UNIVERSITÀ DEGLI STUDI
DI PERUGIA

Dipartimento di Medicina Veterinaria
Corso di Laurea Magistrale in Scienze Biotecnologiche
Mediche Veterinarie e Forensi

NANOTECHNOLOGY: A NEW FRONTIER IN FOOD

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Outline

1. A current issue
2. We eat nanomaterials everyday..
3. Definition of nanotechnology and nanomaterials
4. Uses of nanotechnology in food industry
5. Most frequent nanomaterials in foods
6. The fate of food-related ENMs in the GIT
7. Toxicity and safety studies
8. Detection techniques to identify nanomaterials in food
9. Advantages/disadvantages
10. Future perspectives and conclusion

A current issue

Nanoparticelle negli alimenti e nel packaging: la tossicità è allo studio all`Istituto superiore di sanità

9 maggio 2012 Sicurezza Alimentare 1 Commento

Le nanoparticelle sono sempre più diffuse nel settore alimentare: soprattutto nel packaging, ma anche nei cibi. Grazie a nuovissimi processi tecnologici, la materia viene strutturata in dimensione nanometrica (nm), ossia un miliardesimo di metro e utilizzato su substrati (per rendersi conto basta dire che 1 nanometro è 40mila a 80mila volte più sottile di un capello). Ridurre materiali come argento, ossido di titano e altri a queste nanodimensioni conferisce loro proprietà, fluidificanti, stabilizzanti, antibatteriche che non si trovano nel metallo o nel composto quando è utilizzato a dimensioni standard.

Additivi e ingredienti in formato nano

servono a rendere le salse più fluide, il cioccolato più croccante e le preparazioni in polvere meno grumose oppure a prolungare la conservazione dei piatti pronti. Così, per esempio, la crosta del formaggio Brie diventa più candida con l'aggiunta di biossido di titanio (E171), un additivo usato fin dagli anni Sessanta, e che adesso è disponibile sotto forma di nanoparticelle; mentre il diossido di silicio (E551) nano rende fluido il ketchup.

In Europa triplica in numero di prodotti e di alimenti contenenti nanoparticelle

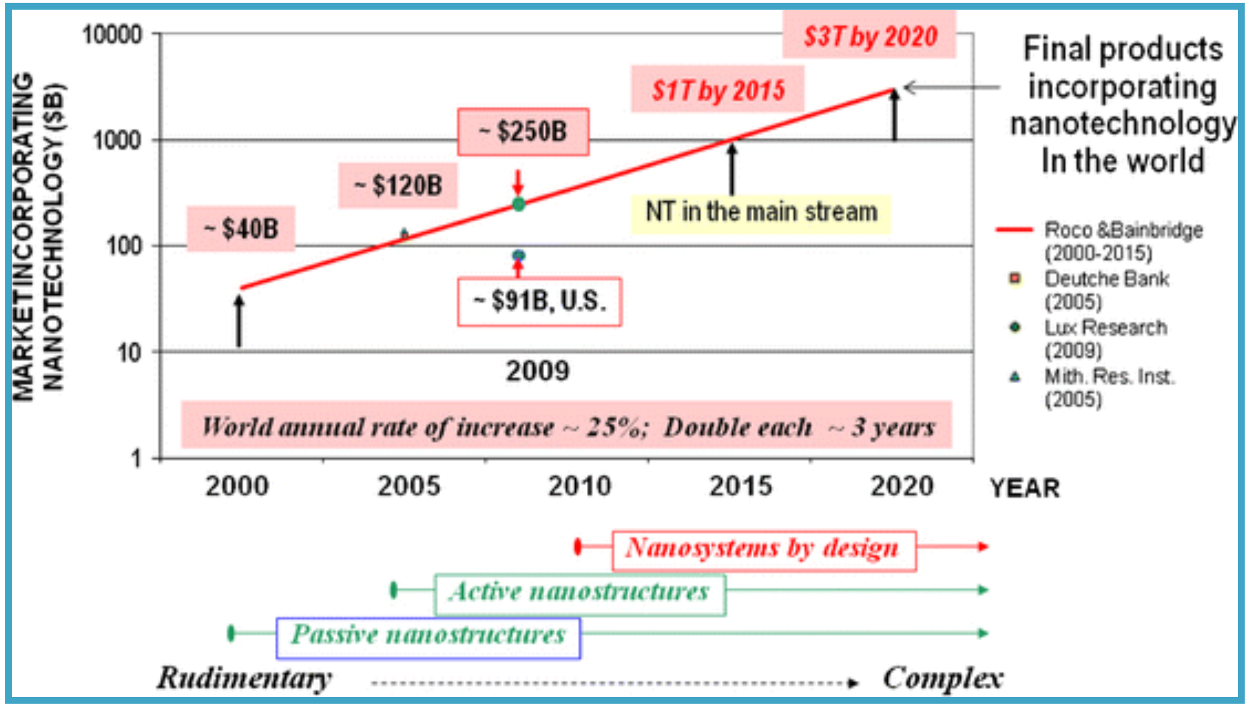
1 novembre 2010 Pianeta

Commenti disabilitati
su In Europa triplica in numero di prodotti e di alimenti contenenti nanoparticelle

In Europa aumenta a dismisura il numero di beni di consumo e di prodotti che contengono nanoparticelle (particelle infinitamente piccole con un ordine di grandezza pari a un milionesimo di millimetro). Secondo una rilevazione firmata dal Beuc (Ufficio europeo delle orrganizzazioni dei consumatori) e dall'Anec l'anno scorso erano commercializzati nei punti vendita e in rete 151 beni di consumo. Un anno dopo si è giunti a 475. Nella lista si trova di tutto, dai prodotti per bambini agli alimenti, dalle bibite ai cosmetici, dagli articoli per l'automobile alle apparecchiature elettriche. Ill Beuc si chiede qual è l'eventuale entità del rischio per gli utilizzatori. Stephen Russell, segretario generale dell' l'ANEC ritiene necessaria una legge specifica per rendere obbligatoria l'indicazione delle nanoparticelle sulle etichette dei prodotti. I consumatori chiedono anche la creazione di un registro europeo per le aziende che operano nel settore, con l'obbligo di indicare tutti i beni di consumo contenenti nanomateriali. Tra le richieste c'è anche l'ipotesi di rendere obbligatoria la tracciabilità delle nanoparticelle come ha proposto la presidenza dell'Unione europea.

- the aim to understand the possible toxicity
- arrive at worldwide applications about this field

Market timeline



- Refers to the projection for the worldwide market of finite products that incorporate nanotechnology

- doubling every 3 years as a result of successive introduction of new products containing nanomaterials

We eat nanomaterials everyday..

Silicon-Aluminum

Iron-Chrome-Nickel

Iron-Chrome

Aluminum-Silver

Iron-Chrome

Silicon-Aluminum-
Titanium-Iron-Chrome

Silver

Iron-Chrome

NIEHS

(National Institute of Environmental Health Sciences)

Control the power of engineered nanomaterials to improve public health

Understand the potential risks associated with exposure to the materials

committed to supporting the **development** of nanotechnologies that can be used to improve products and solve global problems

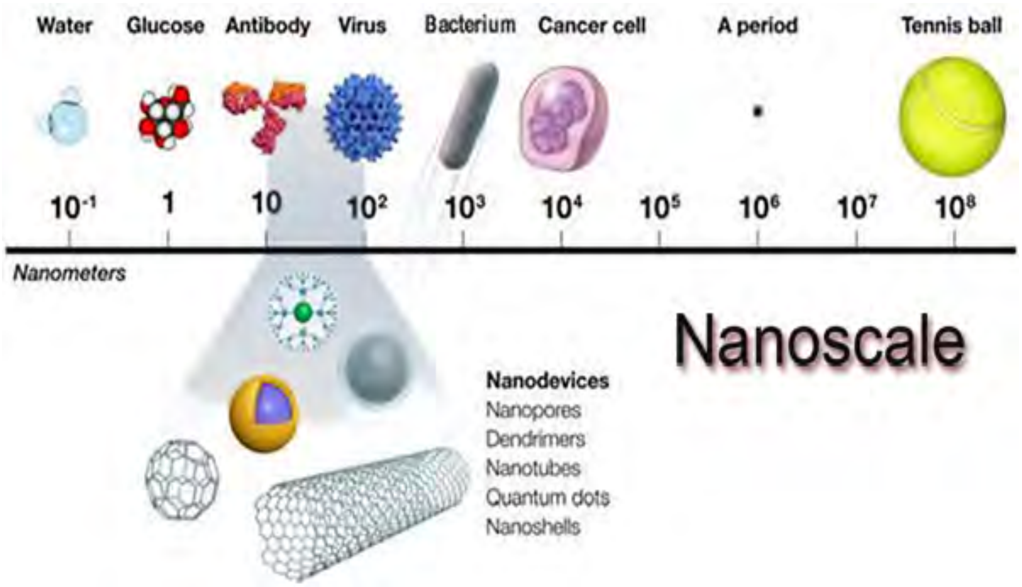
Purpose of our work:

1. **There is no single type of nanomaterial:** Nanoscale materials can in theory be engineered from minerals and nearly any chemical substance.

2. **The small size makes the material both promising and challenging:** often seen as a "two-edged sword", properties that make nanomaterials potentially beneficial in product development and drug delivery, are the same properties that concern about the nature of their interaction with biological systems and potential effects in the environment.

3. **Research focused on the potential health effects of manufactured nano-scale materials is being developed, but much is not known yet.**

What is a "nanomaterial"?

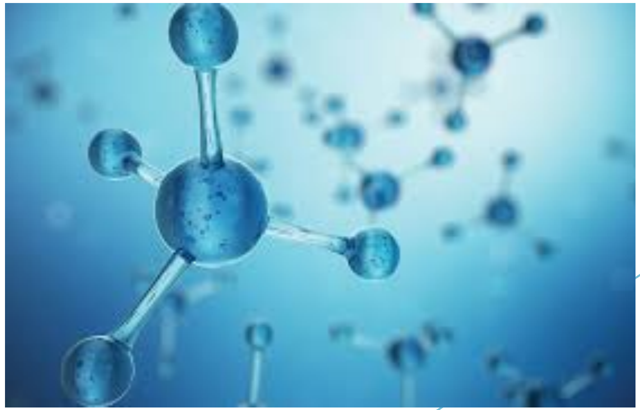


"A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm". (2011/696/EU)

European Commission

What is nanotechnology?

- promising technology
- Nanotechnology involves → characterization, fabrication, manipulation
- dimension at least of **1-100 nm**



SMALL

One nanometer is a **billionth of a meter!**

It's like comparing a millimeter with the distance between Milan and Taranto.

Ability to see and to control individual atoms and molecules.

Everything on Earth is made up of atoms

food

clothes

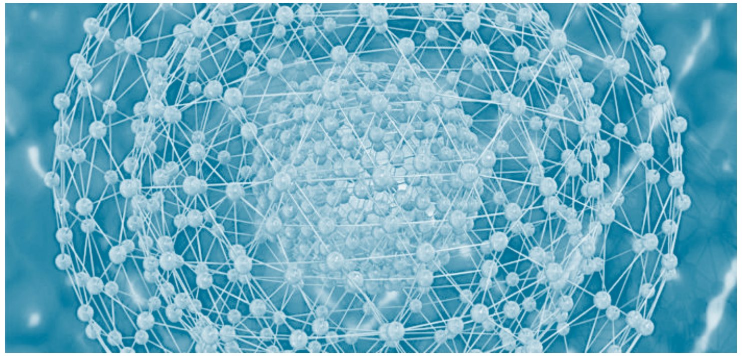
houses

…our own bodies

- scientists and engineers are finding a wide variety of ways to deliberately make materials at the nanoscale to take **advantage** of their enhanced properties

- higher strength
- lighter weight
- increased control of light spectrum
- greater chemical reactivity

Sources



- **Engineered** → Deliberately manufactured by humans to have certain required properties.
- **Incidental** → incidentally produced as a byproduct of mechanical or industrial processes.
- **Natural** → occur through crystal growth in the diverse chemical conditions of the Earth's crust .

Applications of ENMs in the Food Sector

Engineered nanomaterials (**ENMs**)
designed for use in many commercial materials

sunscreens cosmetics sporting goods electronics clothing …

Other applications

Drug delivery

Diagnosis

Biomedical imaging

Food itself contains many nanostructured materials

Nanotechnology in Food Processing

- Texture, Taste, and Appearance of Food
- Nutritional Value (Encapsulation)
- Preservation or Shelf-Life (slowing down degradation processes)
- Food Packaging

Texture, Taste, and Appearance of Food

improve the food quality and
also helps in enhancing food taste.

Nanoencapsulation techniques

↓

improve the flavor release and retention and
to deliver culinary balance.

Nanoparticles provide promising means of
improving the bioavailability of nutraceutical
compounds due to their subcellular size
leading to a higher drug bioavailability.

Nutritional Value

bioactive compounds: lipids, proteins, carbohydrates, and vitamins

↓

high acidic environment and enzyme activity

Encapsulation

resistance to various conditions

assimilate readily in food products

nanocomposite

nanostructuration

nano-emulsification

encapsulate the substances in miniature forms to more effectively deliver nutrients

Preservation or Shelf-Life

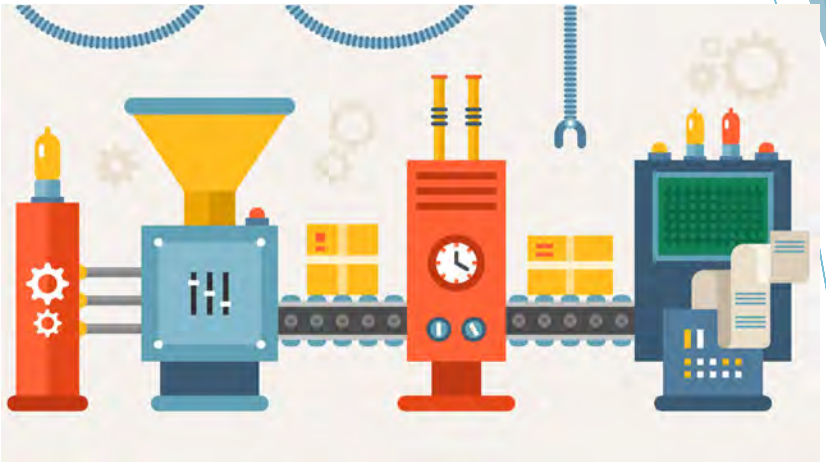
- **Nanoencapsulation**

extends the shelf-life of food because slowing down the degradation processes or prevents degradation until the product is delivered

- **Edible nano-coatings**

barrier to moisture and gas exchange and give improvements that could also increase the shelf-life of manufactured foods

Food Packaging



A desirable packaging

↓

gas and moisture permeability combined with strength and biodegradability

Application of nanocomposites as an active material for packaging and material coating can also be used to improve food packaging

Food Packaging

FOOD PACKAGING

- **IMPROVED PACKAGING**
  Improved physical performance of food
- **ACTIVE PACKAGING**
  Antimicrobial agent
- **SMART PACKAGING**
  Nano-biosensors for pathogen detectio

- silver, copper, chitosan, titanium oxide or zinc oxide

↓

have antibacterial property.

- Not limited to antimicrobial food packaging
- Barrier from extreme thermal and mechanical shock.

Applications of ENMs in the Food Sector

four key focus **areas**

Table 1. (Potential) applications of nanotechnology in food science.

Area of application	Application	Reference
Agriculture (Nano-modification of seed and fertilisers/pesticides)	Pesticides	[27]
	Targeted genetic engineering	[29]
	Preservation	[29,30]
	Agrichemical delivery	[29]
	Sensors to monitor soil conditions	[31]
Processing (Interactive smart food)	Nanoencapsulation of flavors/aromas	[32–37]
	Nanoemulsions	[38]
	Anti-caking agents	[39]
Nutrition (Food fortification and modification)	Nutraceuticals	[40–42]
	Nutrient delivery	[32,41]
	Mineral and vitamin fortification	[43,44]
	Drinking water purification	[45]
	Sensory characteristics of supplements	[46–51]
Products (Smart packaging and food tracking)	UV protection	[52–54]
	Antimicrobials	[55–63]
	Condition and abuse monitors	[46,47,64]
	High barrier plastics	[65–68]
	Security	[45,69,70]
	Contaminant sensors	[51,71–75]

Applications of ENMs in the Food Sector

- The potential for food nanotechnology applications seems **unlimited**.

- Result in promising applications for improved food production, processing, packaging and storage

- major **focus**

↓

processing and formulation of food ingredients to form nanostructures that are claimed to offer improved taste, texture and consistency

Most frequent nanomaterials present in food

Tabella 1 – Principali tipologie di nanomateriali impiegati nel settore agroalimentare, e corrispondenti matrici di interesse analitico

Nanomateriali		***Matrici***
Inorganici		*Mangimi*
→ Biossido di titanio, TiO_2	E171	*Integratori (consumo animale)*
→ Ossido ferrico/ferroso, Fe_2O_3/Fe_3O_4	E172	*Alimenti (consumo umano)*
→ Argento metallico, Ag	E174	*Integratori (consumo umano)*
Oro metallico, Au	E175	*Simulanti alimentari*
Silice amorfa, SiO_2	E551	(migrazioni da materiali a contatto con gli alimenti)
→ Ossido di alluminio (allumina), Al_2O_3		A Etanolo 10%
Ossido di zinco, ZnO		B Acido acetico 3%
Ossido di cerio, CeO		C Etanolo 20%
Nanoargille		D1 Etanolo 50%
Nanotubi e fullereni		D2 Olio vegetale
Organici		Sostitutivi D2 Etanolo 95%, isoottano
Nisina	E234	E poli(ossido di 2,6-difenil-p-fenilene)
Chitosano		
Nano-incapsulati (micelle, liposomi e dendrimeri)		
Compositi		
Nanoargille funzionalizzate		
Nanoparticelle metalliche funzionalizzate		
Nanocompositi a matrice polimerica		

Nanotitanium (E171)

Consumed annually at about **4 million tons** worldwide.

Used in **paints, coatings**, cosmetics , nutritional supplements and food products, e.g., **colorants**.

Reduces E. coli contamination of food surfaces.

FDA approved TiO2 as a food color additive with the stipulation that the additive should not to exceed **1% w/w**. TiO2 was also approved by the US FDA in food packaging.

- Potential to **penetrate the blood-brain barrier,** BUT **evidence is lacking** that could link systemic responses to translocation of particles to target sites.

- Study conducted by **Gerhard Rogler** TiO2 particles are able to penetrate the **intestinal epithelial cells** leading to inflammatory processes

- In Italy → Study of 4 years ago demonstrated that the administration in low doses of titanium bioxide in rats is able to induce alteration of ovary and of **testosterone** metabolism .

Ferrous-ferric oxide (E172)

Iron oxide and hydroxide are **colorants** of variable color of mineral origin. They can be contained in **chewing-gum**, confetti and **sweets**.

- These NPs **bioaccumulate** in the liver.

- In vivo studies have shown that after entering the cells, iron oxide NPs remain in endosomes/lysosomes, release into cytoplasm after decomposing, and contribut to cellular iron pool.

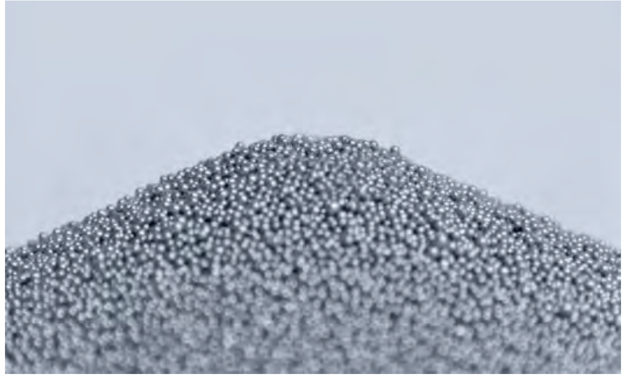
↓

These NPs exert their toxic effect in the form of **cell lysis, inflammation, and disturbing blood coagulation system.**

Metallic silver (E174)

390 products

textiles,cosmetics/hygiene products, cleaning agents (detergents, soaps), kitchen supplies, toys and building materials (glues).



Highly toxic to mammalian cells and human health: damage brain, induce **oxidative stress**. At high doses, it has been shown to cause **neurotoxicity** in rats and mice.

Aluminium oxide

- Contained above all: in **chemical yeast**, in **melted cheeses.**

- One of the most used materials. It is characterized by an excellent **thermal conduction**. But, **not for storage**!!!

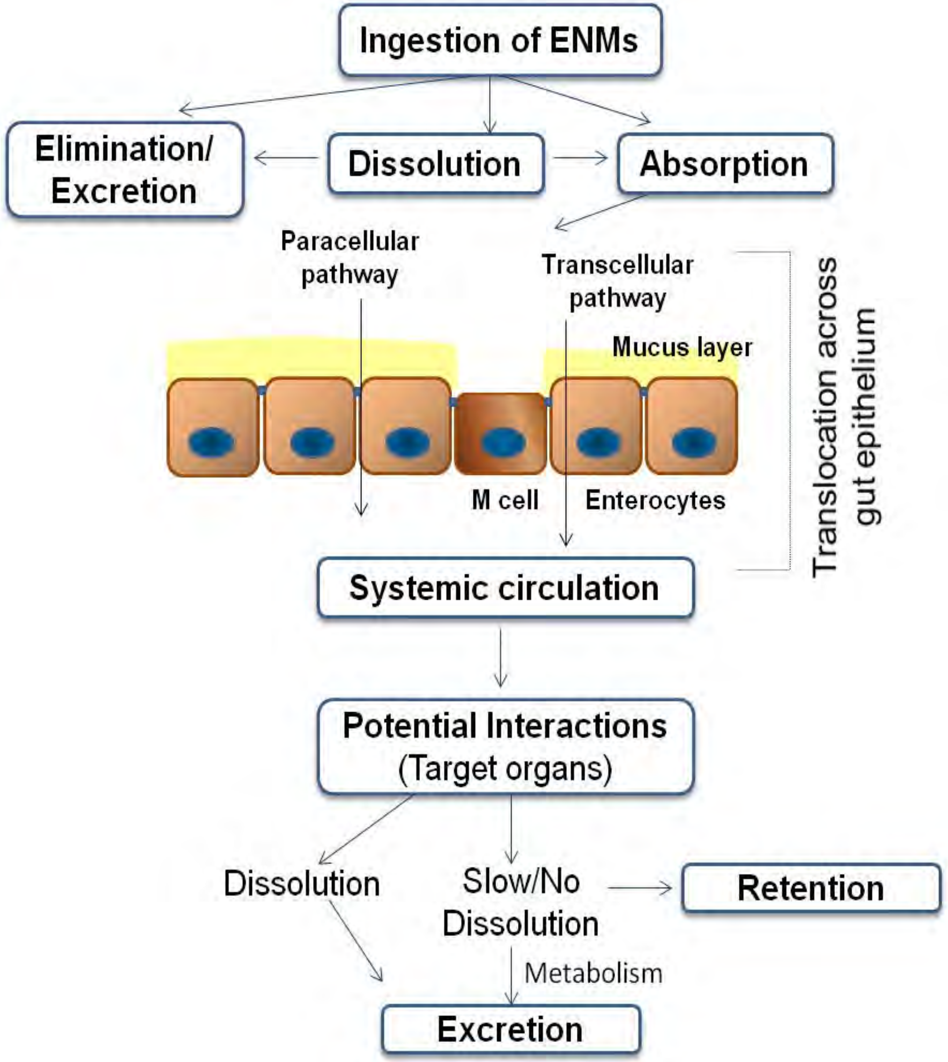
- Cereals and derivatives,vegetables (spinach, horseradish and lettuce), mushrooms, drinks.

Aluminium oxide

- EFSA has restricted the dietary intake of aluminum to **1mg / kg of body weight per week.**

- Toxicity → **muscle weakness, bone pain,** osteoporosis, growth retardation in children. Worsening of mental abilities, **dementia** and convulsions occur mainly **in individuals with**

The fate of food-related ENMs in the GIT



Factors that influence the biological availability of an administered NP:

- Particle size
- Surface area
- Particle number
- Aggregation/agglomeration state
- Surface charge
- Shape
- Aspect ratio

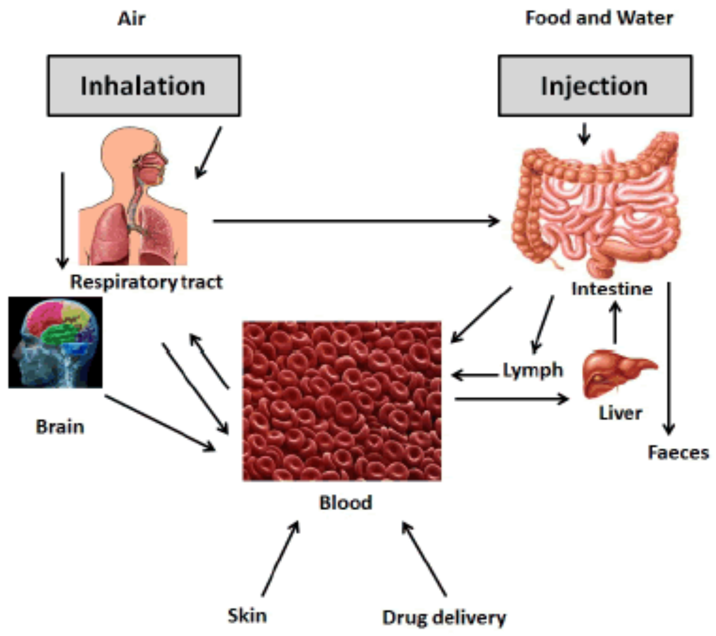


Figure 3: Illustration of possible routes of nanoparticles uptake, allocation and excretion in humans.

- Intestinal barrier

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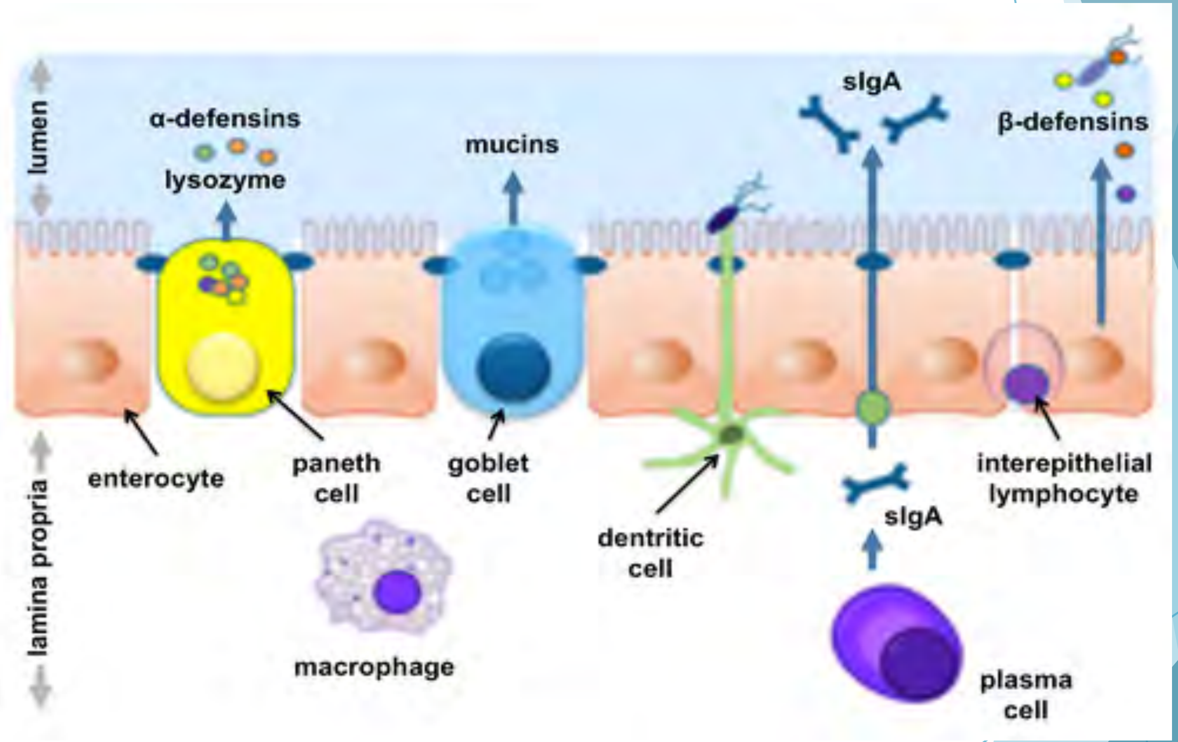
- **Multistep process**

- diffusion through the mucus layer
- contact with enterocytes and/or M-cells
- uptake. The most common mechanism for uptake of NP into intestinal epithelial cells appeared to be **endocytosis.**



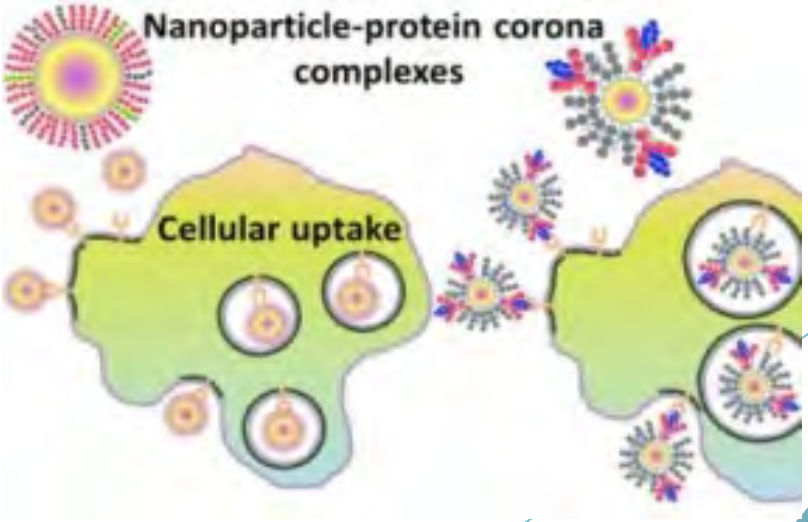
- **Net neutral or positive** surface charge

↓

prevent mucoadhesion, favoring penetration

- **Negatively** charged hydrophilic and lipophilic compounds → hindered.

- NP will develop a **corona** of adsorbed proteins, small molecules, and ions. The effects of the protein corona are variable. In some cases, cytotoxicity is reduced.



The interaction with the Gut Microbiota…

- Titanium dioxide, cerium dioxide, zinc oxide and nanosilver may affect the microbiota and that clinical disorders such as **colitis, obesity and immunological dysfunctions** might follow.

- **Iron** nanoparticles may show advantages over traditional iron-based supplemental treatment because they do not interfere with the microbiota, and some NM-based **therapeutic interventions** might be employed for treating intestinal infections.

Toxicity and safety studies

ANR The French National Research Agency
Projects for science

About ANR | Funding opportunities | Projects and Results | International cooperation | Information

ANR funded project

Scientific Panorama

Blanc – Accords bilatéraux 2013 - SIMI 10 - Nanosciences (Blanc – Accords bilatéraux 2013 - SIMI 10) 2013

Projet ***SolNanoTOX***

Determining factors of thea difference in toxicity in intestine and liver for two similar sized nanoparticles used in food and packaging: In vitro and in vivo investigation on uptake and mechanisms involved

The application of manufactured nanomaterials (MNMs) in food and packaging industries is expected to increase considerably in the near future, and the evaluation of the safety of MNMs present in foodstuff is thus a major concern in Europe and worldwide. Although some consumer food products contain MNMs (additives or contaminants from packaging), little is known concerning the toxicity of these MNMs following ingestion. Moreover, their size, morphology and state of agglomeration together with physiological modifications (e.g. digestion) are likely to play a considerable role in the uptake and toxicity of these materials to humans.
Although numerous in vitro studies have begun to shed light on mechanistic effects, very little data is available concerning the toxic effects of MNMs following oral exposure in vivo. Nevertheless, results from in vivo experiments are the main data useful for risk evaluation. However, due to the vast quantity of different MNMs and the variability of their physic-chemical properties together with the inherent limitations of animal experimentation, the toxic effects in vivo cannot be investigated for each MNM. Therefore it is clearly necessary to establish key guidelines in the classification of MNMs according to their potential adverse effects
Among the properties of MNMs, the solubilisation capacity is likely an important determinant of nanomaterial uptake and the initiation of specific pathways of toxicity. In the SolNanoTox project, representatives of two different classes of MNMs will be investigated: titanium dioxide as an example for insoluble species due to its stability in water and aluminium representing the soluble category.
Moreover, several reports in the literature suggest that aluminium and titanium oxide nanomaterials target different organs following oral exposure. It is hypothesized that aluminum nanoparticles form aluminum ions, either before or during the uptake in the intestine, whilst titanium dioxide nanoparticles may cross the intestine as intact nanoparticles. This difference in behaviour could then explain the different target organs and toxicity for the two MNMs.

Latest News

ERAPerMed

Pre-announcement: a transnational call for proposals on Personalised Medicine to be open soon

Call on AMR Diagnostics & Surveillance

Pre-announcement: JPIAMR Call on Diagnostics & Surveillance 2019 for transnational research projects

Pre-announcement: the second MarTERA call for projects on maritime and marine technologies will be opened soon

SolNanoTox project

↓

two different classes of MNMs will be investigated:

1. **titanium dioxide** as an example for insoluble species due to its stability in water
2. **aluminium** representing the soluble category.

Aluminum nanoparticles form **aluminum ions,** whilst **titanium dioxide** nanoparticles may cross the intestine as **intact nanoparticles**.

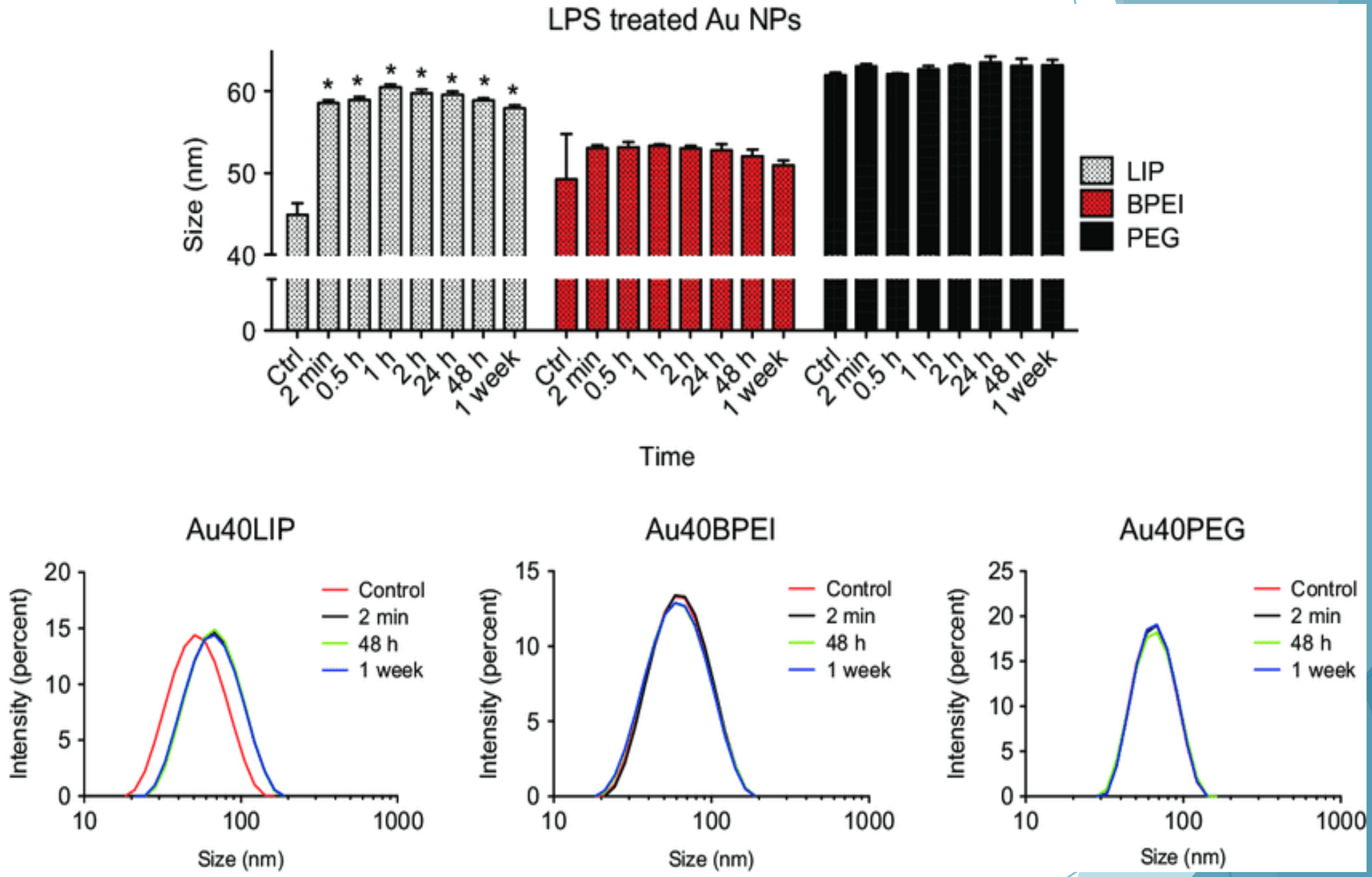
↓

Different target organs and toxicity for the two NMs.

Cellular toxicity:

- The cell uptake, ROS level, cell cycle and aopoptosis were determined for toxicity studies in human gastric epithelial cell **GES-1** and colorectal adenocarcinoma cell **Caco-2**.
- 24 hours exposure time and 100 micrograms of concentration is safe for both cell lines as **silica NPs do not pass** through Caco-2 cell monolayer after 4 hours. These NPs have low capability to cross the gastrointestinal tract *in vivo* while long term effect should be considered.

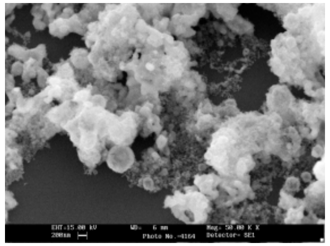
- SiO_2 nanoparticles stimulate the proliferation of human colon carcinoma cells (HT29) causing interference with **MAPK/ERK1/2 signaling pathway**.
- TiO2, ZnO, Au and SiO2, upon their absorption and passage across the GIT adsorb calcium ions and LPS and the resulting **NPs-calcium-LPS conjugates** activate both peripheral blood mononuclear cells and intestinal phagocytes.



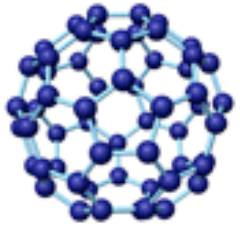
Gastrointestinal disorders:

- Crohn's disease
- Obesity
- IBD
- Ulcerative colitis
- Gastric and colorectal cancer

Nanoparticles: what makes them different

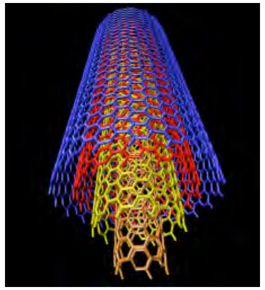


- Large specific **surface**

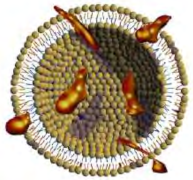


- **Chemical reactivity** very different compared to bulk material

- **Quantum effects** lead to special properties (electronic, mechanical, optical …)



- **Matrix** dependent properties
- **Many forms**: fullerenes, nanotubes, nanocarriers, nanoemulsions, -encapsulates



Nanomaterials characterization issues

For what

- Optimisation for production and quality assurance
- Characteristics for specific applications
- Interaction with biological systems
- Behaviour in the environment

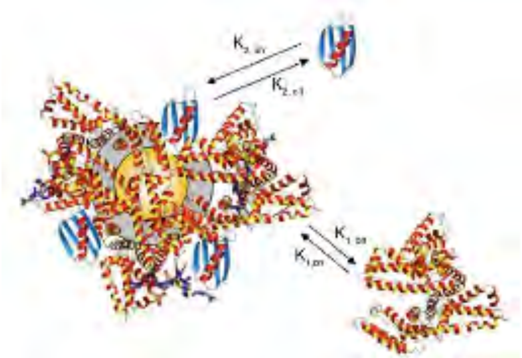
Driving force: safety assessment

- Possible health effects
- Environmental effects (transport, fate, interaction with living organisms)
- Knowledge gaps concerning NM characteristics (SCENIHR…)
- Regulation of nanomaterials (REACH, food, cosmetics, …)

Interaction of NM with biological matrices

Consequences of phys.-chem. Properties

- Thermodynamically unstable or metastable
- Aggregation or agglomeration
- Interaction with surrounding matrix
- Ageing
- Adsorption of ions – surface charge
- Nuclei for heterogeneous crystallisation
- Catalytic effects



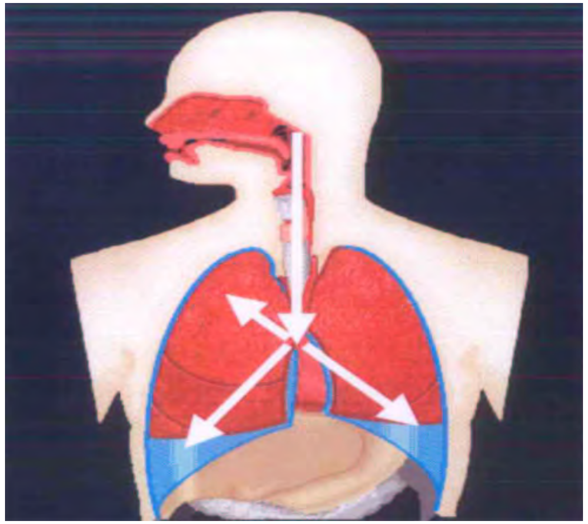
Effects of NM in living systems:

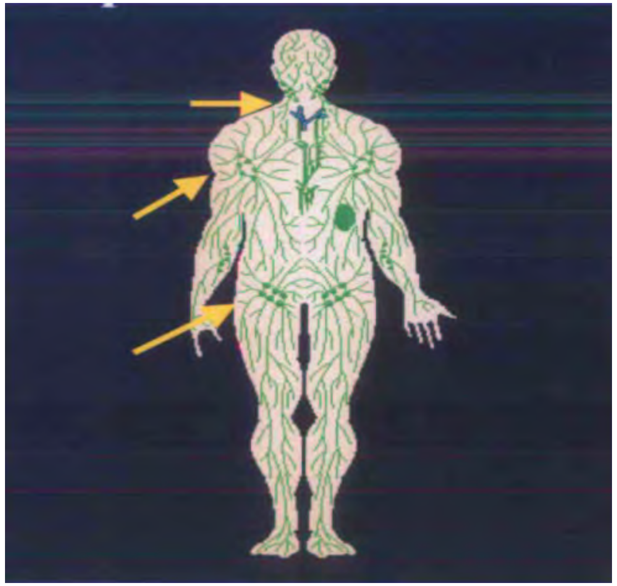
- Interaction with functional groups of biopolymers
- Formation of reactive oxygen species
- Nuclei for induced crystallisation

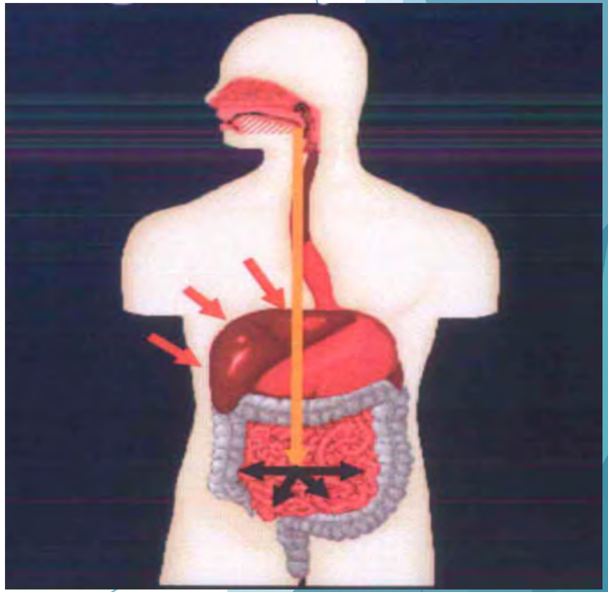
Effects

- Translocation from portal of entry to target organs
- Protein binding
- Cellular uptake
- Accumulation and retention
- Cell/tissue response

Toxicity



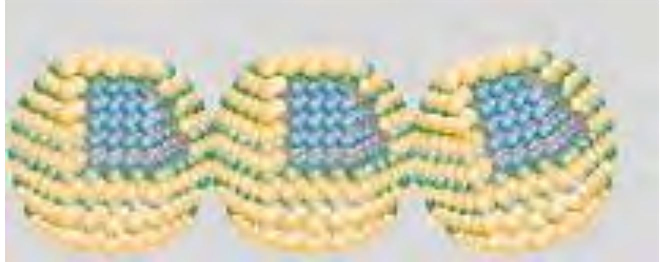




Detection techniques for identification of nanomaterials

- **A number of tools – no best techniques**

Issues



- State of the material
- Sample preparation
- Measurement protocols
- Particle environment
- Laboratory vs routine measurements

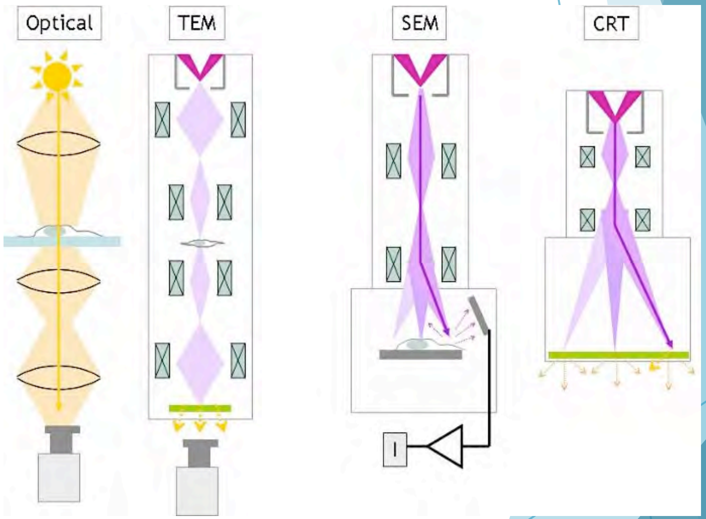
Detection techniques for identification of NMs

Ensemble analytical techniques	Single-particle techniques
• Dynamic Light Scattering (DLS) (= Photon Correlation Spectroscopy, PCS) • Laser Diffraction/Static Light Scattering • Low Pressure Impactor (LPI) Electrical Low Pressure Impactor (ELPI) • Scanning Mobility Particle Sizer • Differential Mobility Analyser (DMA) • Field Flow Fractionation (FFF) • Centrifugal sedimentation • Specific Surface Area (BET) • Time of Flight Mass Spectroscopy (ToF MS)	• Scanning Electron Microscopy (SEM) • Transmission Electron Microscopy (TEM) • Field emission gun scanning/transmission Electron Microscopy (FE STEM) – Energy Dispersive Spectrometry (EDS) – Electron Energy Loss Spectorscopy (EELS) • Atomic Force Microscopy (AFM)

Nanoparticle Tracking

Microscopy and microscopy-related techniques

The typical dimensions of nanoparticles are below the diffraction limit of visible light, so that they are outside of the range for optical microscopy.



The most popular tools:

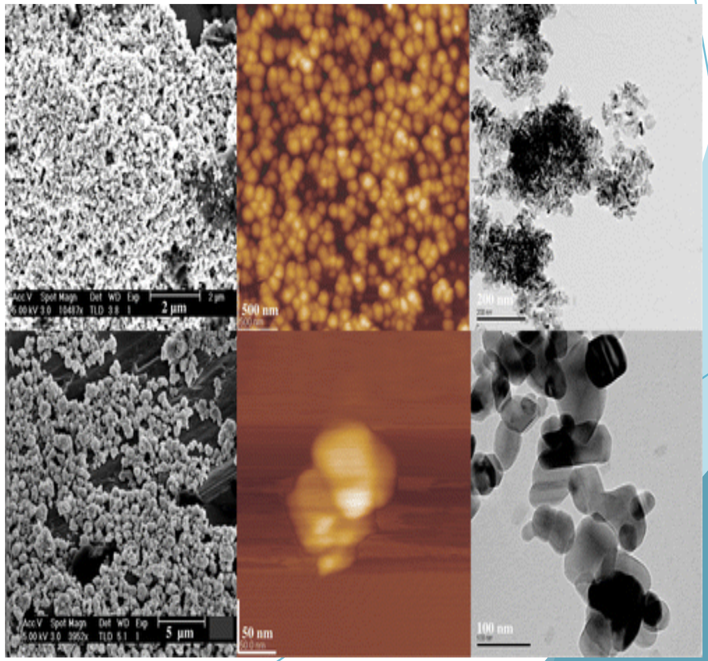
- atomic force microscopy **(AFM)**
- scanning electron **(SEM)**
- transmission electron microscopy **(TEM)**

Nanoparticles can not only be visualized, but also properties such as the state of **aggregation, dispersion, sorption, size, structure and shape** can be observed.

Transmission Electron Microscopy (TEM)

Advantages

- Accessible size < 1 nm, very high resolution
- Direct Method
- No calibration necessary
- Can be directly combined with analytical methods (e.g. EELS)
- Any particle shape is accessible

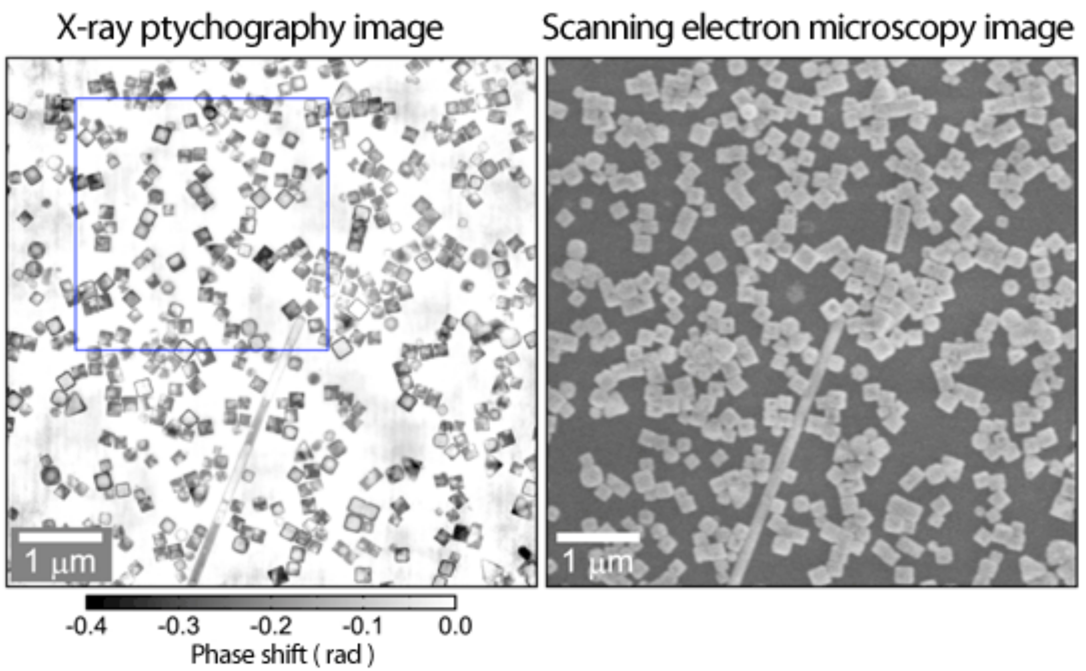


Drawbacks

- Expensive and complex equipment
- High vacuum is needed
- Sample preparation
- Slow: Time-consuming
- Poor statistics
- Artefacts

X-ray microscopy (XRM)

- Can provide spatial resolution imaging of a specimen in the aqueous state without the need for sample preparation, e.g. fixation, staining or sectioning
- The **major limitation** of conventional electron microscopes, such as transmission electron and scanning electron microscopes, is that they have to be operated **under vacuum conditions**.

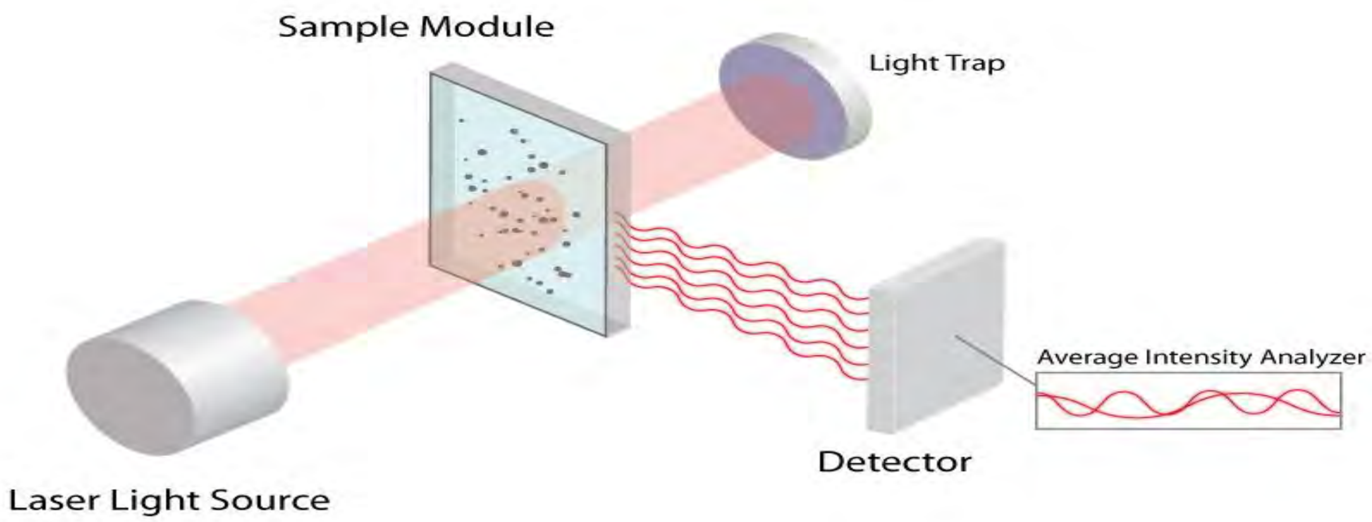


Spectroscopic and related techniques

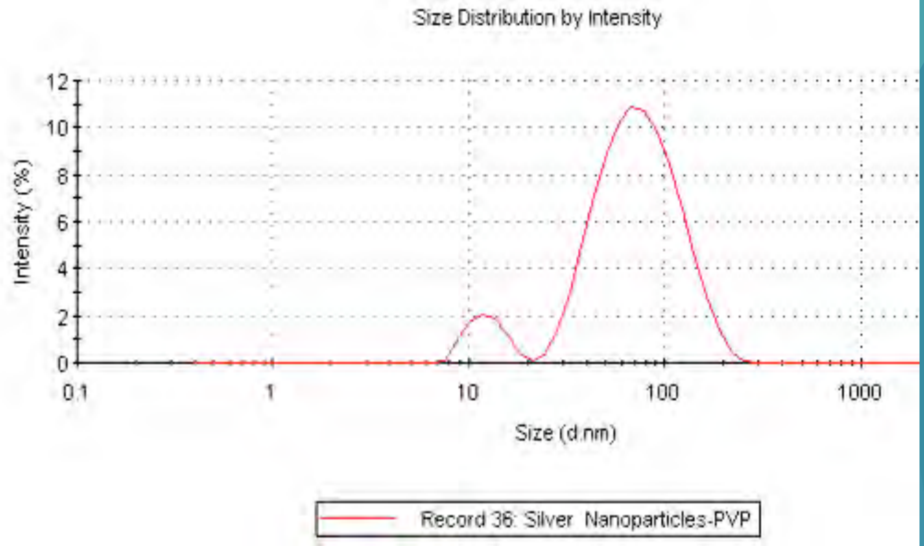
LIGHT SCATTERING METHODS

- static **(SLS)** also known as multi-angle (laser) light-scattering **(MAL(L)S)**, → sizing nanoparticles; state of aggregation in suspensions.
- dynamic light-scattering **(DLS)** or photon correlation spectroscopy **(PCS)** → particle structure; particle shape
- neutron scattering, small-angle neutron scattering **(SANS)**.
- Nuclear magnetic resonance **(NMR)** → dynamics three-dimensional structure

Dynamic Light Scattering



- Particles move due to Brownian Motion
- Measure Fluctuations in Intensity of Scattered Light
- Apply algorithm to determine size distribution



Dynamic Light Scattering

Advantages

- Inexpensive
- Fast
- Good statistics
- No influence of beam
- Weighting for intensity, volume and number possible

Drawbacks

- Indirect measurement
- Only dispersions can be measured
- Influence of medium
- ‘Spherical’ particles
- No model for very elongated or irregular particles

Centrifugation and filtration techniques

Centrifugation and filtration techniques are well-established tools for the preparative, size fractionation of samples.

These are:

- low-cost
- high speed
- high volume

Ultracentrifugation (UC), for example, is a centrifuge system capable of very high spinning speeds for accelerations up to 1,000,000 *g*.

Chromatography and related techniques

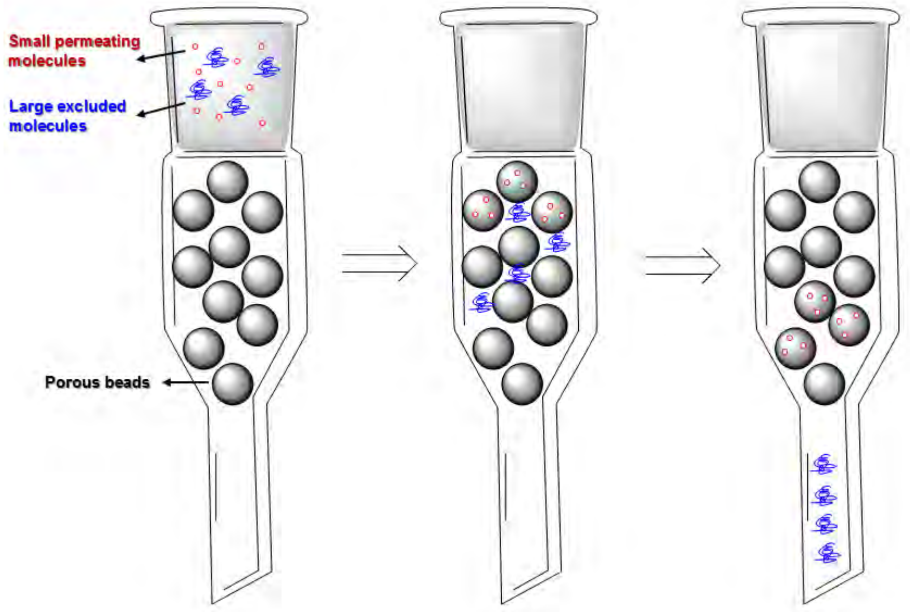
Separation of nanoparticles in samples:

- rapid
- sensitive (detector-dependent)
- non-destructive → samples are available for further analysis.

By attaching traditional analytical tools (e.g. ICP–MS, DLS) as detectors to size separation techniques, it is not only possible to **quantify** different nanoparticles in food, water, biota and soil, but also to **characterise** or elementally **analyse** them.

Size exclusion chromatography (SEC)

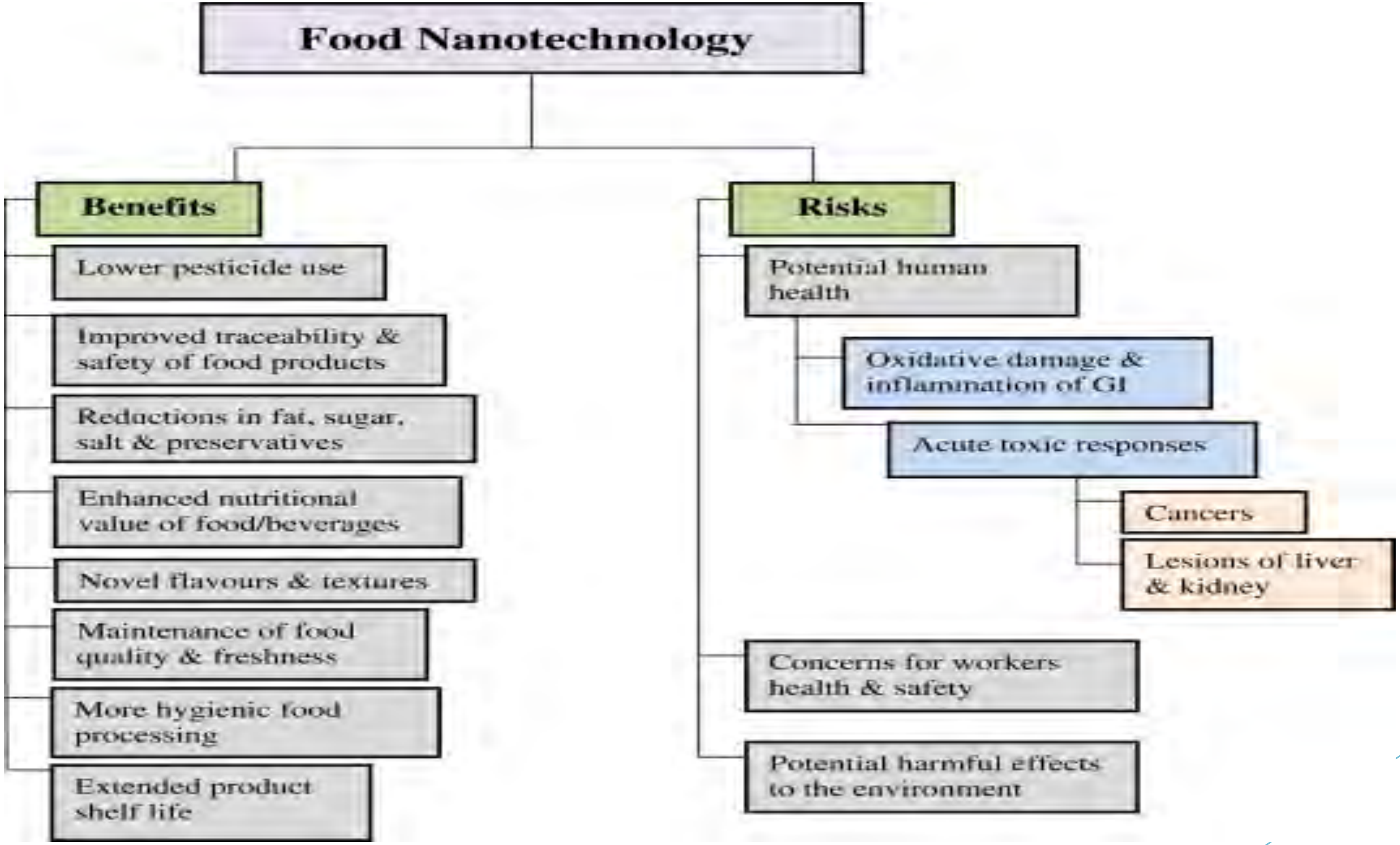
- A size exclusion column is packed with porous beads as the stationary phase.
- The pores of the column retain particles, depending on their size and shape.



Disadvantages

- Possible interactions of the solute with the solid.

Advantages/disadvantages



New EFSA guidelines on nanotechnology in food and feed. Risk assessment for human and animal health

The European Food Safety Authority (EFSA) has published the new guidelines on risk assessment and the effectiveness of nanosciences and nanotechnologies in the food chain. These are new foods, food contact materials, food and feed additives, pesticides.

- **nano-silver**
- **nano-sensors**

To be sure that nanotechnology in food does not harm health:

NMS must be evaluated in terms of safety,

the new risk assessment guidelines have been studied for **exposure** and for the **characterization of the hazards** of nanomaterials.

EFSA guidelines

- The **use of a nanomaterial** in food/feed will need to be assessed for safety to fulfil requirements of the relevant **EU food laws**, and in accordance with the provisions of this Guidance.
- The existing risk assessment paradigm for chemicals is also applicable to nanomaterials.
- The Guidance proposes a structured pathway for carrying out safety assessment of nanomaterial in food/feed and related applications, and provides **practical suggestions for the types of testing needed and the methods that can be used for this purpose**.
- The Guidance also highlights certain **gaps** where further research is needed to facilitate adequate safety assessment of materials that consist of small-sized particles.

efsa
European Food Safety Authority

Future perspectives

- The fate and potential toxicity of nanomaterials **are not fully understood**
- In addition to the benefits, nanotechnology can also assist in the detection of **pesticides, pathogens** and **toxins**, serving in the food quality tracking–tracing–monitoring chain.
- Furthermore, nanotechnology has the potential to transform our future food packaging materials, as part of an **active and intelligent packaging system**.

Conclusion

The associated health, safety, and environmental impacts should be addressed and regulated at the forefront.

To be successful in the long run, **proper education of the public** is also paramount in the introduction and development of nanotechnology in food system and there seems to be an urgent need to gather information on this subject.

THANKS FOR THE ATTENTION