A National Project:
Safe(r) and Ecodesign Research and Education applied to NAnomaterial DEvelopment 2012-2020

"The new generation of materials safer by design"

Coordination CEREGE CNRS-Aix-Marseille Univ
Directors : JY Bottero, J Rose
Deputy director : A Masion

Scientific and outreach manager: C. de Garidel-Thoron

name@cerege.fr

Fourth SNO Conference, Portland , Oregon

Context
Commercialized nanomaterial/nanoproducts

- **Diversity of commercial applications - Economic strength**

Nano "effects"

Stronger and lighter materials
Self-cleaning surfaces
Medical applications
UV absorber
Faster electronic
Antimicrobial
Water treatment

- **Evidences of adverse human effects**

- **Inflammation and the formation of granulomas** (Poland et al., 2008)
- Nano-CeO_2 **are genotoxic to human cells** (Auffan et al, 2009).
- Nano-ZnO **toxic to human cells** (oxidant injury, excitation of inflammation, and cell death) (Xia et al, 2008).
- Etc …

Necessity of an eco-design approach: see in Europe NanoREG1-2, ProgSAFE, SUN, ERA Net SIINN projects….etc…

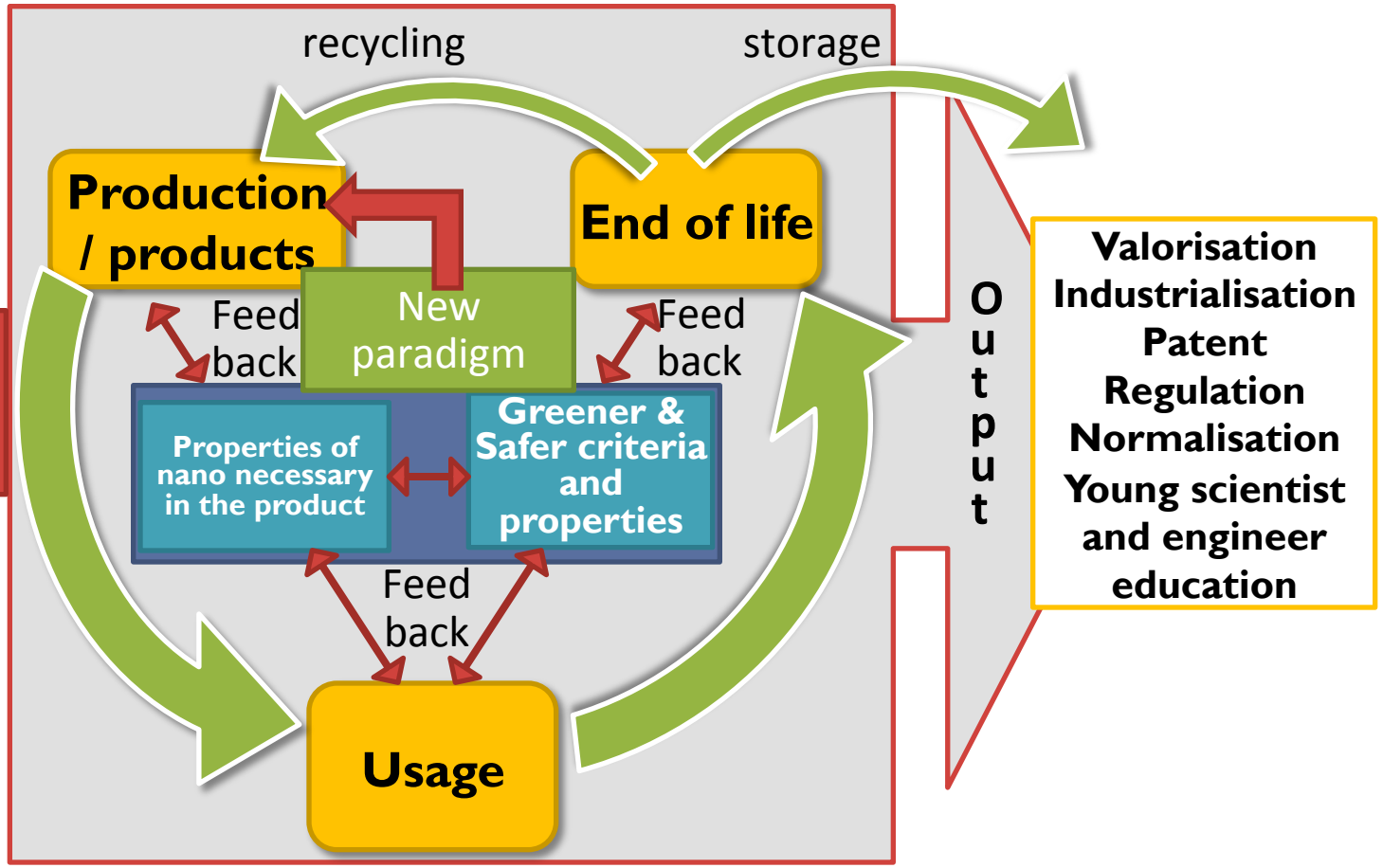
Objectives :

- Design nanomaterials **safer for both human health and the environment** in order to promote the **sustainable and responsible development and competitiveness** of SMES and Companies involved in nanotechnologies.
- Implementation of **metrological tools** for occupational workers, population and environment media
- Develop a **new approach of the entrepreneurship** by integrating findings on marketing, communication or ethics, which are to day at the core of many nanotechnologies debates into a wider frame and shaping a sustainable market infrastructure for their innovations.

(see presentation of Cl Auplat, C DeGaridel et al)

Principles: Towards new generation of Nanomaterials; new concepts of synthesis

Nano-enabled Products life-cycle approach



Partners: 15
13 Public Labs + 2 Companies

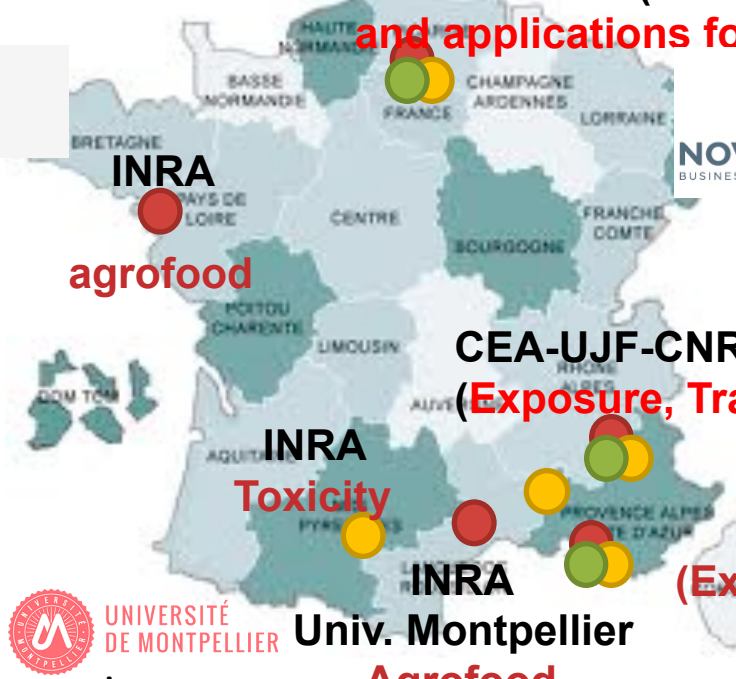
INSERM-INERIS (exposure-metrology-toxicity)-NOVANCIA (entrepreneurship)
SUEZ-ENVIRONNEMENT (end of life and applications for water treatment)

université Paris Est Créteil Val de Marne

INRA SCIENCE & IMPACT

Labex added value:
- All (almost) French research organisations
- Academy + industry
- Multidisciplinary

New



INRA
agrofood

CEA-UJF-CNRS
(Exposure, Transformation)

INRA
Toxicity

INRA
Univ. Montpellier
Agrofood
Packaging

AMU-CNRS
CEA; INERIS
(Exposure, Life cycle, transformation, (eco)toxicity)
ALLIOS (paintings)

- Synthesis and properties
- Ecotoxicity/toxicity
- Life cycle assessment

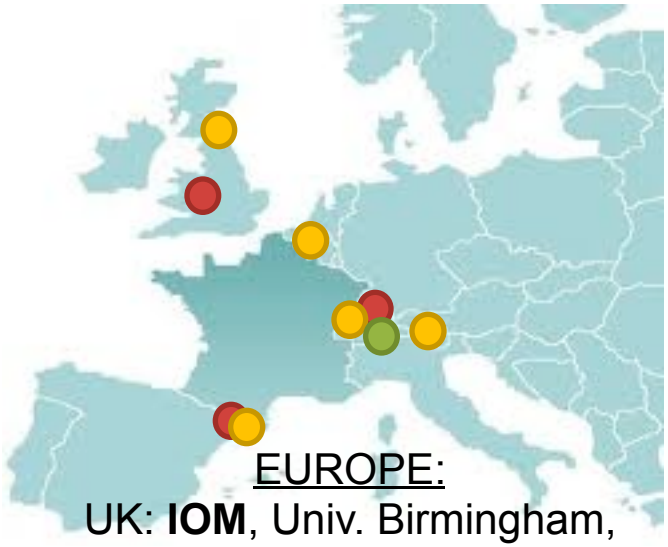
In blue = companies

New participants
SME (Cosmed) : cosmetics
Start Up (Lotus Synthesis): formulation of TiO2

Partners: International networking through associated projects:
CEINT;
ANR…, EU (FP7, H2020, ERA Net SIINN…)

CANADA:
Univ. of Montreal

CEINT Center for the Environmental Implications of NanoTechnology



EUROPE:
UK: **IOM**, Univ. Birmingham,
SZ: EPFL, EAWAG, **EMPA**
AT : Universität **Wien**
Be: Univ Cath **Louvain**
SP: Inst Cat Nano 2 **Barcelona**

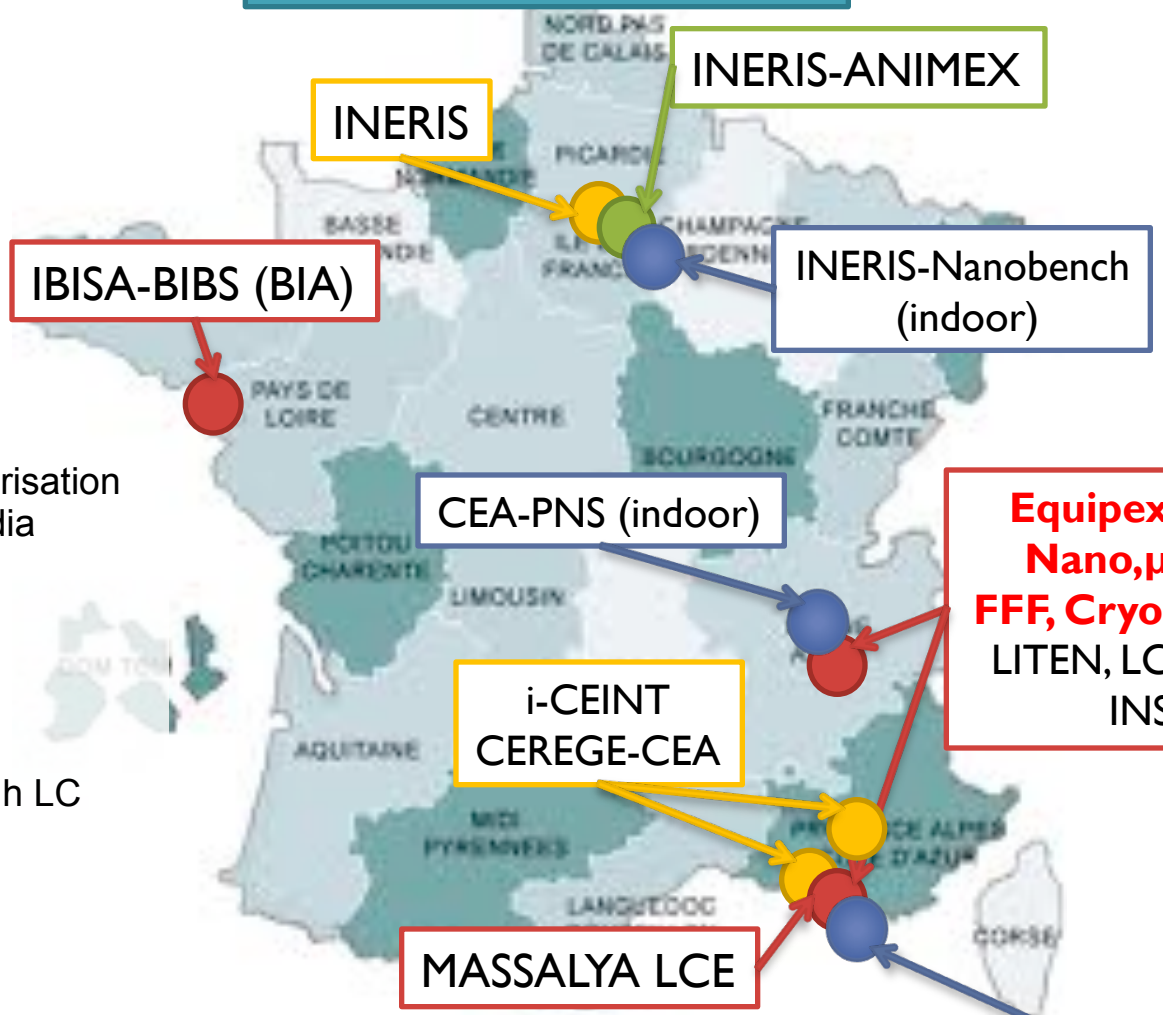
- Synthesis and properties
- Ecotoxicity/toxicity
- Life cycle assessment

Platforms associated to SERENADE

Labex added value:

- •Cryo-TEM EELS-EDX-HAADF
- •LAAP-ToF
- •Nano-micro X-ray CT
- •FFF
- •ICP-MS
- •SMPS
- •AFM
- •Confocal Microscopes
- •LIBS
- •...

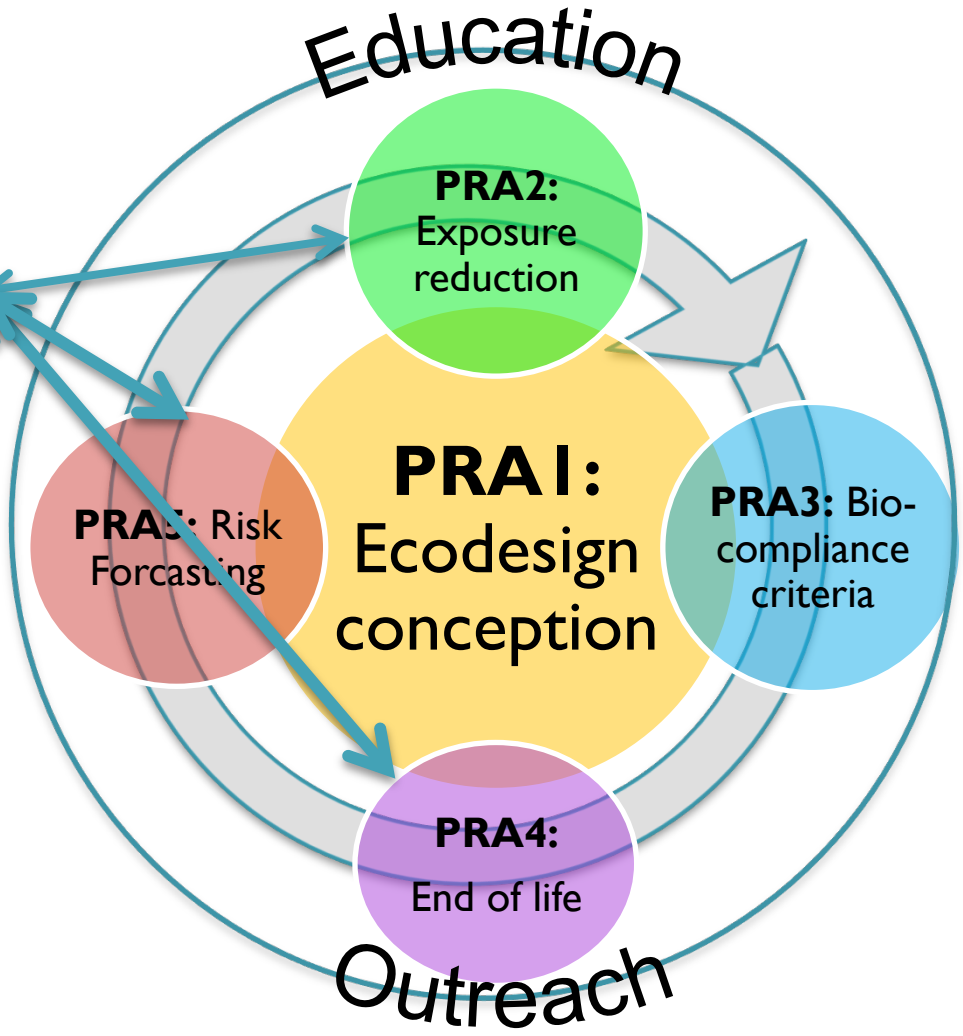
- Detection and characterisation of NMs in complex media
- Micro/Mesocosms
- *In-vivo* Nanotox
- Aging, exposure through LC



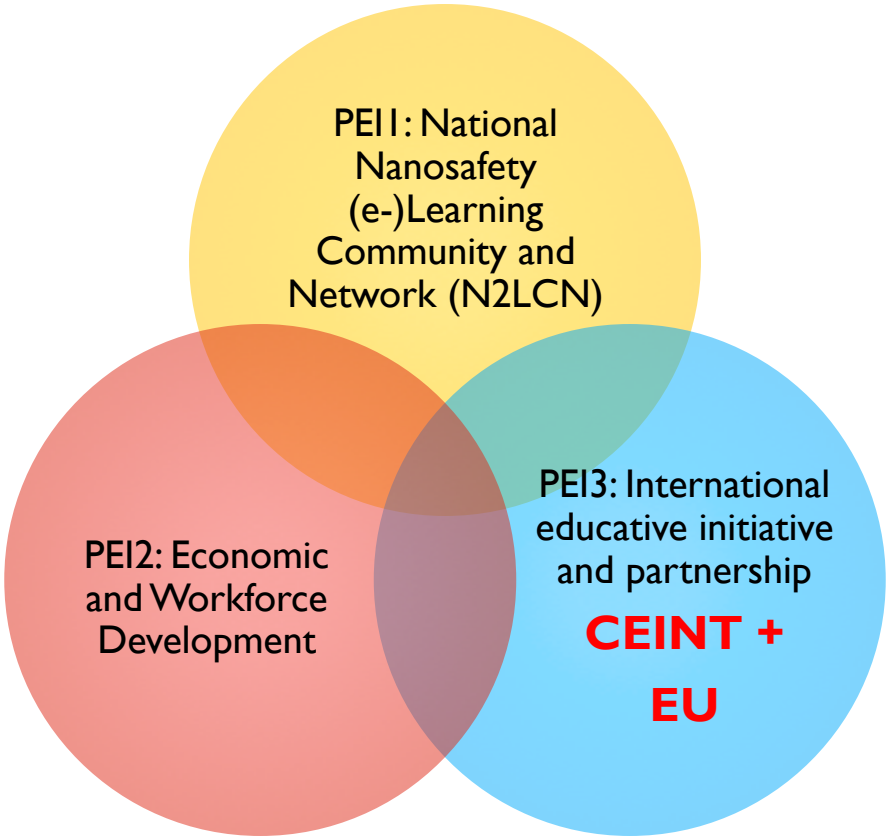
Priority Research Actions (PRA) & Priority Educative Initiatives (PEI) necessary to fulfil the objectives:

Strong Links with

CEINT Center for the Environmental Implications of NanoTechnology

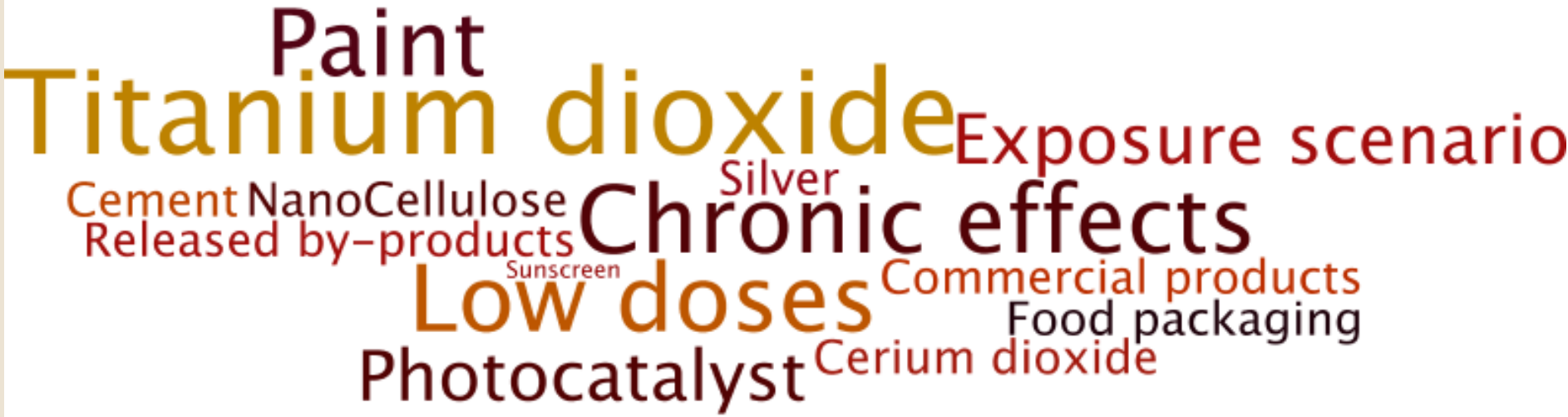


Priority Research Actions (PRA) & Priority Educative Initiatives (PEI) necessary to fulfill the objectives:



Progress of the project: research

- Diversity of studied nanomaterials,and Nano Enabled Products: exposure scenario, …



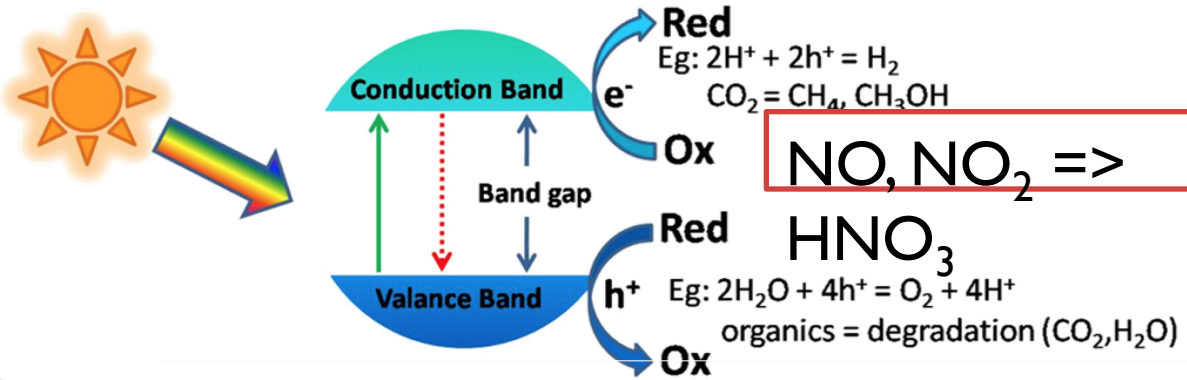
http://www.wordle.net

Labex added value:

Context

Commercialized nanomaterial/nanoproducts

Nano-TiO_2 photocatalytic properties



$NO, NO_2 \Rightarrow HNO_3$

Degradation of compounds in contact with cement surface

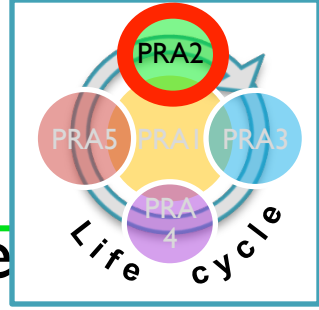
allios

Production of formulations

Abating Pollution

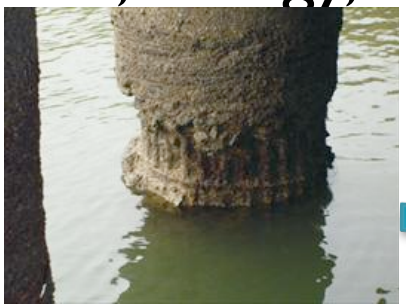
Preserving aesthetics

Progress of the project: research



- Ex: Release of Nano-by-products during the use stage (consumer and Env. Exposure): determination of the physical-chemical nature and quantity vs time, water, energy, formulations…number of layers, supports.

Release

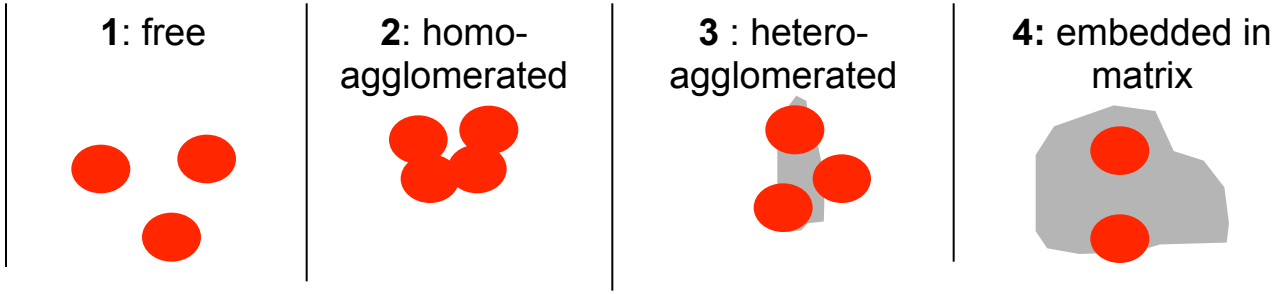


http://www.masterbuilder.co.in/critical-chloride-content-in-reinforced-concrete/

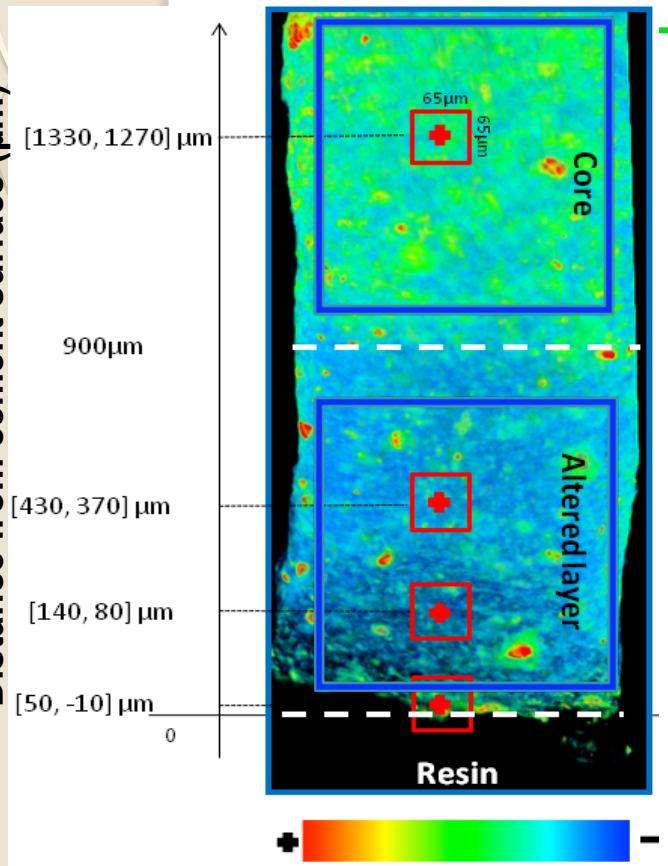
Aging
Weathering

http://www.dcpolish.com/concretegrindingdanger.html

Abrasion
Before/after
weathering



Ex 1 Cement: Porosity gradient along altered cement profile



Micro-CT
Resolution 3 µm

Core
Porosity :10 %
Connectivity : 55%

Altered layer
Porosity :18 %
Connectivity : 83%

Nano-CT
Resolution 150 nm

Core
Porosity :17%
Connectivity : 92%

Altered layer

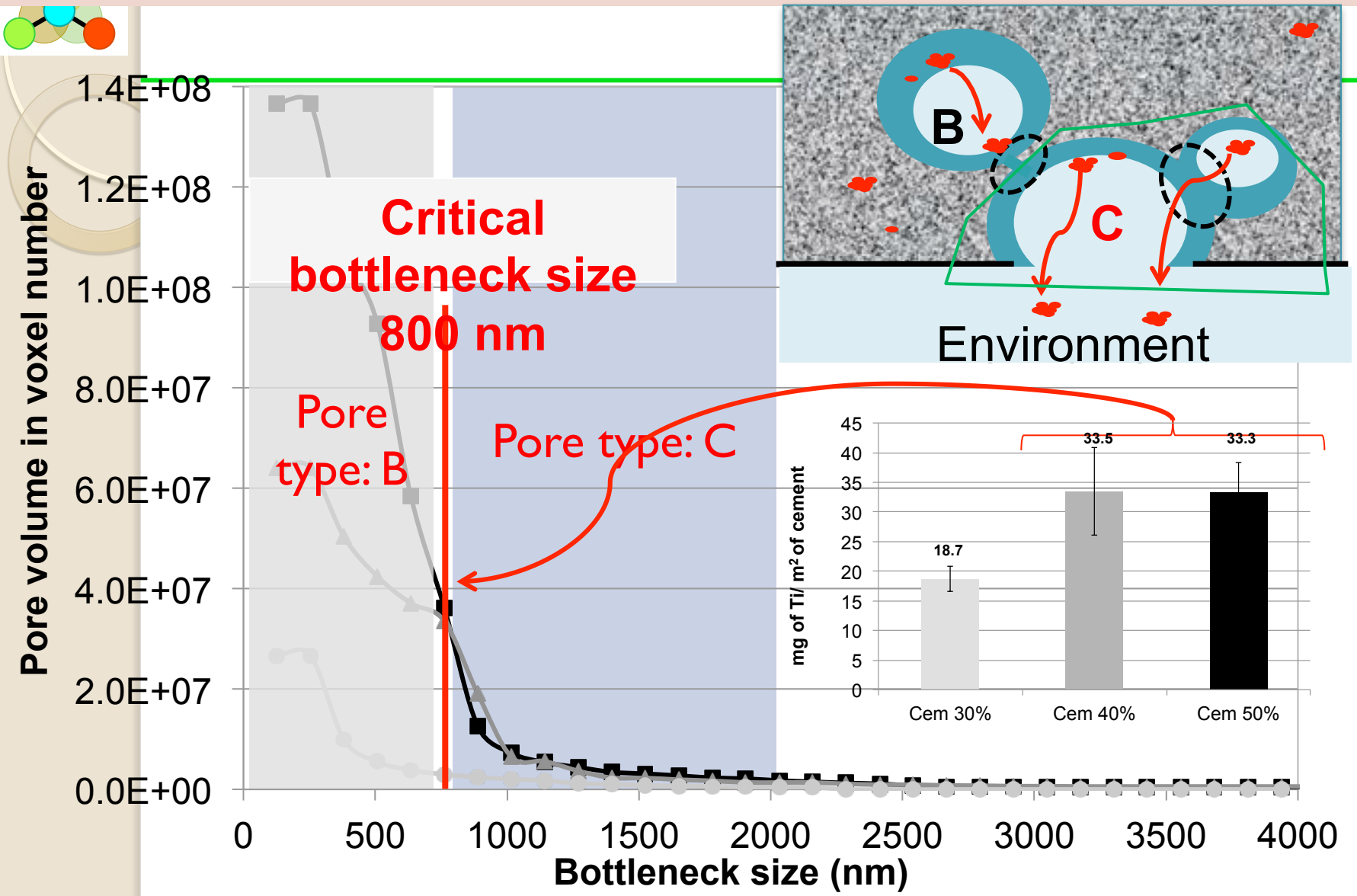
0-50 µm
Porosity : 58%
Connectivity : 99%

Porosity
+

-High porosity heterogeneity

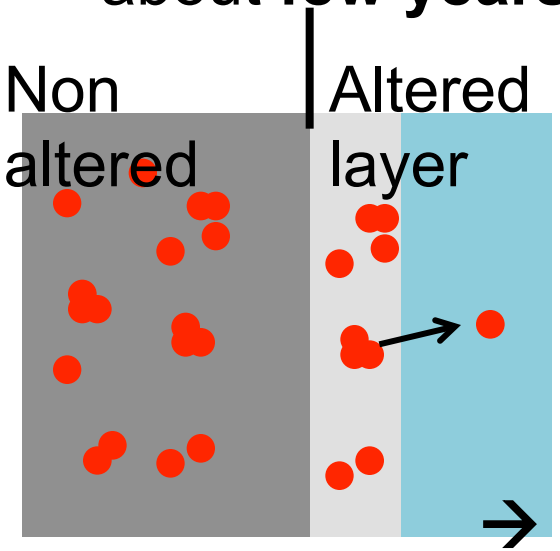
-Evidence of a very altered layer at the cement water/ interface

Pore volume connected to cement surface



Nano-TiO_2 exposure during use stage

According to bibliography, the leaching test could simulate about **few years** (2- 3 years) of cement use in real conditions

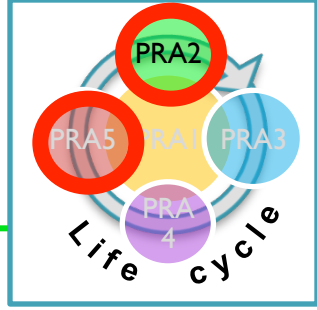


Release quantities **< 1%** of nano-TiO_2 present in the altered layer

→ **2 000 000 m²** of cement surface

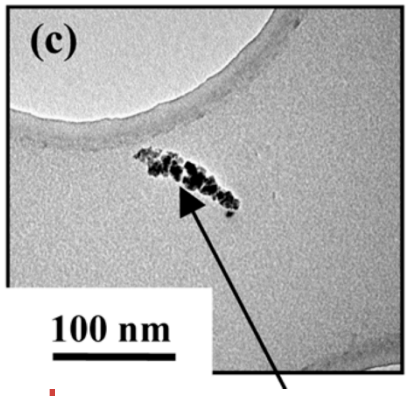
37 – 64 kg of nano-TiO_2 (2-3 years)
<<< **120 tons** incorporated in photocatalytic cement

Ex 2: Photocatalytic Paints (indoor and outdoor)



Release

Abrasion
After weathering



3 different aging platform
LABEX added value

Shandilya et al, 2015; 2014 a,b,c; Fiorentino et al, sub.

Progress of the project: research

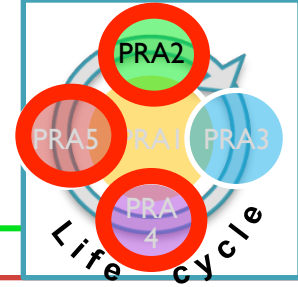
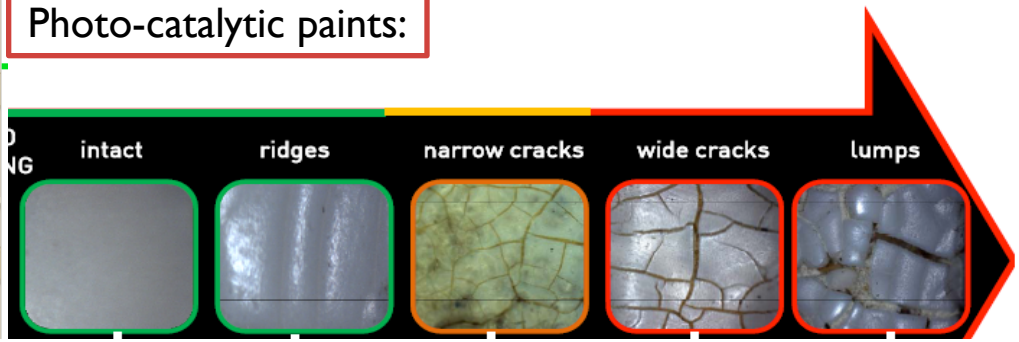
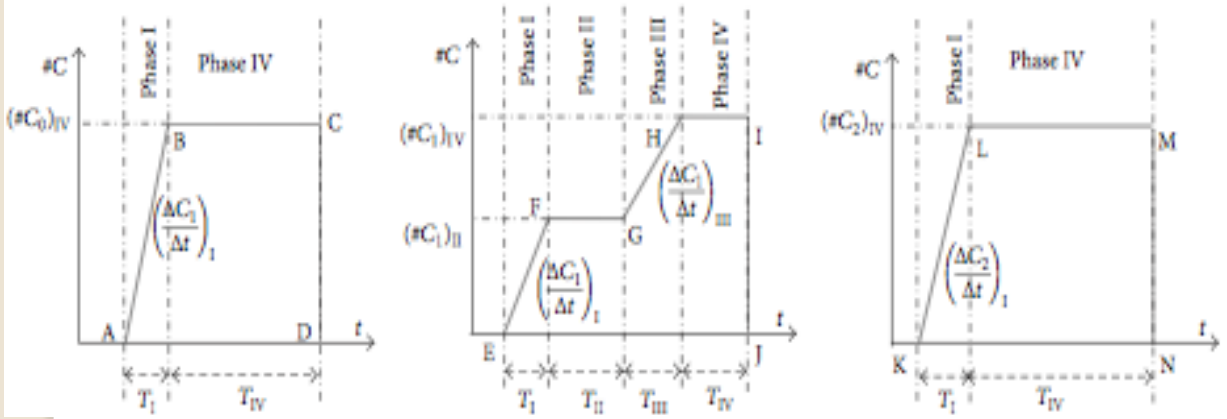


Photo-catalytic paints:



Model:
Particle aerosol release is modelized = f(layer number; support material (Brick, Wood, Stainless Steel), energy, And formulation

Release



Generalized forms of the variation of aerosol particle number concentration generated from (a) uncoated reference, (b) nanocoating 1, (c) nanocoating 2

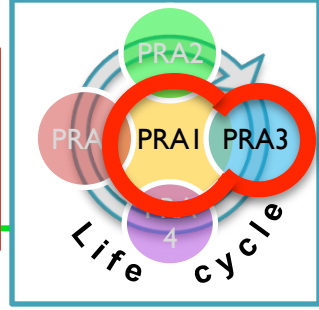
New

Material	90% of the number of wear particles have a size less than or equal to	% of the number of wear particles having size < 100 nm
Stainless Steel	7.3 μm	40%
Brick	14.3 μm	18%
Wood	23 μm	2%

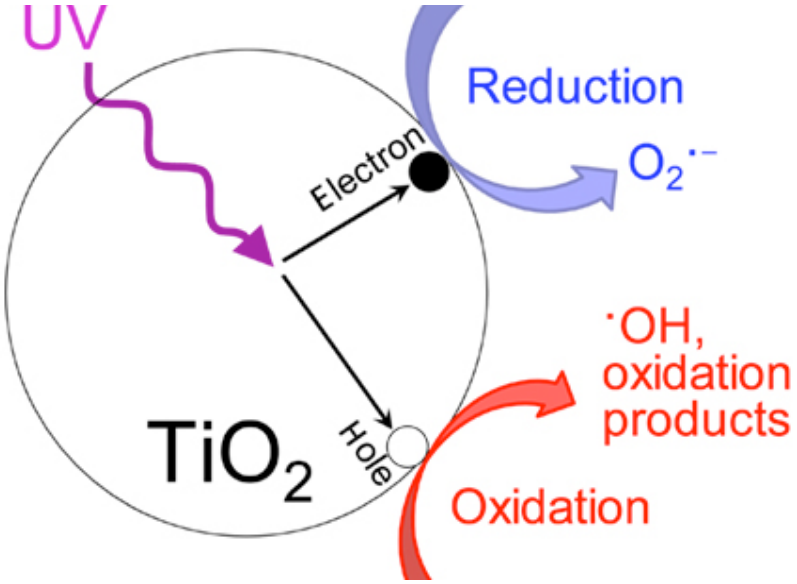
Table 6.3: Effect of the material type on the predicted size dist. of the wear particles as seen in figure 6.4 (b)

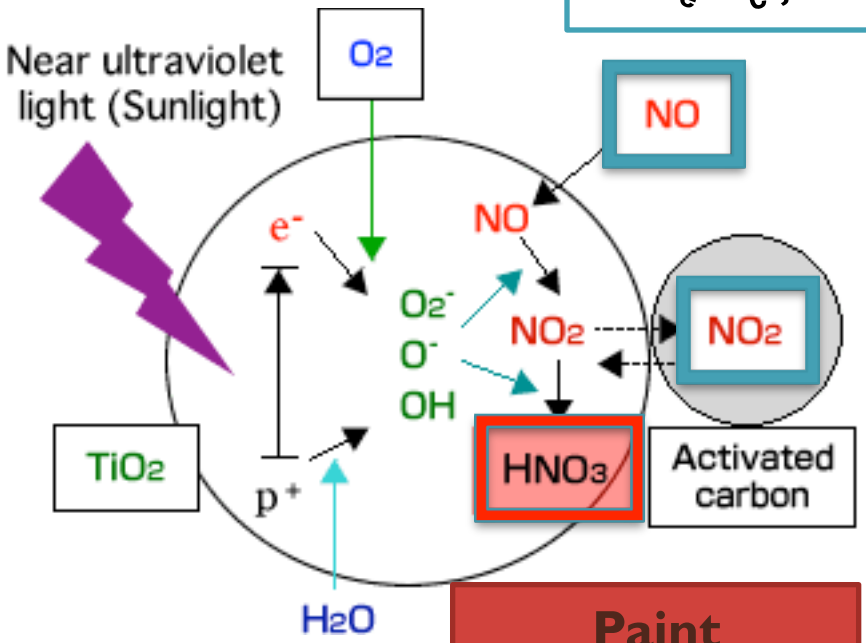
Shandilya,N et al, 2015, 2014 a,b,c

Ex3: Indoor paints and reaction with air



Contaminant





http://www.newkast.or.jp/english/Photocatalyst_Group.html

$$2NO_2 + H_2O \xrightarrow{+h\nu, TiO_2} HONO + HNO_3$$

$$NO_2(ads) \xrightarrow{+h\nu, TiO_2} NO(ads) + O(^3P)$$

$$NO(ads) + OH(ads) \xrightarrow{TiO_2} HONO$$

HONO = hazardous gas

Paint composition optimization: (<7% of TiO_2 in the surface layer)

Gandolfo et al, 2015

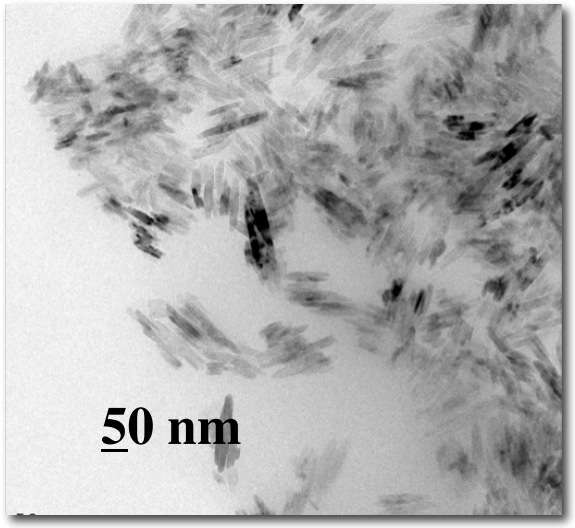
allios

New

Serenade

Ex 2: cosmetics

- TiO_2 nanocomposites added to sunscreen behave in a different way compared to bare TiO_2 nanoparticles (no extrapolation….)

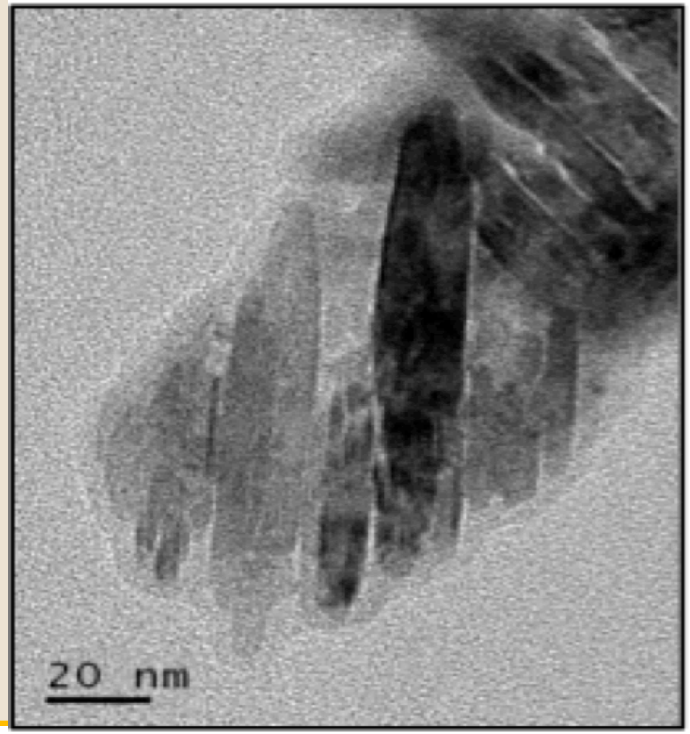


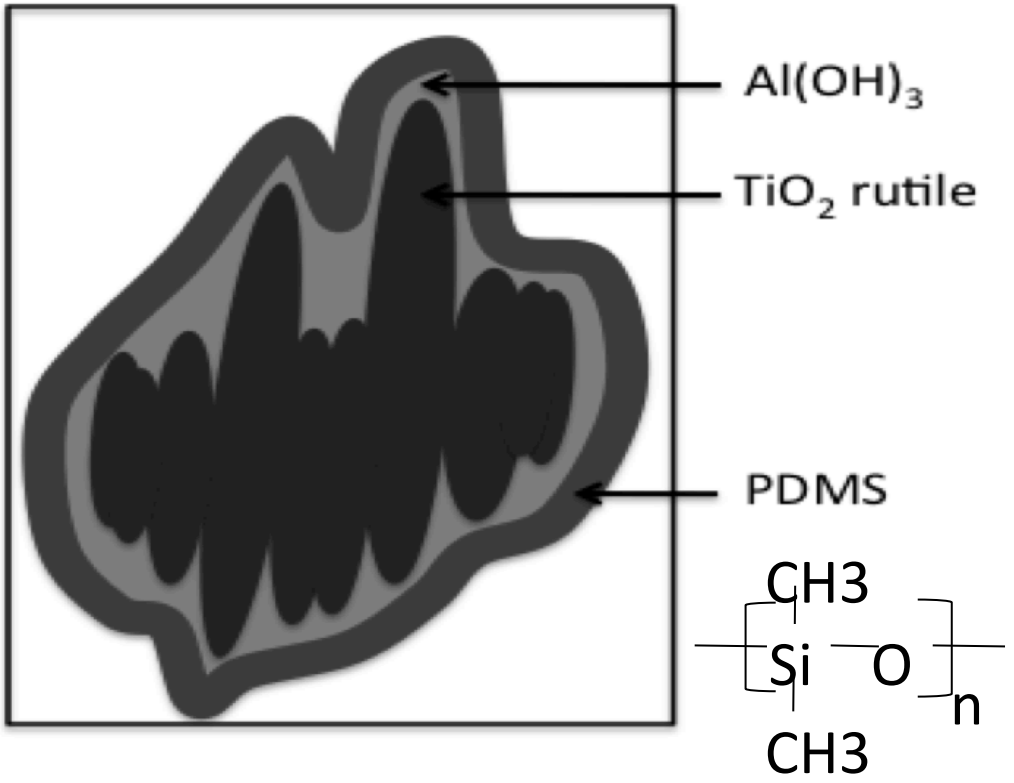
≈ 4.6% per weight of TiO_2

But in the environment: the Nps are obtained from the alteration of nano-products (plastics, cosmetics, paints, …..). These Nanomaterials are complex and may be they do not reveal the same properties as the pristine Nps

$TiO_2 + Al(OH)_3 + PDMS$ or $TiO_2 + SiO_2 + PDMS$

Size of particles: 10x50 nm



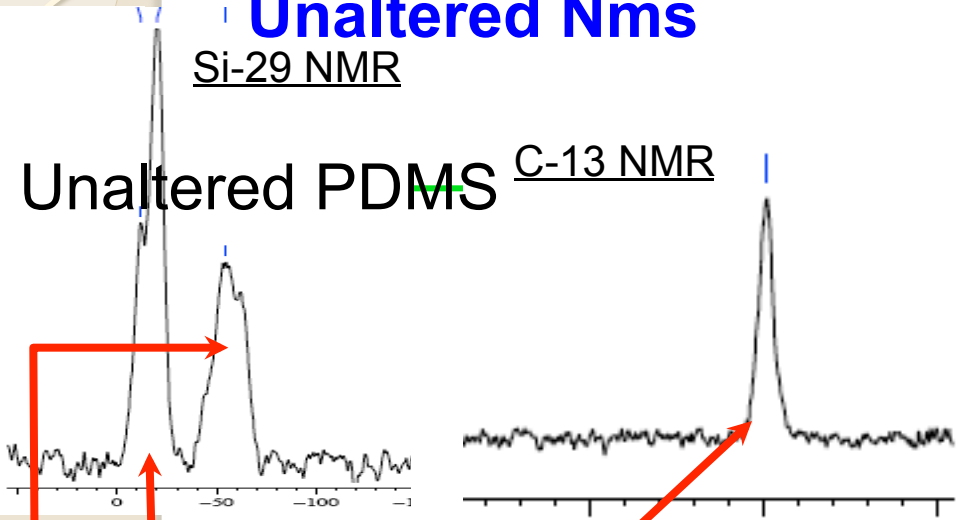


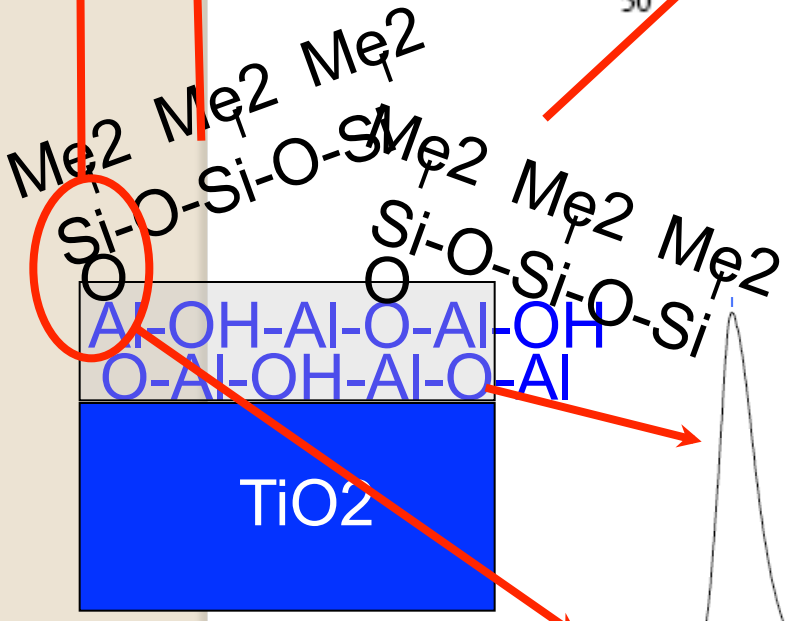
Unaltered Nms

Si-29 NMR

Unaltered PDMS

C-13 NMR





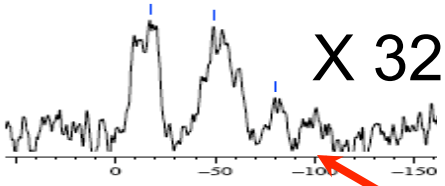
Al_{IV}-O-Si

Aged particle

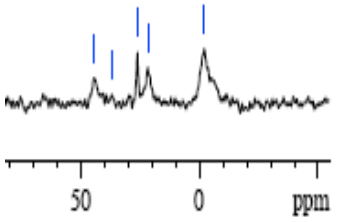
Strongly altered organic lay

Degradation of PDMS

X 32



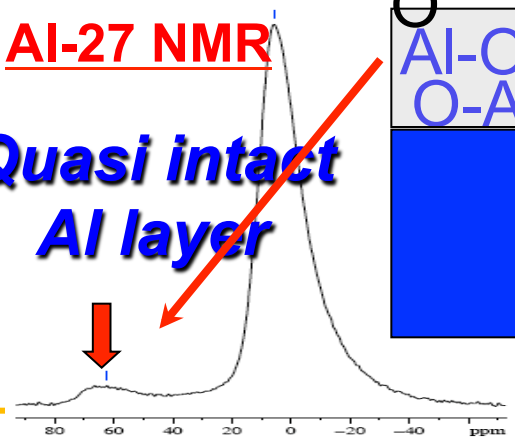
Loss of C signal



Si-29 NMR

C-13 NMR

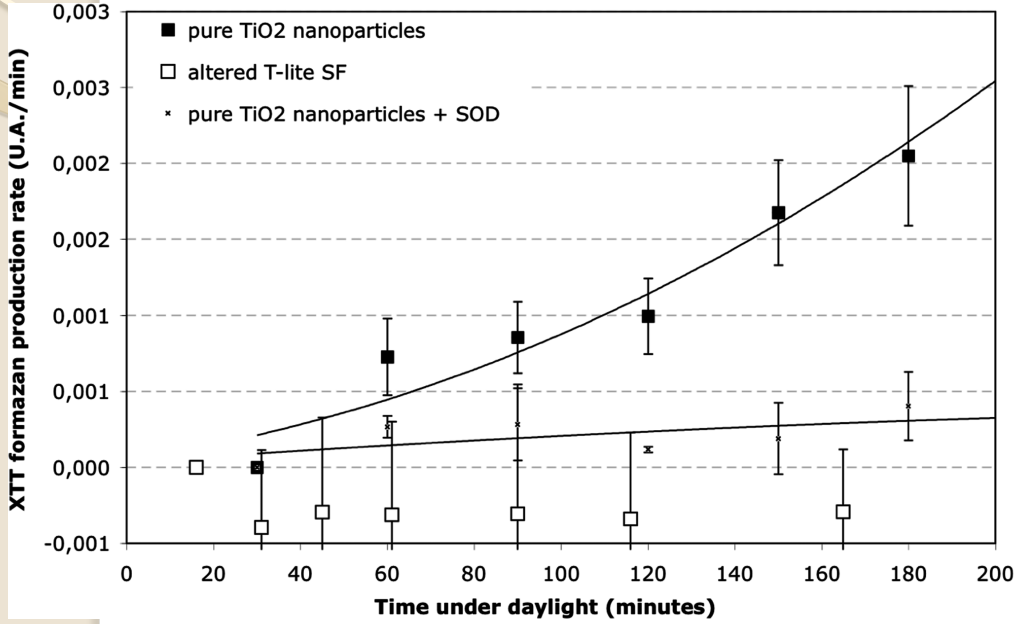
Al-27 NMR



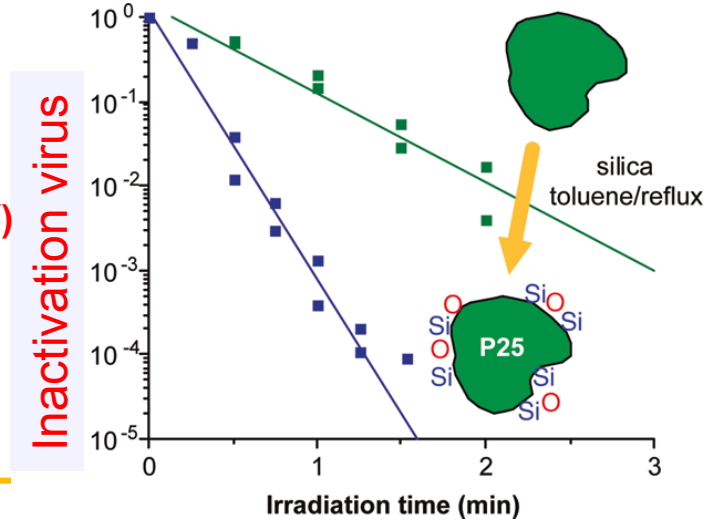
Quasi intact Al layer

Production of $O_2^{-\circ}$: « altered sunscceen NP » vs pure pristine rutile TiO_2

The $Al(OH)_3$ layer prevents the production $O_2^{-\circ}$



Not in the case of « SiO_2 » layer

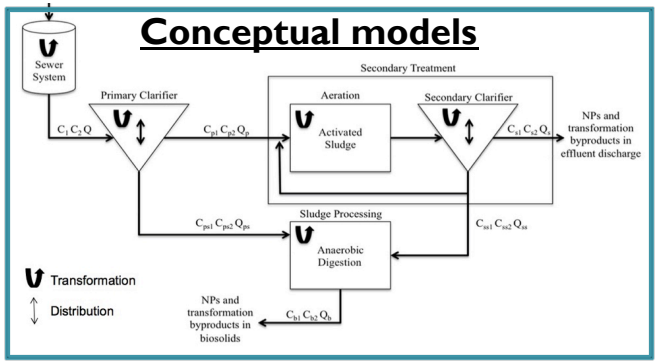


Band Gap Calculations (eV)	
TiO2(P25)	3.42
TiO2(P25)-SiO2(2.5%)	3.43
TiO2(P25)-SiO2(10%)	3.45
TiO2(P25)-SiO2(20%)	3.47

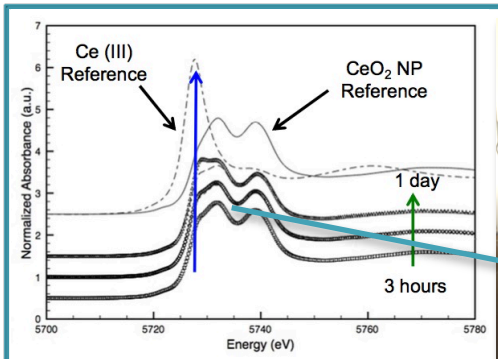
END OF LIFE in WWTP : Elimination modeling and evolution of the processes

PRA2 PRA5 PRA1 PRA3 PRA 4 Life cycle

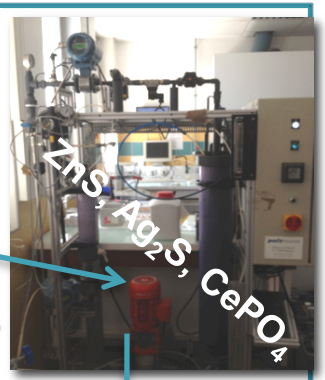
Conceptual models



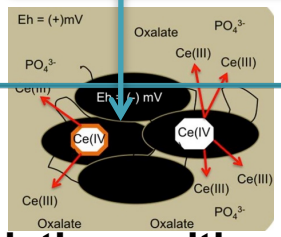
Transformation: XANES



Pilot experiments



Transformation and Distribution of NPs in bio-sludge



Removal > 85% for TiO_2, ZNO, CeO_2 but ~70% for Ag, Ce with sulfidation and phosphatation of Zn, Ag, Ce

NP	d_p (nm)	C_p (mg/L)	Final Removal (%)	Porous α_{calc} (2.3µm)
GA Ag	25	10	71.1 ± 0.4	0.0017
		50	72.8 ± 1.8	0.0020
	6	10	70.8 ± 2.1	0.0003
		50	65.2 ± 3.8	0.0003
Pristine CeO_2	8	10	90.8 ± 1.7	0.0064
		50	98.8 ± 1.6	0.0088
Citrate CeO_2	10	10	86.4 ±1.3	0.0023
		50	85.4 ± 0.9	0.0018
TiO_2	20	10	95.1 ± 1.0	0.0080
		50	98.9 ± 1.0	0.0094
ZnO	30	10	91.2 ± 0.3	0.0088
		50	94.2 ±1.7	0.0090

Predicted concentrations in sludge, affinity for bio-sludges (α)….

Biodiversity

Effluent concentrations

=> Coupling R and D of formulations with:

a)Efficacy of Elimination by WWTP

b)Modifications of bacteria communities

c)Adapt the WWTP processe

d)Agriculture landscape

e)Energy applications (CH_4)

cein International Consortium for the Environmental Implications of Nano Technology

L. Barton et al, 2014a, 2014b, 2015a,b

Duke UNIVERSITY

Call for 2015….a systemic approach based on 7 Case Studies: Paint,Food Pakaging,Cosmetics, End of Life WWTP, Safer QD, Safer Ag, Business Case Studies, gathering Labs and Companies

Pre-proposals received: 27 → Synergized into 7 case studies

SafeTiPaint	Ag-NW	Eco – SUN	Food Packing	Nano-WWTP	SAQUADO	Business Case Studies
CEA-LR2N, CEREGE, INRA, INERIS, IMBE, LCE, CEA-LCBM, Allios and *Lotus-Synthesis*	ISTerre, CEA-LITEN, Novancia Business School, IATE-INRA, CEREGE, CEA-iRSTV and *Protex, ETI, Cityzen Sciences, Armor Group, EMPA*	CEREGE, ISTerre, CEA-LEMiRE, INERIS, CEA-LITEN, and *Biocos, Helioscience, Cosmed, Cosmebio, CRIOBE, CNR italien*	INRA-IATE/ CEREGE/ ISTerre, LEMiRE, INERIS, CEA-PNS and *GET*	CEREGE, LEMIRE, MSPS, LITEN, CIRAD, CEINT and *Suez, Allios, Lotus Synthesis*	CEA – LEMOH – L2N – LBM, ISTerre, CEREGE, IMBE	All SERENADE Partners
PRA1,2,3 and 4 6 post-docs + 1 PhD	PRA 1,2,3 and 4 PEI 2 1 post-doc + 2PhD	PRA1,2,3 and 4 2 post-docs	PRA1,2,3 and 4 1 post-doc + 1 PhD	PRA1,2,4 and 5 1 post-doc + 1 PhD	PRA1 and 3 2 post-docs + 1PhD	PE1 and PE2

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

Conclusion

The Human and Environmental risk assessment must be evaluated taking into account the **low concentration** of Nms (**pristine** and along the **Nano-products Life Cycle**), the necessity to follow the **bio-markers** during a long time associated to a **chronic exposure**.

The use of **terrestrial and aquatic mesocosms** and **in vivo tests** is a necessity in order to **convolute exposure , transformation and bio- effects (Human and Trophic Chains)**.

Develop tests to i) evaluate the transfer and transformation of Nms issued from Paints, Cements, Food, Plastics,.Cosmetics…. to the environment (air, water, soils, sediments….), ii) the efficacy of WWTP (elimination, CH4 production…), and bio-sludge recycling risks….in order to have the best evaluation of the Life Cycle of Nanoproducts (see for example OECD WP-PW reports).

This implies to develop ***SAFER BY DESIGN*** Nanoproducs by associating i) Nanomaterials with the best efficiency and the lowest hazard effects and ii) the lowest release by developping organo-mineral formulations increasing the life time and limiting the rejects (See http:www.SERENADE.org, the H2020 PROgSAFE and NanoREG 1 and 2 projects)

Thank you
Merci !

http://Se3d.cerege.fr & http://nano.cerege.fr

Ste Victoire
Aix-en-Provence

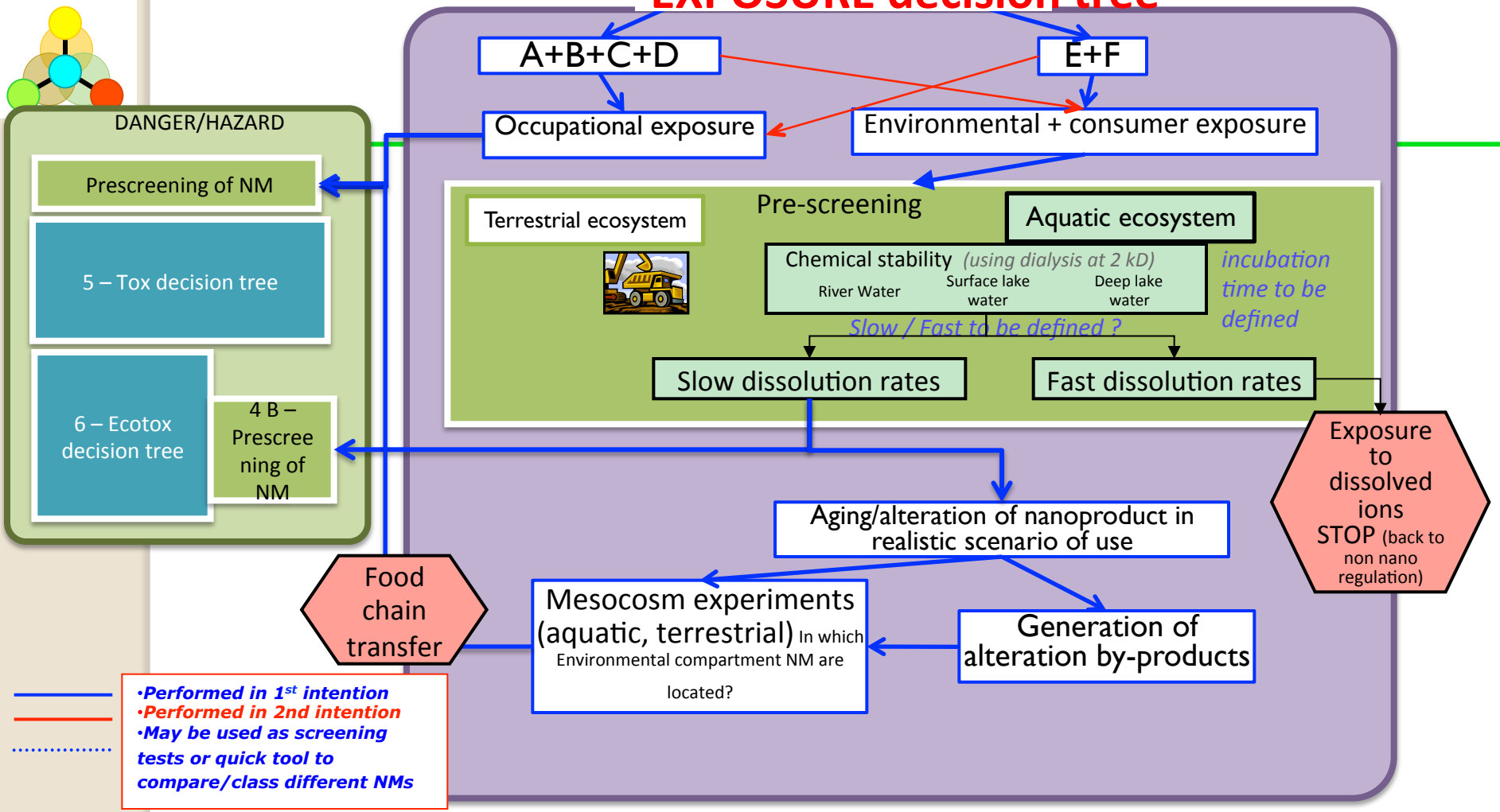
http://www.aixenprovencetourism.com

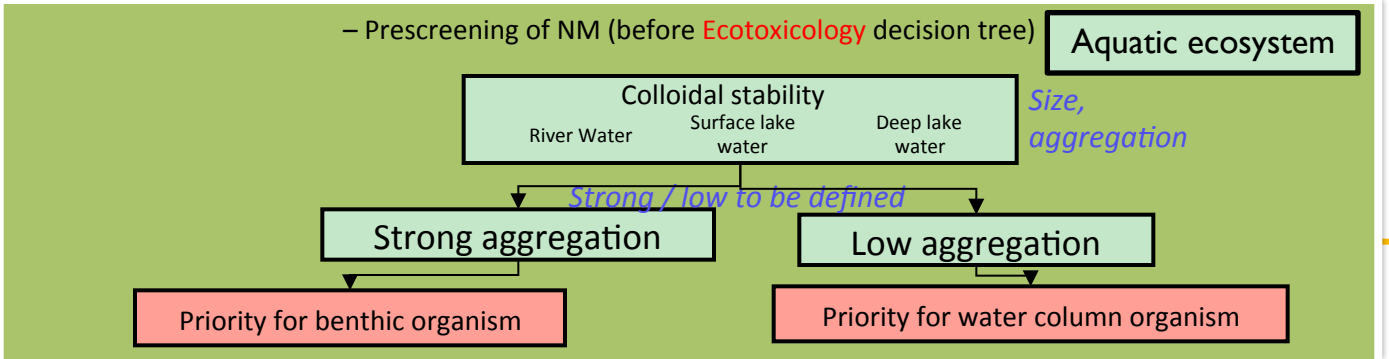
http://www.tourisme-marseille.com/parc-du-pharo-marseille.html

Aix Marseille Univ

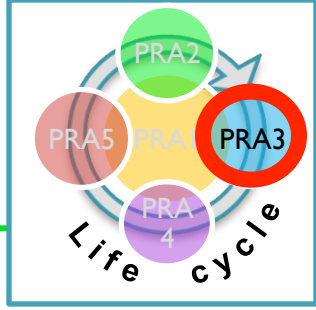
http://www.labex-serenade.org

EXPOSURE decision tree



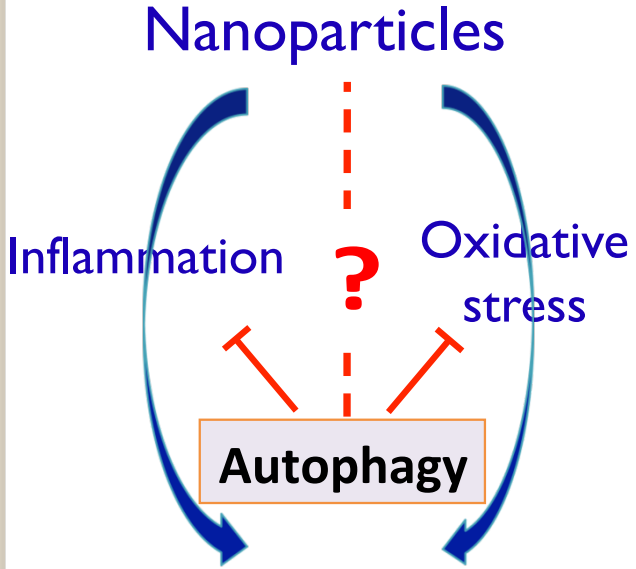


Ex: Autophagy Perturbation



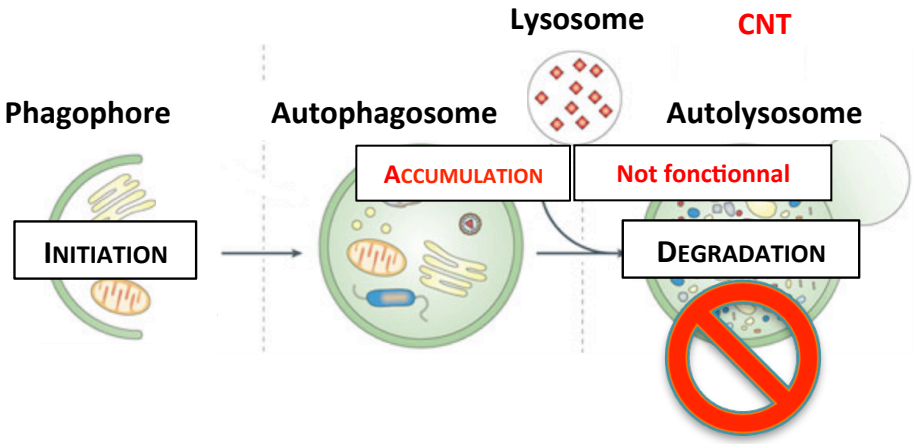
Biological hazard

- New mechanisms underlying nanoparticles toxicity?



Respiratory toxicity
(lung remodeling)
Long term effects

The autophagy process



Major results of the project :
TiO_2 NPs induce autophagy perturbation

New

Progress of the project: education

- 3 junior-chair positions:
  - Novancia Business School
  - University Joseph Fourier
  - University Paris Est-Créteil

To Identify, harmonize and strengthen the master programs

- E-learning pre-project (collab. with PREAU from Paris Île-de-France Regional Chamber of Commerce and Industry)
- Summer school: Bio-Health Erasmus mundus
- Internal SERENADE meeting (once a year)
- H_{2020}: Marie Curie (ITN) Project NECTAR
- Research Experiences for Undergraduates (REU) (Duke University, Carnegie Melon, Virginia Tech, Univ. Kentuky – CEREGE since 2011).

Education : links with research
Nanotechnologies, Eco-design, Innovation and Strategy

- Partnership with leading French Business School (ESCP – Paris Dauphine University) on Innovation Programs related to Sustainable Development (Junior Chair).
- The purpose is to link economic and innovative challenges related to nanotechnologies with ecological concerns (Eco-Design).

New

Actions:

Research into Business Development strategies for nano-based products in the context of sustainable development.

- Conferences and workshops in Business Schools on eco-design, innovation and entrepreneurship for nano-based products.
- Training program in Universities about innovation and eco-design.
- Publications in several technical network.
- Business cases studies.

Outreach actions :

- Conferences organisation:
  - 8th International Conference on the Environmental Effect of Nanoparticles and Nanomaterials
  - Nanoparticles: biology, health and environment
  - Recent advances in sustainable bio-based nanocomposites for food packaging
- SERENADE and H2020:
  - INERIS: NanoregII coordinator(CEREGE)
  - **PROSAFE :WP1 international networking (CEREGE) Europe-US (CEINT, Duke Univ., Univ. of Kentuky, Virginia Tech, Stanford Univ. Carnegie Melon, …)**
- SERENADE and FP7 and H2020 EU Projects

Financial Leverage

  - Member of the review committee (FP7 nanosafety projects)
  - SERENADE= entry ticket to join NANOREG (European pre-standardization, Ministry of the Environment)
  - Members of SUN, Nanorem, Nano MILE, NanoETHER, NANO-Index

Project Impacts: links with Companies, Agencies, Organisms…

- Socio-economical impacts:
  - SERENADE responding to market and end-users needs and fears
  - SERENADE seminar tour
    - **SUEZ - Environnement => new partner**
    - L'Oréal, FIPEC (2 meetings + SC), Solvay (Invitation to CSP), Association des Entreprises pour l'Environnement
    - Colas (March 2015), Technic (Kemesys)
    - **Cosmed/ Lotus-Synthesis (SMEs.)(new projects)**
  - SERENADE promoting dialogue between scientists and policy makers
    - Debates: Forum NanoRESP, SPPPI : « Nanotechnologies : amies ou ennemies »
- SERENADE is a pre-competitive action:
  - Translation of academia research into legally binding regulation:
    - Member of ANSES
    - Standardization agencies AFNOR, CEN, ISO (Allios, CEA, CEREGE, Suez Env.)
    - OECD committees (INERIS, CEREGE)

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

SERENADE attractiveness

- PhD and Post-doc task force: 9 foreigners (international calls)
- Invited professors:
  - USGS, Berkeley, Virginia Tec., Baylor Univ., Duke Univ.(USA), EPFL(Switzerland), National Institute Chemistry (Slovenia), Univ. Wuppertal (Germany)
- Analytical platforms: collaborations (USA & EU PhD and Post-doc)