



Nanotubes : le futur des biomatériaux



13, 14 et 15 octobre 2009



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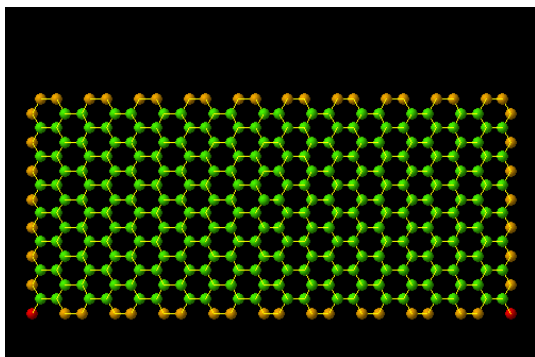
Content

- *Introduction: carbon nanotubes (CNT) and their potential in nanomedicine*
- *Functionalization of carbon nanotubes (f-CNT): a route towards biocompatibility*
- *Capacity of f-CNT to penetrate into the cells*
- *An example of delivery of therapeutic agents by f-CNT*
- *Conclusion and perspectives*

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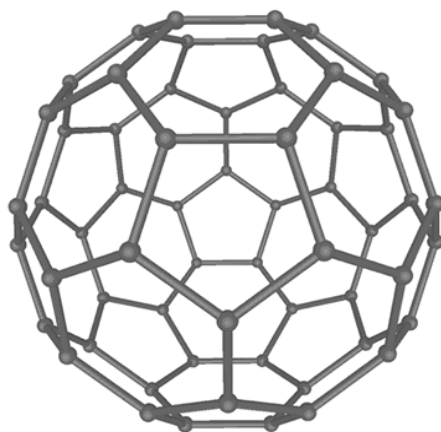
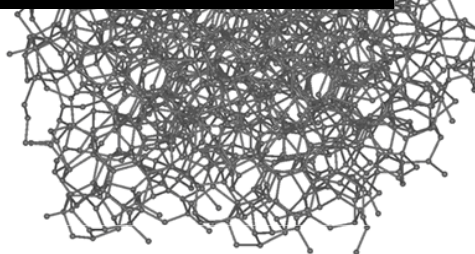
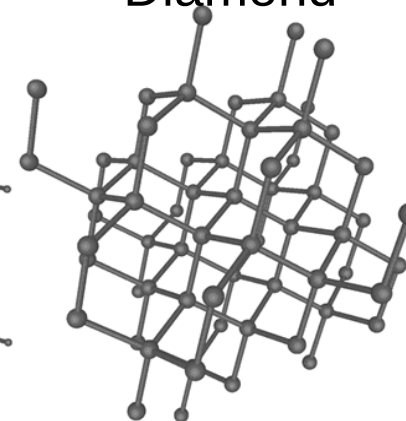
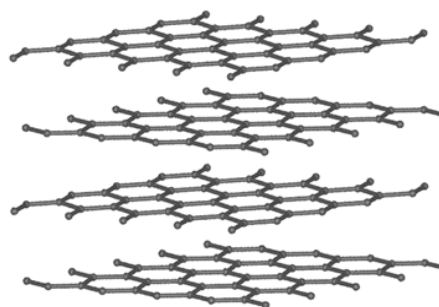
The Allotropic Forms of Carbon



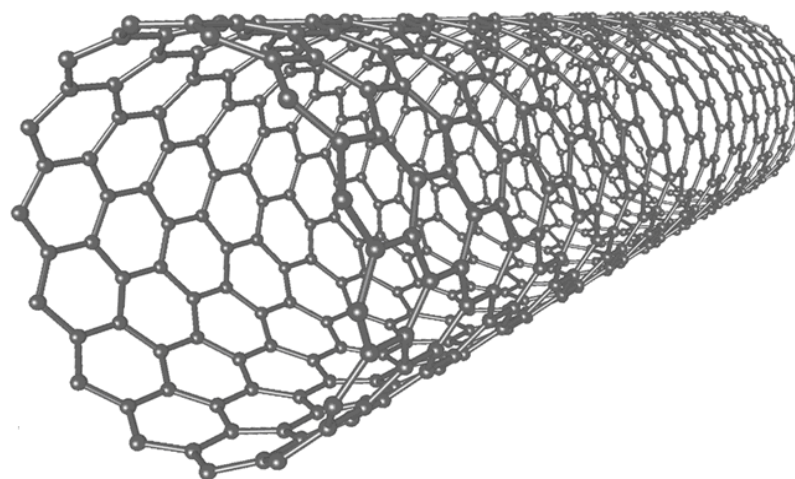
on

Graphite

Diamond



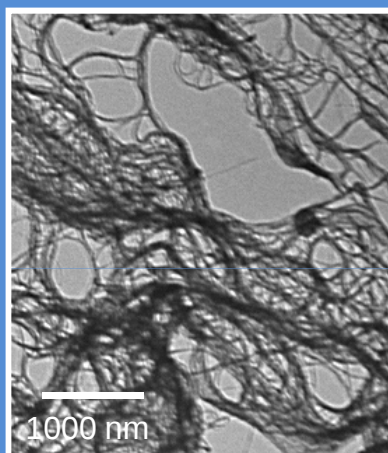
Fullerene



Carbon nanotube

Different Types of Carbon Nanotubes

- ▶ Single-walled carbon nanotube (SWNT) presents only one graphene layer
- ▶ Multi-walled carbon nanotube (MWNT) presents several graphitic concentric layers

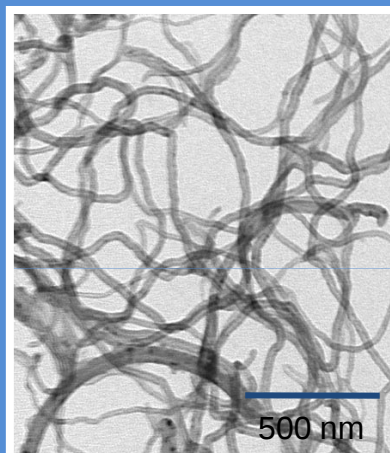


SWNT

$\varnothing = 0.4 - 2 \text{ nm}$
 $L = 20 - 1000 \text{ nm}$

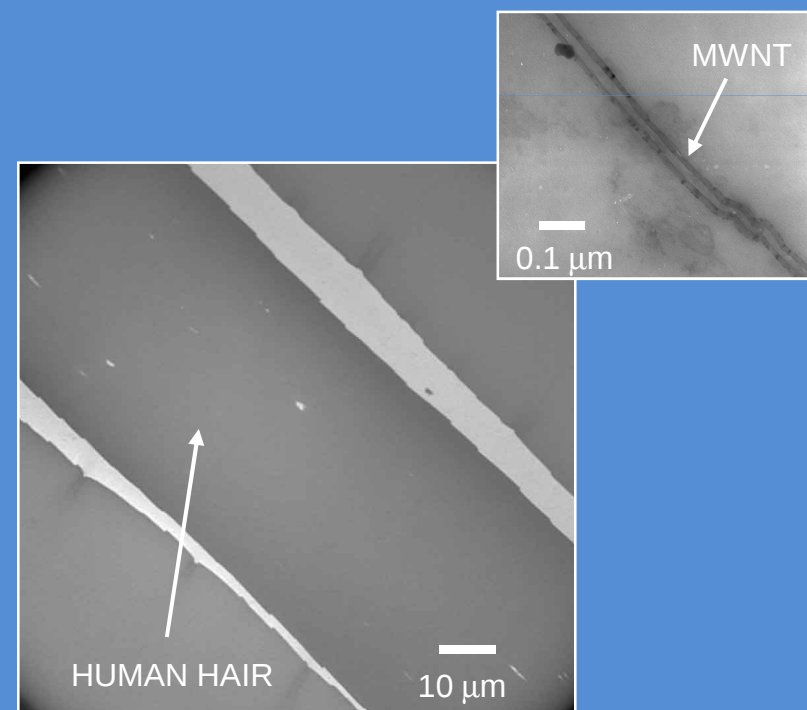
Bundles

$\varnothing = 10 - 50 \text{ nm}$
 $L = \text{several } \mu\text{m}$



MWNT

$\varnothing = 1.4 - 100 \text{ nm}$
 $L = 1 \mu\text{m} - \text{cm}$





Characteristics of Carbon Nanotubes

(from cars to medicine, nanotubes may be miracle material)

ELECTRICAL CONDUCTIVITY

Ballistic transport means that electrons in nanotubes travel much faster than in metals, and they don't dissipate. This conductivity could be useful in making electric paint, absorbing static, storing energy or replacing chips' silicon circuits.

STRENGTH

Six times lighter than steel but more than 500 times stronger.

FLEXIBILITY

Nanotubes can be bent 120 degrees and snap back. Potential failure is therefore reduced.

SELF-ASSEMBLY

Unlike silicon circuits, which need to be "drawn," nanotubes form on their own in the presence of a catalyst.

THERMAL CONDUCTIVITY

The best material ever discovered for moving heat from one place to another, nanotubes are potentially handy for cooling confined spaces like PCs.

LUMINESCENCE

Because they emit light, nanotubes could be used in optical fiber.

SELF-RECOVERY

Strong covalent bonds mean that if an atom goes missing, the remaining carbon atoms will fill the gap.

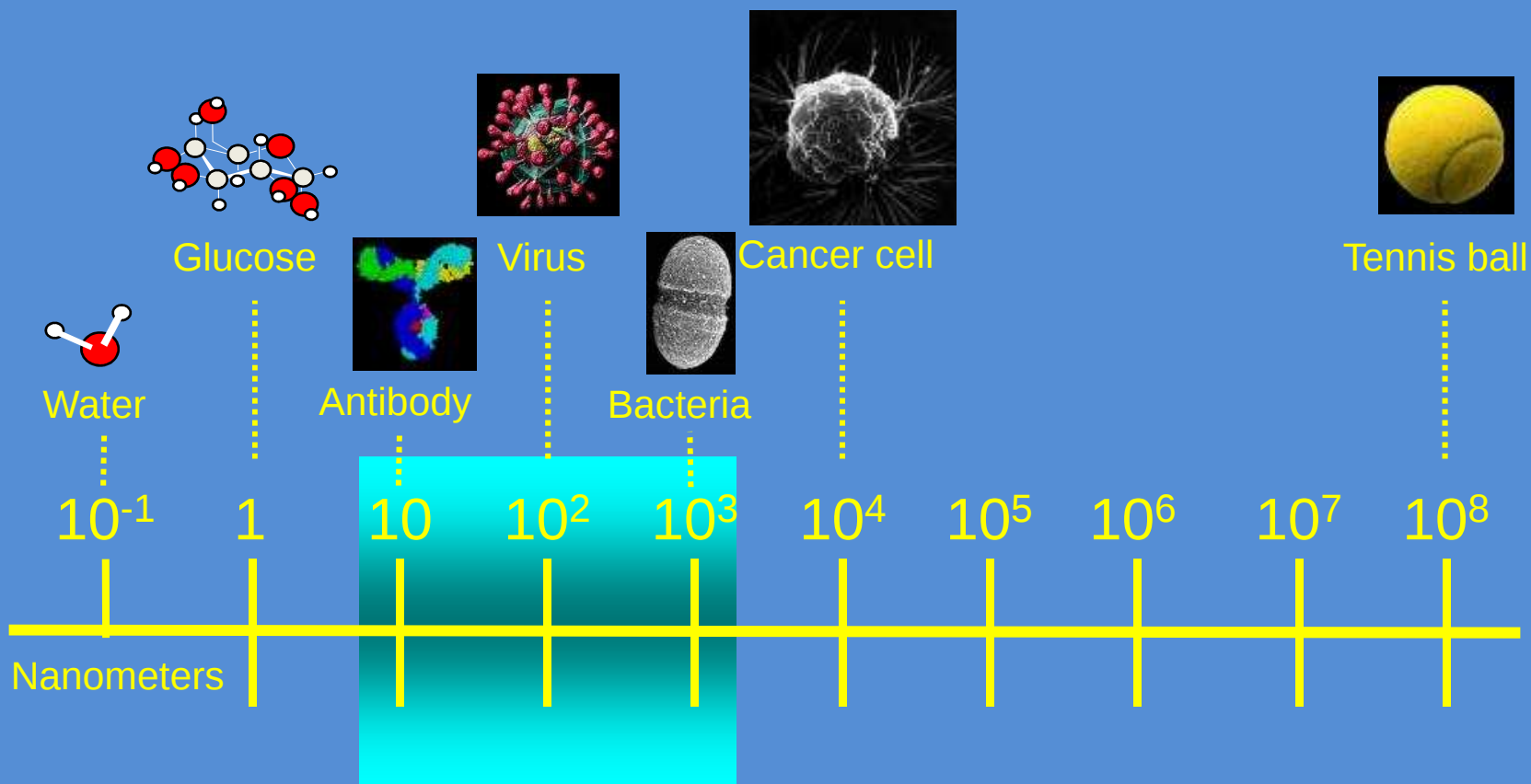
TEAM PLAYER

Almost chemically inert, nanotubes won't prompt reactions in other materials. That quality is potentially useful in atomic microscopes or for drug delivery.



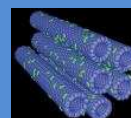
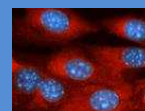
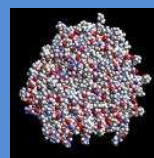
The Right Size of Nano-objects

Nanoscale devices are of the same scale of biologically important molecules



Nanodevices:

- Nanoparticles
- Dendrimers
- Quantum Dots
- Carbon nanotubes



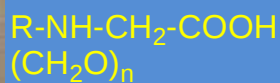
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Functionalization of Carbon Nanotubes via Cycloaddition



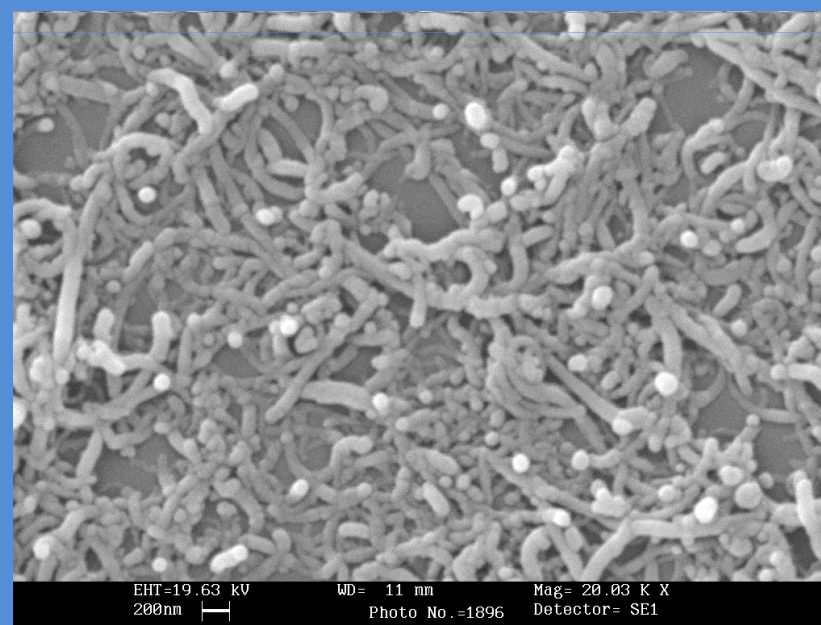
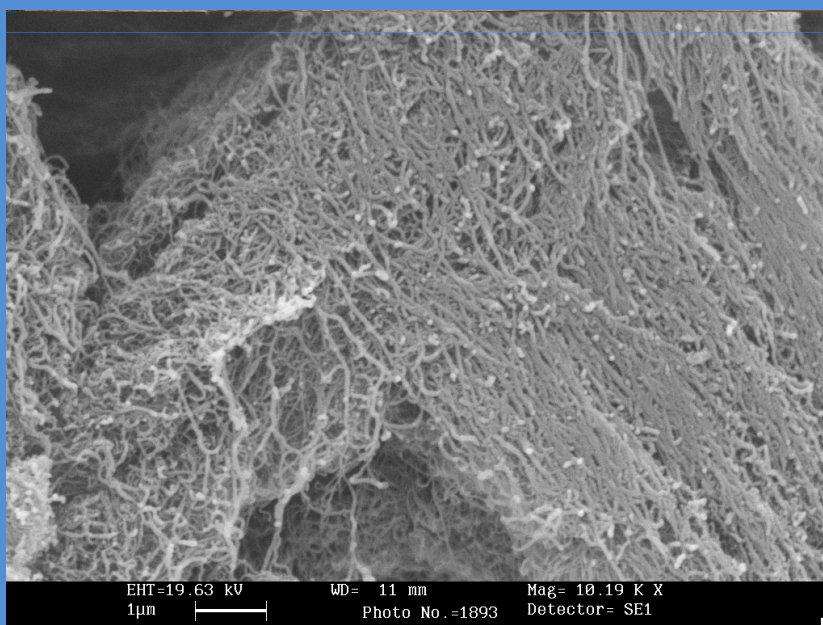
SWNT-NH₃⁺



130°C

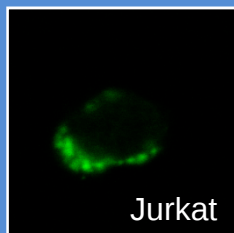
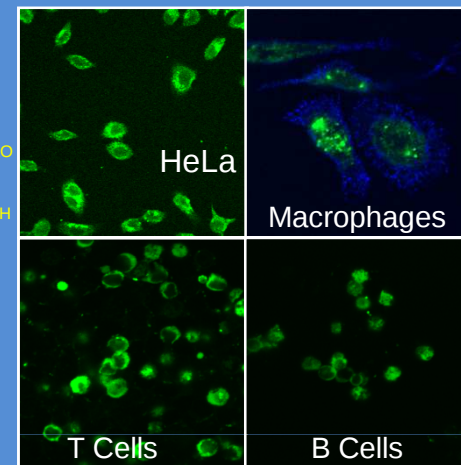
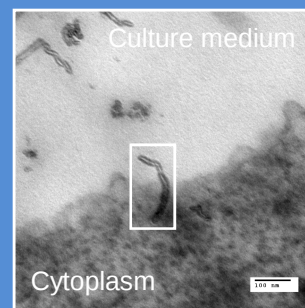
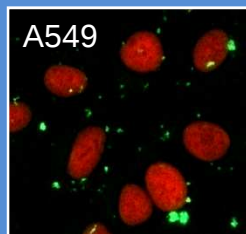


H₃⁺



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Can Functionalized Carbon Nanotubes Penetrate the Cells?

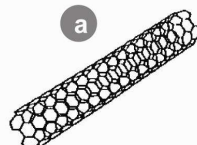


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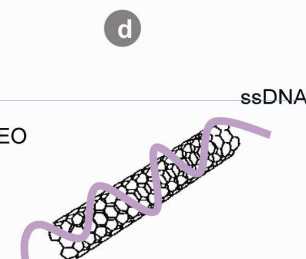
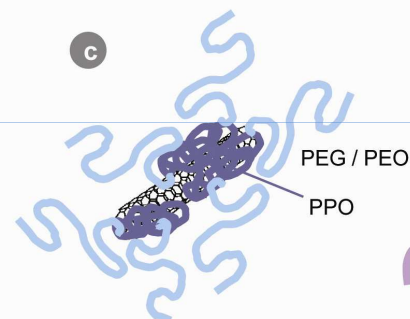
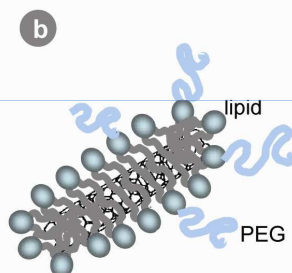
Carbon Nanotubes in Medicine

Only a few types of CNTs used in medical applications

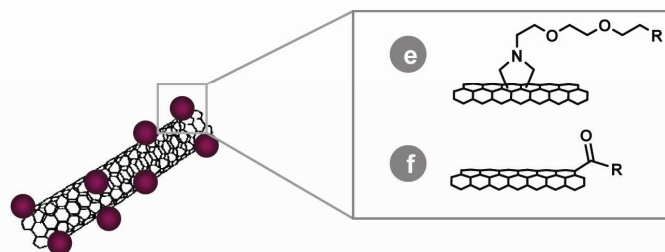
Pristine CNT



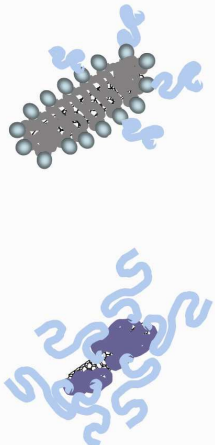
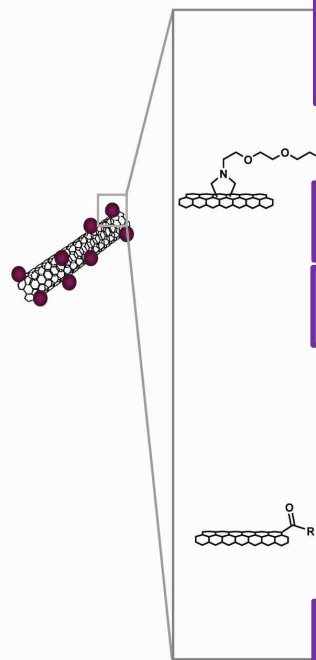
Coated CNT (non-covalent surface modification)



Functionalized CNT (covalent surface modification)



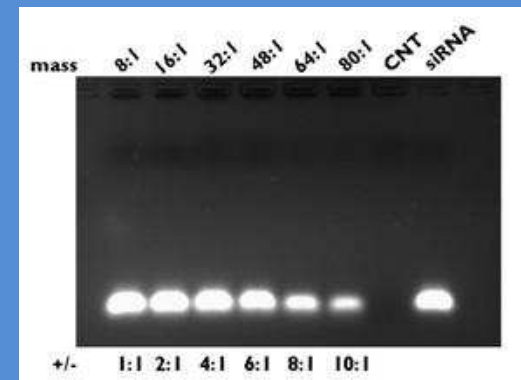
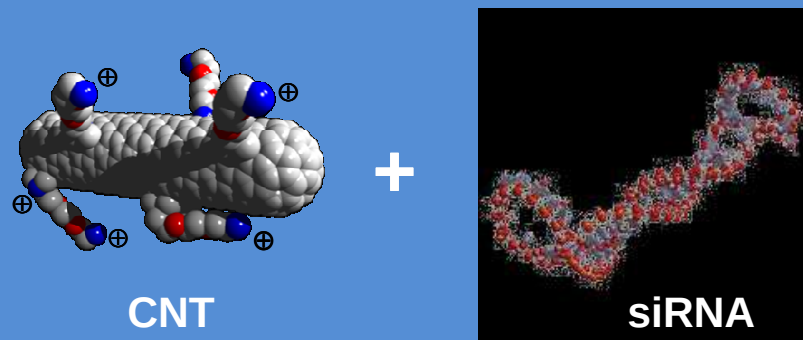
Carbon Nanotubes in Medicine

Type of Carbon Nanotube	Biomedical Application	Therapeutic/Imaging Agent	Preclinical Model
	Cancer imaging (systemic)	Radionuclide (Cu-64)	solid tumor model
	Cancer treatment (systemic)	Paclitaxel	solid tumor model
	Cancer imaging (systemic)	Intrinsic Raman & Ultrasound signal	solid tumor model
	Cancer Treatment (localised)	Hyperthermia by Radiofrequency Activation	solid tumor model
	Vaccination	FMDV-derived Peptides	normal mice
	Vaccination	(AMA-1) Peptide	rodent malaria
	Imaging (systemic)	Radionuclide (In-111 and Y-86)	normal mice
	Cancer treatment (systemic)	Monoclonal Antibody (Rituximab)	bone marrow tumor model
	Cancer treatment (localised)	Gene silencing (siRNA)	solid tumor model
	Imaging (systemic)	Radionuclide (I-121, C-14)	normal mice
	Cancer treatment (localised)	Gene silencing (siRNA)	solid tumor model
	Tumor Vaccination	Tumor-lysate Proteins	solid tumor model
	Cancer treatment (systemic)	Cisplatin	solid tumor model

Preclinical animal models only

- Oncology is the prime indication when CNTs are used in medicine
- Proof-of-principle systemic targeting of CNTs (both coated and functionalised) using peptides (RGD) and antibodies shown
- Only a single recent study reported therapeutic efficacy to prolong survival of tumor-bearing animals
- Disease models in immunology and neurology at the proof-of-principle

Carbon Nanotubes for Silencing-based Cancer Therapy

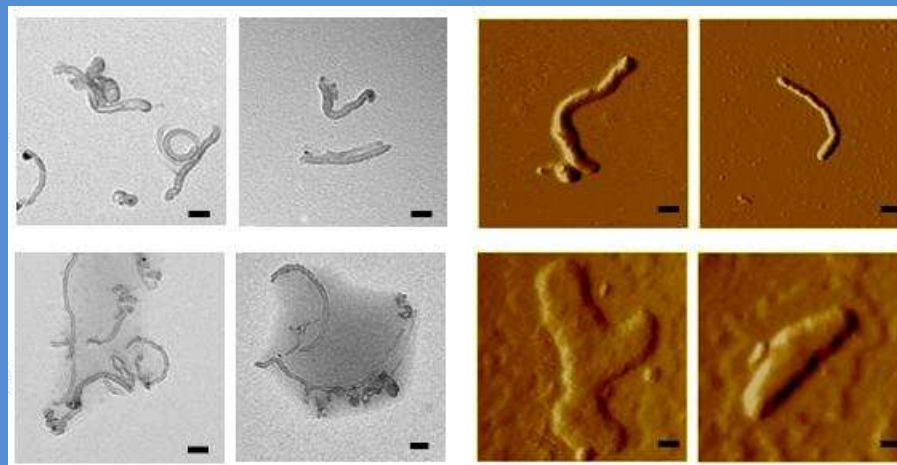


TEM

AFM

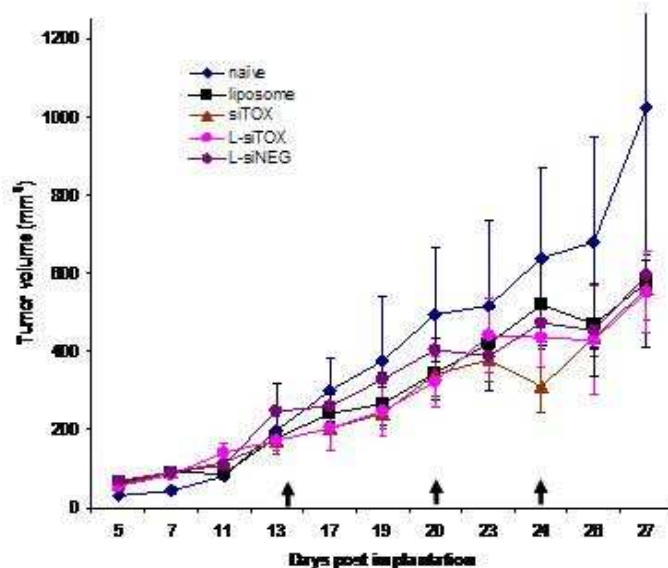
CNT

CNT:siRNA

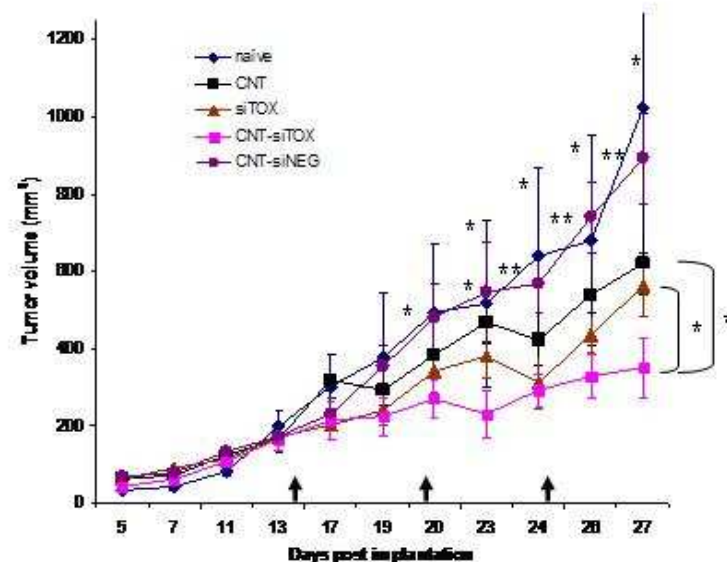


Tumor Growth and Survival after Intratumoral Administration of CNT:siRNA and Liposome:siRNA Complexes

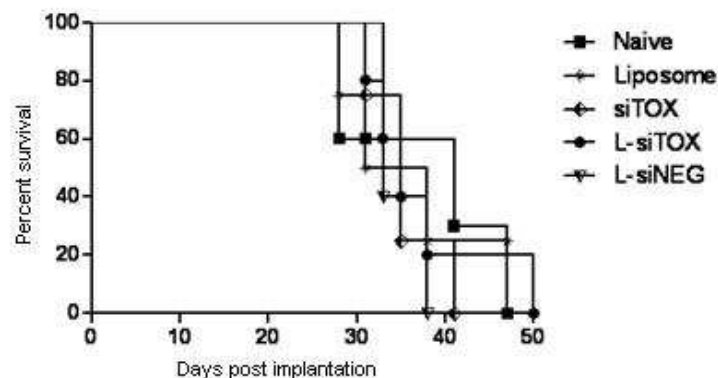
Liposome:siRNA treated groups



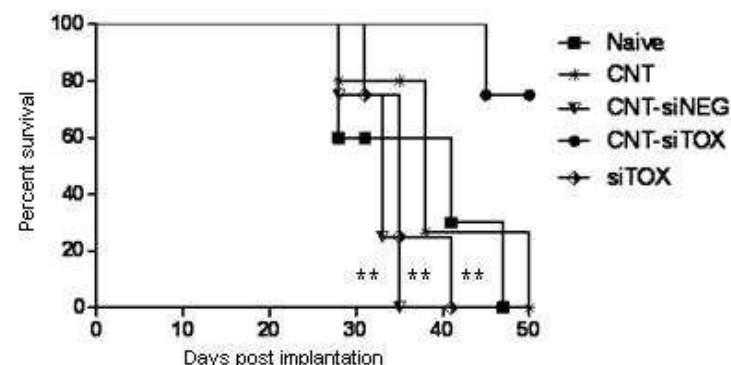
CNT:siRNA treated groups

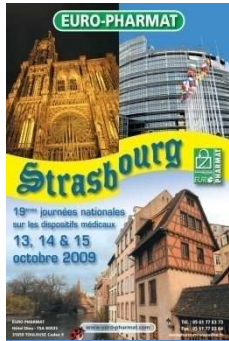


Liposome:siRNA treated groups



CNT:siRNA treated groups





Conclusion and Perspectives

Which are the expectations in the development of carbon nanotubes in the biomedical field?

- Innovative technology
- Alternative drug delivery system
- Advantages

Biocompatibility/Biofunctionality

Reduced toxicity

Lack of immunogenicity

Possibility to simultaneously exploit the uptake and the electric properties

- Impact of health and environment

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Thank You

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