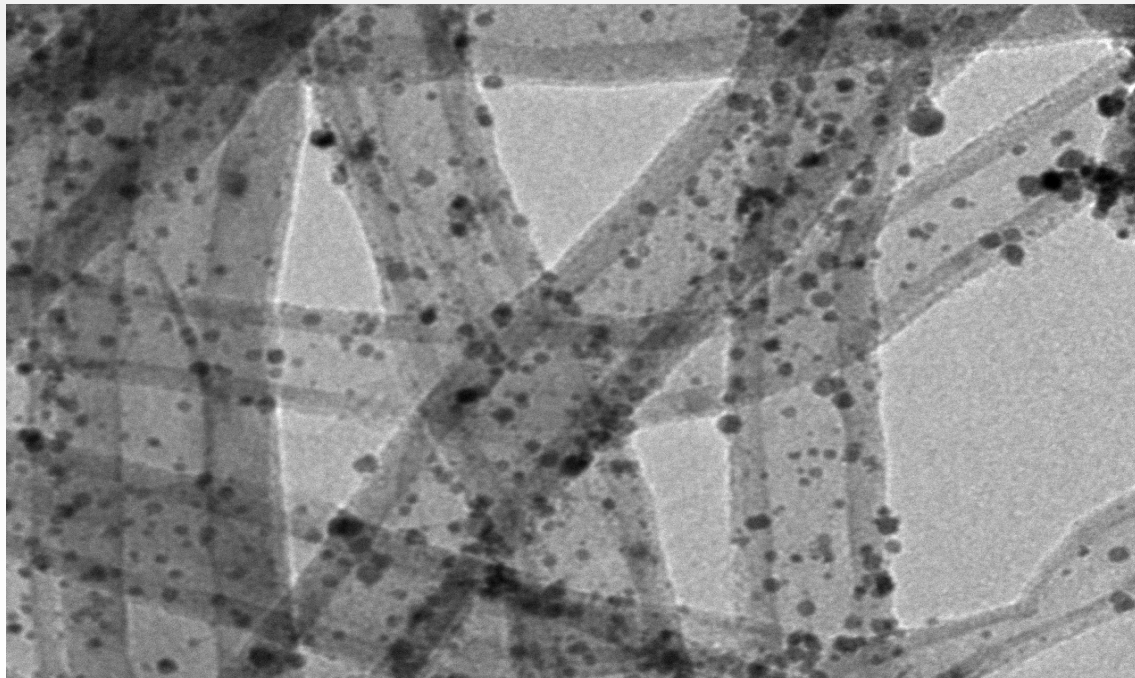


- MS2 virus: ~ 30 nm
- $N_0 \approx 1.5 \times 10^6$  virus/mL
- pH 5.7
- 0.9 % NaCl
- 22 °C
- Flow rate, 125 LMH



# Novel Application for Wastewater Treatment Contaminated by Organic Matters

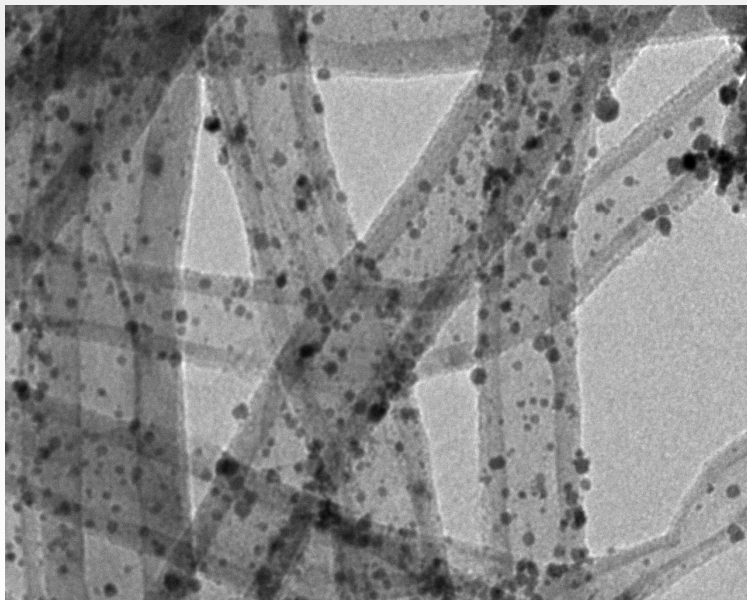
## Hybrid Filter with novel nanoparticles



6.jpg  
Print Mag: 112000x @ 51 mm  
13:08 05/23/06

20 nm  
HV=300kV  
Direct Mag: 50000x

# 'Catch-and-Shoot' of Organic Contaminants by CNT Filter



6.jpg  
Print Mag: 112000x @ 51 mm  
13:08 05/23/06

20 nm  
HV=300kV  
Direct Mag: 50000x

- ▶ High permeability with thousands of layers
- ▶ Very high surface area (adsorption, filtration)
- ▶ Physically and chemically stable
- ▶ Elevated chemical reaction rate
- ▶ Can be combined with A.O. process

# Conclusion

- ▶ Novel CNT filter achieves **complete retention of *E. coli***, and more than 80 % inactivation.



# Conclusion

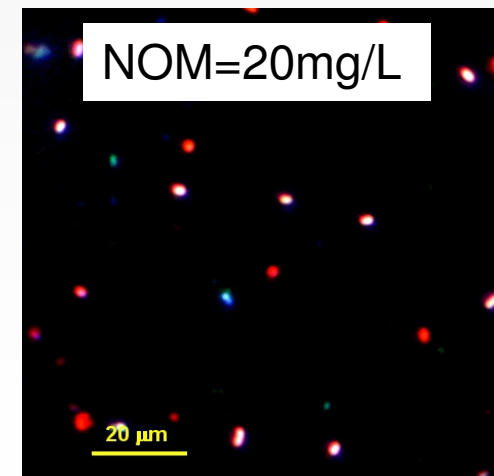
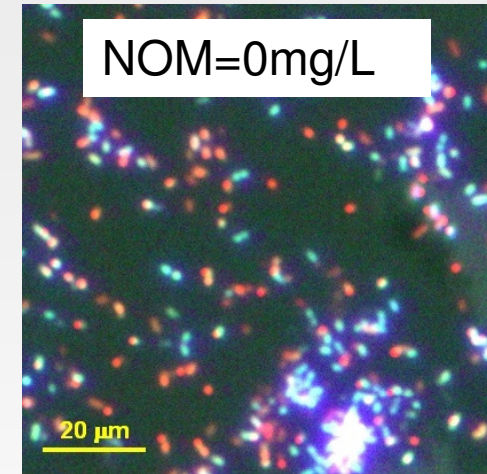
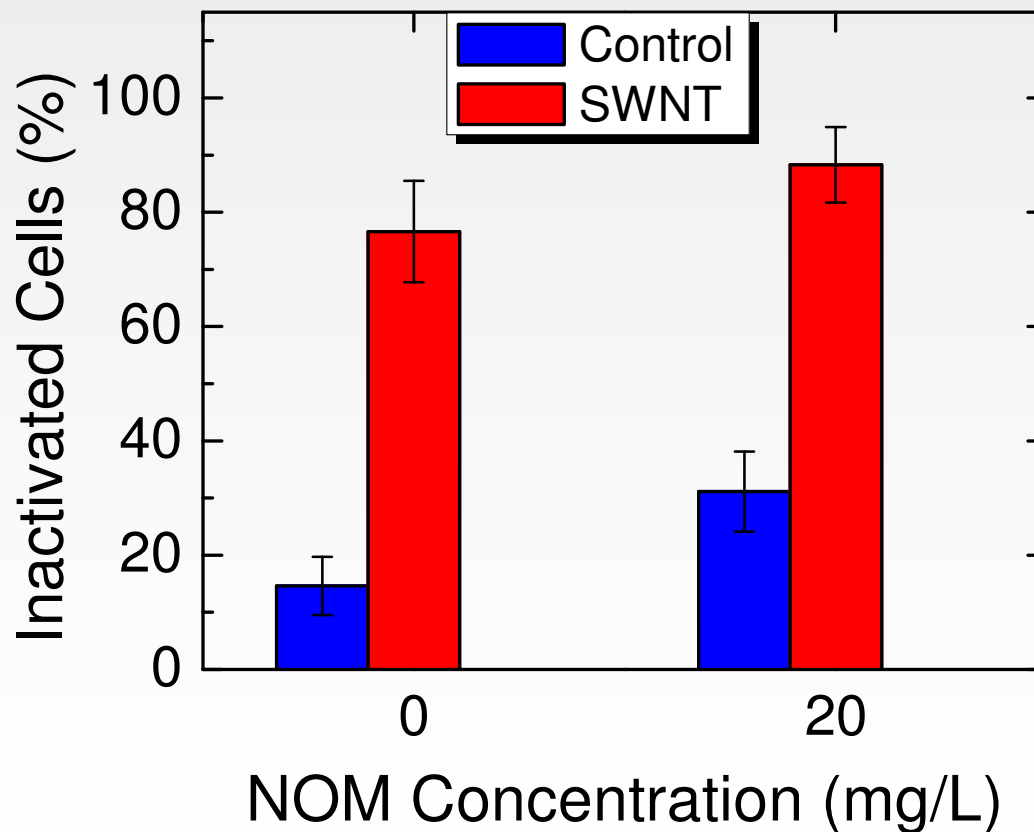
- ▶ Novel CNT filter achieves complete retention of *E. coli*, and more than 80 % inactivation.
- ▶ Novel CNT filter is capable of **high viral removal** at gravity-driven pressures.

# Conclusion

- ▶ Novel CNT filter achieves complete retention of *E. coli*, and more than 80 % inactivation.
- ▶ Novel CNT filter is capable of high viral removal at gravity-driven pressures.
- ▶ Novel CNT filter has potentials to **catch and shoot** of organic contaminants

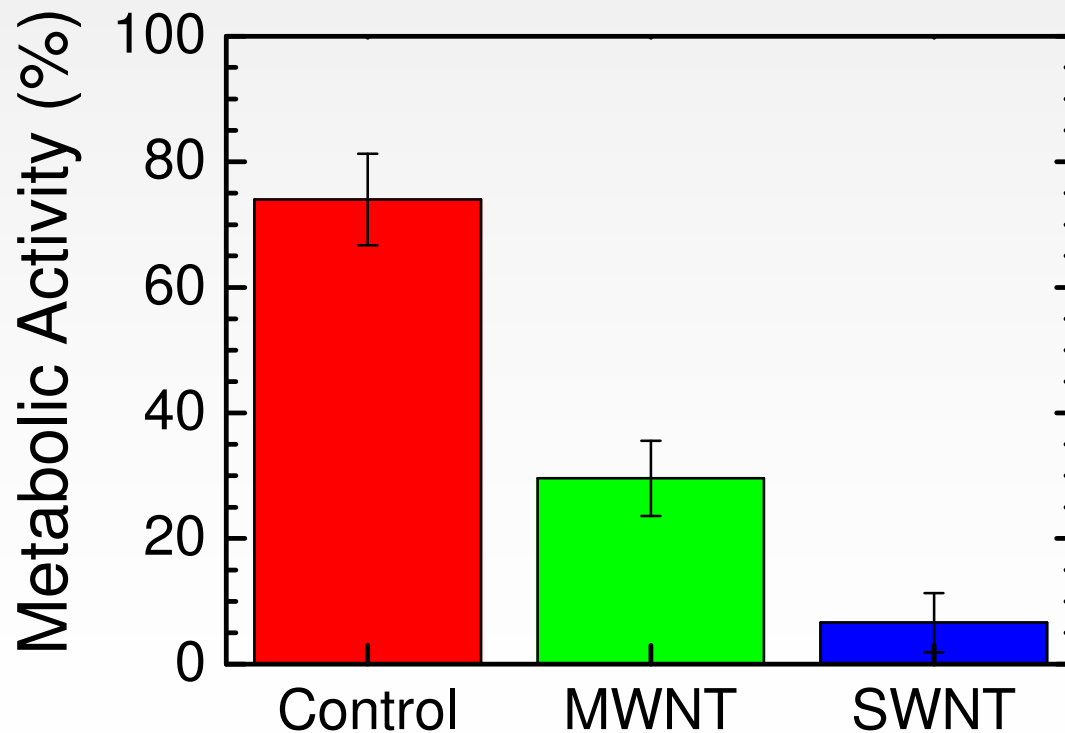
# Thank you !

# Impact of Natural Organic Matters



# Cytotoxicity of CNTs

## ▶ Metabolic activity measured by CTC



*E. coli* cells

0.9% (154 mM) NaCl solution

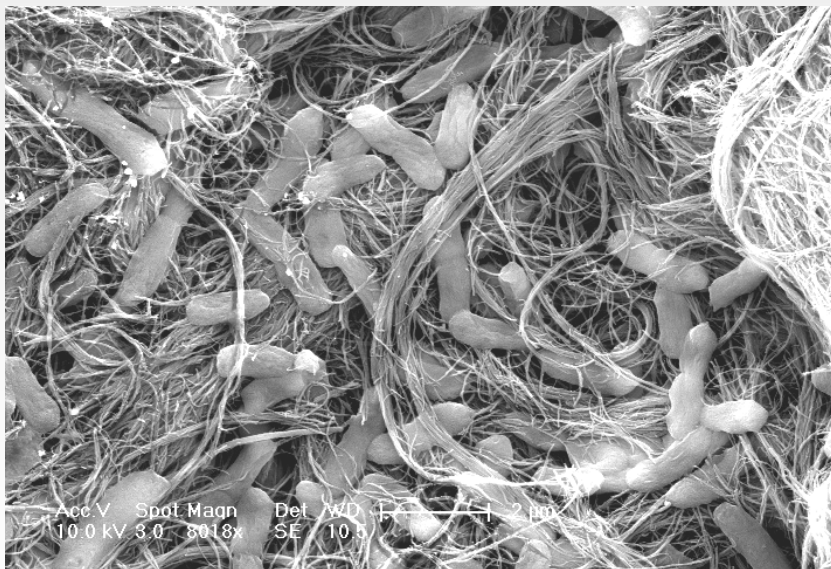
pH=5.6±0.3

Incubated at 37°C

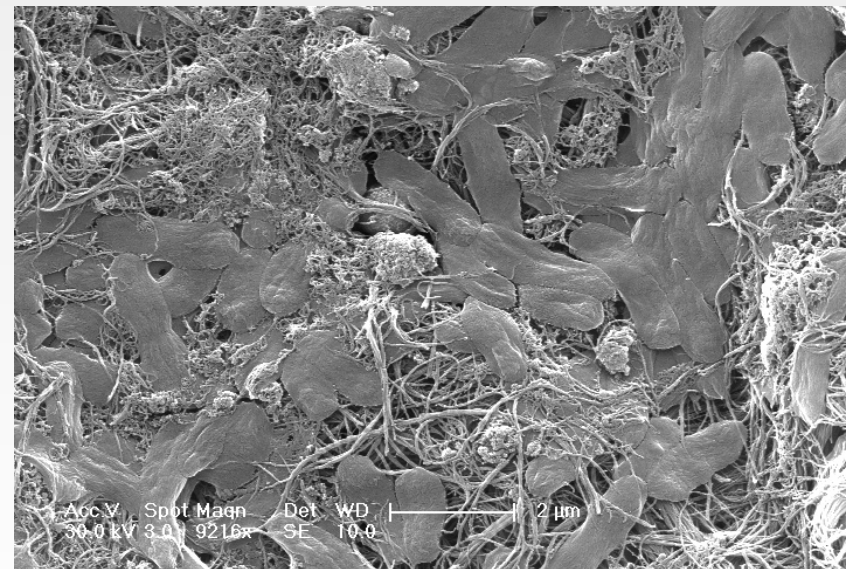
Kang *et al.*, *Langmuir*, 2008

# Cytotoxicity of CNTs

► Morphological changes: SEM images of *E. coli*



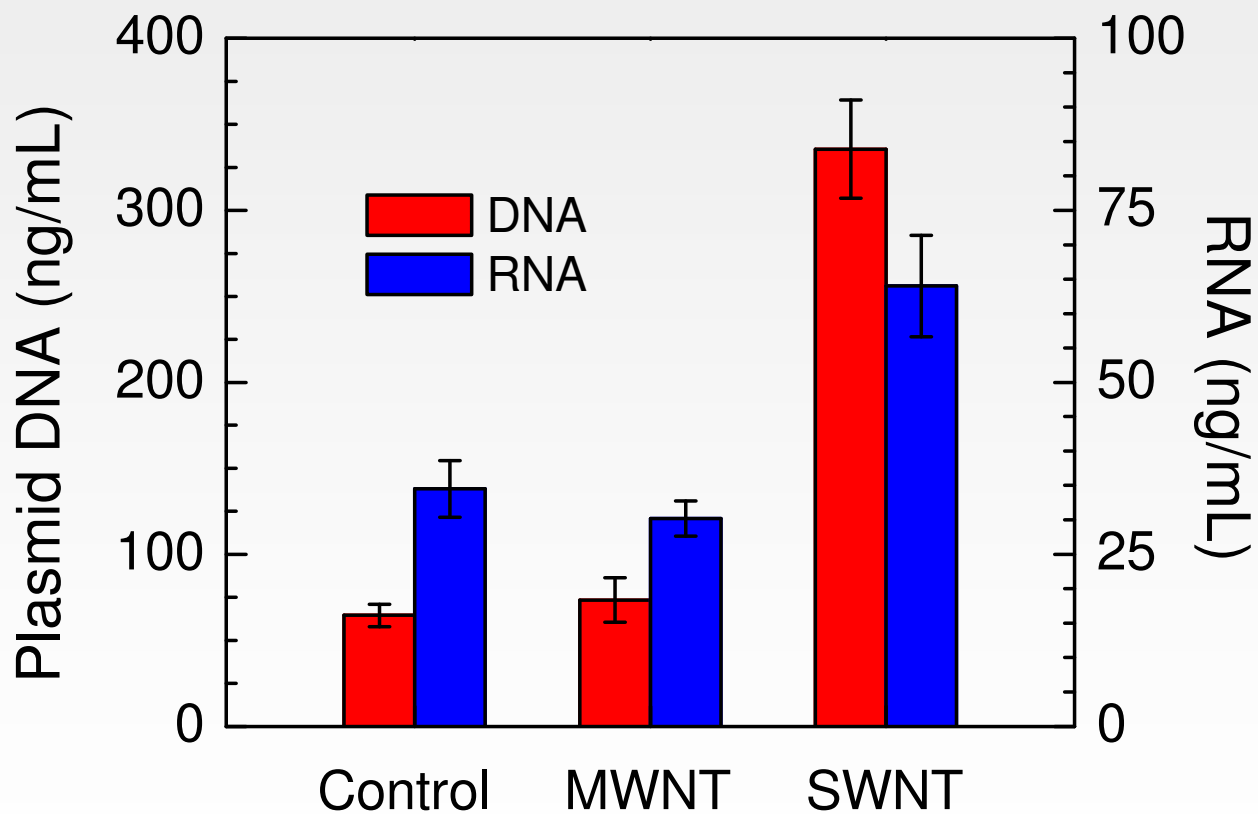
**MWNT**



**SWNT**

Kang *et al.*, *Langmuir*, 2008

# Leakage of Intracellular Materials



Kang *et al.*, Langmuir, 2008