

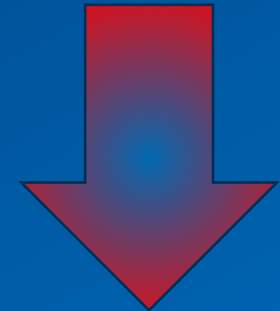
Route to international standardisation of advanced nanomaterials via pre-normative interlaboratory studies

Charles Clifford

Chair ISO/TC 229 Nanotechnologies

Surface Technologies, National Physical Laboratory, UK

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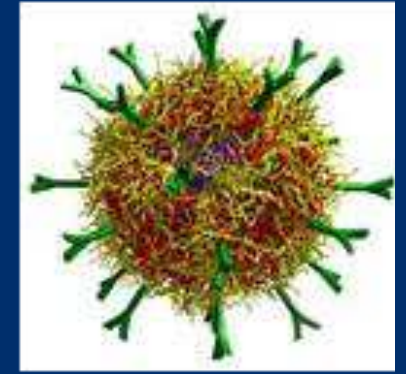
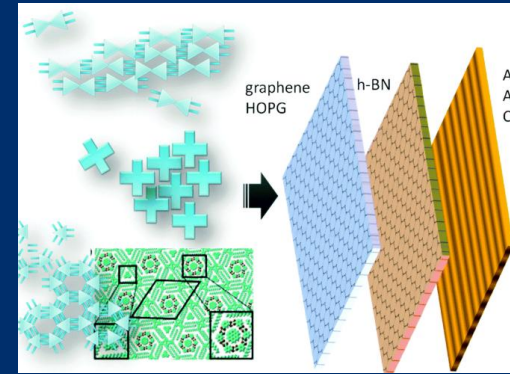
Industrial Developments in Nanomaterials including 2D materials

High Volume, low Cost



- Many companies producing low cost material
- Race to the lowest price
- Leads to poor quality and inconsistency
- Garbage in, Garbage out
- Need Standards for quality and assurance

Highly specialised



- Material properties tailored to application
- Highly specific surface functionalisation, size/shape
- Need Standards!

Why standardised (developing ‘norms’)

- ISO Standards represent the best practice
- Improve reproducibility and repeatability
- Reduce time to market – valid methods that speed up regulatory approval and industry adoption.
- Standards are made by consensus of all stakeholders
 - Developed by the community, for the community
- Standards allow global harmonisation, ensuring international compatibility, reducing trade barriers and improving EU industry competitiveness
- Standards facilitate industry acceptance
- Standards can form the basis of regulations

From Lab to Standards



Lab
Develop method



International
interlaboratory
testing

Test and validate
method

TWA 2 - surface chemical analysis

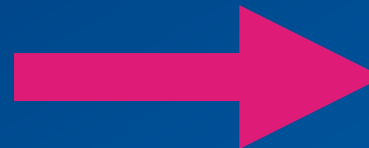
TWA 34 - nanoparticle populations

TWA 40 - synthetic biomaterials

TWA 41 – graphene and related 2D materials

TWA 42 – Raman spectroscopy

Applications



Standards

**ISO/TC 229
Nanotechnologies**

ISO /TC 24/ SC4
Particle sizing

**CEN/TC 352
Nanotechnologies**

**ISO/TC 201
Surface Chemical
Analysis**
XPS, SIMS, SPM,
Nanomaterials, optical



1982 Versailles

8th - G7 Economic Summit



Formed as one of 18 cooperative projects to stimulate **world trade** in new technologies using **advanced materials** through **pre-standards research**

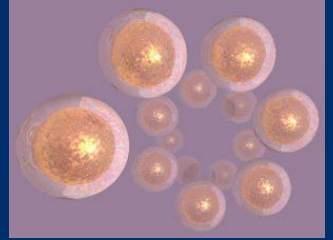
- **only one surviving and growing**

VAMAS (Versailles Project on Advanced Materials and Standards)
- **International Interlaboratory comparison organisation**

To promote world trade by innovation and adoption of **advanced materials** through international collaborations that provide the technical basis for harmonization of measurement methods, leading to **best practice, reference materials and standards**



Interlaboratory comparison – how they work



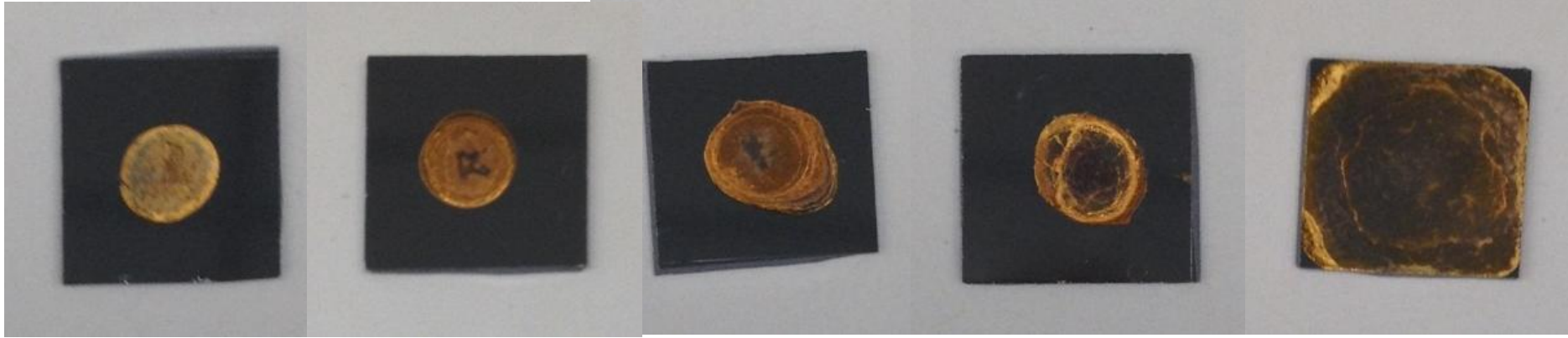
- Define measurement method to test
- Develop protocol and test “reference” samples
- Recruit participants
- Send samples and protocol
- Participants do the expt and send results back
- Analysis and find issues
- Method improvements – feeds into ISO standard

Interlaboratory comparisons – - where they do wrong?

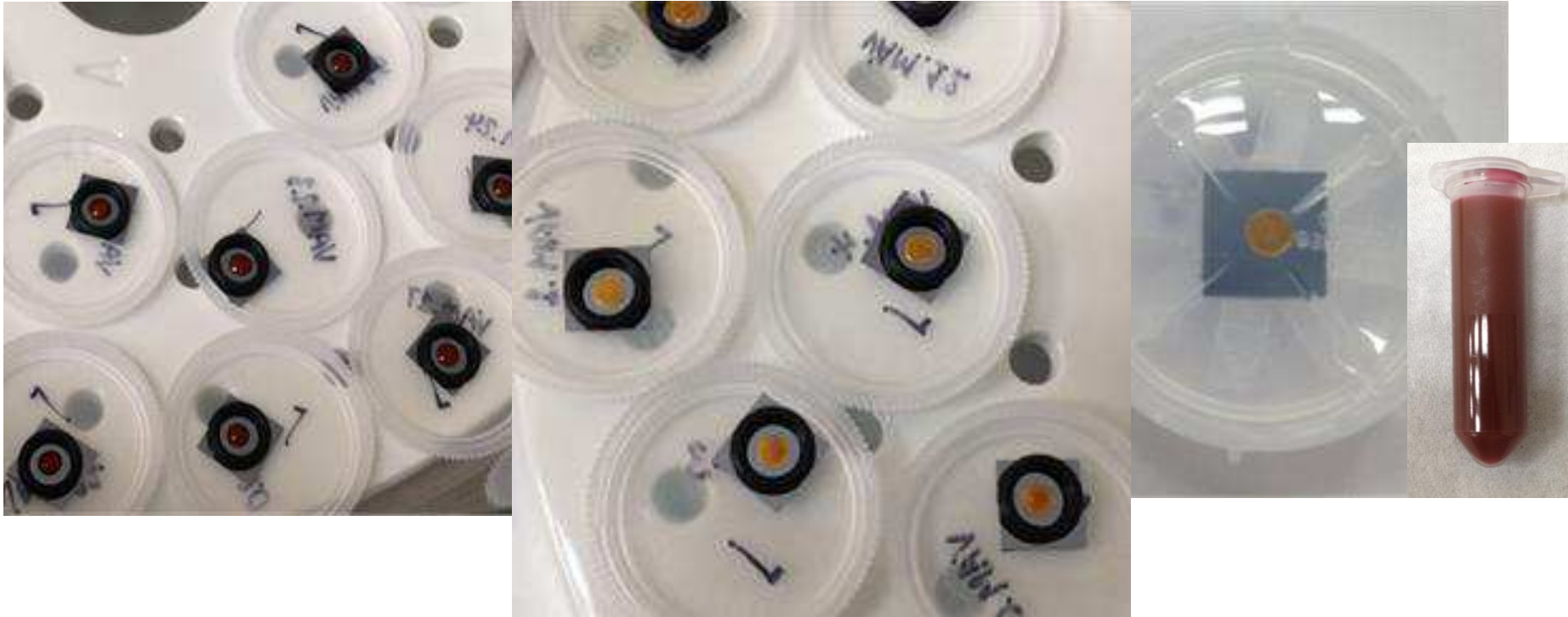
- Sample preparation
- Instrument calibration
- Instrument issues
- Sample variability
- Participants not reading the protocol!
- Enables better standards



Example – Poor sample preparation



Participants prepared



NPL prepared

Project A50

Determination of shell thickness and chemistry of core-shell nanoparticles using X-ray photoelectron (XPS) spectroscopy

Objectives

- To validate an XPS-based measurement protocol for measuring the shell thickness and chemistry of core-shell nanoparticles.
- Support revision and development of ISO/TR 23173 into a full ISO standard.

The results will support the revision of ISO/TR 23173 and contribute to the development of a full ISO standard under ISO/TC 201.

This work also aligns with a proposed pilot studies under BIPM CCQM SAWG, helping to establish reference materials

Background

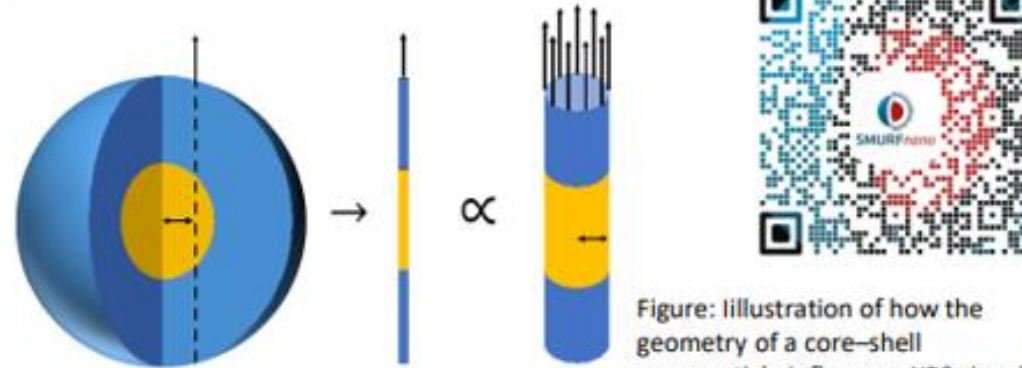


Figure: illustration of how the geometry of a core-shell nanoparticle influences XPS signal interpretation.

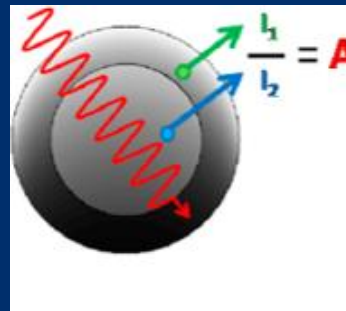


Gold-silica nanoparticle for XPS ILC study

3 thicknesses prepared



ISO ISO 23173 Surface chemical analysis — Electron spectroscopies — Measurement of the thickness and composition of nanoparticle coatings



Example: VAMAS ILC periodicity measurements

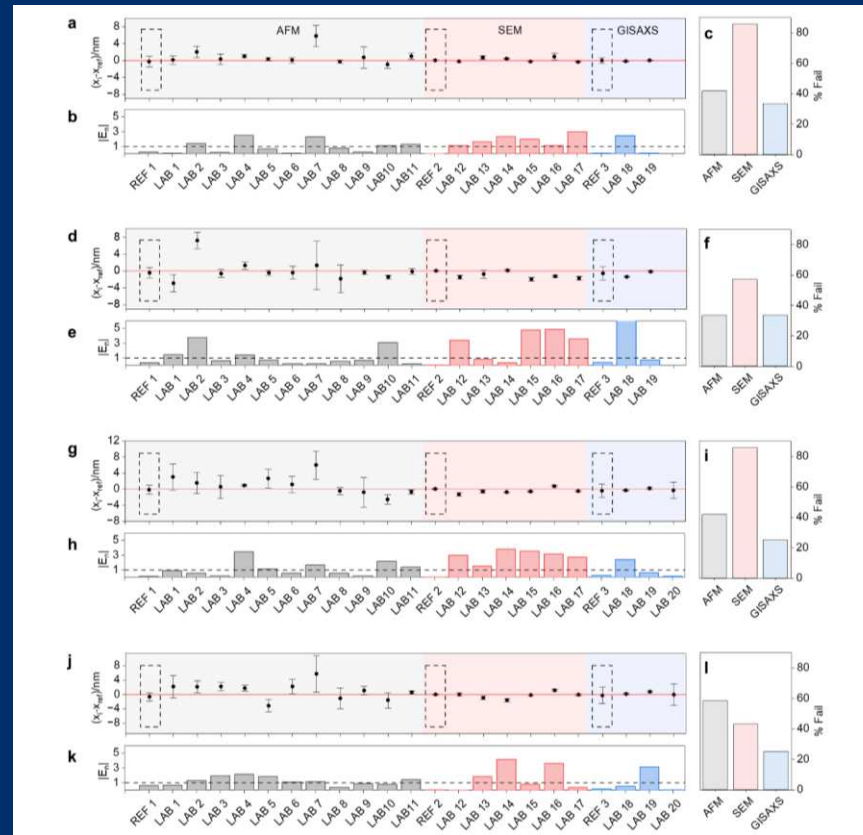
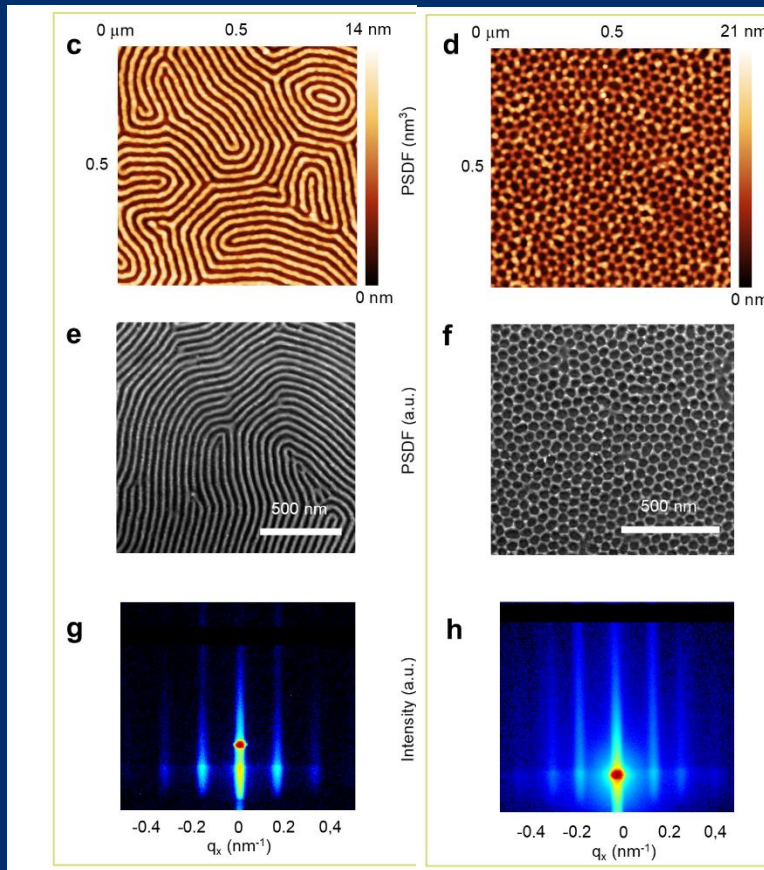
Led by F Ferrarrese, G Milano, INRIM

Using AFM, SEM, GISAXS to measure periodicity in block copolymers

> 30% of AFM,
> 55 % of SEM
> 20% GISAXS results not
consistent with reference
value.

calibration issues, where
incorrect or incomplete
calibration procedures
introduced systematic shifts
in the measured periodicity,

procedural variability, since
for each technique there are
some procedures (also
subjected to human variability,
such as parameter adjustment)



ISO/TC 229 Nanotechnologies - Structure

38 P members, 18 O members, 27 internal liaisons, 11 external liaisons

(including OECD, EC, NIA, ECOS, ANEC, ETUI, IUPAC)

Secretariat: UK: Chairman: Charles Clifford (UK)



JWG 1 Terminology and Nomenclature (Canada)

JWG 2 Measurement and Characterization (Japan)

WG 3 Health, Safety and Environment (USA)

WG 4 Material Specification (China)

WG5 Products and Applications (Korea)

NLCG Liaison coordination group

TG2 Sustainability, consumer and societal dimensions of nanotechnologies

AHG1 Advanced Materials

AHG2 Nano-bio

116 published documents and over 60 under development

Meeting twice yearly, Last meeting: 18- 22 May 2026 Sydney

Next Meeting: 19-23 Oct, Mexico.

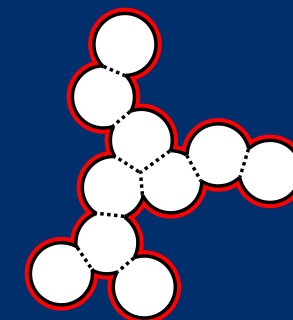
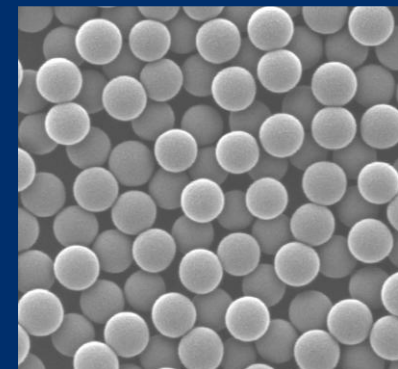
2027: Spring – Europe?? (host required)

Examples of Nano Standards supporting regulation



Measurement standards
– microscopy SEM (19749), TEM (21363) (US led)

- Suspension based techniques
- Aerosol based techniques



Nanoparticle number concentration – ISO TS 24672

NPL, UK.

Agglomeration aggregation state – CEN published 2026

NPL, UK

Manufactured nano-objects in food additives – CEN published 2026

LNE, France

Measurands ISO TS 23302

NPL, UK

Terminology Standard ISO TS/80004-1

Evonik, Germany,

Example: Graphene Standardisation

Terminology Standard ISO TS/80004-13:2024

NPL, UK

Classification framework for GR2M - TS 9651:2025

Mito/Graphene Council, US

Measurement Technical Report TR 19733

US, Korea

**Structural
Characterisation of
CVD graphene**

DTS 21356-2

NPL, UK

**Structural Characterisation
of Graphene Flakes
TS 21356-1:2021**

NPL, UK

**Structural Characterisation
of GO Flakes
DTS 23879**

NIM, China

**Chemical
Characterisation of
graphene related 2D
material flakes
TS 23359**

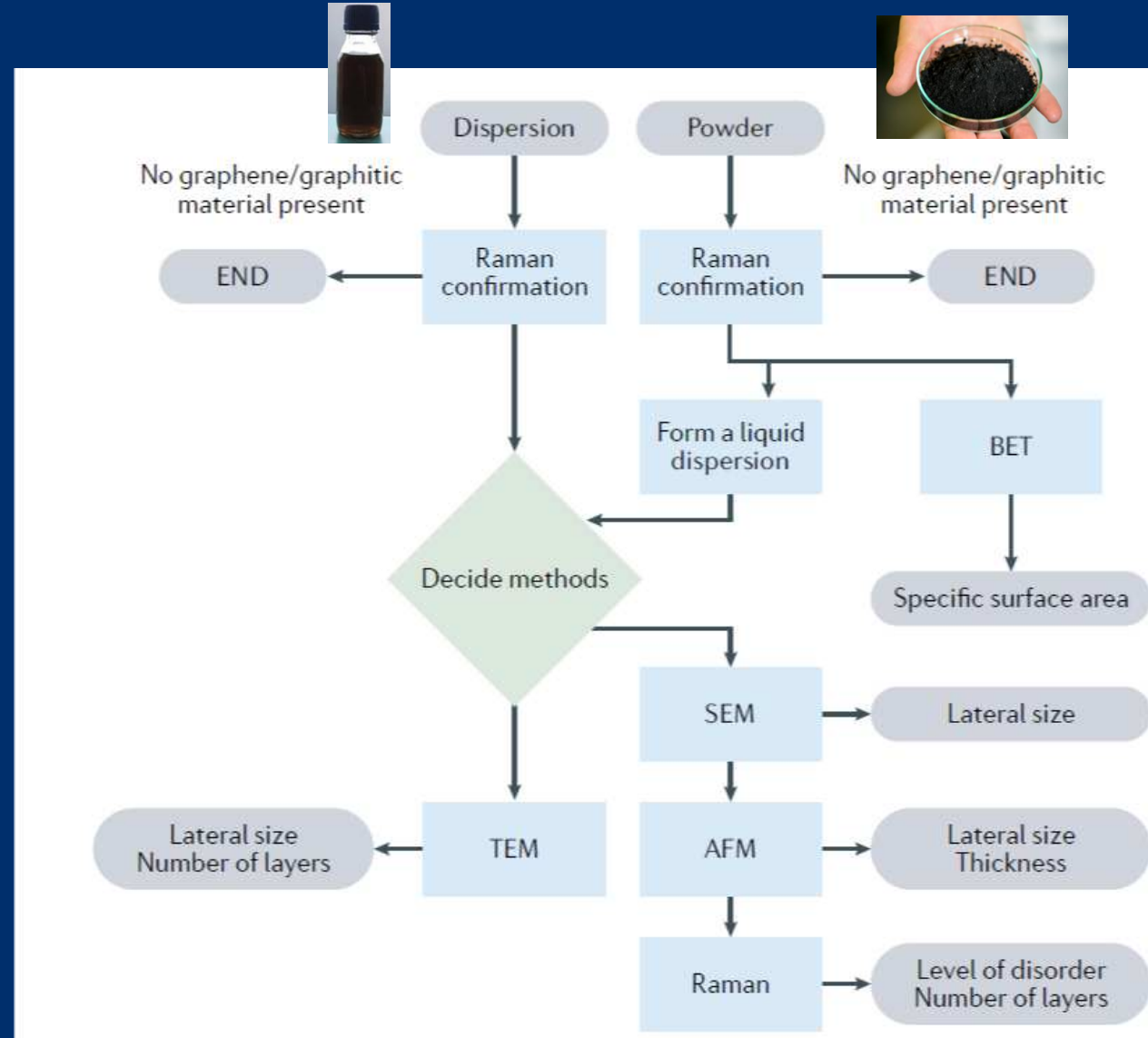
NPL, UK



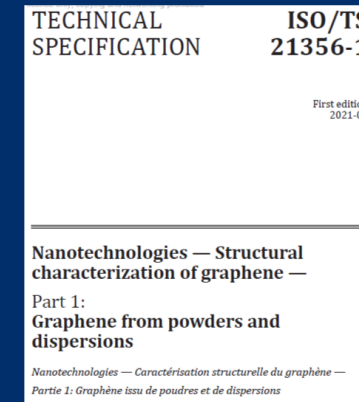
Developed in ISO TC229 (nanotechnologies) , Documents are dual logo ISO/ IEC
MUCH FUNDED VIA EUROPEAN METROLOGY PROJECT – ISO GScope

ISO/TS 21356-1 Structural characterization of graphene

– Part 1: Graphene from powders and dispersions



- Order of methods for characterising graphene flakes
- Number of layers (thickness), lateral flake size, the level of disorder, layer stacking and specific surface area
- Suggested measurement protocols, sample preparation routines and data analysis given



- Published 2021
- Next step – full international standard
- Validate measurement methods via ILCs¹⁴

Terminology standards

ISO TS 80004: series

- Part 1: Core terms – now full ISO standard (combining parts 1,2,4 and 11)
- Part 3: Carbon nano-objects
- Part 5: Nano/bio interface
- Part 6: Nano-object characterisation
- Part 7: Diagnostics and therapeutics for healthcare
- Part 8: Nanomanufacturing processes
- Part 9: Electrotechnical products and systems
- Part 12: Quantum phenomena in nanotechnology
- Part 13: Graphene and other 2D materials

ISO/TS 4958:2024 Nanotechnologies — Vocabulary — Liposomes

Future: ISO DTS 19255, Nanotechnologies — Vocabulary — Innovations in materials and technology: advanced materials.

ISO terms and definitions AVAILABLE FOR FREE at www.iso.org/obp

ISO 80004-13:2D materials

Terminology Standard

- 2nd edition published 2024
- *** Freely available at www.iso.org/obp ***
- Defines graphene, 2D material and 97 other terms.

4 Abbreviated terms

1L	monolayer/single-layer
1LG	monolayer/single-layer graphene
2D	two-dimensional
2L	bilayer
2LG	bilayer graphene
3L	trilayer
3LG	trilayer graphene
CVD	chemical vapour deposition
FL	few-layer
FLG	few-layer graphene
GNP	graphene nanoplatelet
GO	graphene oxide
hBN	hexagonal boron nitride
rGO	reduced graphene oxide

3.1.1.1

two-dimensional material

2D material

material, consisting of one or several layers with the atoms in each layer strongly bonded to neighbouring atoms in the same layer, which has one dimension, its thickness, in the nanoscale or smaller and the other two dimensions generally at larger scales

Note 1 to entry: The number of layers when a two-dimensional material becomes a bulk material varies depending on both the material being measured and its properties. In the case of graphene layers, it is a two-dimensional material up to 10 layers thick for electrical measurements, beyond which the electrical properties of the material are not distinct from those for the bulk [also known as graphite].

Note 2 to entry: Interlayer bonding is distinct from and weaker than intralayer bonding.

Note 3 to entry: Each layer may contain more than one element.

Note 4 to entry: A two-dimensional material can be a nanoplate.

3.1.2.1

graphene

graphene layer

single layer graphene

monolayer graphene

single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure

Note 1 to entry: It is an important building block of many carbon nano-objects.

Note 2 to entry: As graphene is a single layer, it is also sometimes called monolayer graphene or single layer graphene and abbreviated as 1LG to distinguish it from bilayer graphene (2LG) and few-layered graphene (FLG).

Note 3 to entry: Graphene has edges and can have defects and grain boundaries where the bonding is disrupted.

3.1.2.10

few-layer graphene

FLG

two-dimensional material consisting of three to ten well-defined stacked graphene layers

3.1.2.13

graphene oxide

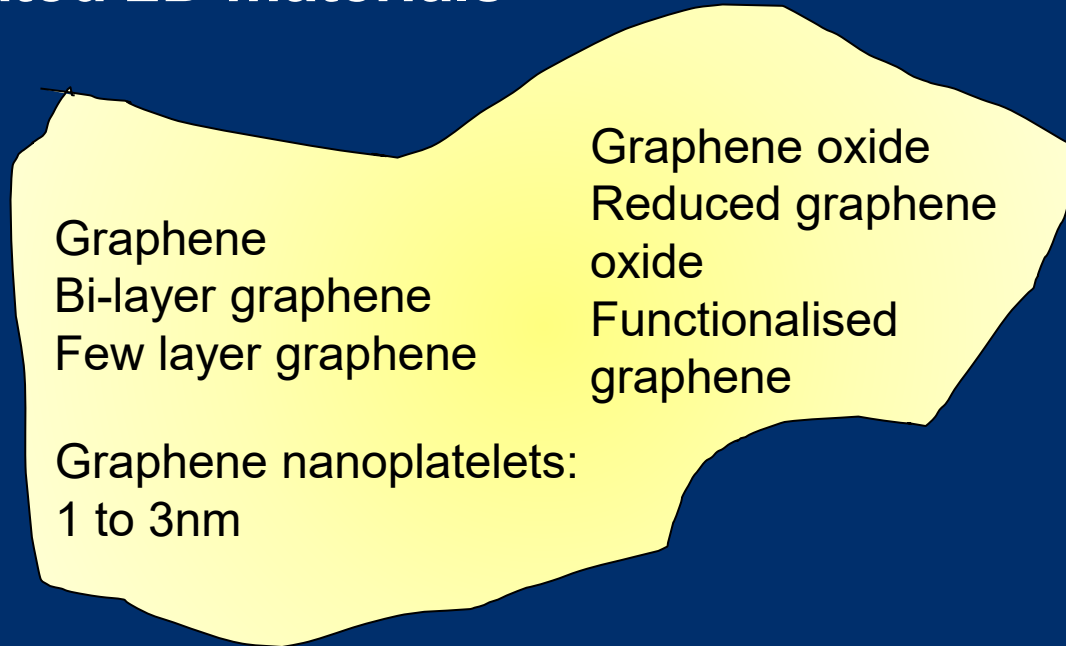
GO

chemically modified graphene prepared by oxidation and exfoliation of graphite, causing extensive oxidative modification of the basal plane

Note 1 to entry: Graphene oxide is a single-layer material with a high oxygen content, typically characterized by C/O atomic ratios of approximately 2,0 depending on the method of synthesis.

Introduces an over-arching term to describe carbon-based 2D materials:
graphene related 2D materials

INCLUDES



EXCLUDES

graphite

Flakes of any carbon
chemistry > 10 layers



3.1.2.3

nanographite

flake (3.1.1.3) that consists of *layers* (3.1.1.8) of graphene with a thickness of 11 or more *layers*, with a total thickness of up to 100 nm

3.1.1.2

graphene-related 2D material

GR2M

DEPRECATED:graphene-based material, graphene-material

carbon-based two-dimensional material consisting of one to 10 *layers*, including *graphene*, graphene oxide, reduced graphene oxide and functionalized variations thereof

Note 1 to entry: This includes *bilayer graphene*, trilayer graphene, and *few-layer graphene*.

Note 2 to entry: The terms graphene-based material and graphene-material are deprecated here. They have been used to describe materials other than graphene, such as graphene oxide.

Note 3 to entry: "Graphene-related 2D material" is defined in contrast with *graphene-based*. and *GR2M -based*.

Advanced materials

ISO DTS 19255, Nanotechnologies —
Vocabulary — Innovations in materials and
technology: advanced materials —
publication due 2026

3.3.4

advanced material

material with significant improvements in properties or performance for a specific application or measure

Note 1 to entry: Improvements in properties or performance can be related to efficiency, sustainability, capability or other measures. ...

Note 2 to entry: Materials that are considered to be advanced materials today are anticipated to be displaced or to become conventional materials in the future.

Note 3 to entry: Some but not all advanced materials are created by an *advanced technology* (3.2.3).

Note 4 to entry: Some but not all nanomaterials are *advanced materials* (3.3.4).

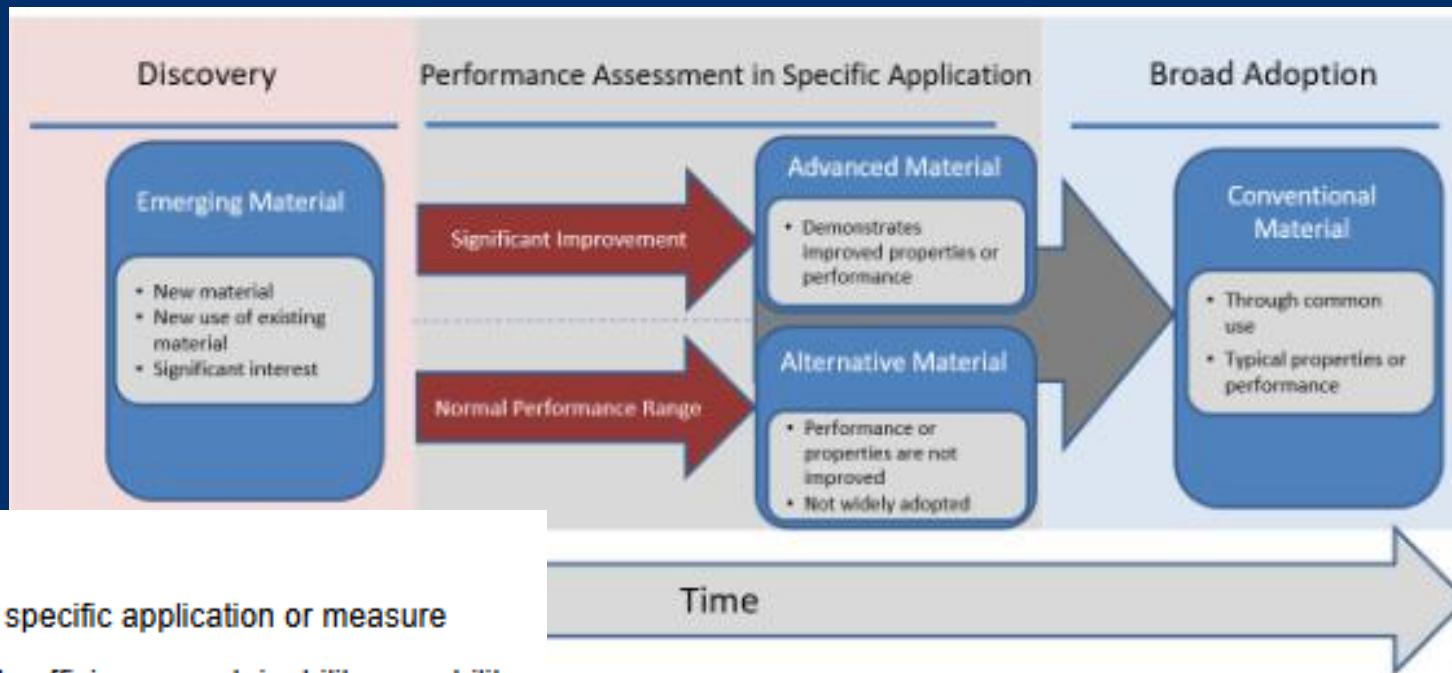
Note 5 to entry: Advanced materials can be, but are not always *complex materials* (3.3.3).

Note 6 to entry: Might include new functionality or emergent properties of a material

Note 7 to entry: significant improvements in performance and properties relate to conventional materials (when they exist)

Note 8 to entry: Commonly used in *advanced technologies* (3.2.3) or *specialty applications* (3.2.5)

Note 9 to entry: Some advanced materials gain their improved properties through modification of their internal or surface structure



Also defining:
Conventional material (and
technology)
Emerging material
Etc

NOTE DRAFT – STILL UNDER
REVISION

- Advanced materials
- Other 2D materials
- Nano-bio, Engineering biology, advanced biotech, nanomedicines
- Incorporating AI and digital tools into standards
- Sustainability and environment, Nanoplastics
- Energy storage materials
- Industrial complex systems

Summary

- Measurement enables innovation in advanced nanomaterials
- Reproducibility requires
 - interlaboratory studies and
 - International standards
- If you're not in the room you have no voice – do get involved!



Thanks

NPL standards makers particularly Alex Shard, Caterina Minelli, Andrew Pollard, Fernando Castro

BAM, INRIM, LNE colleagues

ISO TC201, ISO TC229 experts

VAMAS participants



The project (23NRM02 SMURFnano) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.



This project "Standardisation of structural and chemical properties of graphene" (ISO-G-SCoPe) has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme under Grant agreement No. 19NRM04 ISO-G-SCoPe

Advanced Materials from a (pre-) regulatory perspective: Status Quo and Challenges

Andrea Haase

German Federal Institute for Risk Assessment (BfR)

17.06.2026, NANOTECH Conference, Paris

Overview

- **Advanced Materials**

- *Introduction & Regulatory Perspective*
- *Importance of Risk Governance & Activities at the OECD*

- **Lessons learnt from EU HARMLESS Project**

- *Early Warning System & Safe-and-Sustainable-by-Design*
- *Insights into Case Studies*

- **Next Steps**

- *German Interagency Working Group*
- *Strategic Research Agenda*
- *Malta Initiative*

- **Take Home Messages**

Advanced Materials & Risk Governance

Advanced Materials (AdMa)

Strategies



Global challenges



Advanced Materials (AdMa)

OECD working description:

“AdMa are understood as materials that are rationally designed to have

- (i) **new or enhanced properties**, and/or
- (ii) **targeted or enhanced structural features** with the objective to achieve **specific or improved functional performance**.

This includes [...] **new emerging manufactured materials**, [...] **materials that are manufactured from traditional materials**.
[...] **materials from innovative manufacturing processes** [...].

[...] what are currently considered as AdMa will change with time.”]

AdMa in EU Chemicals Legislations

No harmonized, legally binding definition of „Advanced Materials“ & „Material“

For example, in EU REACH the following terms are defined:

➤ **„Substance“**

means a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.

➤ **„Mixture“**

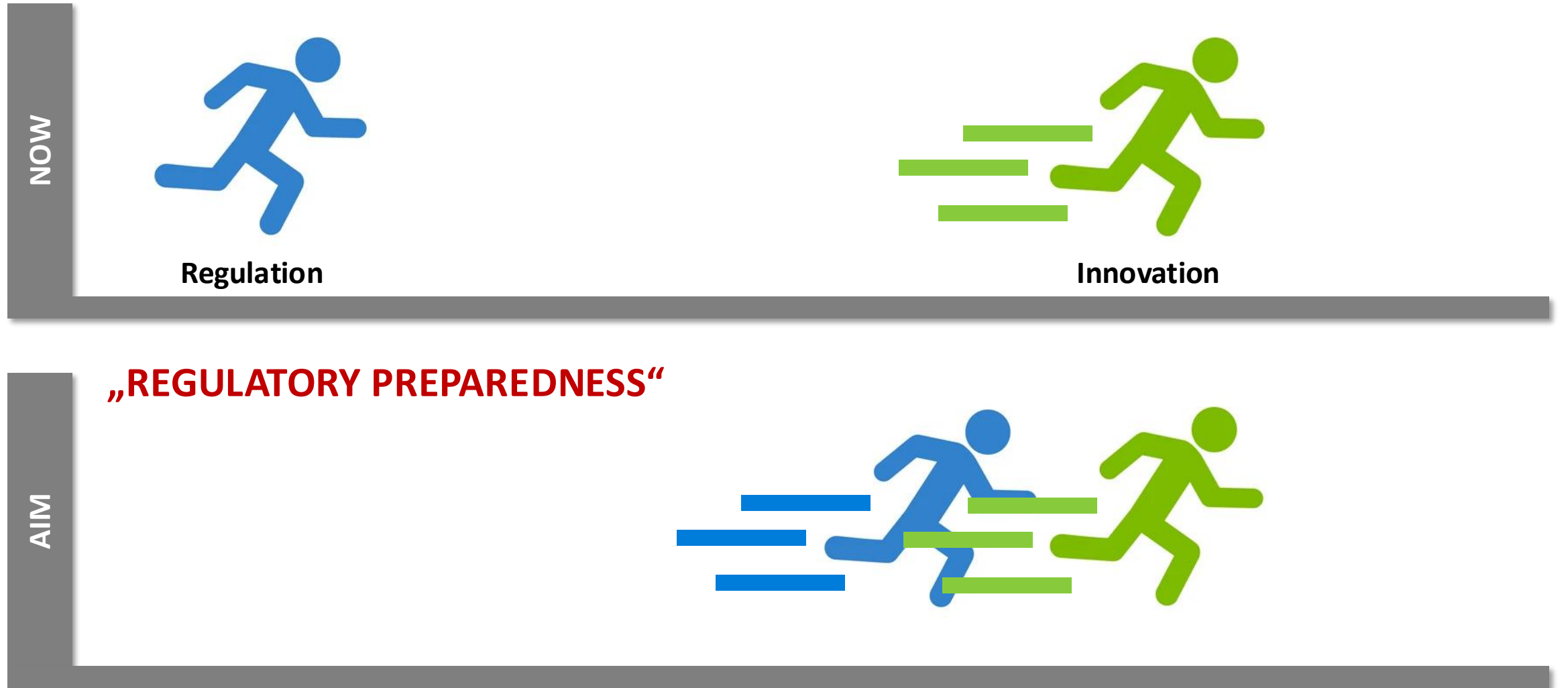
means a mixture or solution composed of two or more substances.

➤ **„Article“**

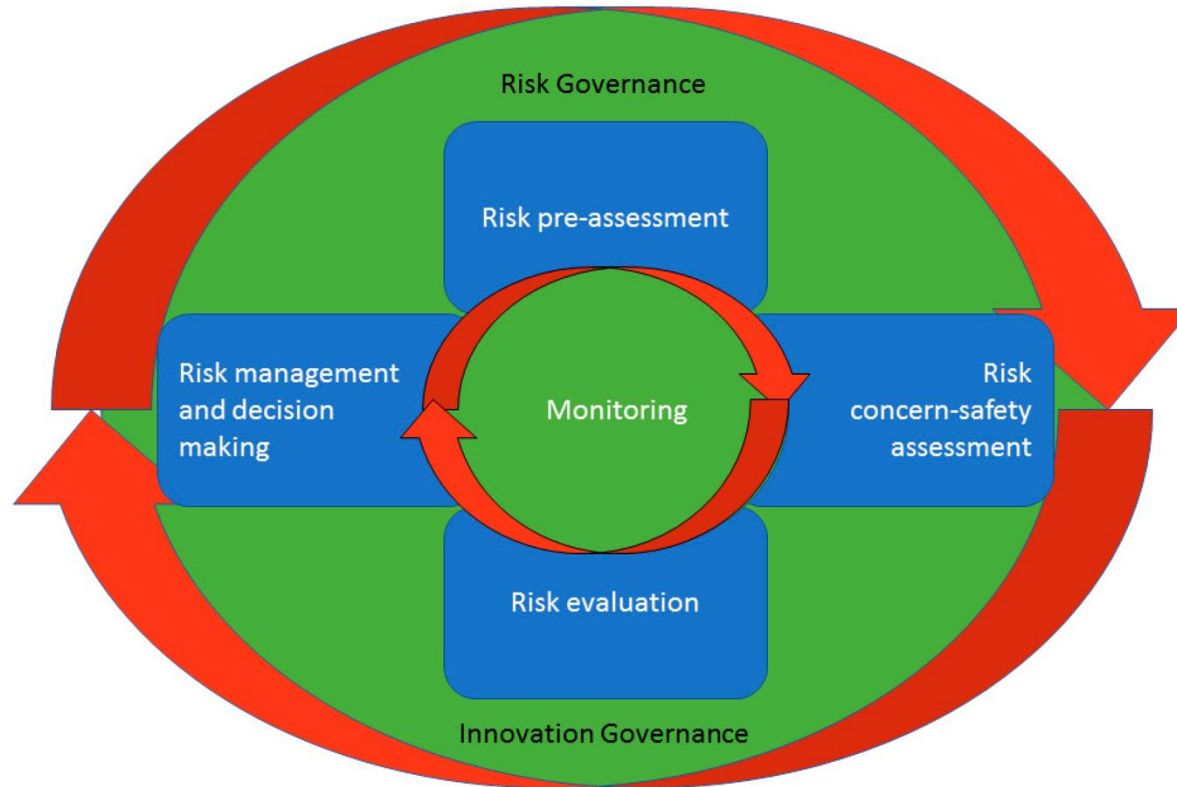
means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition.

Some AdMa are “substances” (e.g. graphene), some “mixtures” (e.g. nanocarriers), or “articles”.

How to better align regulation and innovation?



Risk Governance



Risk Pre-Assessment (Framing of Risks):

- Early Warnings important
- Consider risks & benefits
- Include different actors and stakeholders to
 - broadly collect information
 - capture different perspectives
 - develop appropriate strategies

[1] Isigonis et al., Nanomaterials 2019, 9, 696. <https://doi.org/10.3390/nano9050696>.

Existing Tools & Concepts

Control Banding Tools (NMs)

- Manage workplace risks

NM Risk Governance

- Include **risk pre-assessment** to “frame the risks”
- Initial hints for possible concerns (= **early warnings**) 

Safe (and Sustainable) Innovation Approach S(S)IA

- during an innovation process safety and sustainability aspects should be addressed as early as possible
- Two perspectives:
 - 1) Innovators → **Safe-and-Sustainable-by-Design (SSbD)**
 - 2) Regulators → **Regulatory preparedness (RP)** 

SSbD Framework (JRC)

- Stepwise, hierarchical approach
- Societal and economic sustainability not yet in
- Might need to be tailored

Early4AdMa

= *Early Awareness and Action System for advanced materials*

- Pre-regulatory (anticipatory) risk governance tool
- Identify gaps and possible concerns on safety and sustainability issues
- **PROS:**
 - Very useful
 - Considers all relevant issues
- **CONS:**
 - Time consuming
 - Very detailed

TIER 1
Screening
(optional)

TIER 2
Detailed
Assessment

2010

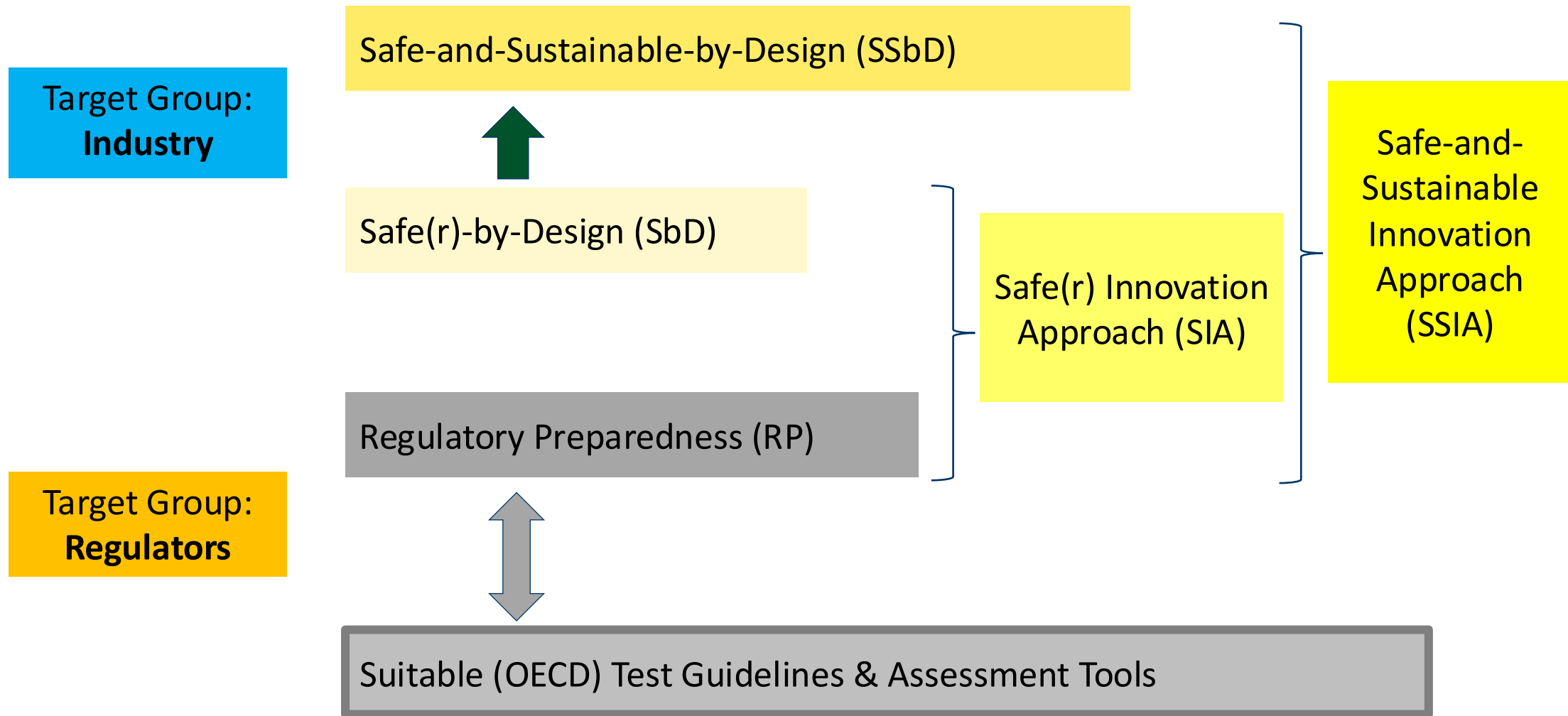
2012

2020

2022

2023

Safe and Sustainable Innovation Approach (SSIA)



based on:

Sustainability and Safe and Sustainable by Design: Working Descriptions for the Safer Innovation Approach ENV/CBC/MONO(2022)30

OECD Case Studies on Early4AdMa



OECD (2023), *Early Awareness and Action System for Advanced Materials (Early4AdMa): Pre-regulatory and anticipatory risk governance tool to Advanced Materials*
<https://doi.org/10.1787/326fb788-en>



OECD (2023), *Advanced Materials Assessment Schemes HARMLESS - OECD WPMN Workshop Report ENV/CBC/MONO(2023)34* –
[https://one.oecd.org/document/ENV/CBC/MONO\(2023\)34/en/pdf](https://one.oecd.org/document/ENV/CBC/MONO(2023)34/en/pdf)

OECD (2024), *Advanced Materials: Case Study on NanoCarriers - Workshop Report ENV/CBC/MONO(2024)3*–
<https://doi.org/10.1787/b25d8c0c-en>

OECD (2025), *Advancing the development of SSbD for advanced materials: Similarities between the SUNSHINE SSbD approach and Early4AdMa Step 5*. <https://doi.org/10.1787/633eb341-en>

OECD (2025), *2D Titanium Carbide MXenes: Case Study Report on Advanced Materials, OECD Series on the Safety of Manufactured Nanomaterials and other Advanced Materials*.
<https://doi.org/10.1787/8437c5bf-en>

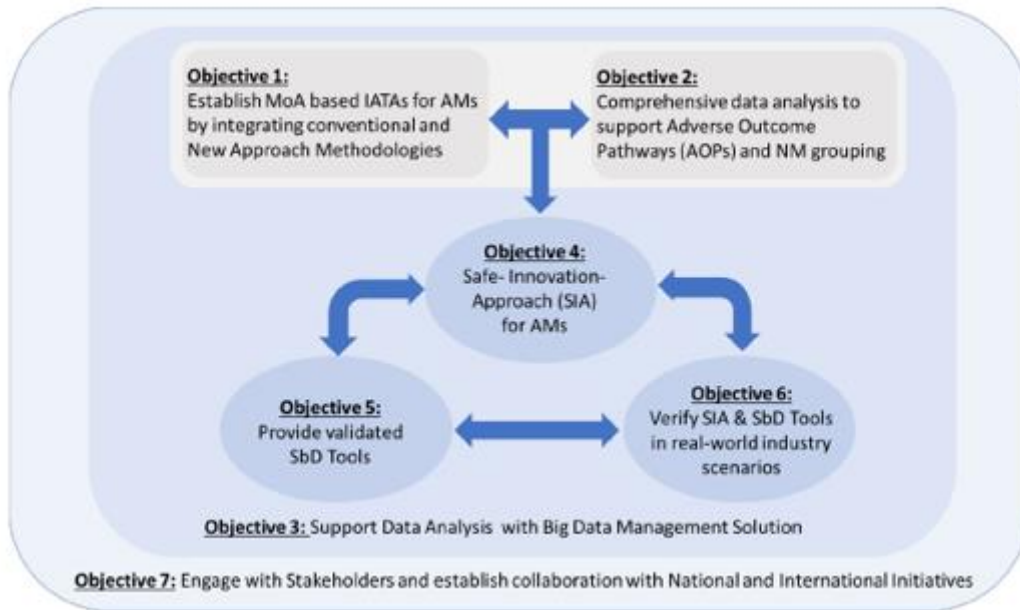
OECD (2026), *Advanced materials case study on graphene related materials (GRM)*.
[https://one.oecd.org/document/ENV/CBC/MONO\(2026\)1/en/pdf](https://one.oecd.org/document/ENV/CBC/MONO(2026)1/en/pdf)

EU HARMLESS

Safe- and Sustainable Innovation & Case Studies

HARMLESS Project: Overview

Advanced High Aspect Ratio and Multicomponent Materials:
Towards comprehensive intelLigent tEsting and Safe by design Strategies



Industrial relevant AM (broad material selection)

- **Pesticides** (e.g. Metal-doped Imogolite)
- **Paint formulations** (e.g. Silica-polymer)
- **Papermaking** (e.g. Silica-rod-cellulose)
- **Catalysts** (e.g. perovskite)
- **Solar cells** (e.g. perovskite, Ag-nanowires)
- **Facade insulation** (e.g. fibre-supported aerogel)

HELMHOLTZ
MUNICH

BfR
Bundesinstitut für
Risikoerkennung

Karolinska
Institutet

TNO

NATIONAL RESEARCH CENTRE
FOR THE WORKING ENVIRONMENT

BBC
NANONET

DTU

INIA
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria

IOFA
consult

BASF
We create chemistry

Nouryon

LUND
UNIVERSITY

baua
Bundesinstitut für Arbeitsschutz und Arbeitsmedizin

Swansea
University
Prifysgol
Abertawe

cea

misvik biology

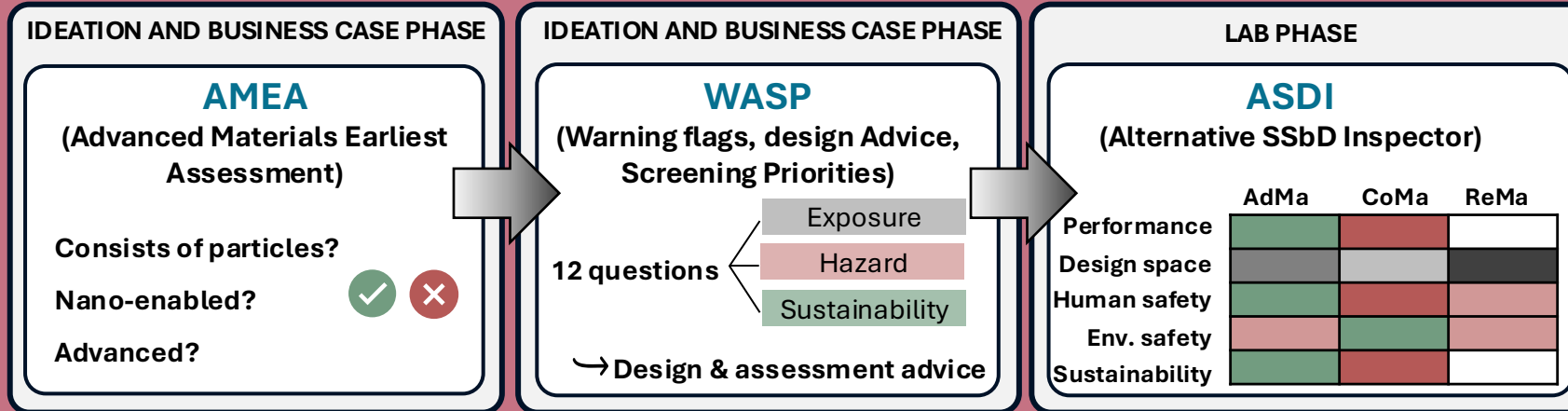
misvik biology

europa
research
services

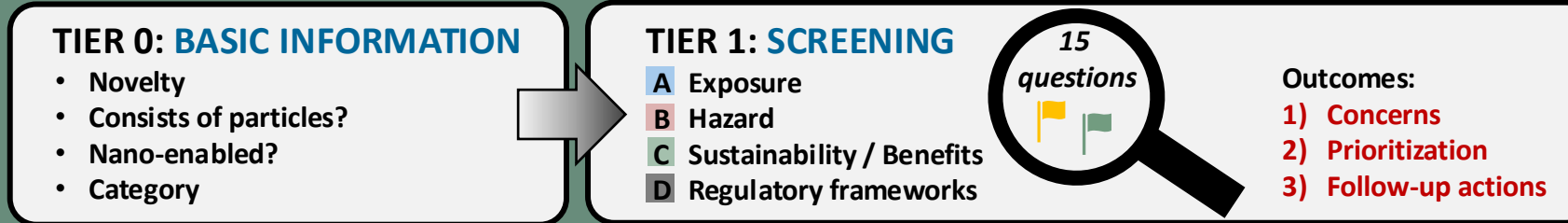
TEMAS Solutions
Safe and Sustainable Innovation

HARMLESS Safe and Sustainable Innovation Approach (SSIA)

HARMLESS Safe and Sustainable by Design (SSbD) Approach (for innovators)



HARMLESS Early Warning System (EWS) (for regulators)

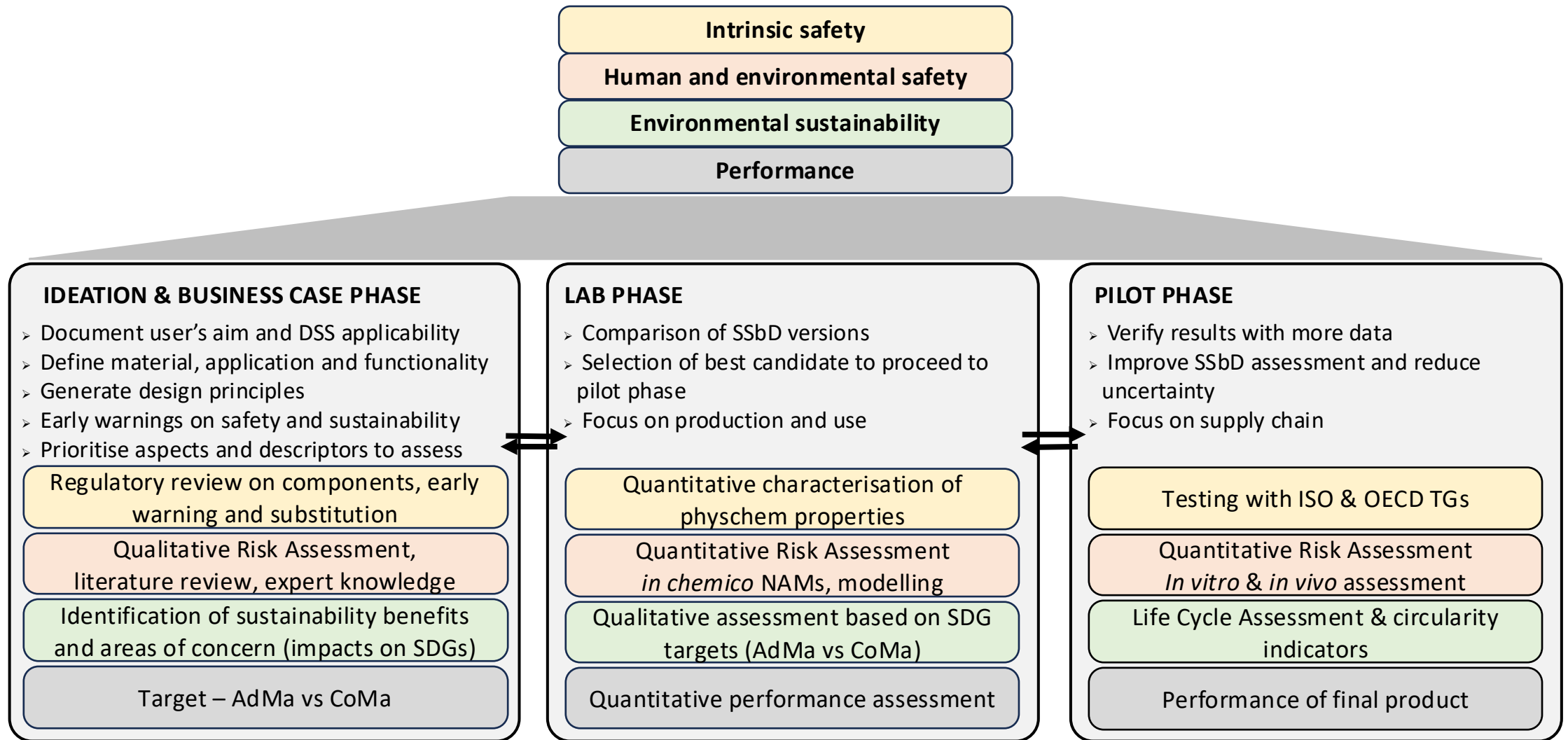


Dekkers et al. (2025)

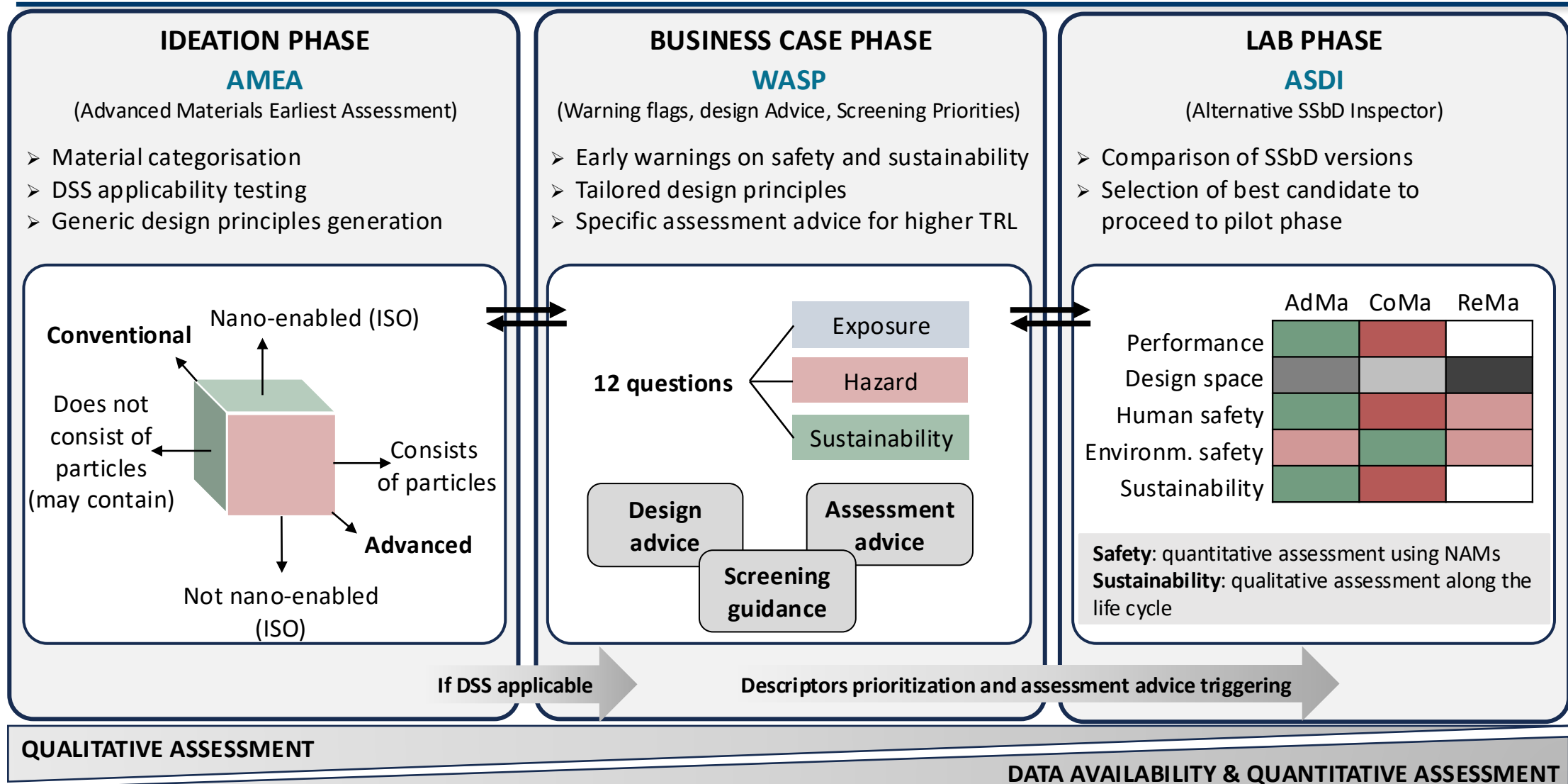
<https://doi.org/10.1002/adsu.202500208>

Prinz et al. (2025)

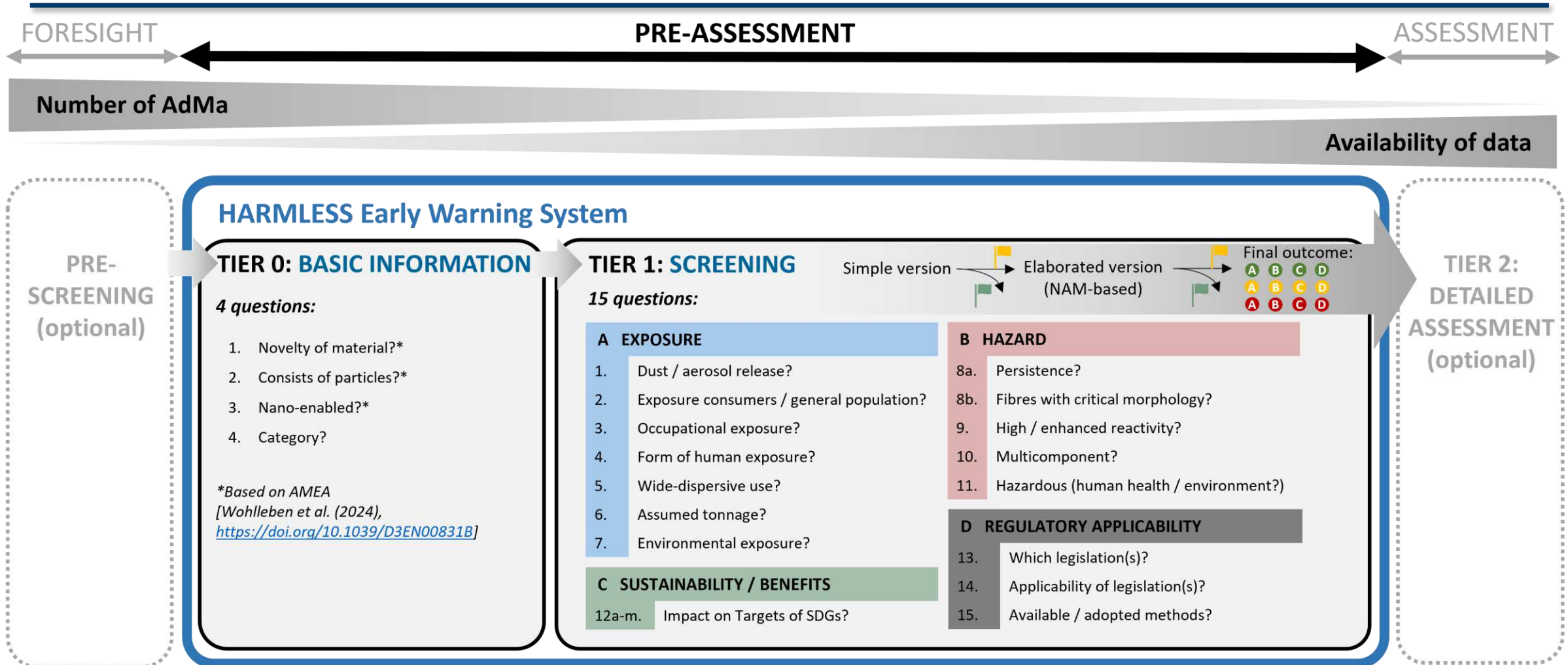
<https://doi.org/10.1002/adsu.202500217>



HARMLESS Project: SSbD

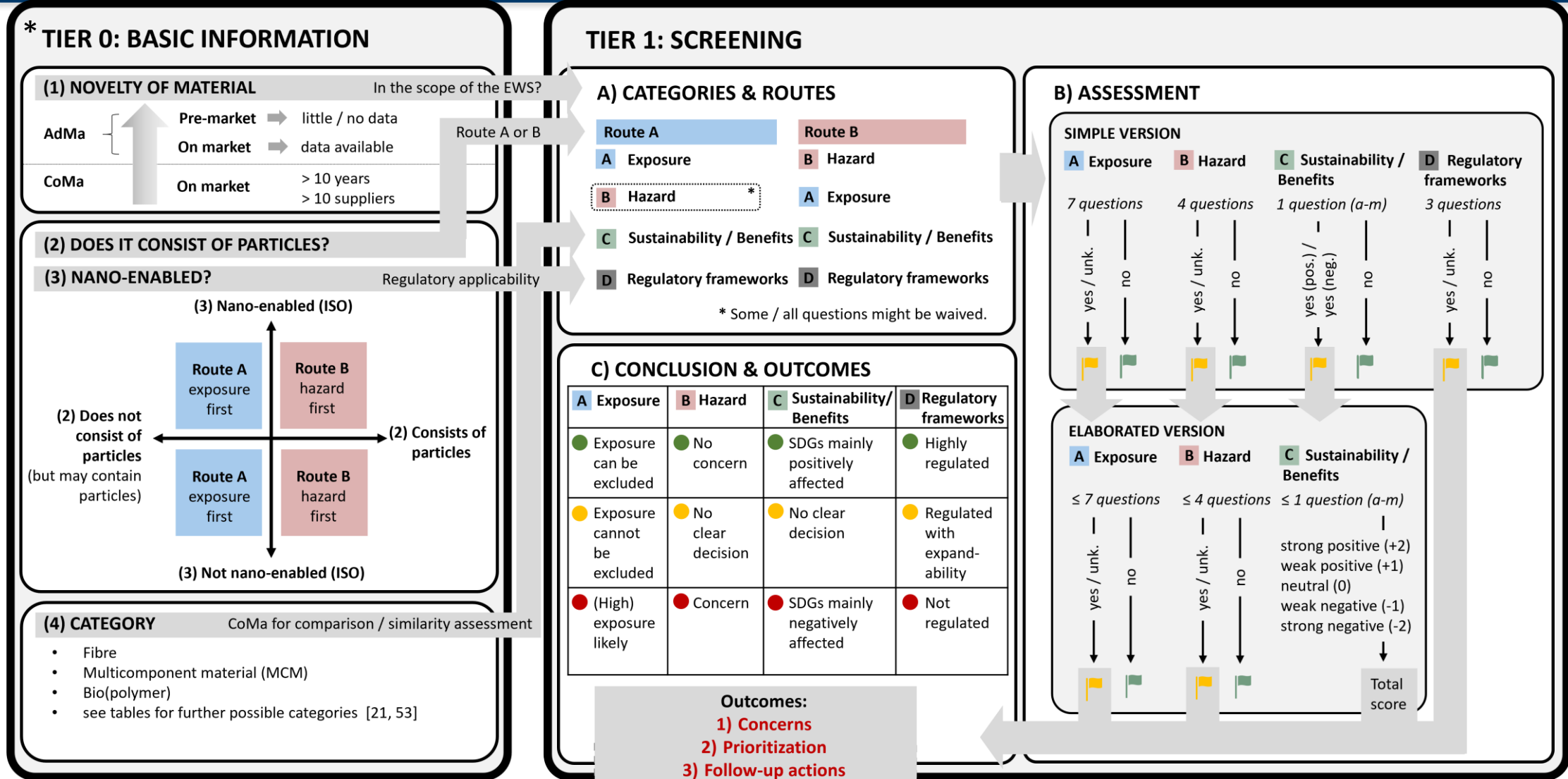


HARMLESS Project: Early Warning System



J. Prinz, G. Nagel, S. Dekkers, E. P. van Someren, V. Adam, V. D. Battista, B. Suarez-Merino, W. Wohlleben, M. Persson, A. Baun, O. Schmid, A. Haase, HARMLESS Early Warning System for Advanced Materials. *Adv. Sustainable Syst.* 2025, 2500217. <https://doi.org/10.1002/adsu.202500217>

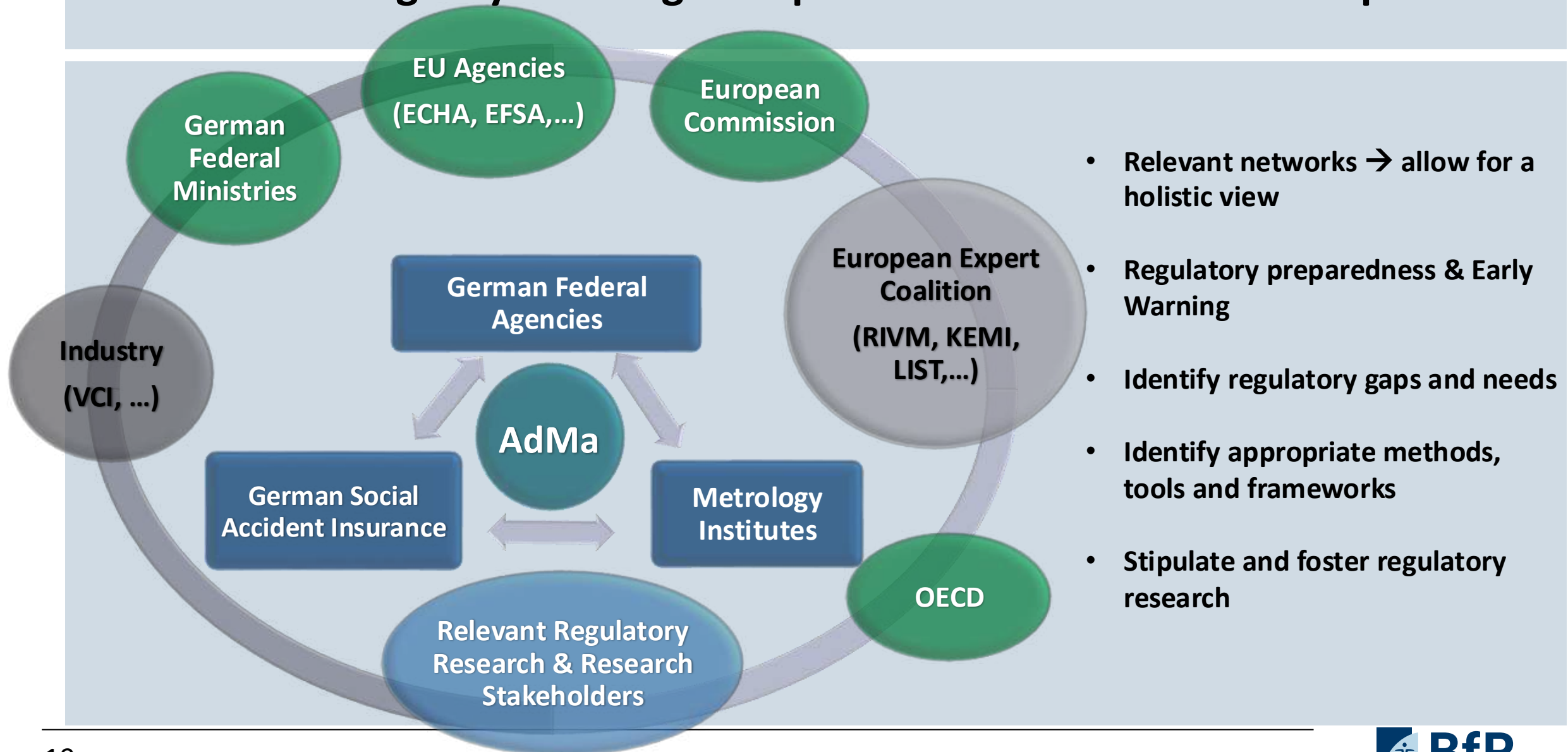
HARMLESS Project: Early Warning System - Details



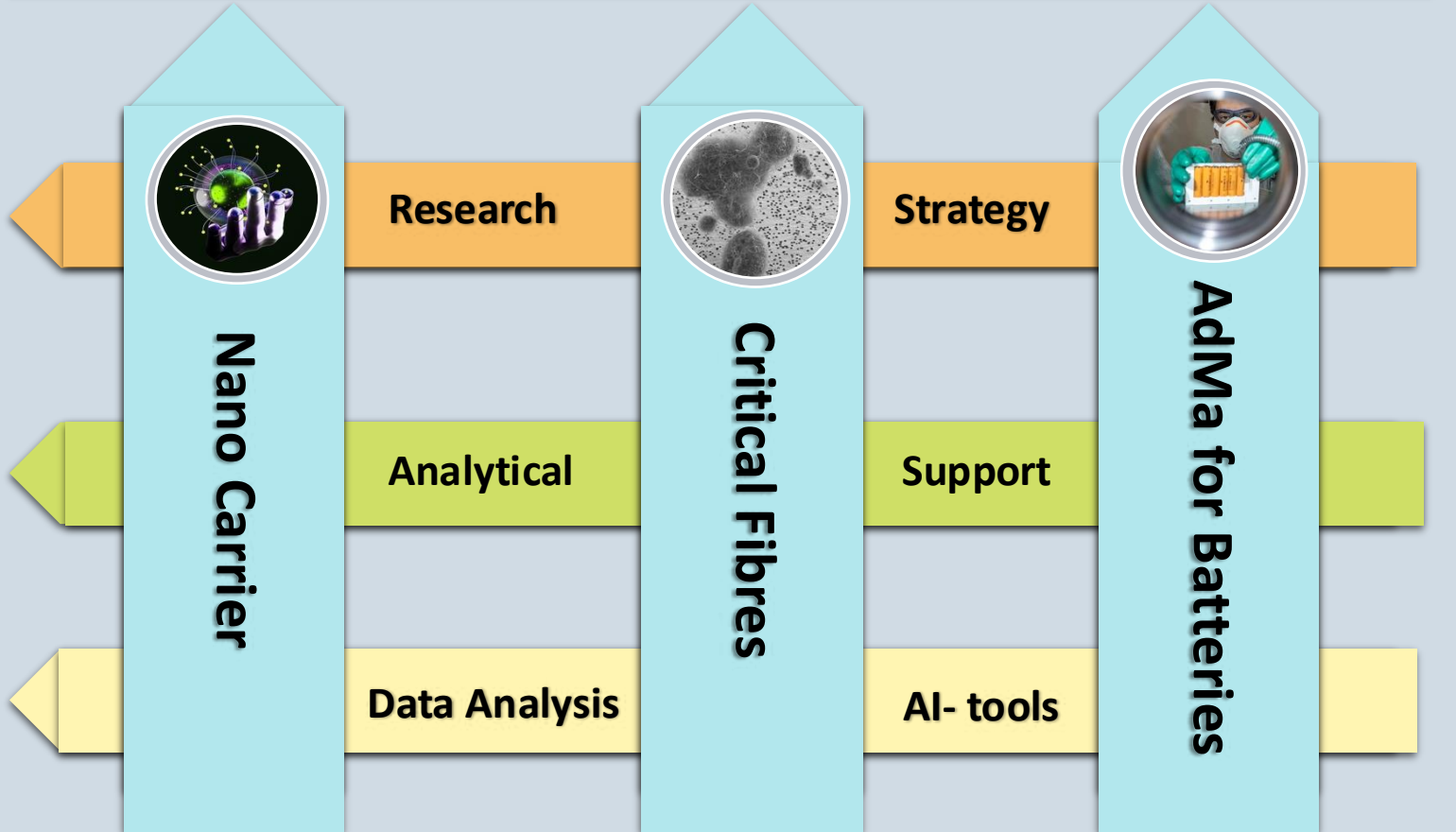
*W. Wohlleben et al., *Environ. Sci.: Nano*, 2024, 11, 2948.

Next Steps:
German Interagency Working Group AdMa
Strategic Research Agenda
Malta Initiative

German Interagency Working Group AdMa in the wider Landscape



German Interagency Working Group AdMa – collaboration platform



Vertical Columns:

- **Selected materials classes:** overarching importance & “need to act”
- Bridge research & regulation
- All experts with relevant knowledge are invited to participate

Horizontal Columns:

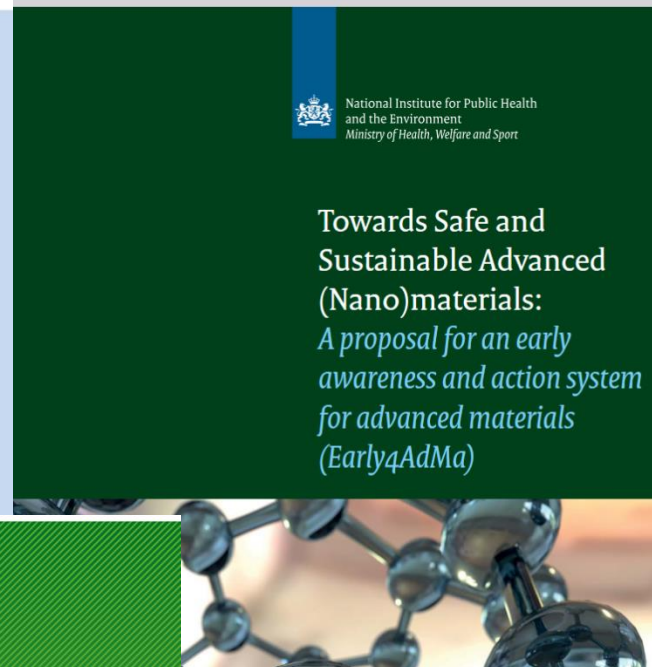
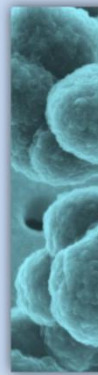
- Overarching activities to support the topics of the vertical columns
- Temporary (e.g. research strategy, finished now) or longer lasting (e.g. analytics, AI-tools)

Relevant Documents



Review of the joint research strategy
of the higher federal authorities

Nanomaterials
and other advanced materials:
Application safety and
environmental compatibility



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Contents lists available at ScienceDirect

NanoImpact

journal homepage: www.elsevier.com/locate/nanoimpact



Boosting advanced material's innovation – Are we regulatory prepared?

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b a u a :
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BfR
German Federal Institute for Risk Assessment

Umwelt
Bundesamt

BAM
Bundesanstalt für
Materialforschung
und -prüfung

PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

21. May 2026

Strategic Research Agenda for Safe Advanced Materials

Joint Perspective of the German Higher Federal Authorities on safe use and
chemical safety throughout the entire material life cycle



1

<https://www.umweltbundesamt.de/publikationen/strategic-research-agenda-for-safe-advanced>

Strategic Research Agenda for Advanced Materials

Scope and Aim

- Research needs in the context of chemical safety for AdMa
- Aligned with different goals and strategies of the EC related to AdMa and the “Chemieagenda 2045” of the German Government
- Aligned with OECD WPMN Programme of work
- Joint/agreed position of the German Federal Agencies, orientation/priorisation for own research activities
- Supports external communication, e.g. to Federal Ministries, research funding institutions, research community

Table of Content

List of Abbreviations

Executive Summary

1. Introduction
2. Identify relevant advanced materials, signals of concern and knowledge gaps
 - 2.1. **Horizon Scanning** on material Innovation
 - 2.2. **Early Awareness** Raising
3. Perform safety research for regulatory preparedness
 - 3.1. Close **knowledge gaps** on safety of advanced materials
 - 3.2. Develop **testing and assessment strategies**
4. Develop and validate **standards and harmonised test methods**
5. Develop **methods for Safety and Sustainability by Design**
6. Research enablers
7. Summary
8. Profiles of the involved higher federal authorities
9. List of references

<https://www.umweltbundesamt.de/publikationen/strategic-research-agenda-for-safe-advanced>



Steer attention towards priorities for the validation of test methods and development of OECD Test Guidelines

Support international exchange and cooperation

Bring together different stakeholders in a constructive dialogue

Strengthen trust in enforceable legislation and safe innovation

The Malta Initiative is a voluntary network without an official mandate.





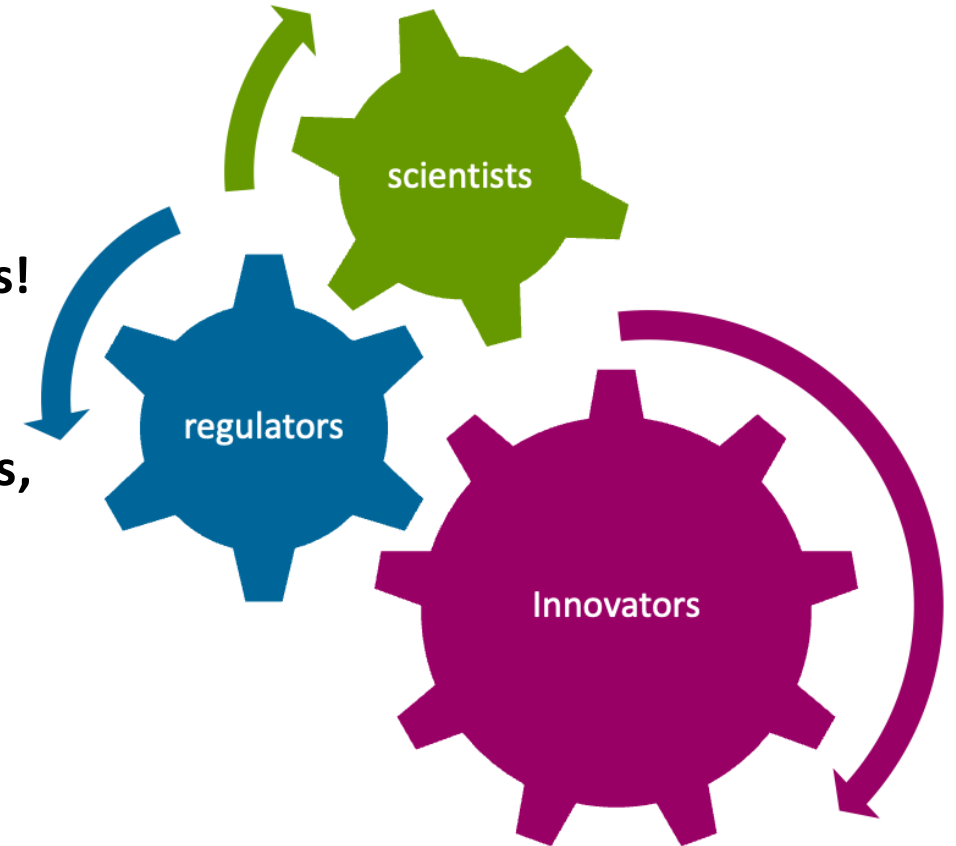
To be leading in Advanced Materials the **EU needs to become a global leader in Test Guidelines and Standards!**



To be leading in Test Guidelines and Standards **innovators, scientists and regulators need to work hand in hand.**



A European strategy for the development of Standards and Test Guidelines for Advanced Materials is needed.



Take Home Messages

- AdMa are crucial to address several of the current global challenges. However, their safety and sustainability needs to be properly addressed, already during innovation.
- Innovation and Regulation need to be aligned. SSbD & Regulatory Preparedness needs appropriate tools and concepts.
- The HARMLESS SSIA (SSbD + Early Warning System) for AdMa has proven to be useful for selected AdMa (in industrial relevant case studies). It could be further explored for other types of AdMa. Importantly, SSbD & Early Warning System are aligned and supported by an online tool.
- The German Federal Authorities assessed the Status Quo and the further research needs in the context of chemical safety for AdMa
- A European strategy for the development of Standards and Test Guidelines for AdMa is needed

Thank you very much! Questions?



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 953183.



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Blanca Suarez-Merino, Véronique Adam



Susan Dekkers, Eugene P. van Someren



Wendel Wohlleben, Veronica Di Battista



Michael Persson



Anders Baun



Otmar Schmid

German Interagency Working Group AdMa

Thanks to all experts! Special thanks to:



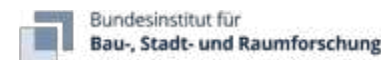
Jutta Tentschert, Fatemeh Zabihi, Claudia Voss



Elisabeth Heunisch



Kathrin Schwirn, Doris Völker



MALTA Initiative



Advanced Materials (AdMa) Nano and Beyond

Impulses from the perspective of VCI,
(VCI = German Chemical Industry Association)
Standardization and SMURFnano

NANOTECH FRANCE 2026, PARIS

Gottlieb G. Lindner

Evonik Operations GmbH / [Chair VCI Project Group AdMa](#)

16. Juni 2026

WHAT YOU MAY EXPECT FROM TODAY

- **Why focus on AdMa in the first place ?**
 - » UN, EC ... green transition, resilience, ... growth, ...
- **What are AdMa ?**
 - » OECD/WPMN Working Description
 - » AdMa by German Federal Higher Authorities
 - » ISO/TC 229 Nanotechnologies / AdHoc Group 1 AdMa
 - » CEN/TC 352 Nanotechnologies's scope explicitly naming AdMa & applications
 - » DIN Workshop on AdMa and its outcome
 - » Examples Evonik
 - » Metrology project SMURFnano dealing with AdMa
- **VCI PG AdMa - Impulses from the perspective of VCI / Nano & Beyond**



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WHY FOCUS ON ADMA ?



Examples of translation in Industries



WHY FOCUS ON ADMA: EUROPEAN COMMISSION

Statement from the European Commission 2024:

Advanced materials are engineered materials with innovative properties and functionalities. They are key for European competitiveness and the green and digital transitions. The demand for advanced materials is expected to significantly increase in the coming years, for instance for the production of renewable energy, batteries, zero-emission buildings, semiconductors, medicines and medical devices, satellites, space launchers or planes. Advanced materials are crucial building blocks for the EU's resilience and open strategic autonomy. They are on the list of ten critical technology areas for the Union's economic security.

https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/chemicals-and-advanced-materials_en

Well accepted by industry

In this context, AdMa are understood as materials that are rationally designed to have

- new or enhanced properties, and/or
- targeted or enhanced structural features

with the objective to achieve specific or improved functional performance. This includes both new emerging manufactured materials, and materials that are manufactured from traditional materials. This also includes materials from innovative manufacturing processes that enable the creation of targeted structures from starting materials, such as bottom-up approaches. It is acknowledged that what are currently considered as AdMa will change with time.

2022, OECD Environment, Health and Safety Publications Series on the Safety of Manufactured Nanomaterials No. 104

STRATEGIC RESEARCH AGENDA FOR SAFE ADVANCED MATERIALS MAY 21ST, 2026 BY GERMAN HIGHER FEDERAL AUTHORITIES

Advanced Materials (AdMa)

The term “advanced materials” can be interpreted broadly. A universally or legally accepted definition of AdMa does not yet exist.

The Organisation for Economic Co-operation and Development (OECD) **describes** that (OECD, 2022a): “..., **Advanced materials** are understood as materials that are rationally designed to have new or enhanced properties, and/or targeted or enhanced structural features, with the objective of achieving specific or improved functional performance.

This includes both new emerging manufactured materials, and materials that are manufactured from traditional materials. This also includes materials from innovative manufacturing processes that enable the creation of targeted structures from starting materials, such as bottom-up approaches. It is acknowledged that what are currently considered as AdMa will change with time. ...”

In the context of this research strategy, we follow this description with a focus on AdMa that fall under chemicals legislation and have a nanometre size range (i.e. 1-100 nm) (European Commission, 2022b) and beyond, generally up to potentially a few micrometres. Thus, we focus mainly on AdMas such as particulate materials including fibres or platelets. Materials from advanced manufacturing are not in focus of this strategy. A definition by the International Organization for Standardization (ISO) is currently under development (ISO, 2026).

ISO/TC 229 NANOTECHNOLOGIES

» Project on „Nanotechnologies – Vocabulary – Innovations in materials and technologies: advanced materials“

» Including terms like

» Emerging Material

» Advanced Material

» Alternative Material

» Conventional Material

» and their corresponding timeline

» AdHoc Group 1 Advanced Materials (AHG 1 AdMa)

» Will define ‚Term and References‘ for the future Taks Group 1 Advanced Materials

» The topic ‚nano-bio‘ will be delt within the corresponding AHG 2

Standardization in the field of nanotechnologies that includes either or both of the following:

- i. understanding and control of matter and processes at the nanoscale, typically, but not exclusively below 100 nanometers in one or more dimensions, where the onset of size dependent phenomena usually enables novel applications;
- ii. utilizing the unique properties of nanomaterials that differ from those of individual atoms, molecules or bulk matter, to create relevant innovative and advanced materials, products, devices and systems that exploit new or improved performance and functionalities.

Specific tasks include developing standards for: classification, terminology and nomenclature; metrology and instrumentation (including specifications for reference materials and traceability); test methodologies; modelling and simulation; health, safety, environmental practices and life cycle assessment; societal dimension, sustainable and responsible development; nanotechnology products and processes, quality control and performance evaluation. Standards in each of these areas could be specific to a product, process or industrial sector as for example food, cosmetic, health, mobility, construction, energy and electronics.

DIN WORKSHOP 2024: INNOVATION IN DIALOGUE - FUTURE MATERIALS/ADVANCED MATERIALS

- 'Advanced Materials' is not a material category, but a status labelling for innovative materials or existing materials with new applications (no SI-unit to describe AdMa); besides: there is a 'time stamp' (e.g., bronze was a typical AdMa at the beginning of the Bronze Age)
- Addressing the horizontality of the topic of 'future materials/AdMa'

More common remarks

- There is a general need for new and/or further development of characterization methods
- Study of the correlation between functionality and toxicity, and the underlying phys.-chem. properties is required
- Differentiation with regard to the role of legislators and technical rule-makers required

EXAMPLES OF ADMA BY EVONIK

PRESENTED AT EUINDTECH 2025

Evonik's broad variety of advanced materials are crucial key components to enable, e.g., a green transformation

**Advanced
materials for:**

Hydrogen production



Hydrogen transport



Lightweight



Batteries



Energy effic. construction



Carbon capture



CO₂ use/art. photosynth.



Chemical recycling

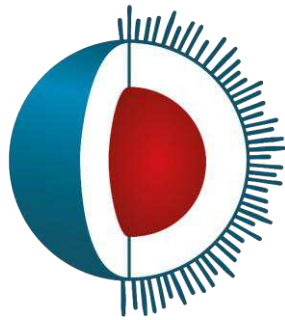


...and more

EXAMPLES OF ADMA: SURFACE FUNCTIONALIZED NMS

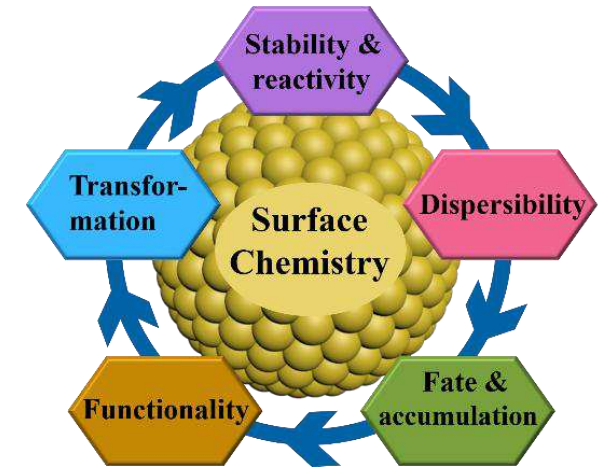
However, for industry, costumers and regulators:

standardized measurement methods are needed



SMURFnano

Standardised measurements of
surface functionalities on nanoparticles



EUROPEAN PARTNERSHIP



METROLOGY
PARTNERSHIP



Freie Universität Berlin

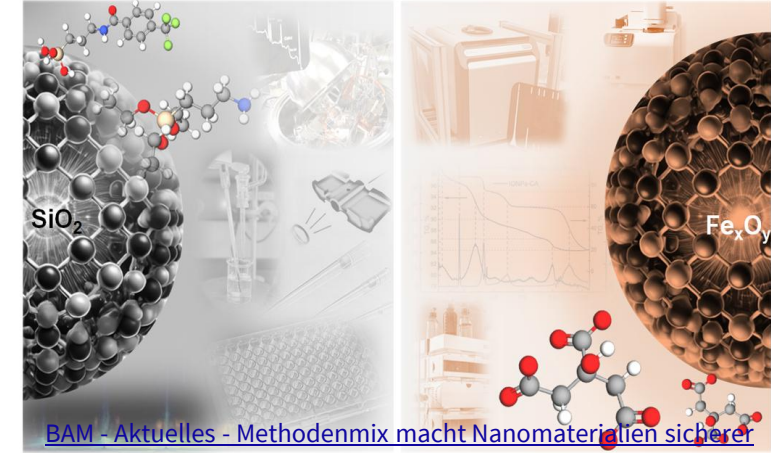


National Research
Council Canada

<https://www.bam.de/Content/DE/Projekte/SMURFnano/SMURFnano.html>

Needs behind SMURF nano:

- Engineered nanoparticles (NPs) with various chemical composition and surface chemistry have reached a multi-billion market with application in, e.g. sensing, energy conversion and storage, medical diagnostics, catalysis, and opto-electronics.
- Industry and regulators are increasingly requesting validated and standardised measurement protocols to support the manufacturing, quality control, and safe use.
- To meet these demands, there is a need to further develop, validate, and standardise currently available methods quantifying NP surface functionalities and provide reference materials and data.
- The inclusion of real industrial products (>10,000 t/year) represents a significant challenge, indeed



BAM - Aktuelles - Methodenmix macht Nanomaterialien sicherer
[Source: Federal Institute for Materials Research and Testing – a multi-method approach enhances the safety of NMs](#)

VCI PROJECT GROUP ADMA – THE ORIGIN: NANO AND BEYOND

Why there is a project group on AdMa and where do we come from ?

- The topic of AdMa has been a focus point & brought up by different bodies: industry, standardization, regulation, federal institutes, 'politics', NGOs, ...
- Most of the members of the PG AdMa originated from the former coordination group on nanomaterials

Scientific reasoning for reaching beyond nanomaterials:

- The vast majority of AdMa are either based on NM or so-called nano-enabled

VCI is not unique in moving from Nano to AdMa

- OECD/WPMN added AdMa to its scope quite some years ago
- ISO/TC 229 Nanotechnologies considers AdMa (as far as being based on NM) as intrinsically within its scope - and AHG 1 AdMa has been founded
- CEN/TC 352 Nanotechnologies include AdMa (and their applications) directly in their scope

Our main task: Expert exchange with Federal Higher Authorities on a regular basis – addressing:

- What influence of AdMa is seen on the research and production of innovative materials in the field of key technological industries in Germany and Europe?
- How can AdMa-related product safety questions be identified in time?
- How should the topic of AdMa be dealt with between stakeholders from politics, authorities, industry and science in the sense of the EU Industry Initiative, for example?

REFLECTIONS ON THE “DEFINITION” OF ADMA BY VCI PG ADMA

Again a recap

- Heterogeneous group of materials, overarching horizontal topic
- Criteria & Parameters not physical-chem. derivable (no identifying SI unit)
- Status description $\neq$ material category: Who decides upon the status?
- Definitions of AdMa in specific environments (e.g. marketing, patents, etc. existing regulations in the UK)?
- Define sector-specific "categories of AdMa"? – like in existing case studies: fibres, nanocarriers, battery materials, graphene, MXenes, advanced manufacturing, aerogels
- Intersections with SSbD (intrinsically connected)

VCI PG ADMA POSITIONS, CHALLENGES & NEXT STEPS

- A general "regulatory definition" is rejected as not being constructive
- AdMa can include nanomaterials, but they do not have to
- A distinction on AdMa to the NM discussion seems appropriate
- As a minimum requirement: AdMa not to be equated with a hazard
- The discussion about the safety of advanced materials should be conducted on the basis of scientific findings (evidence-based)
- Prerequisite: Common understanding regarding AdMa

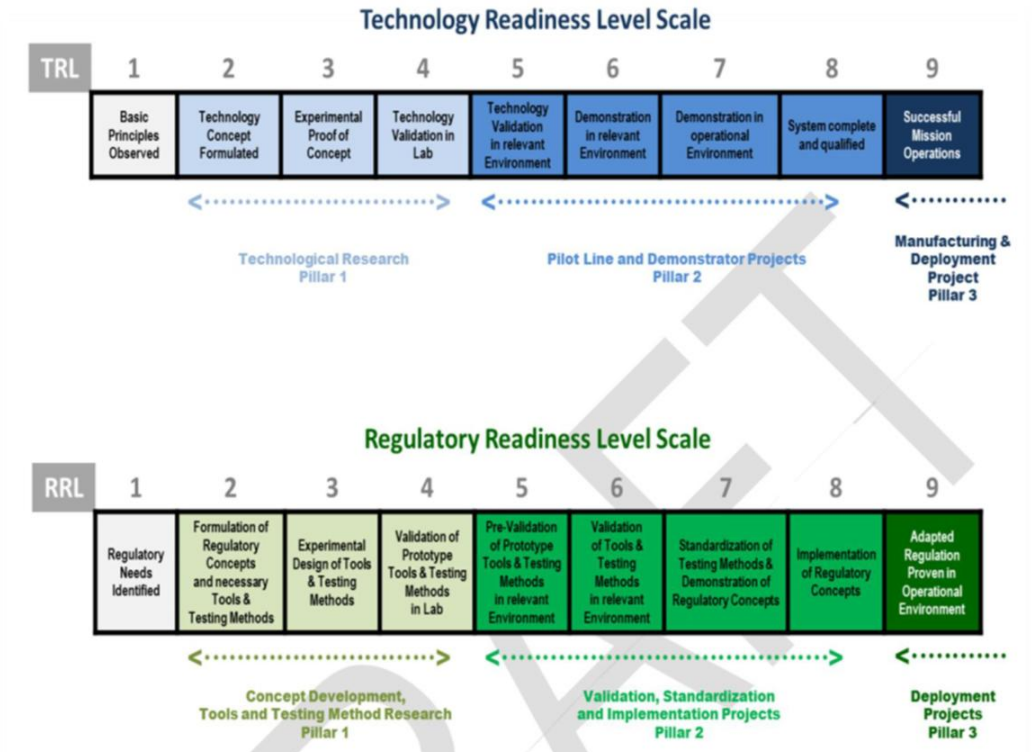
READINESS LEVELS TO BE CONSIDERED

Mostly know aspects concerning AdMa:

- Technical Readiness Level
- Regulatory Readiness Level

However, mostly omitted

- Market Readiness Level



Comparison of TRL to RRL, source: BAuA Federal Institute for Occupational Safety and Health / Germany

Advanced Materials have been, are and will be an integral part of innovation - constantly created, applied and regulated

MUCH APPRECIATION TO THE AUDIENCE & ACKNOWLEDGEMENTS



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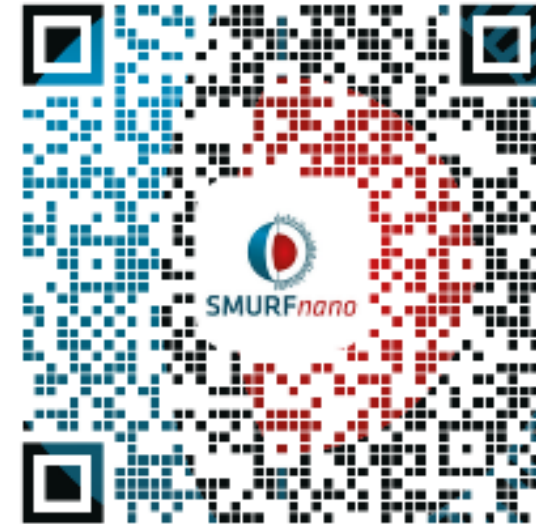
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Verband der
Chemischen Industrie e.V.
ELEMENTAR FÜR DEUTSCHLAND



Ute Resch-Genger, Jörg Radnik
Federal Institute for Materials Testing / BAM,
Berlin, Germany

ABSTRACT

- ▶ The topic of AdMa has been – and still is – a focus point by different bodies: industry, standardization, regulation, federal institutes, ‘politics’, NGOs on national, European and international levels. Thus, end of 2024 the VCI (German Chemical Industry Association) started the project group on Advanced Materials (PG AdMa) with the main task having expert level exchange with Federal Higher Authorities on a regular basis. Topics for discussions are manifold and include: influence on the research and production of innovative materials in the field of key technological industries in Germany and Europe; questions on AdMa-related product safety and even more generally how the topic of AdMa should be dealt with between stakeholders from politics, authorities, industry and science in the sense of the EU Industry Initiative, for example.
- ▶ As the vast majority of AdMa are either based on NM or so-called nano-enabled, AdMa may be very well seen as being a topic of ‘nano and beyond’. This is reflected in the PG AdMa, where most members originate from the ‘nano community’.
- ▶ In standardization AdMa has now been added to the scope of the CEN/TC Nanotechnologies and ISO/TC 229 Nanotechnologies is working on a document titled ‘Innovations in materials and technologies; advanced materials. Additionally an AdHoc Group on AdMa currently defines the ‘Terms and References’ for an anticipated Task Group AdMa. However, as the basis for all this activities the so-called working description of AdMa by the OECD/WPMN (Working Party of Manufactured Nanomaterials) is used. Nevertheless, addressing the horizontality of the topic of ‘future materials/AdMa’, in a German DIN workshop on AdMa we came to the conclusion that: ‘Advanced Materials’ is not a material category, but a status labelling for innovative materials or existing materials with new applications (no SI-unit to describe AdMa); besides: there is a ‘time stamp’ (e.g., bronze was a typical AdMa at the beginning of the Bronze Age).
- ▶ One very important group of AdMa are those specifically designed, e.g. nanomaterials with functionalized surfaces. Here the EURAMET project SMURFnano (Standardised Measurements of sUrfce functionalities on nanoparticles) comes into play, where SOPs (Standard Operation Procedures) are being developed in order to quantitatively determine the functional surface groups. A very important aspect of this project is that an industry partner provides ‘real life’ surface functionalized nanomaterials that are being produced in several 10 thousand tons /per year, reproducibly and within rather narrow specifications – and some very much ‘aha moments’ in the practical handling occurred.
- ▶ Keywords:
- ▶ Advanced Materials; Nanomaterials; VCI; standardization; DIN/CEN/ISO; OECD; surface functionalization; SMURFnano; real life samples



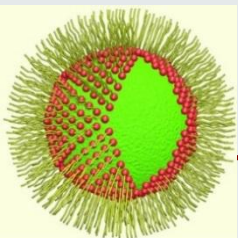
METROLOGICAL CHALLENGES FOR SURFACE FUNCTIONALITIES ANALYSIS

I. Tavernaro, A. Matiushkina, L. Scholtz, M. Richter,
C. Homann, J. Radnik, and U. Resch-Genger*

Federal Institute for Materials Research and Testing (BAM)

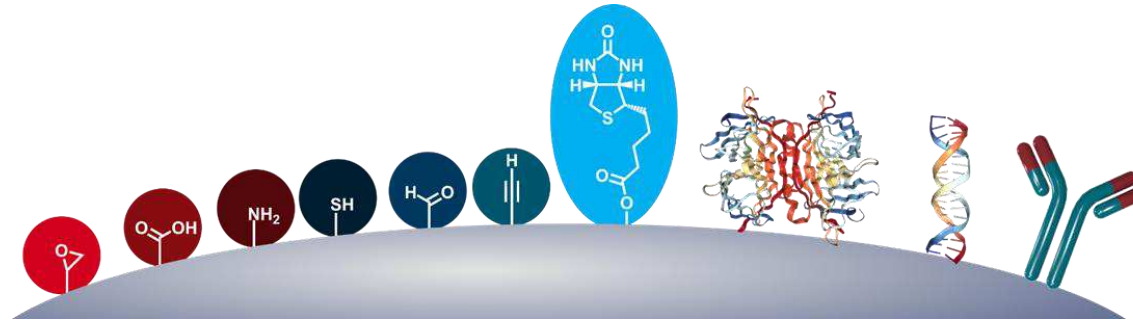
ute.resch@bam.de

17.06.2026



Unlocking Surface Chemistry of Engineered NMs & (N)AMs

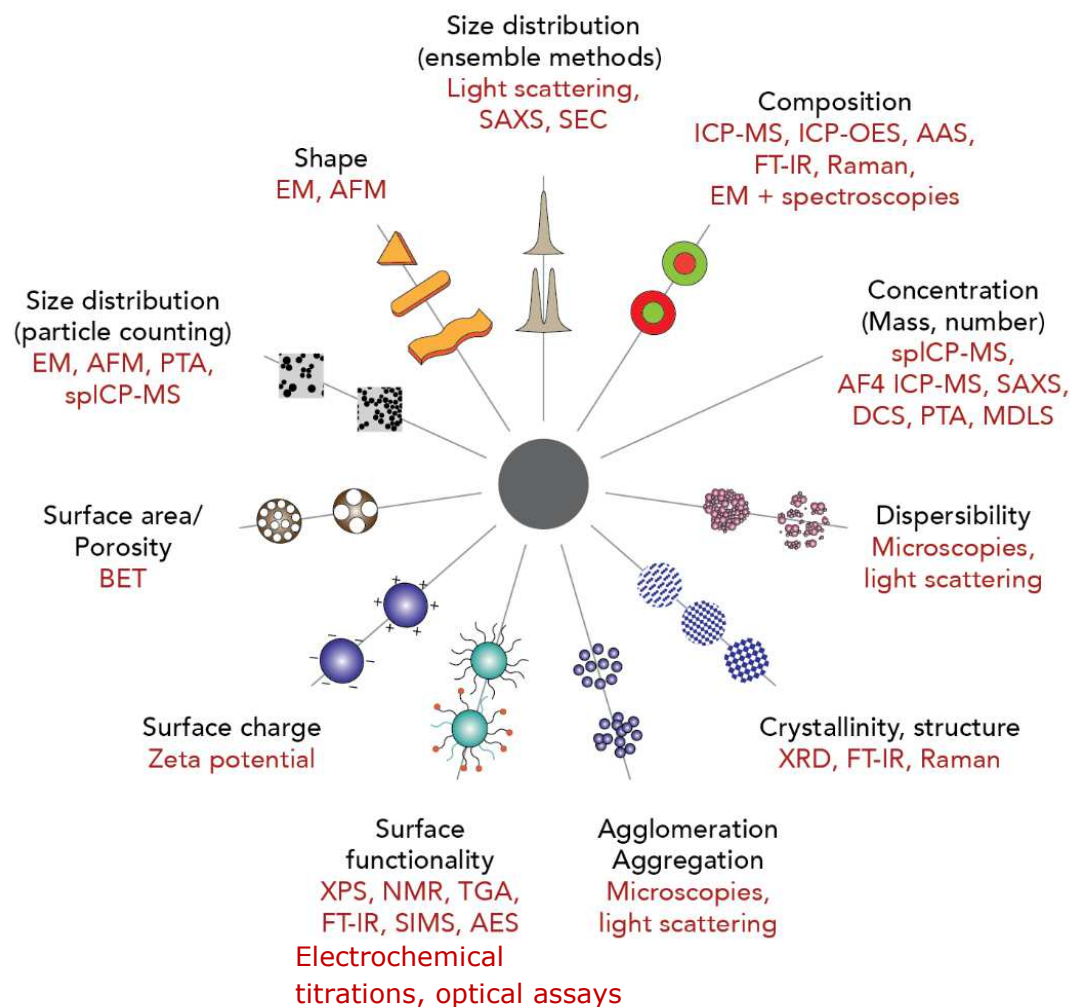
- Key Properties for Performance, Application and Safety Aspects



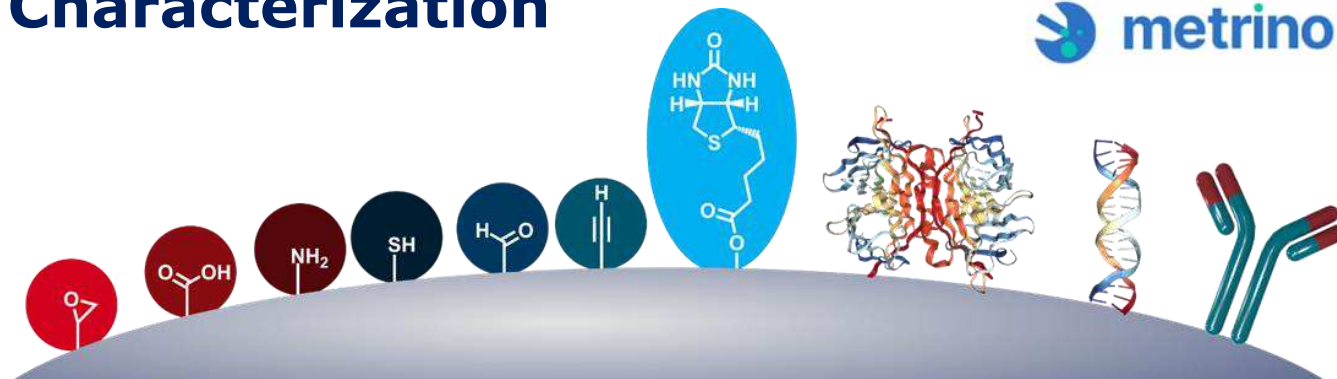
- Engineered nanoparticles (NPs) with various chemical composition and surface chemistry have reached a multi-billion market with applications in, e.g., sensing, energy conversion and storage, medical diagnostics, catalysis, and opto-electronics.
- Industry and regulators are increasingly requesting validated and standardized measurement protocols to support the manufacturing, quality control, and safe use of engineered NPs.
- To meet these demands, there is a need to further develop, validate, and standardize currently available methods for quantifying NP surface functionalities and provide reference materials and reference data.

Unlocking Surface Chemistry of Engineered NMs & (N)AMs

- Key Properties for Performance, Application & Safety Aspects

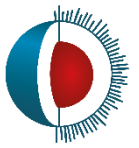


Characterization



- > Quantification of surface functional groups (FGs) is essential for NM process control, quality control, monitoring of NM aging, and risk assessment as well as for subsequent processing steps
- > No standardized methods are currently available for FG analysis and quantification
- > No reference materials with known FG density are currently available

Unlocking Surface Chemistry of NMs & NAMs

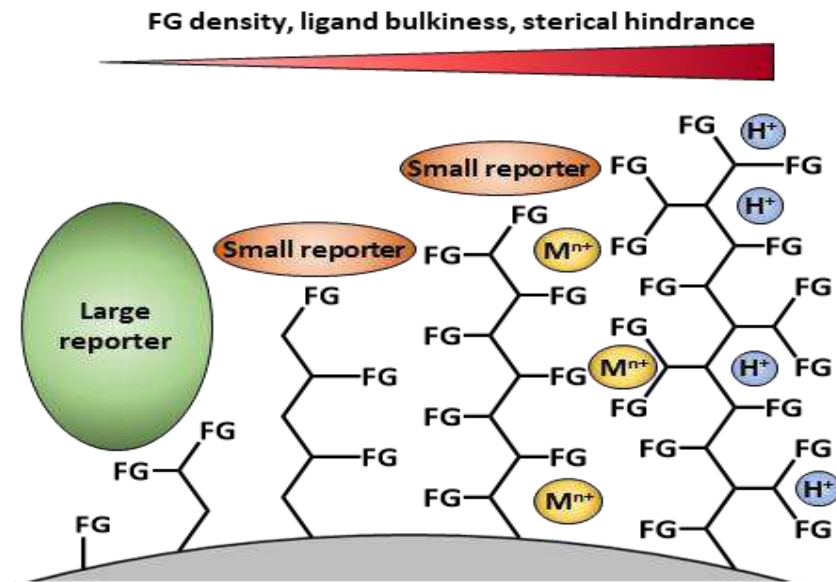
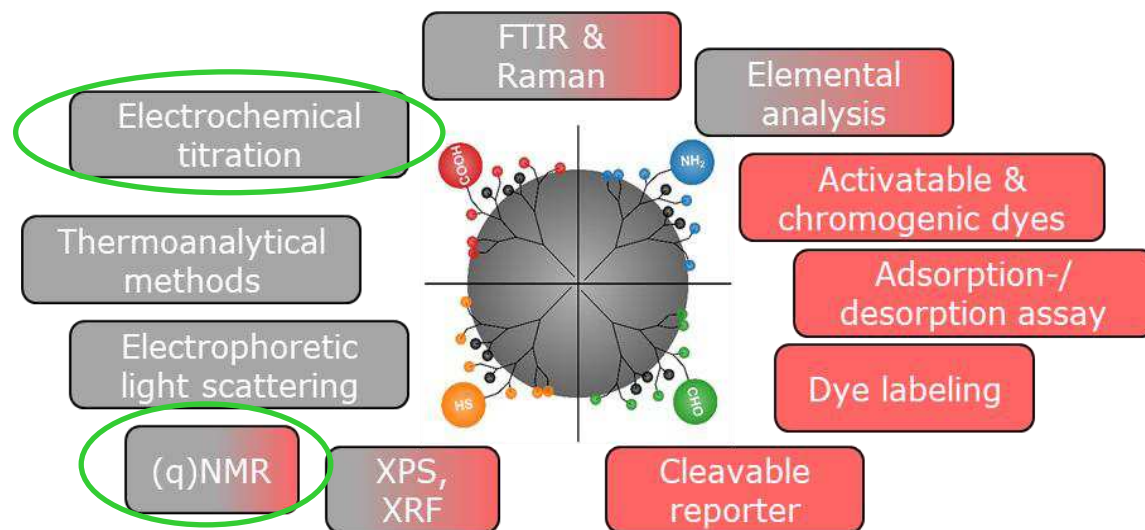


SMURF^{nano}

Why Surface Chemistry and Quantifying Functional Groups (FGs) & Coatings on Nanomaterials (NMs) & (Nano-enabled) Advanced Materials (NAMs)

- > **NM surface chemistry** controls **dispersibility** (hydrophobicity/hydrophilicity), **stability** (e.g., agglomeration behavior), **processability**, often **function / performance** in applications, and the **interaction with the (biological) environment** and thus their **safe use**
- > **For engineered NMs & nanoenabled NMs (NAMs)**, the surface chemistry is relevant for NM **biocompatibility** and NM **circulation time** in the blood (e.g., **biodistribution** & **excretion**) as well as to ensure a highly selective binding to the desired target
- > **Targeted NMs, AMs, NAMs & nanomedicines: surface modification of (drug) nano-carriers** such as lipid nanoparticles or mesoporous silica nanoparticles, **NM reporters, beads,** and **2D-supports** with **molecular recognition moieties** such as antibodies that selectively bind to disease-specific biomarkers overexpressed on the surface of cancer cells or other targets
- > Making targeted NMs, NAMs, and AMs for life sciences & nanomedicines requires to **covalent bind targeting ligands** (recognition moieties) to **surface functional groups** (FGs) using common (biorthogonal) **conjugation chemistries**

Requirements on Suitable Methods for Quantifying FGs and Ligands on NM and (N)AM Surfaces



- Suited for routine use: fast, easy, inexpensive; possibly automatable; screening vs. quantification
- **Measurand:** Discrimination between methods measuring the **total** and **accessible** amount of FGs
- **Methods:** Discrimination between **label-free** and **labeling** methods, which are affected by **label size** and **labeling efficiency**; sample preparation workflows (often the most error-prone step)
- **Method validation is mandatory!** This requires **characterization workflows** with methods differing in signal generation principles, measurands, and sample preparation steps for identical samples or interlaboratory comparisons (ILCs)

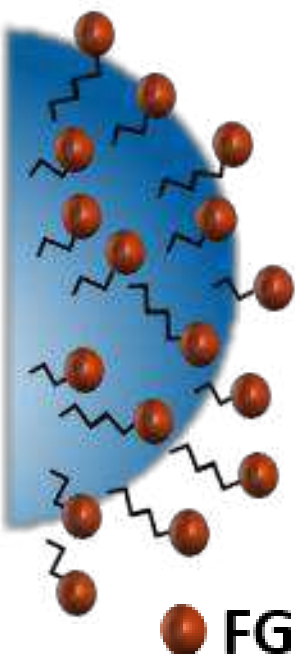
Unlocking Surface Chemistry on NMs & (N)AMs – Multi-method Concepts for Measuring FG Surface Concentration

Optical assays

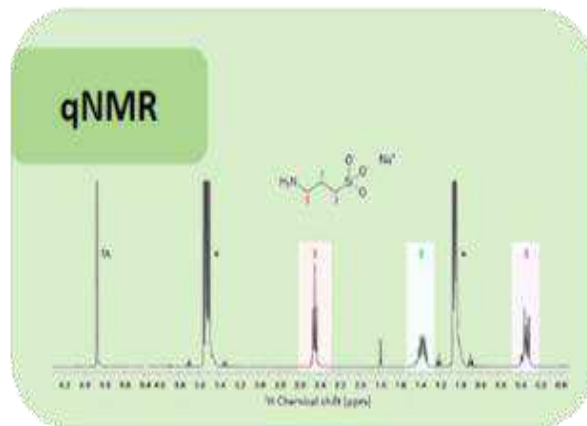
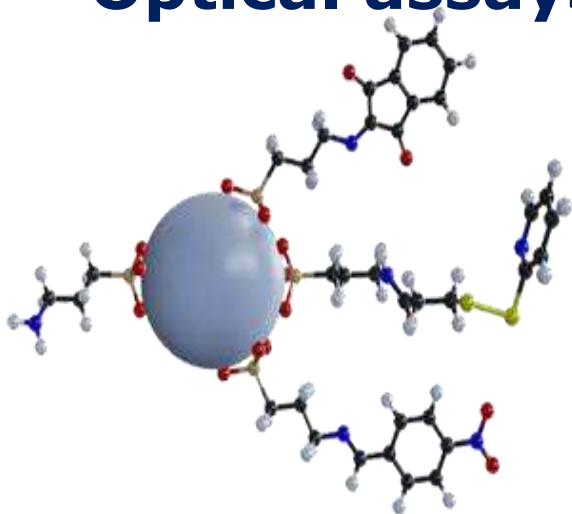
qNMR

Titration

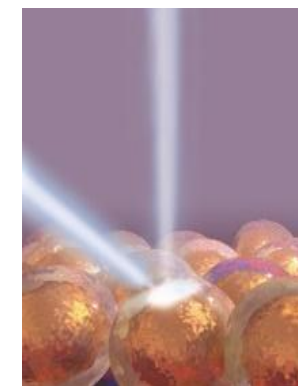
XPS



-NH₂
-COOH
-SH
-N₃



Solution & solid state



with Div. 6.1
(J. Radnik)

Other methods used by Div. *Biophotonics* (also collaboration)

- DLS, Zeta potential; TEM; NTA; TGA; FTIR; elemental analysis
- Separation techniques such as HPLC (e.g. with optical detection)
- ICP-OES, ICP-MS; LA-ICP-MS
- AAS; pyroGC-MS;
- ToF-SIMS

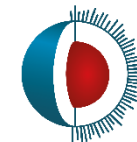
Optical Assays - Labeling with Dyes Bearing Reactive Groups Orthogonal to NM FGs or Surface Adsorption

Types of optical reporters/labels assessed

measured on NM or in solution after bond cleavage, NM removal or NM dissolution

- **Conventional dyes bearing a reactive group** for the covalent attachment to NM surface FGs that do not undergo a change in their optical properties upon binding to NM surface FGs
- **Chromogenic reporters** that undergo strong changes in their optical, i.e., absorption and/or fluorescence properties upon binding to NM surface FGs
- **Cleavable probes** consisting of a reporter, a cleavable linker, and a reactive group that can be detected on particle and in solution after NM removal after controlled, quantitative, and preferably fast cleavage of the linker
- **Adsorption/desorption assays** that rely on electrostatic interactions between oppositely charged FGs and dyes (adsorption) followed by controlled dye desorption with the aid of surfactants; $-\text{COOH}/-\text{NH}_2$: positively/negatively charged dyes

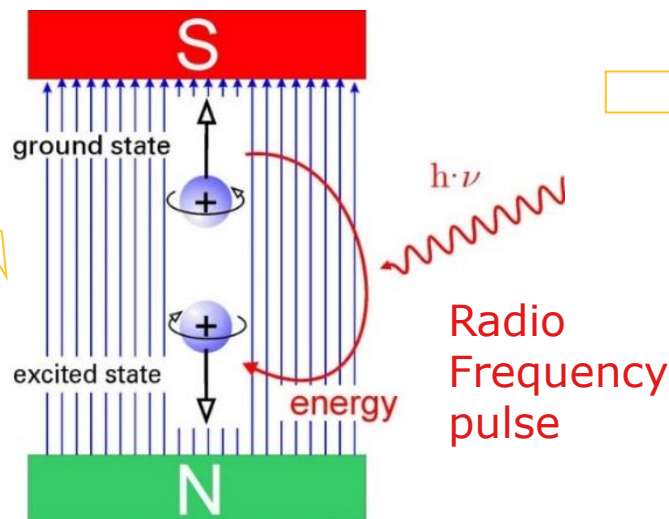
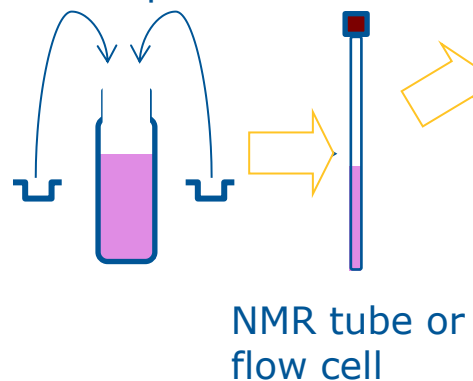
NMR – a Chemoselective Method for Qualitative and Quantitative Analysis



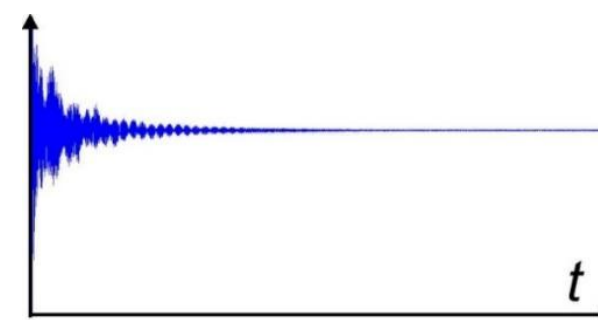
SMURF^{nano}

Internal standard
(for quantification)

Sample

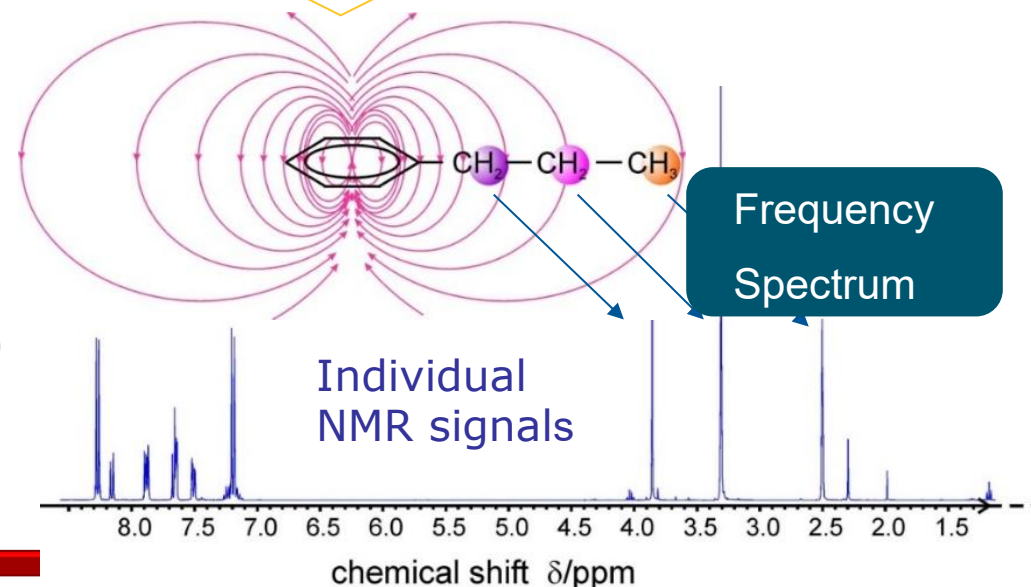


Free Induction Decay (FID)



Time Domain

Fourier Transformation

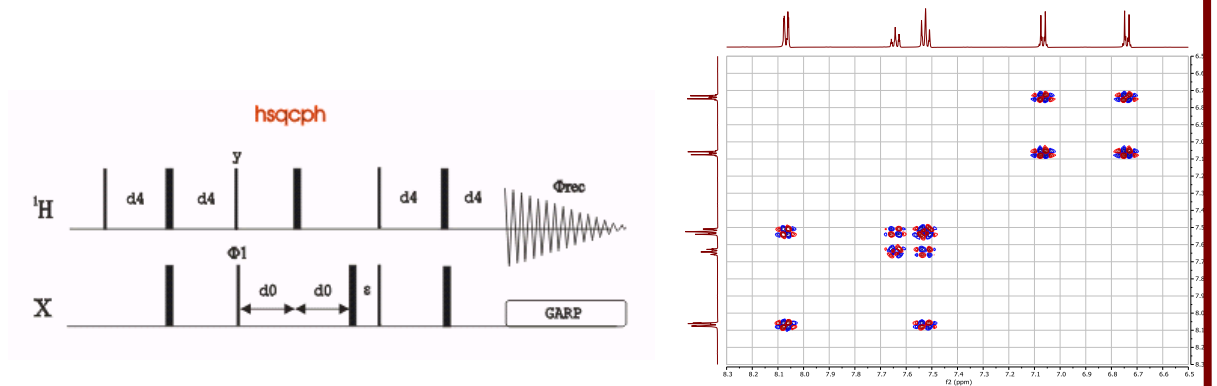


- Non-invasive & chemoselective
- Structural information
- Direct quantitative information ("Counting of Spins")
- No need for specific standards
- Lower sensitivity than other analytical methods

NMR – a Chemoselective Analytical Method for Qualitative and Quantitative Use

Qualitative NMR

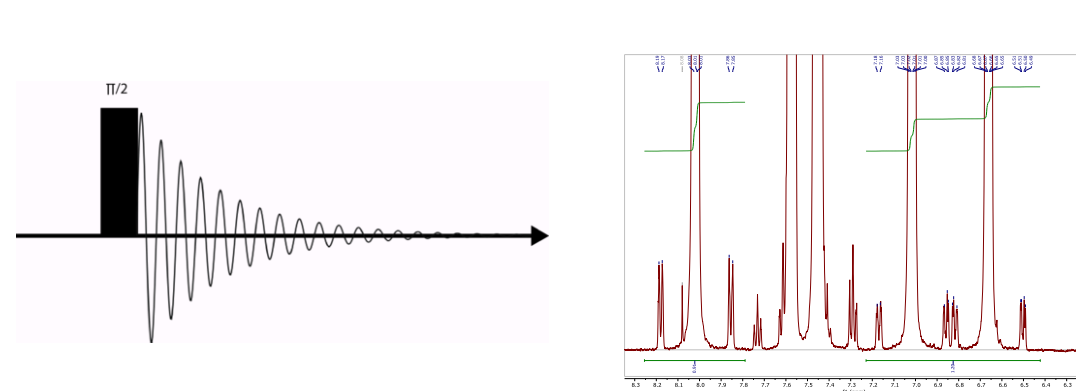
- Chemical s
- J-Couplings
- NOE, RDC, etc.
- 2D-correlation methods



Chemical Identity and Structural Information

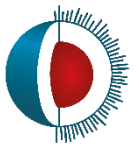
Quantitative NMR (qNMR)

- Signal area
- Relaxation times
- Mostly 1D-NMR spectra
- Often ^1H -NMR, other nuclei possible



Concentration/Purity

Surface Analysis with X-Ray Photoelectron Spectroscopy (XPS) & Hard X-ray Photoelectron Spectroscopy (HAXPES)



SMURF^{nano}

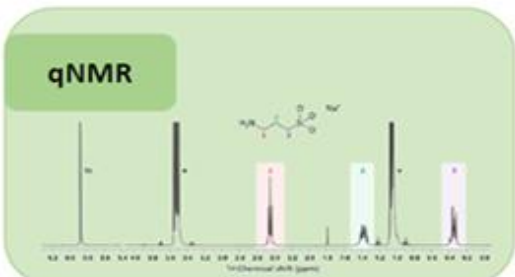
Analytical method for detecting elements near the surface of 2D (film) or 3D (particle) solid samples in vacuo

- **Measurand:** element ratios in the near-surface region (information depth of ~5 nm (XPS) or 10 nm (HAXPES))
- **Survey spectra & high-resolution spectra**
- **Qualitative analysis:** Which elements are present in the near-surface region
- **Qualitative analysis:** Relative composition of the near-surface region
- Information on chemical species /binding & valence (oxidation) states (qualitative and quantitative)
- Suitable **for all elements except H and He**
- XPS can also be performed with tags/labels that are covalently bound to surface FGs to enhance the detection sensitivity. These tags contain heteroatoms such as N or S and often F.
- **Limitations:** Limited information depth, depending on energy of X-Ray source/electrons
Use of X-ray beam can lead to beam damage of the sample → destructive
NM Surface analysis requires simulation of (size-dependent) NM surface

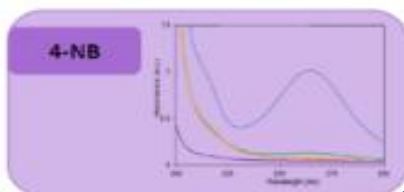
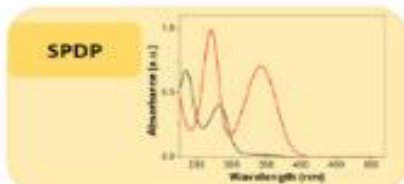
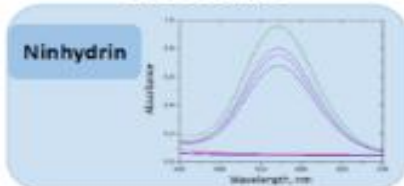
curvature

BAM-NRC Multimethod Comparison - Total & Accessible -NH₂ Amount on Commercial Aminated SiO₂ NPs

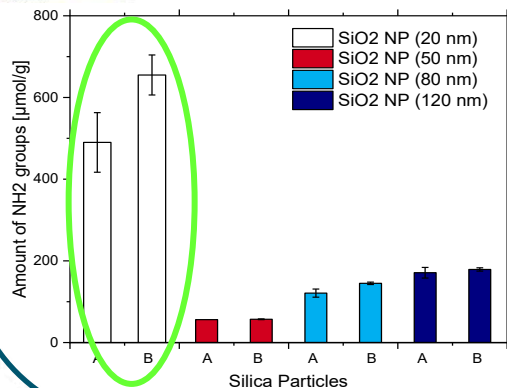
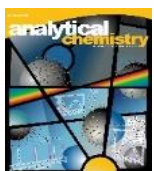
Total FGs



Accessible FGs



First ILC
BAM & NRC
2021



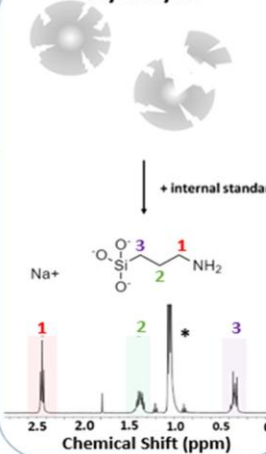
National Research
Council Canada
NaOD

BAM



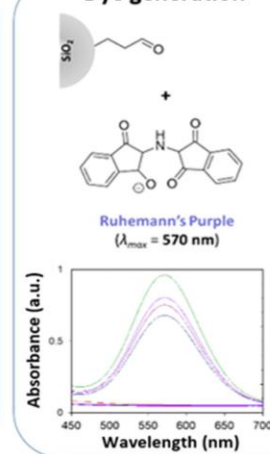
A

Hydrolysis



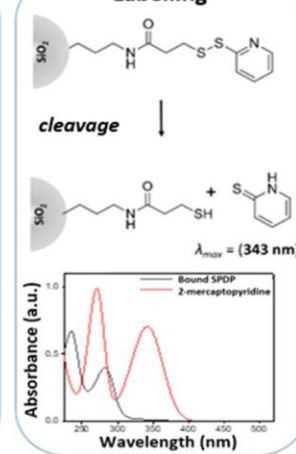
B

Dye generation



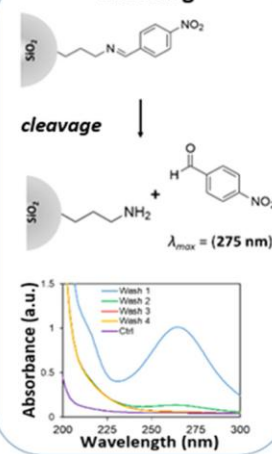
C

Labelling



D

Labelling



More multimethod studies in 2023-2026

- Self-made & commercial SiO₂NPs varying in size, amounts of NH₂ groups, porosity, and sol gel route used for NP synthesis
- IONPs and LnNPs with different FGs & ligands

Characterization of Nanoparticles – Standardization

PWI 19257 - Nanotechnologies – Characterizing and Quantifying Functional Groups (FGs) & Coatings on Nanoobjects



Developing validated and standardized measurement protocols to support the manufacturing, quality control, and safe use of engineered NPs

L. Johnston (NRC, Canada)
U. Resch-Genger (BAM)
approved Sept. 22, 2022

The basis of SMURFnano

NMR
(focus on solution qNMR;
not solid state NMR)

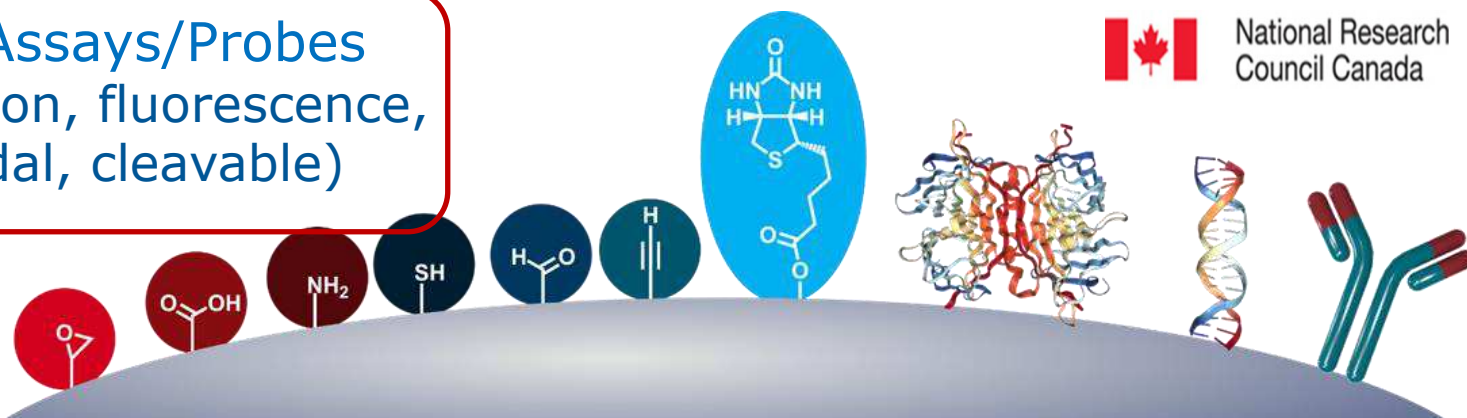
X-ray Photoelectron
Spectroscopy (XPS)
HAXPES

 BAM



Optical Assays/Probes
(absorption, fluorescence,
multimodal, cleavable)

 National Research
Council Canada



EMP SMURFnano - Objectives

- 1) Traceable **reference methods, reference data, and reference materials** for surface analysis of industrially relevant functional NMs
NMs: Silika & polymer NPs (model systems & industrial NMs); FGs: -NH₂
- 2) **Standardized protocols for quantifying NM surface functionalities** with advanced methods (XPS, ToF-SIMS; qNMR) & assessment in **ILCs** (CCQM & VAMAS)
Different SiO₂-NH₂ NMs (model systems & different commercial products)
- 3) Assessing simple optical and electrochemical methods for use in process control of the manufacturing and the quality management of functional NP-based products; target uncertainties of 10% to 20%.
First methods & protocols established by BAM as screening tools for ILC samples
- 4) **Four new guidance documents and standards** for industry and regulators:
ISO TC 201 TR 23173, TC 229 PWI 19725, IEC TC 113, and OECD WNT 1.6
Based on outcome of currently running ILCs on qNMR & XPS/HAXPES
- 5) Initiation of **future standardization projects** (after M18) according to the PSIS ("Putting (more) Science into Standards") initiative of the European Commission
PRT HTSURF with focus on simpler & less expensive methods & automation & AI

BAM – NRC Comparison Measuring **Total** & **Accessible** –NH₂ Amounts of 20-100 nm SiO₂ NPs-NH₂ & Method Correlation

Goals

- Developing standardized workflows and optimize protocols for qNMR by assessing sample preparation, measurement, and data evaluation steps
- Improving the comparability of qNMR measurements and relative standard deviations (RSDs) for 20 – 100 nm aminated SiO₂ NPs to about 5%

Self-made & commercial SiO₂ NP-NH₂ varying in

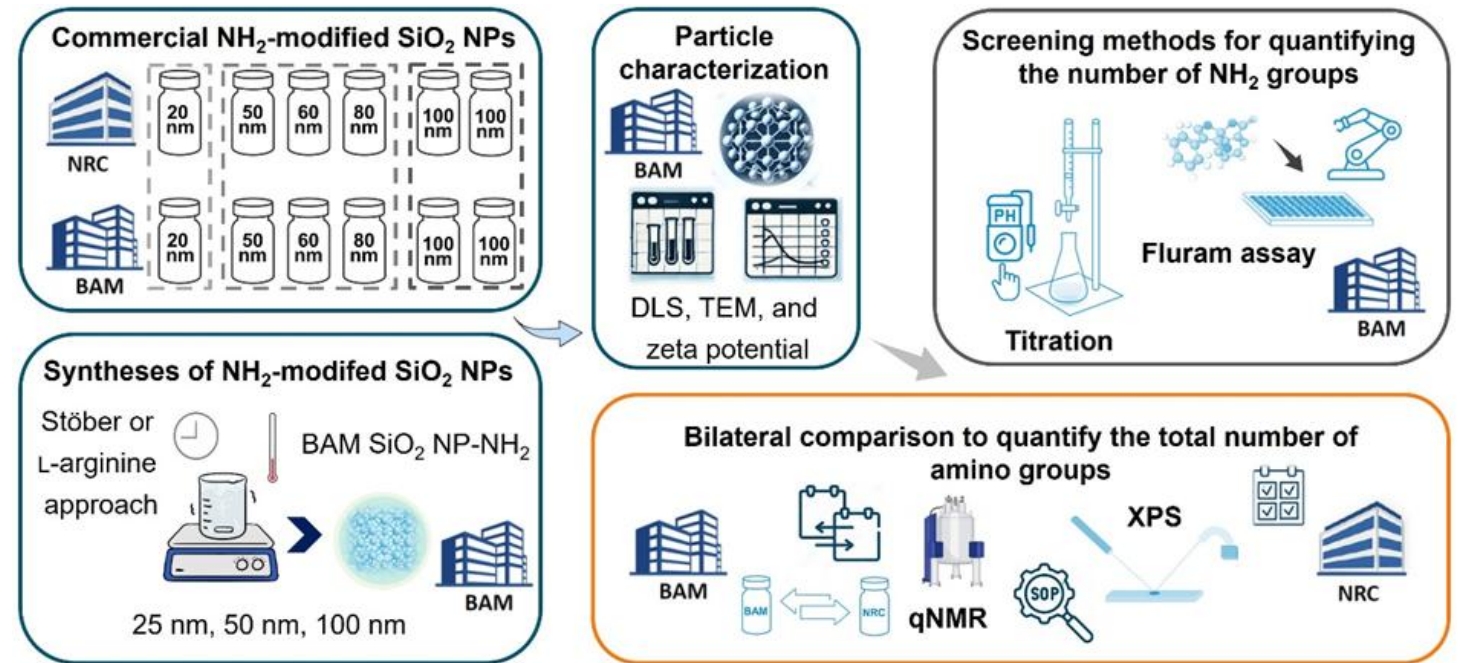
- Size
- Amount of NH₂ groups
- Porosity/morphology
- Sol gel route used for NP synthesis

Methods – Screening* & validation

- **Optical fluram assay (automated)***
- **Potentiometric back titration***
- qNMR
- XPS



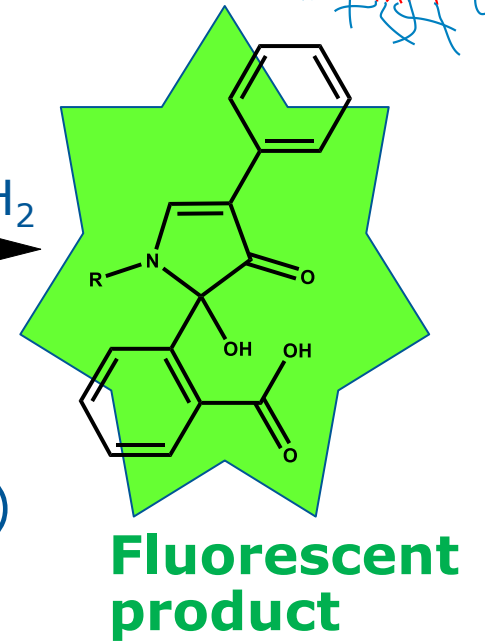
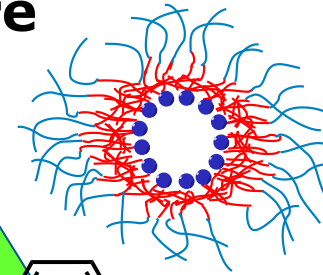
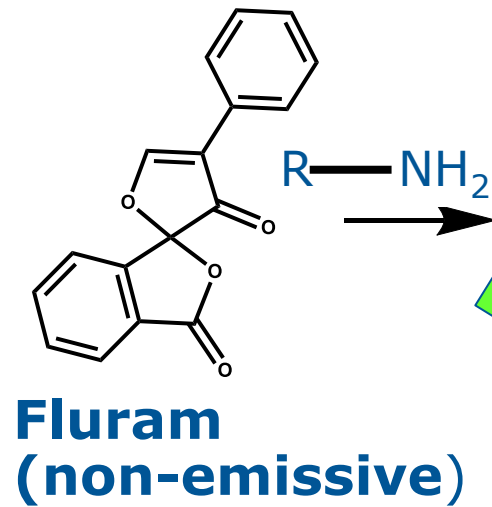
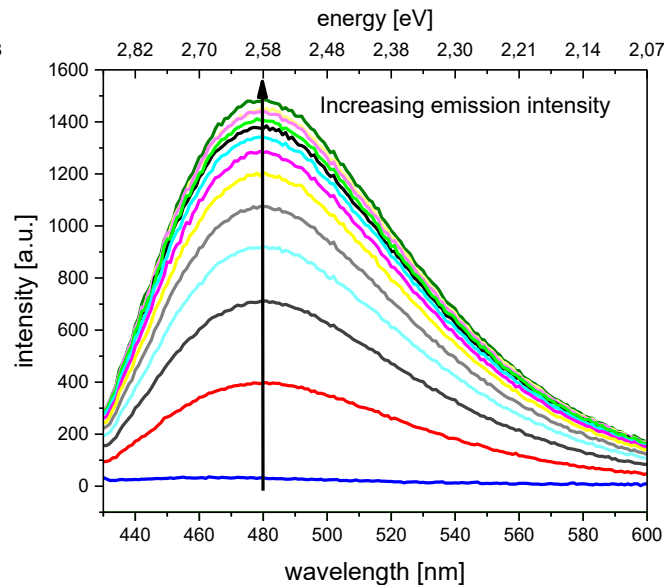
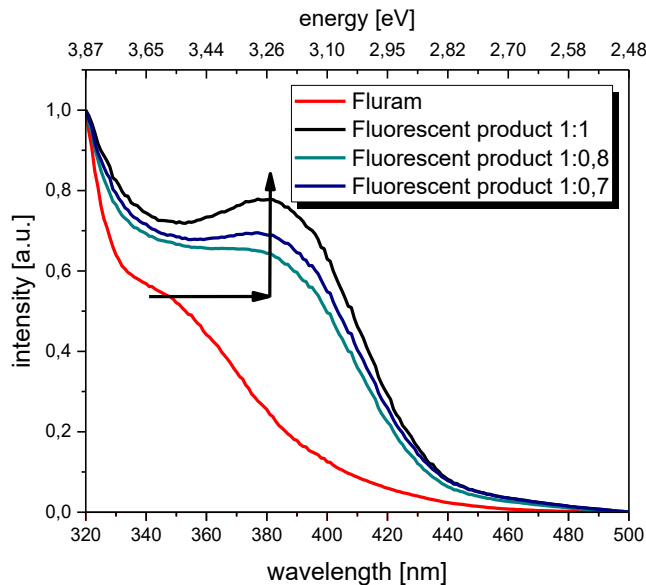
National Research
Council Canada



Setting Up Screening Tools for Process Control – Colorimetric & Fluorogenic Fluram Assay for Primary NH₂ FGs



- **Chromogenic** labels & probes change their optical properties upon analyte (FG) binding:
Reaction with primary –NH₂ FGs turns non-emissive **fluram** into **fluorophore**
- Used by us first for quantifying NH₂ groups on QDs encapsulated in micellar structures and later for NH₂ FGs on different types of NMs



D. Geissler *et al.*, *Nanoscale* **2019**; I. Tavernaro *et al.*, *Nano Research* **2024**

Setting Up Automatable Screening Tools for Quantifying Surface FGs on NMs for Homogeneity & Stability Studies



Fluram Assay: Accessible NH_2 FGs

Analyzing large numbers of NM samples for NM process, quality, and stability control calls for **validated automated workflows** for the screening, monitoring, and quantifying functional groups (FGs) on NMs

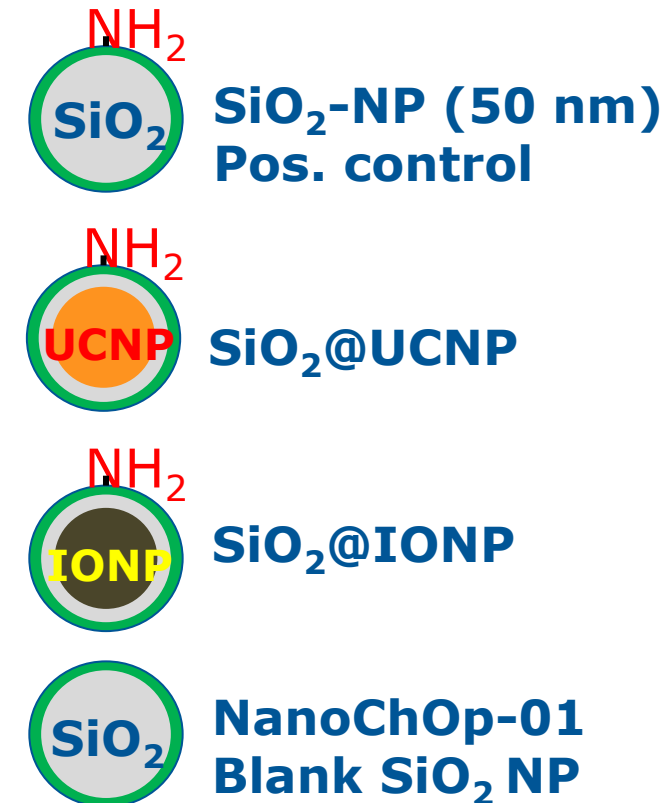
NM- NH_2 tested
(different sizes, morphology, opt. properties)

Automating the Fluram assay for $-\text{NH}_2$ quantification

- Detection of the NM-bound product – no washing steps
- But the assay is error-prone due to
 - Different pipetting & dilution steps
 - Stability issues with fluorescamine solutions
 - Time-dependent stability of the NM-bound product

Reliable data require standardized workflows

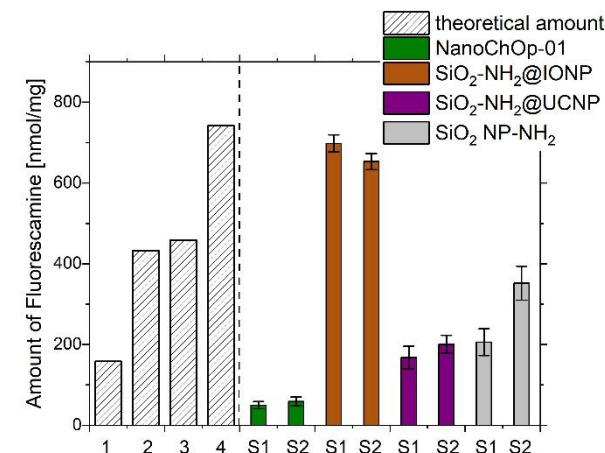
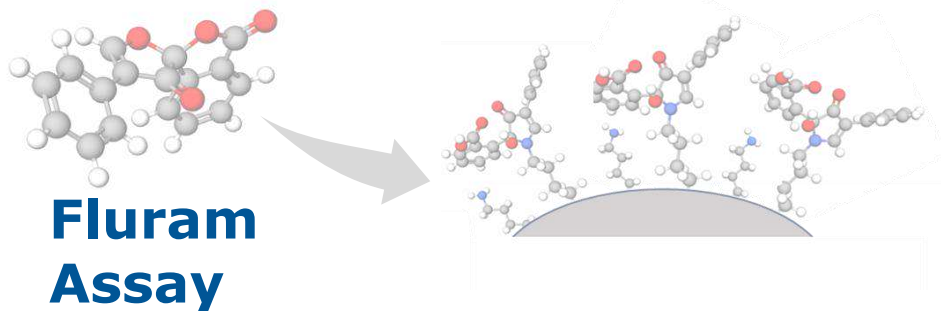
pH titration for (de)protonable FGs



Automated Fluram Assay – Our Workhorse

Reporter-accessible Amount of NH_2 FGs

Calibration of fluorescence intensities with the primary amine ethanolamine



1

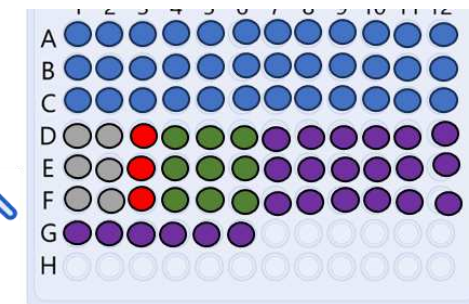
sample preparation

2

incubation

3

sample transfer



sample analysis

5

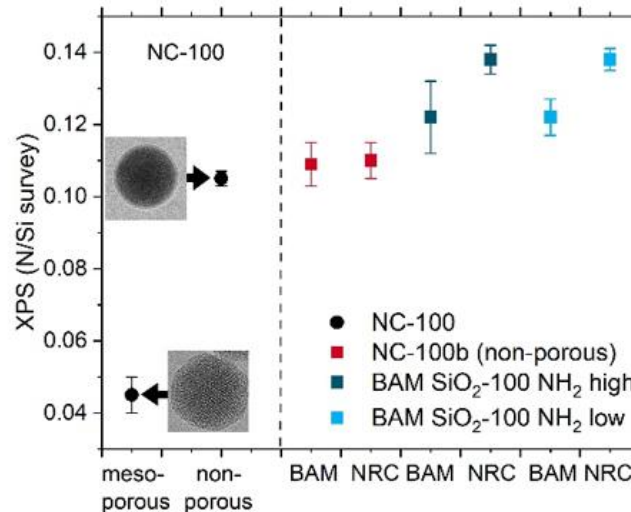
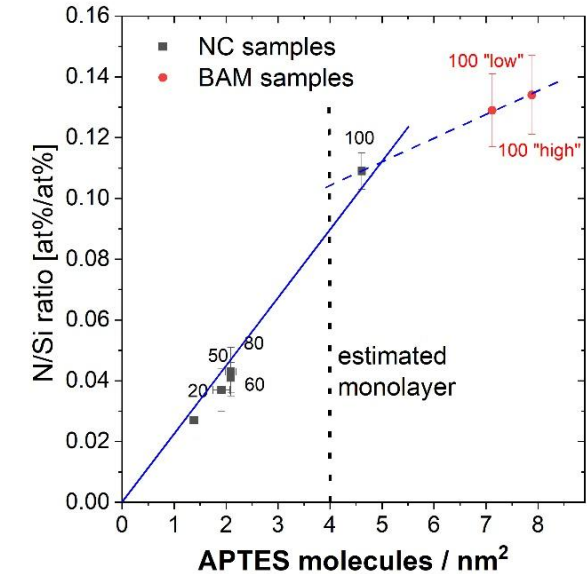
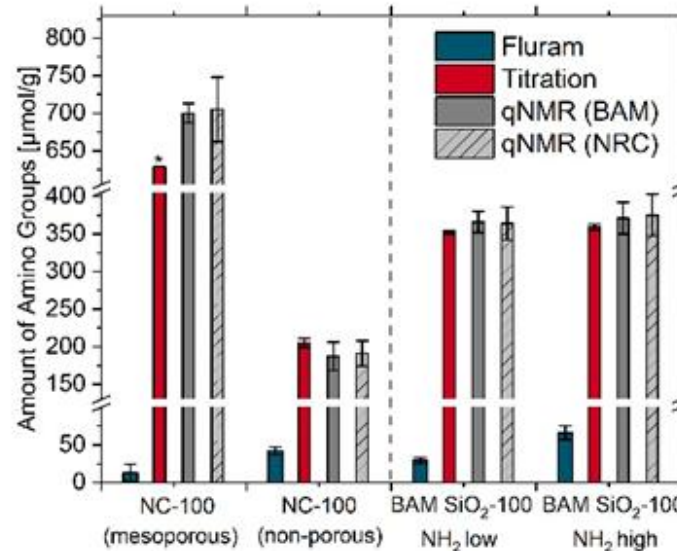
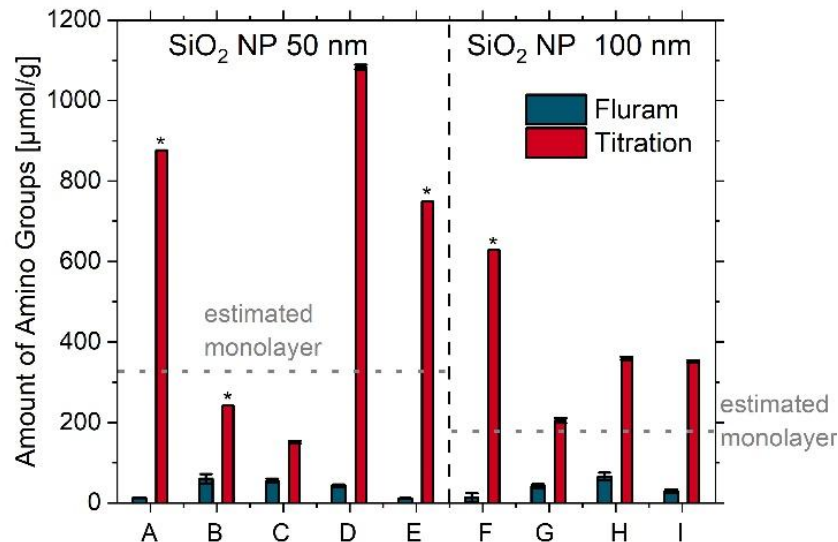
Manual & automated performance for validation

I. Tavernaro *et al.*, *Nano Research* **2024**

BAM – NRC Comparison Measuring **Total** & **Accessible** –NH₂ Amounts of 20-100 nm SiO₂ NPs-NH₂ & Method Correlation

Screening of SiO₂ NPs-NH₂ varying in

- Preparation method
- Size
- Amount of surface NH₂
- Porosity



Correlating XPS & qNMR

- i.e., N/Si ratio (XPS) and number of APTES molecules per nm² (qNMR)
- XPS underestimates –NH₂ amount for mesoporous SiO₂-NPs-NH₂
- pH titration data correlate with qNMR



National Research
Council Canada

ILC Solution qNMR - Quantifying Surface FGs on Dissolved NMs - Total NH_2 FG Amount on SiO_2 grafted with APTES

Centrifugation of NM dispersion (standardized protocol) and removal of supernatant to separate amines that are noncovalently bound to SiO_2 NPs or released by hydrolysis from the NM surface

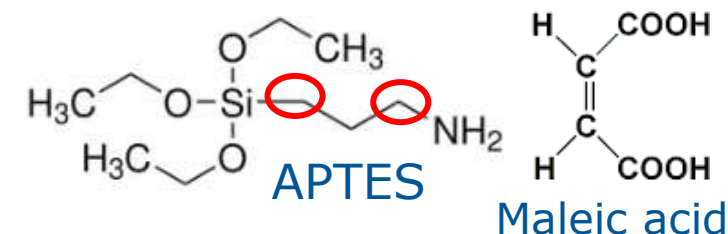
Drying of NMs at elevated T in an oven **& weighting**

Dissolution of dried NMs in 1M NaOD/ D_2O at 50°C

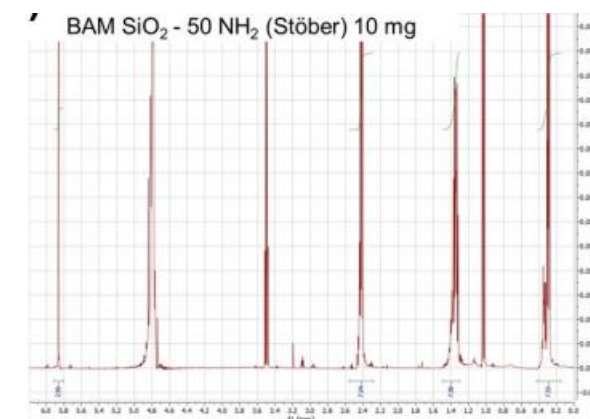
Addition of internal standard: ultrapure maleic acid (for quant.)

NMR data acquisition parameters: number of scans, pulse angle of 90° , pulse delay of 50 s, acquisition time of 3.60 s, spectral width of 30 ppm

Data processing: satellites of amine aliphatic $-\text{CH}_2-$ signals at 2.50 and 0.38 ppm included in integration for FG quantification



^1H -NMR signals for 2 $-\text{CH}_2-$ at 2.50 ppm and 0.38 ppm used; Signal at 1.3 ppm close to $-\text{CH}_3$ signal of residual EtOH omitted



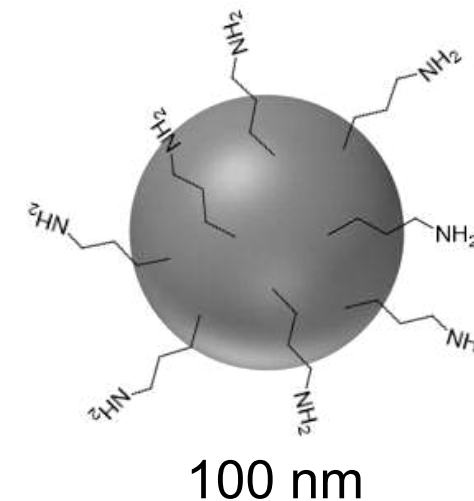
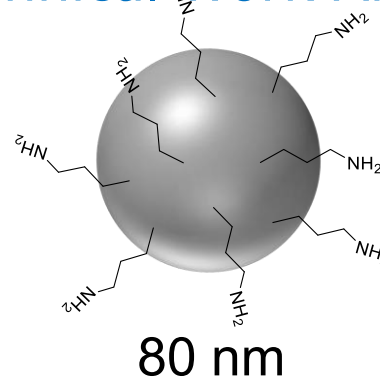
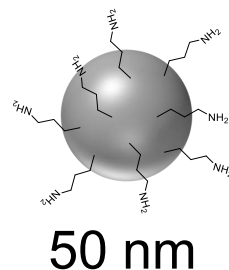
Workflow & protocol development by BAM and NRC for custom-made particles (BAM SiO_2 - NH_2) with sizes of 25 nm, 50 nm, and 100 nm as well as for particles with different FG densities

CCQM Pilot Study on qNMR involving SAWG & OAWG

VAMAS Project 19: *Analysis of total functional group content on aminated silica nanoparticles using quantitative NMR (qNMR); Lead: U. Resch-Genger & K. Meyer, BAM*

VAMAS Nanoparticle Populations – Technical Work Area 34

SiO₂ NPs



36 (23) participants from NMIs, industry, and academia contacted, 20 (14) positive replies; Countries involved: UK, DE, CN, FR, CA, USA, IT, AT, BR, AR, AU

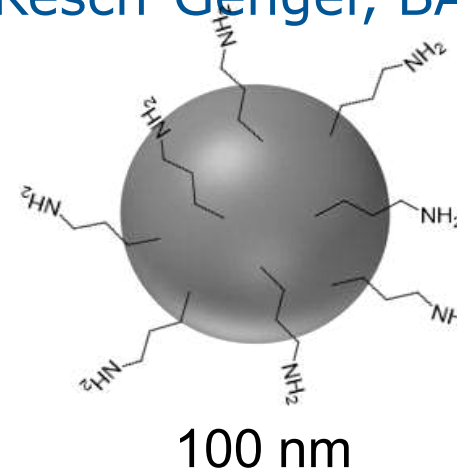
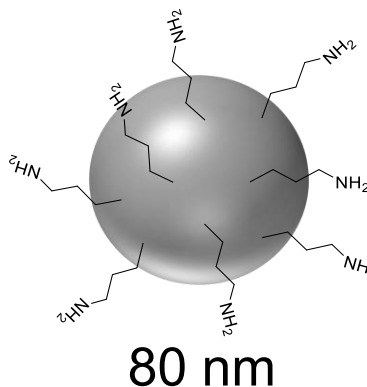
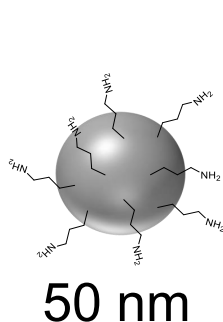
Timeline: Sample preparation including homogeneity and begin of stability studies in fall 2025, sample shipment in Dec 25/Jan 26, supply of data in April/May/June 2026, followed by statistical data evaluation by BAM, and discussion with all participants; joint publication in 2026/2027

ILC on qNMR and XPS – CCQM & VAMAS

CCQM Pilot Study on XPS under the roof of SAWG

VAMAS Project A51: *Analysis of the amount of surface functional groups on silica nanoparticles using XPS and SIMS*; Lead: J. Radnik & U. Resch-Genger, BAM

SiO₂ NPs



25 potential participants from NMIs, industry, and academia contacted, 15 positive replies
Countries involved: UK, DE, CN, SG, SI, FR, CA, MX, SE, USA

Timeline: Sample preparation including homogeneity and begin of stability studies of dispersed NPs in fall 2025, sample preparation on Au coated Si wafer by BAM and shipment in June 2026, supply of data by participants in July/Aug 2026, followed by statistical data evaluation by BAM, and discussion with all participants; joint publication planned in 2027

Reference datasets for measuring surface functionalities with qNMR

- Publishing reference datasets based on the results of the ILCs (depending on agreement of participants)

Test and reference materials for measuring surface functionalities

- Protocols for qNMR sample preparation, measurement, and data evaluation workflows shared with ILC participants and possibly further refined based on ILC results

Putting sciences into standards – NWIP (ISO 229(JWG2): qNMR & XPS)

- Protocols for qNMR sample preparation, measurement, and data evaluation workflows have been used for NWIP; later, the results of the ILC will be considered
- A similar procedure is planned for XPS

Unlocking NM & (N)AM Surface Chemistry

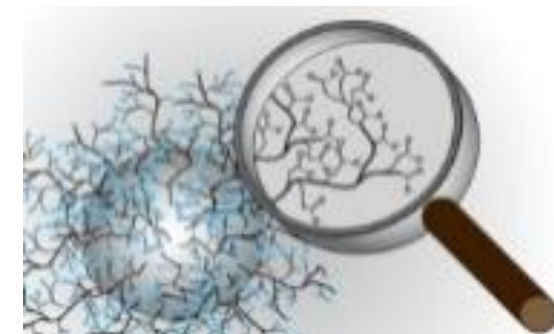
Current Gaps & Future Needs – Methods for High Throughput Analysis of (Nano-Enabled) Advanced Materials in Industrial Workflows

- Develop fast, cost-efficient, robust, and quantitative methods & workflows for reliable high throughput measurements of surface FGs in surface engineering & QC processes
- Establish validated and traceable workflows for the automated quantification of NAM surface FGs for fast, cost-efficient, robust methods (preferably with uncertainties of $\leq 15\%$)
- Provide multi-method measurement workflows for method validation by cross comparison with accurate and/or traceable measurement techniques (i.e., qNMR; XPS) and establish the data basis for modeling and deriving surface chemistry-NAM property relationships
- Develop artificial intelligence (AI)-driven metrological frameworks that leverage machine learning (ML) for automated multi-source data fusion and predictive modeling of surface chemistry-NAM property relationships to accelerate characterization workflows
- IICs to establish best practice for industry and (traceable) laboratory-scale methods for valid quantification, routine monitoring, and QC of AM surface chemistry, with steadily increased levels of automation
- Multi-method quality control samples, reference materials, and reference data for AM community

THANK YOU For Your Attention

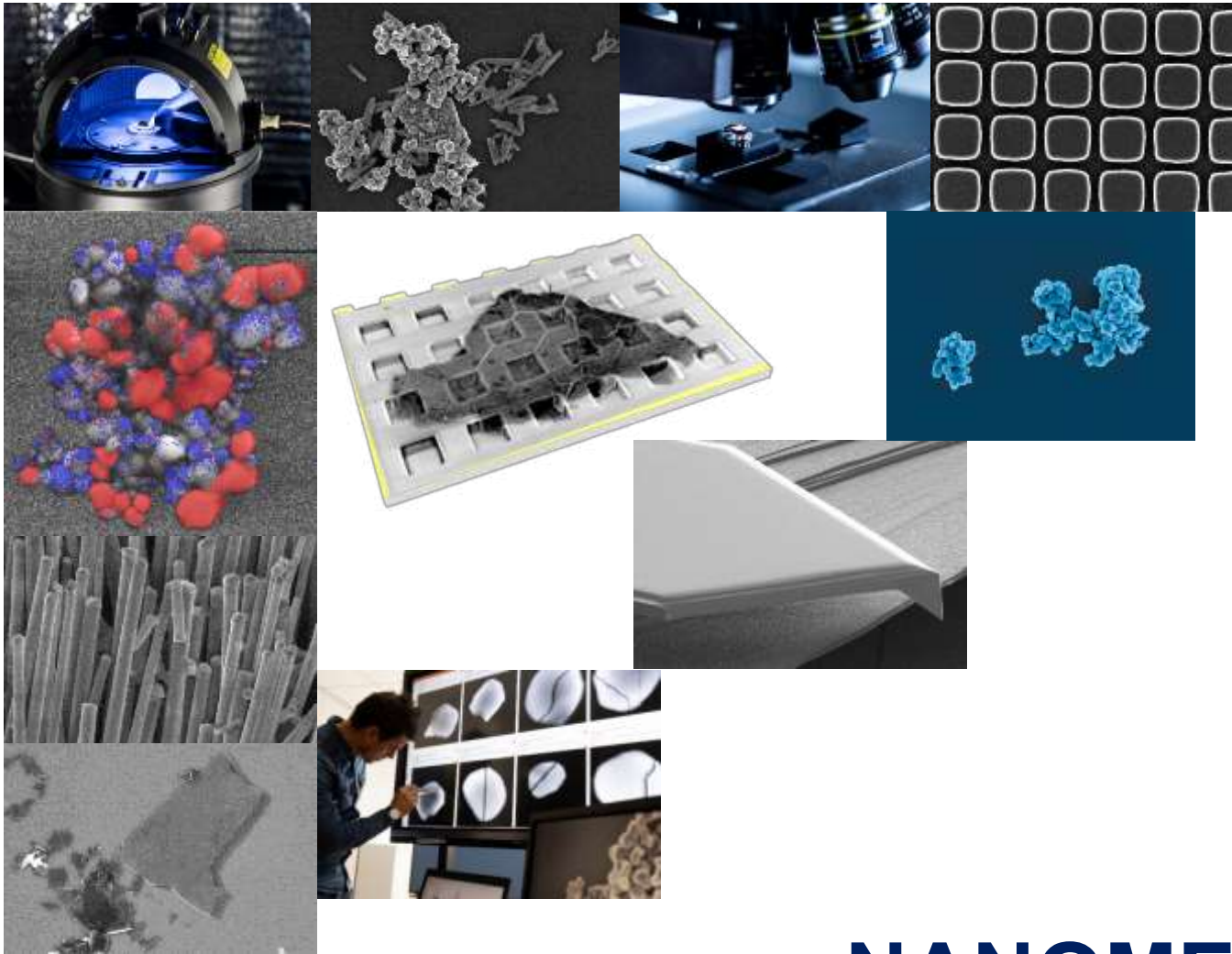
Ute Resch-Genger

ute.resch@bam.de



The projects **MetrINo** and **SMURFnano** (23NRM02) have received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States

SMURFnano consortium



NANOMESUREFRANCE:
A **public-private initiative** to build
common characterization solution

USE OF NANOMATERIALS: *CHALLENGES*



<https://euon.echa.europa.eu/fr/uses>



**REGULATORY
FRAMEWORK**



TRUST

https://euon.echa.europa.eu/documents/2435000/3268573/nano_perception_study_en.pdf

**NEED FOR RELIABLE
& COMPARABLE
TEST DATA**



GOVERNANCE

NANOMESUREFRANCE: *GENESIS*

Nanomaterials are at the heart of industrial innovation, but their **characterization** and regulation remain **major challenges**



- ④ **DECOMPARTMENTALISING** INDUSTRIAL SECTORS
- ④ ACCESS TO **CENTRALISED INFORMATION**
- ④ FACILITATING **ACCESS TO EXPERTISE**
- ④ **HARMONISATION** AND VALIDATION OF TEST METHODS
- ④ **SHARING** GOOD PRACTICE/TRAINING
- ④ **VALIDATION** OF STAKEHOLDERS' SKILLS

How is France organizing itself to address these issues?



NANOMESUREFRANCE: *GENESIS*



2018

Request from the LNE's supervisory body (DGE) to consider setting up a structure to address the obstacles identified in the PIPAME prospective study

2018 - 2020

2 years of exchanges with multiple (> 100) stakeholders



2020

Project submitted as part of the *Plan d'Investissement d'Avenir* program (Call for **Industry structuring**)



2021 – 2024

Project supported by Ile-de-France region and the French government → **Grant for LNE**



September 2024

End of PIA → NMF financially independent

NANOMESUREFRANCE: CREATION

September 2022
CREATION OF



NON-PROFIT
ASSOCIATION

3 FOUNDING
MEMBERS

FRANCE
CHIMIE

PRESIDENCY



VICE-
PRESIDENCY



TREASURER
& SECRETARY



ASSOCIATION « NANOMESUREFRANCE »

STATUTS DE L'ASSOCIATION

Article 1^{er} - Constitution

Entre les soussignés

- Laboratoire National de métrologie et d'Essais (LNE) - 1 rue Gaston Bourcier 75724 Paris Cedex 15
- France Chimie - 14 Rue de la République, 92025 Puteaux
- Fédération des Entreprises de la Beauté (FEBEA) - 127, rue de l'Université, 75007 Paris

Et les autres parties en nombre illimité qui acceptent ces statuts, a été créée une association à but non lucratif régie par les présents statuts et par la loi française du 1^{er} juillet 1901 (et les textes subséquents) sur les associations à but non lucratif.

Article 2 - Dénomination de l'Association

L'Association (ci-après dénommée « l'Association ») a pour dénomination « NanoMesureFrance ».

Article 3 - Objet

L'Association a pour objet de :

- Fédérer et primer le réseau d'acteurs nationaux de la future filière industrielle « nanomatériaux » à travers la coordination des efforts français sur les problématiques d'identification et de caractérisation des nanomatériaux, ainsi que d'évaluation de l'exposition de nanosopos à différentes étapes du cycle de vie des produits ;
- Définir les besoins de la filière et élaborer des feuilles de route et documents d'orientation stratégique sur ces sujets ;
- Diffuser des informations auprès des adhérents (veille technologique et scientifique, documents pertinents dans un cadre réglementaire, normes et documents de référence, bonnes pratiques, événements et les opportunités des dispositifs de financement) ;
- Cartographier les moyens pertinents et disponibles à l'échelle nationale sur ces sujets afin de faciliter leur accès aux adhérents de l'Association et d'identifier les investissements à réaliser ;
- Participer et promouvoir au développement, à la validation et à l'harmonisation de méthodologies pour l'identification et la caractérisation des nanomatériaux, ainsi que pour l'évaluation de l'exposition de nanosopos à différentes étapes du cycle de vie des produits ;
- Valoriser les travaux réalisés en son sein dans différents réseaux d'influence à l'échelle européenne et internationale (AFNOR, ISO, CEN, OCDE, VAMAS) afin d'accroître la visibilité de positions françaises coordonnées.

Article 4 - Siège

Le siège de l'Association est fixé à :

Laboratoire National de métrologie et d'Essais (LNE)
1 rue Gaston Bourcier
75724 Paris Cedex 15

Il pourra être transféré en tout autre endroit par simple décision du Conseil d'Administration.

Article 5 - Durée

La durée de l'Association est illimitée.

Article 6 - Composition

Statuts de l'Association « NanoMesureFrance », version du 29 Août 2022

December 2022 : LAUNCH EVENT



- ❑ Over 120 participants ($\frac{3}{4}$ from private sector/industry)
- ❑ Video highlights (FR & EN)
<https://www.youtube.com/watch?v=pmx241GxcEg>
- ❑ European visibility

NANOMESUREFRANCE: *OUR DNA*



Identify

nanomaterials in support
of increased traceability of
their use in value chains



Characterise

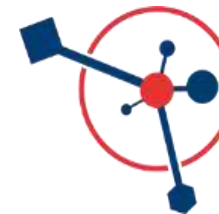
their key physical and chemical
properties and their possible
changes during the life of the
substance with regard to
regulatory requirements



Evaluate

emissions of nano-objects
at different key stages of the
product life cycle as part of the
risk analyses to be conducted

BUILD COLLECTIVE
SOLUTIONS



Nano
Mesure
France



TRUSTED
THIRD-
PARTY

NANOMESUREFRANCE: *AMBITIONS*

*A **single entry point** for structuring a nanomaterials industry based on reliable and comparable data*



- ☐ Promoting collaborations
- ☐ Identify & ease access to experts/techniques
(→ **Mapping of analytical platforms**)

NANOMESUREFRANCE: *FOR WHOM?*

1

PRODUCERS AND
USERS OF
NANOMATERIALS

Expression of needs & prioritisation of actions to be implemented

Facilitated access to expert actors and relevant tools

A bridge towards normative and regulatory bodies/public authorities

2

INSTRUMENT
MANUFACTURERS

Visibility / inclusion of new instrumental technologies in initiated actions +
Identification of stakeholders' needs for future instrumental developments

Framework for validation of characterisation instrument performances

Development of harmonised methods / protocols & recognition of methods
within a standardisation framework

3

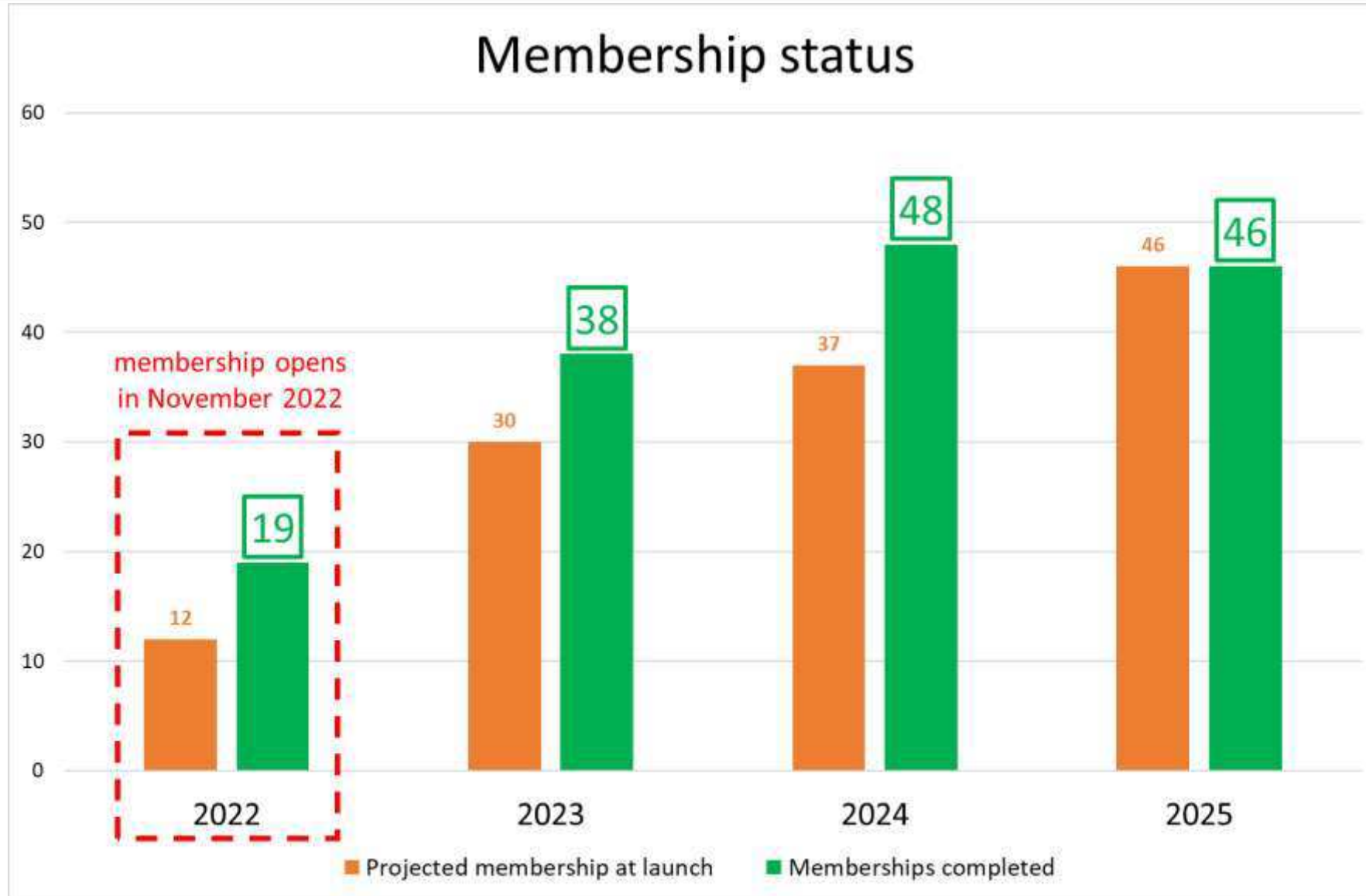
SERVICE PROVIDERS/
ANALYTICAL PLATFORM

Access to harmonised and validated state-of-the-art methods

Training / Transfer of good practices

Proficiency Testings to demonstrate skills

NANOMESUREFRANCE: *CREATE A NATIONAL NETWORK*



NANOMESUREFRANCE: *OUR MEMBERS IN 2025*

Materials & Chemistry



Cosmetics



Others



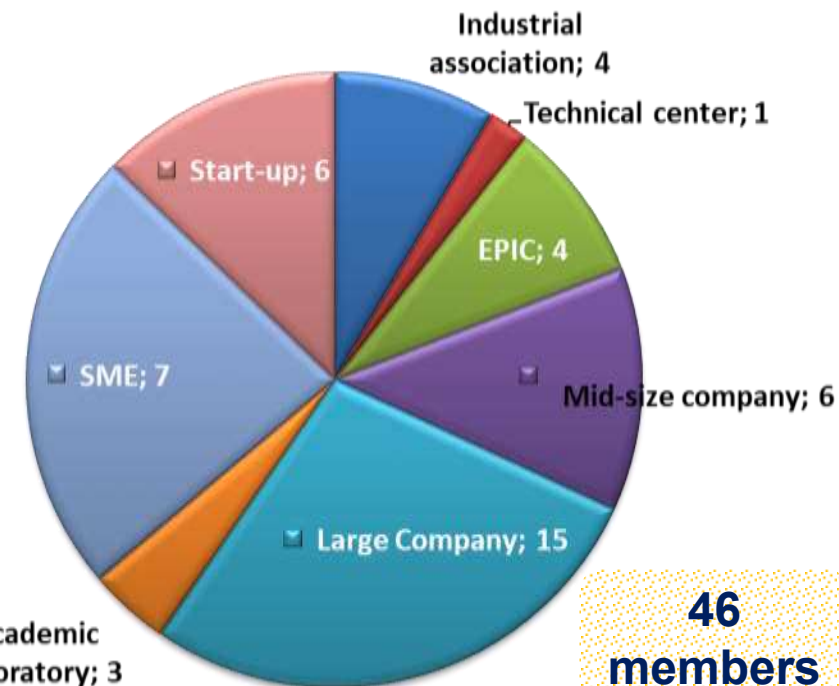
Service providers / Analytical Platforms



Instrumentation



Nanomedecine



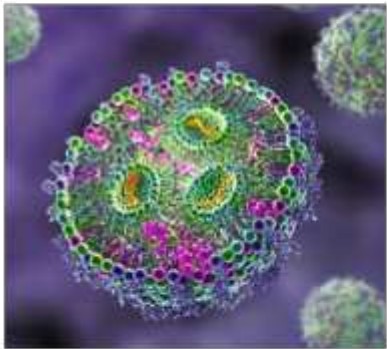
NANOMESUREFRANCE: *OUR WORKING GROUPS*



Materials & Chemistry



Cosmetics



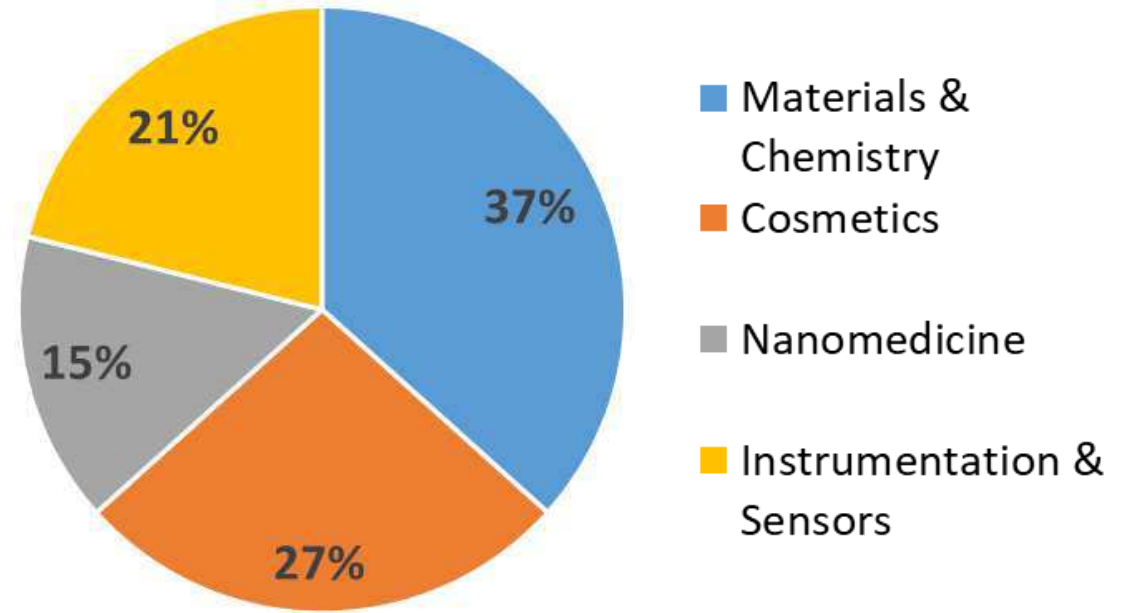
Nanomedicine



Instrumentation & Sensors

- Identification of **sectoral concerns**
- Sharing **cross-cutting issues** and view / **analytical approaches / initiatives**

Distribution of members by WG



SOME MEMBERS PRESENT IN SEVERAL WGs

NANOMESUREFRANCE: *AMBITIONS*

*A **single entry point** for structuring a nanomaterials industry based on reliable and comparable data*



- ☐ Promoting collaborations
- ☐ Identify & ease access to experts/techniques
(→ **Mapping of analytical platforms**)



- ☐ Identification of needs/priorities in terms of **pre-standardisation** of characterisation and testing methods & Coordination of French efforts
- ☐ Framework for **evaluation** of performances and **recognition** of techniques, methods and laboratories

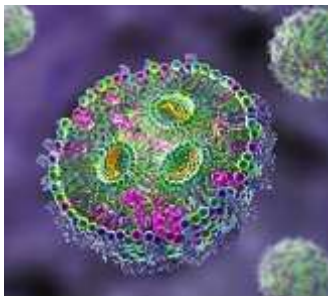
INCREASE CONFIDENCE IN TEST METHOD DATA



Materials & Chemistry



Cosmetics

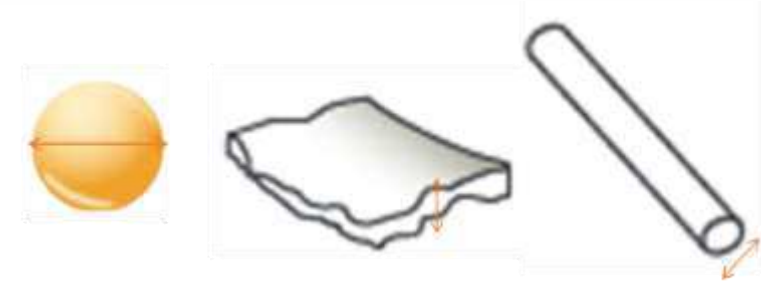


Nanomedicine



Identify

nanomaterials in support
of increased traceability of
their use in value chains



❑ How to tackle complex industrial « real life » samples?

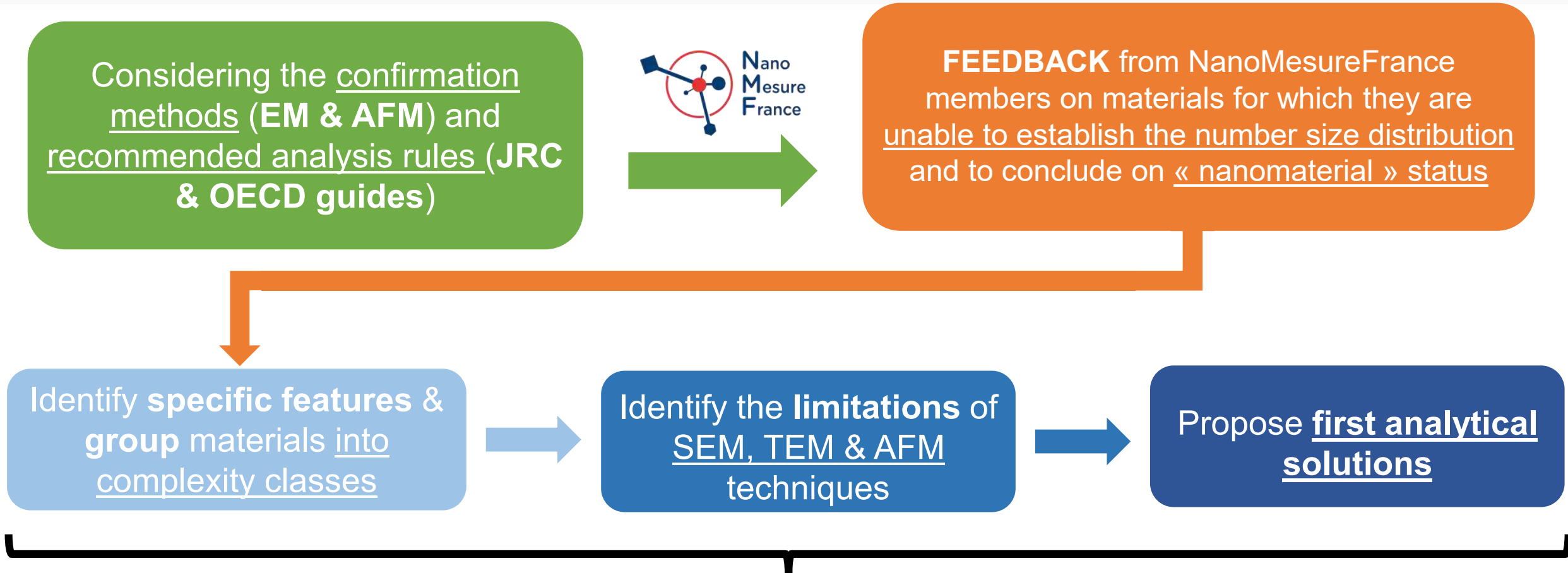
➔ Applicability of available guidances

❑ How to improve the collection of **relevant and robust data** from ingredient suppliers to support « *nanomaterial* » or « *non nanomaterial* » statements

➔ **Improve exchanges** between users & suppliers

➔ **Provide easy-to-use documents** for non-experts

INCREASE CONFIDENCE IN DATA: *APPLICABILITY OF AVAILABLE GUIDANCES*

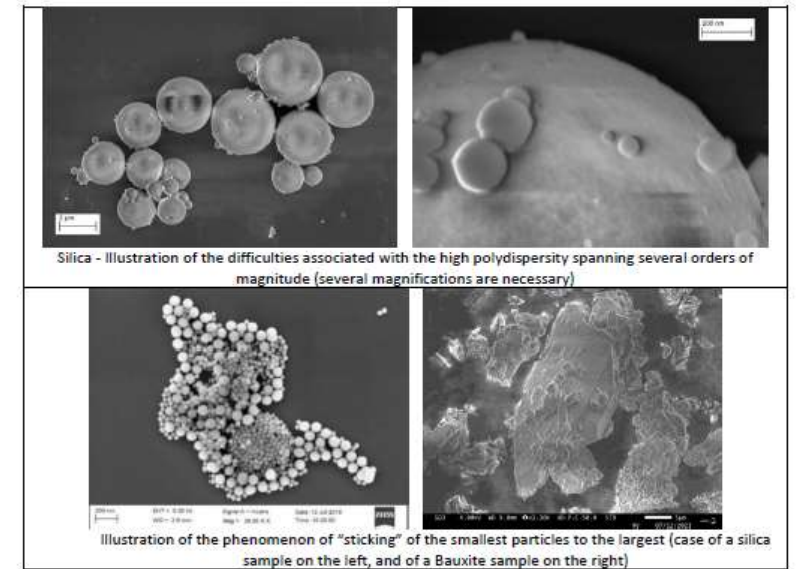


NanoMeasureFrance guide outlining the **limitations of SEM, TEM & AFM techniques** for characterising the size of **some commonly encountered particulate materials**

INCREASE CONFIDENCE IN DATA: *GUIDE BY EXAMPLE*

- **Summary** and introduction of complexity class
- **Issues** (limitations of EM/AFM techniques to analyse the complexity class)
- Most « illustratives » **SEM/TEM/AFM images**
- **State of the art of existing technologies** able to respond to these difficulties
- **Recommendations** and **development areas**

Table 1: Illustration of the difficulties associated with class "A. Materials exhibiting high size polydispersity"



OVERVIEW OF EXISTING TECHNOLOGIES

- SEM is the method best suited to producing images highlighting all the particles and identifying the presence of agglomerates that group together small and large particles;
- TEM, subject to prior deagglomeration of the particles constituting the sample, has a resolution and magnification covering wide size ranges;
- The manufacturers of electron microscopes offer software to automate the process of obtaining images. This automation makes it possible to generate large number of images while reducing operator time (and therefore the costs of analysis);
- Related to this automation, functionalities for assembling microscopy images ("image stitching") are offered on new generation equipment, making it possible to merge data obtained for different magnifications and cover a wide range of sizes;
- Automated recognition software based on artificial intelligence (AI) and machine learning is also being developed.

RECOMMENDATIONS AND DEVELOPMENT AREAS TO CONSIDER

- First of all, it is necessary to define this complexity class based on a measurand allowing a characterisation of "high size polydispersity";
- After defining this complexity class, efforts must focus on determining the minimum number of particles to analyse to ensure representative data. The number of particles to be analysed must be set based on the standard deviation of the size distribution and estimated uncertainty, using the recommendations of the ISO 19749:2021 and NF EN ISO 21363 standards. For instance, in the case of samples showing relatively low polydispersity (geometric standard deviation below 1.5), and following its

"Difficulties encountered during the dimensional analysis of particles by electron and atomic force microscopy: Guide by example, complexity classes, and initial considerations" - version December 11, 2024

INCREASE CONFIDENCE IN DATA: *GUIDE BY EXAMPLE*

Full version

(~ 50 pages with tables & appendices)



Documents available in French and English

<https://www.nanomesurefrance.fr/publications-nanomesurefrance/>

Summarised version

(~ 10 pages with glossary)



1. Supporting **analytical experts** when implementing microscopy techniques
2. Assisting **stakeholders** in the process of identification of « **Nanomaterials** » in a regulatory framework

1. Sharing key information with **non-experts** in order to anticipate possible identification difficulties
2. Inform the **regulatory authorities** so that they are aware of the problems encountered

NANOMESUREFRANCE: *AMBITIONS*

A single entry point for structuring a nanomaterials industry based on reliable and comparable data



- ☐ Promoting collaborations
- ☐ Identify & ease access to experts/techniques
(→ **Mapping of analytical platforms**)



- ☐ Sharing of information
- ☐ Dissemination of good practices

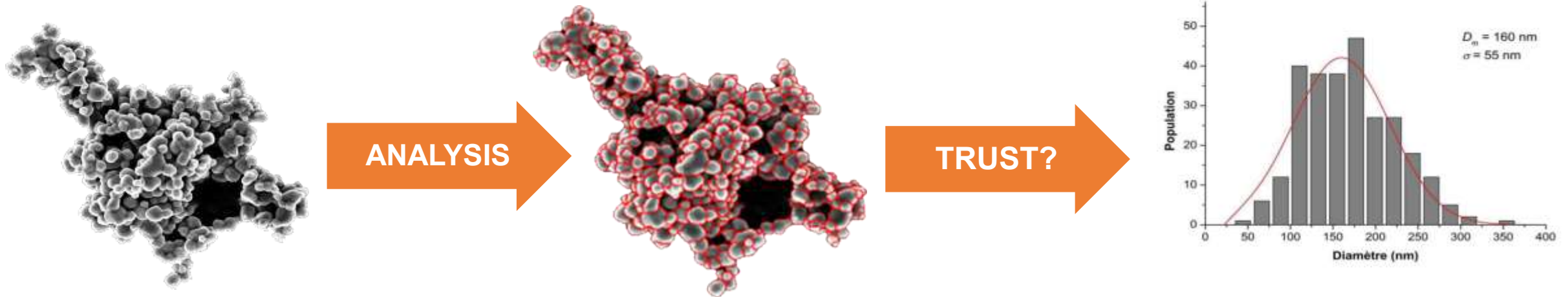


- ☐ Identification of needs/priorities in terms of **pre-standardisation** of characterisation and testing methods & Coordination of French efforts
- ☐ Framework for **evaluation** of performances and **recognition** of techniques, methods and laboratories

QUALIFY TECHNOLOGIES: *INTER-LAB COMPARISONS*

INTER-LABORATORY COMPARISON ON SEM ANALYSIS

- To review the performance of manual or automatic **scanning electron microscopy (SEM) image analysis tools** for determining the size distribution in terms of numbers of constituent particles.
- To define a **harmonised framework** for using, demonstrating and comparing the performance of **such tools**, which could be used in the future for more complex applications.



QUALIFY TECHNOLOGIES: *INTER-LAB COMPARISONS*

5 SAMPLES

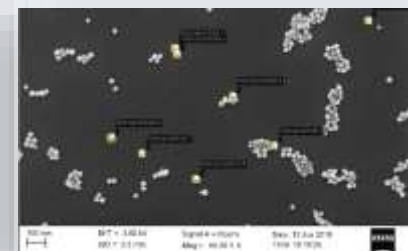
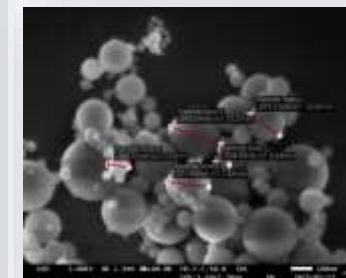
- Spherical monodisperse
- Spherical with D50 close to 100 nm
- Aggregates-agglomerates poorly dispersed
- High polydispersity with spherical or complex shape

17 PARTICIPANTS

BASF / CSTB / Digital Surf / FILAB / Groupe Mérieux / IFPEN /
Institut NAOS / **JRC** / LNE / L'Oréal / Merck / MICHELIN /
Nanobiotix / SENSIENT / ThermoFisher Scientific/ TRONOX

PRESENTATION OF RESULTS

- Webinar : 12 June 2026 ➔ publication under progress

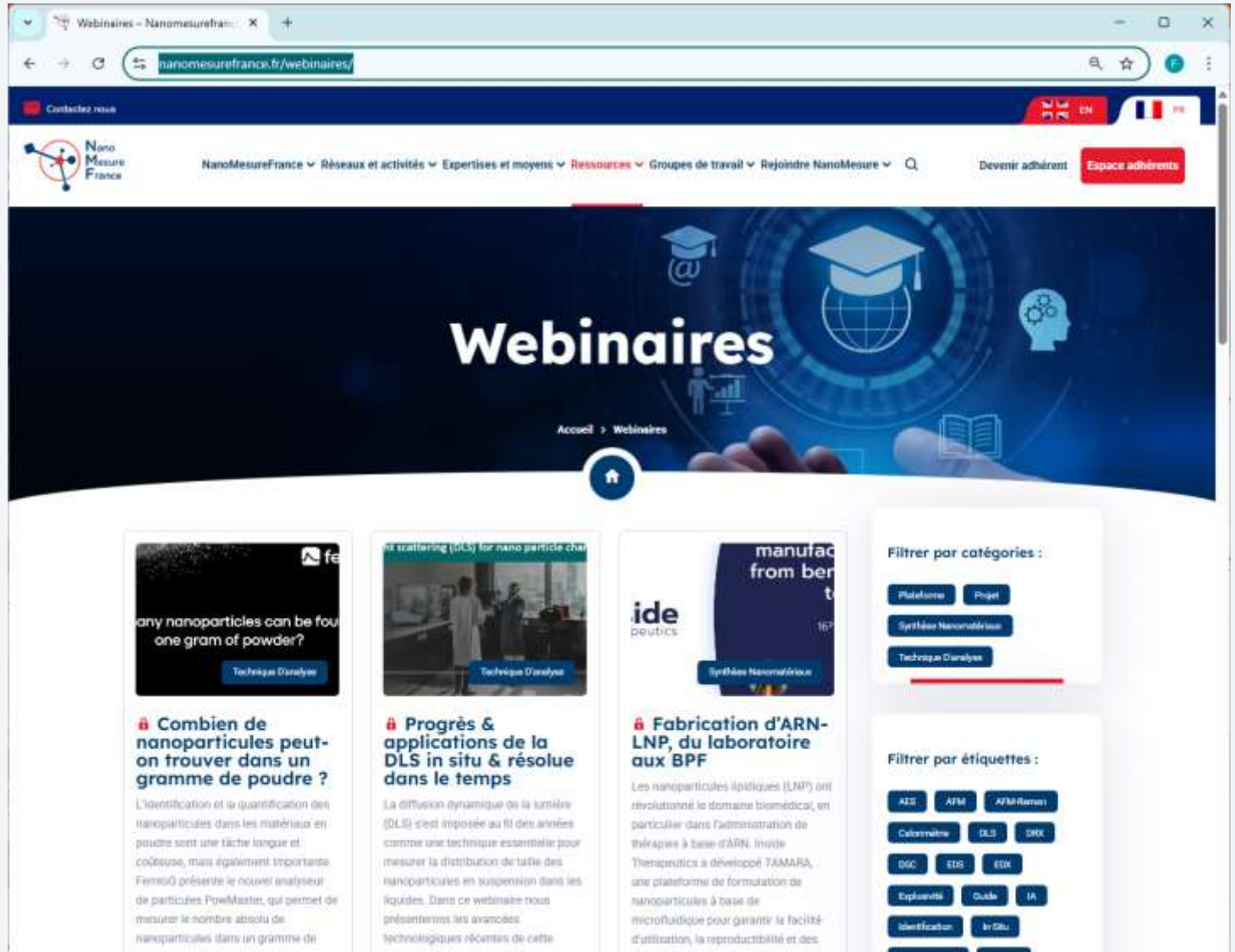


PROMOTE TECHNOLOGIES & INITIATIVES: *WEBINARS*

■ AIMS

- ✓ to highlight innovative **characterisation technologies**
- ✓ to present pre-standardisation **key initiatives**

■ Free replay for members



SHARE INFO – BEST PRACTICES: *EVENTS*



Joint workshop: Metrology and Industrial Advanced (Nano)Materials: Collaborative Approaches to Method Development, Assessment, and Global Standardization



<https://setcor.org/conferences/nanotech-france-2026>



Contribution de l'IA au développement, à la caractérisation et à la conformité réglementaire des nanomatériaux

2 juillet 2026, LNE (Paris 15^{ème}), Event in French

<https://www.lne.fr/fr/service/formation/journee-technique-nanomateriaux-ia>

NANOMESUREFRANCE: *AMBITIONS*

A single entry point for structuring a nanomaterials industry based on reliable and comparable data



- ☐ Promoting collaborations
- ☐ Identify & ease access to experts/techniques
(→ **Mapping of analytical platforms**)



- ☐ Sharing of information
- ☐ Dissemination of good practices



- ☐ Identification of needs/priorities in terms of **pre-standardisation** of characterisation and testing methods & Coordination of French efforts
- ☐ Framework for **evaluation** of performances and **recognition** of techniques, methods and laboratories



- ☐ Interface with **public authorities**
- ☐ Relay to **standardisation bodies & OECD**
- ☐ Relay to research funding agencies

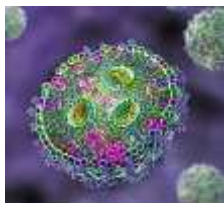
EXCHANGES WITH KEY ENTITIES ON REGULATORY TOPICS



Materials & Chemistry



Cosmetics



Nanomedicine

EXCHANGES WITH KEY
ENTITIES ON
REGULATORY SUBJECTS
TO IMPROVE THE TOPIC
OF CHARACTERISATION
/ TESTING



- ❑ NanoMeasureFrance's ADVISORY BOARD
- ❑ EVENTS / WORKSHOPS / JOINT MEETINGS
- ❑ MALTA INITIATIVE BOARD / OECD WPMN



NANOMESUREFRANCE: *TAKE HOME MESSAGES*

PUBLIC-PRIVATE ASSOCIATION CREATED IN 2022

AMBITIONS

- To contribute to the **structuring of the nanomaterials industry** by bringing together the relevant stakeholders around reliable and recognised data.
- To build a **common foundation of trust**, promoting competitiveness and safety of innovations.

46

Members

135

Experts

4

Working groups

25

Webinars

7

Events

90

Documents
(minutes, report, guides)

NANOMESUREFRANCE: *PROSPECTS*

SUPPORTING SMES AND STARTUPS:

- By offering tailored services, the association seeks to facilitate access for smaller structures to metrology tools and knowledge for nanomaterials (**open platforms, training, proficiency testing**).

DEVELOPING NEW MEASUREMENT PROTOCOLS:

- In response to the rapid evolution of nanotechnologies, NanoMeasureFrance plans to anticipate future needs in characterization and standardization (**library of representatives materials, review of available recommendations, confrontation of methods**).

STRENGTHENING INTERNATIONAL PARTNERSHIPS:

- By collaborating with foreign organizations (**OECD WPMN, JRC, CEN, ISO**), the association aims to harmonize metrological practices globally.



NANOMESUREFRANCE: QUESTIONS?



<https://www.nanomesurefrance.fr/en/>



contact@nanomesurefrance.fr



<https://www.linkedin.com/company/association-nanomesurefrance>



Would you like to join us?

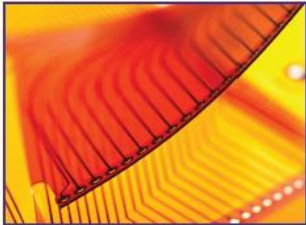
Memberships for 2026 are now open...



17.06.2026

RELIABLE WORKFLOWS FOR THE ELEMENTAL ANALYSIS OF GRAPHENE- RELATED 2D-MATERIALS WITH SEM/EDS AND XPS

P. Mrkwitschka, V-D. Hodoroaba, **J. Radnik**



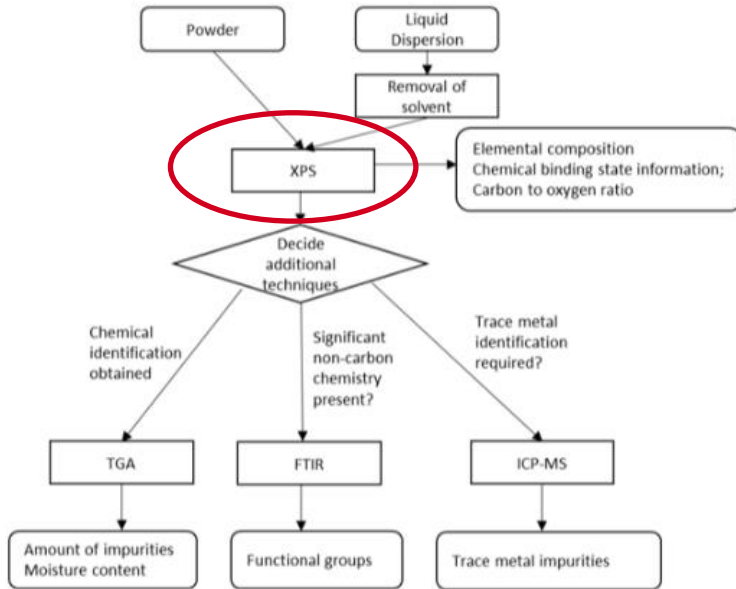
- Aerospace
- Automotive
- Energy storage
- Batteries
- Photovoltaics
- Flexible electronics
- Consumer products
- Clothing
- Coatings

Graphene in a matrix:

- Solid (composites)
- Liquid (e.g. inks, dispersion)

**Functionalization
determines the
interaction between
graphene and matrix**

How to measure the elemental composition?



O/C ratio:

- < 0.1 : G - graphene
- $0.1 - 0.5$: rGO - reduced graphene oxide
- approximately 0.5 - GO: graphene oxide

ISO TS 23359:2025 Nanotechnologies — Chemical characterization of graphene in powders and suspensions

ISO TS 80004:2024 Nanotechnologies — Vocabulary — Part 13: Graphene and other two-dimensional (2D) materials

EDSpectrometers and their development

- faster, more sensitive & accurate

Tabletop SEMs with
integrated EDS (2020..)



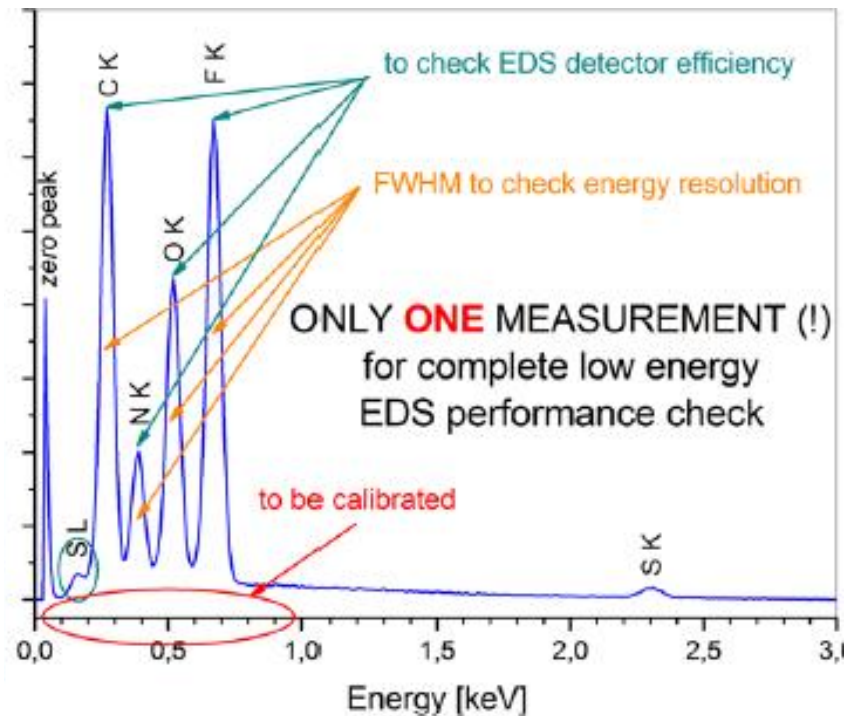
Is EDS an alternative to XPS?

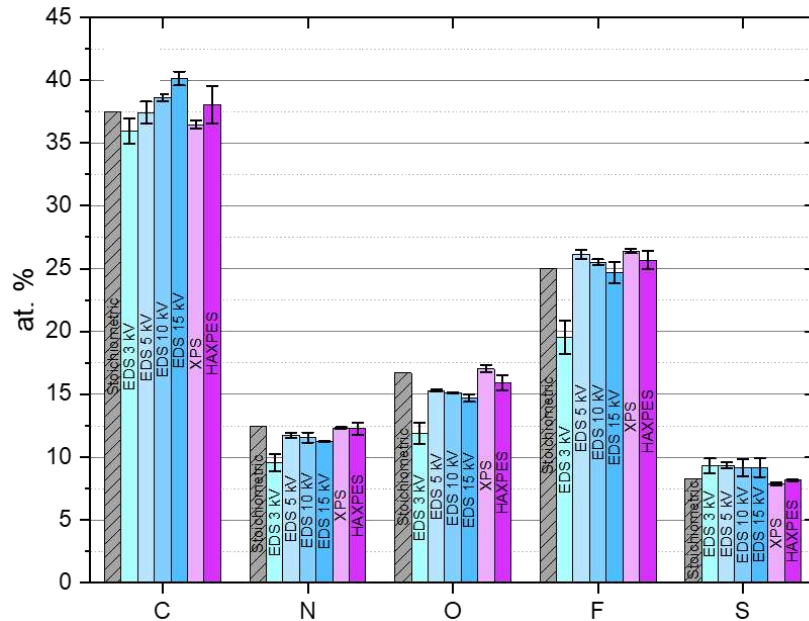
- XPS is suitable for light elements (except H and He), EDS is standardized for elements with atomic number ≥ 11 (Na).
- XPS equipment is rather expensive, EDS is standard equipment together with SEM.
- XPS is a UHV method, EDS is used in HV.
- Information depth: XPS approximately 10 nm, EDS approximately 500 nm and more depending on the electron energy

EDS and XPS at light elements

Ionic liquids as reference materials:
Salts with a melting point < 373 K

- Typically consisting of light elements, e.g. C, N, O, F, S, P, (B, Cl, Fe)
- Homogeneous (lateral and vertical)
- UHV-stable
- X-ray stable
- Suitable for XPS and EDS





Relative deviations:

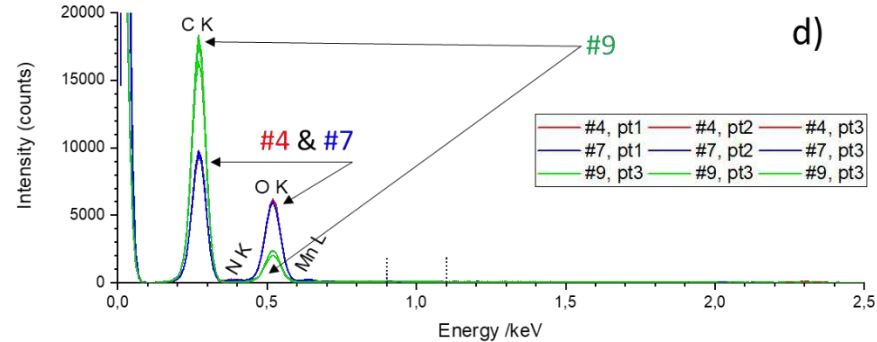
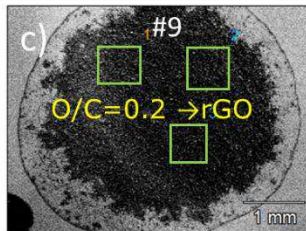
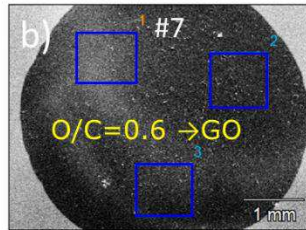
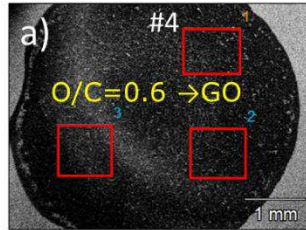
- max. 5 % for HAXPES
 - max. 6 % for XPS (F and S)
 - max. 10 % for EDS
 - best voltage for EDS: 5 kV
- Quantification of light elements is possible with EDS

Wire-printing as new sample preparation method



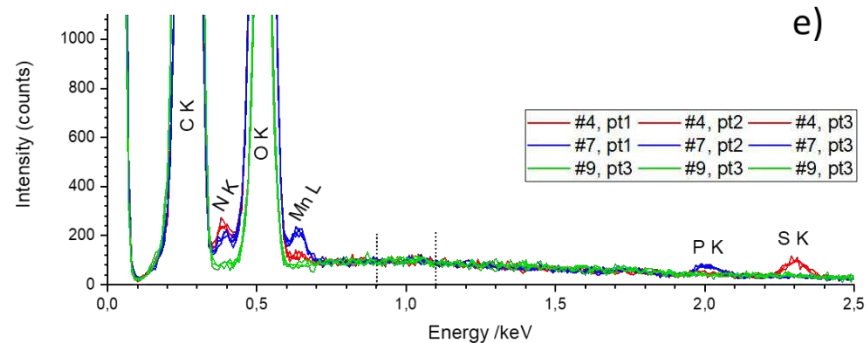
XPS/EDS

- Small amount of sample is necessary.
- Reproducible sample preparation.
- Task determines the sample preparation.

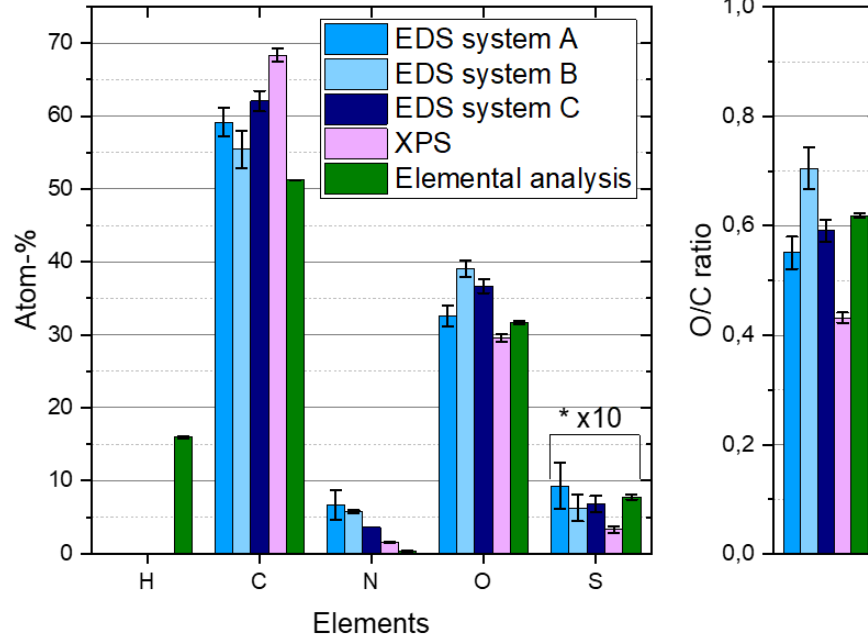


➤ O/C ratio can be determined

➤ Impurities can be detected



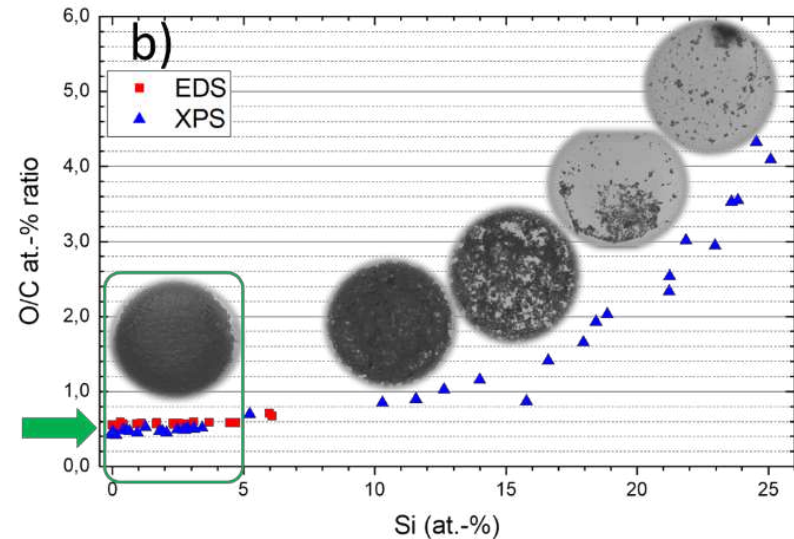
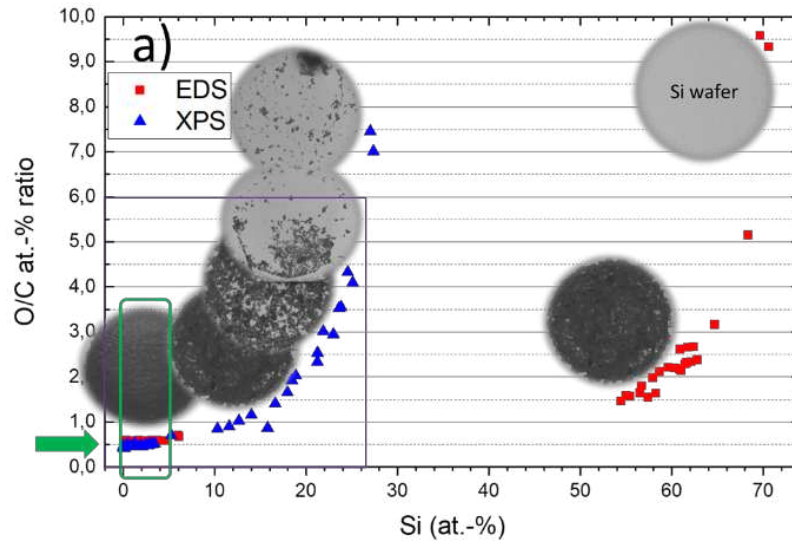
Measurements at commercial monolayer GO flakes?



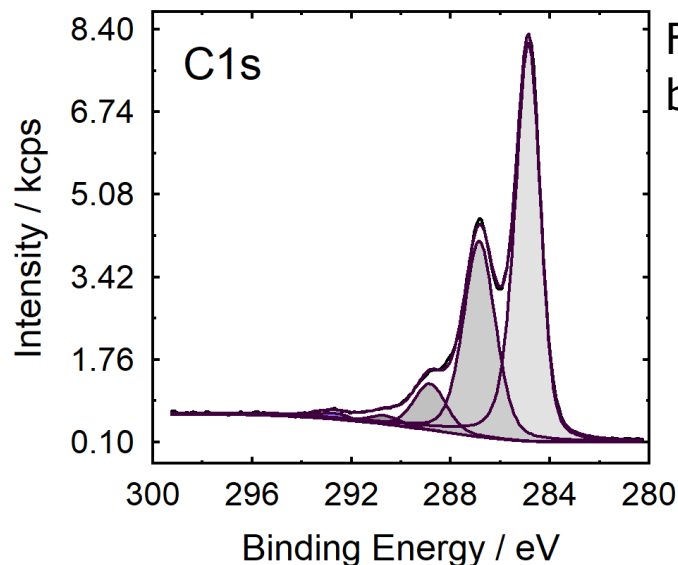
How reliable are the determined O/C ratio?

- EDS and elemental analysis lead to similar results (bulk analysis)
 - O/C ratio of XPS is lower (near-surface region analysis)
- Adventitious carbon

Influence of the substrate



On Si wafer with native oxide: below 5 at% Si in the spectra



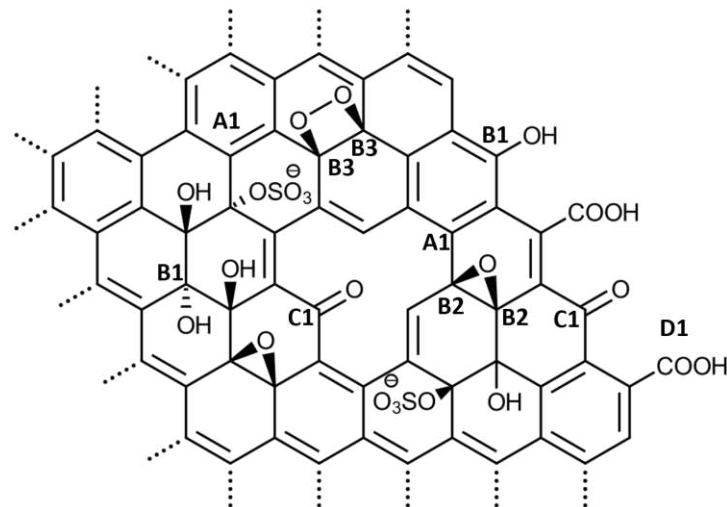
Functional group analysis is possible with XPS, but not with EDS.

Peak name	Peak height/ cps	Lorentzian	Position/ eV	FWHM/ eV	Asymmetry	abs. Area/ cps·eV	rel. Area/ %
C1s							
A	8019.8	0.3	284.8725	1.20382	-0.04852	11770	55.64
B	3946.5	0.3	286.8461	1.52	0	7139	33.75
C	938.072	0.3	288.8317	1.52	0	1700	8.04
D	176.305	0.3	290.6625	1.52	0	319.53	1.51
C-N	0	0.3	285.859	1.52	0	0	0
PI-PI*	124.448	0.3	292.7328	1.52	0	225.11	1.06

5 peaks were found



Peak	Species	O/C ratio
A	A1	0
	B1	1
B	B2	0.5
	B3	1
C	C1	1
D	D1	2
C-N	C-N species	0
π - π^*	A1	0



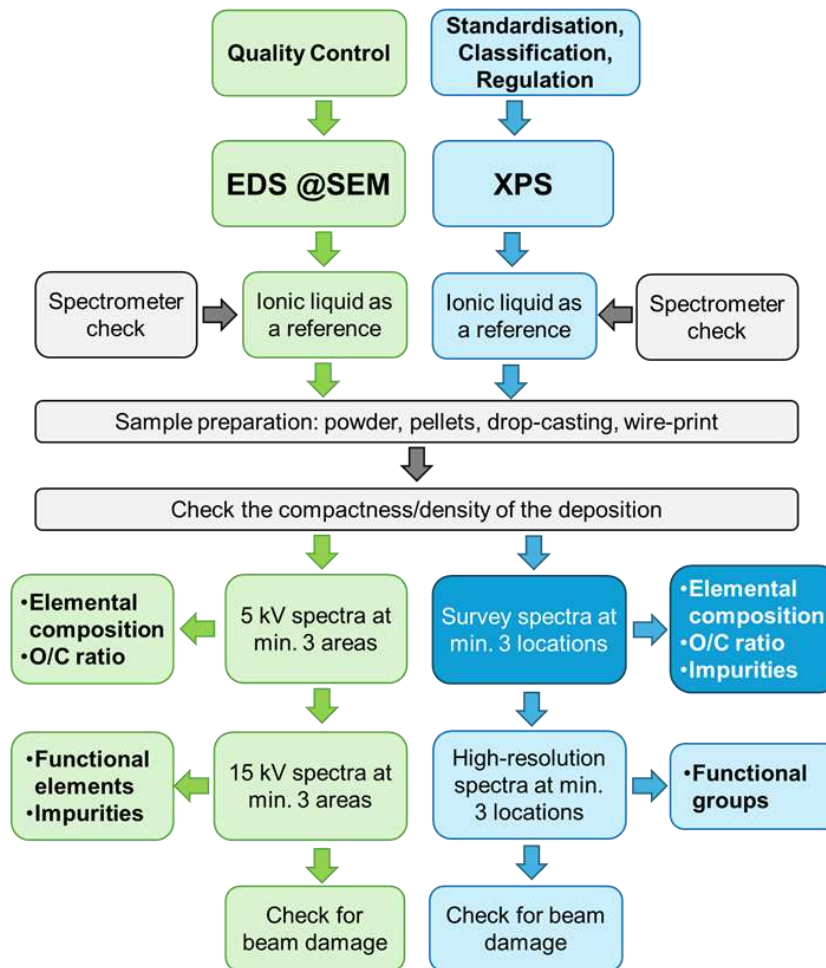
- Not unique assignment of all peaks possible (peak b) → O1s spectra can help
- Compare O/C ratios from survey spectra with the estimated O/C ratio from the high-resolution spectra

	EDS@SEM	XPS
Overall uncertainty (rel.)	20 – 30 %	10 – 20 %
▪ Instrumental conditions	< 10 %	< 5 %
▪ Sample (preparation) - related	10 – 20 %	10 – 15 %
▪ Data Treatment	10 – 20 %	10 – 15 %

Summary: Methods

	EDS @SEM	XPS
Information depth	<1 μm (at 5 kV)	~ 10 nm
Influence of adventitious carbon	minor	significant (<10 at-% for C)
Influence of surface adsorbates	negligible	moderate due to evaporation in UHV
Influence of the substrate	should be <5 at-%	should be <5 at-%
Charging	negligible	charge compensation recommended
Beam damage	may be significant, e.g. in point-analysis mode	relative decrease of O/C by <15%

Workflows:



From Lab to Standards

Lab

Initial method
development



DIN

National Standardisation Body

Project proposal

Validation

Drafting

Commenting

Approval



From Lab to Standards

Lab

Initial method
development

National Standardisation Body

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Commenting

Approval



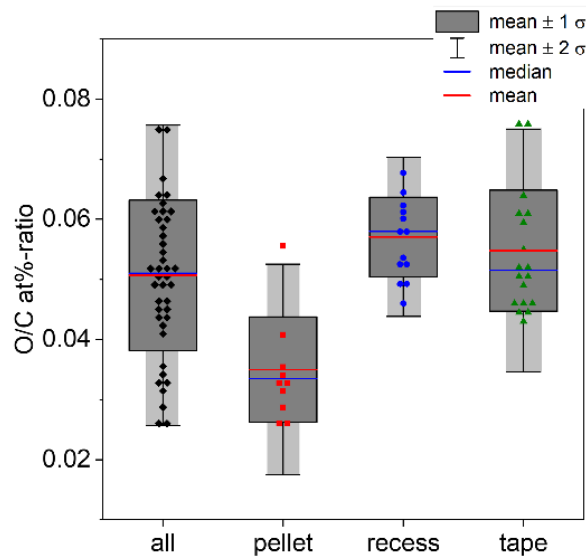
VAMAS

Bureau
International des
Poids et
Mesures

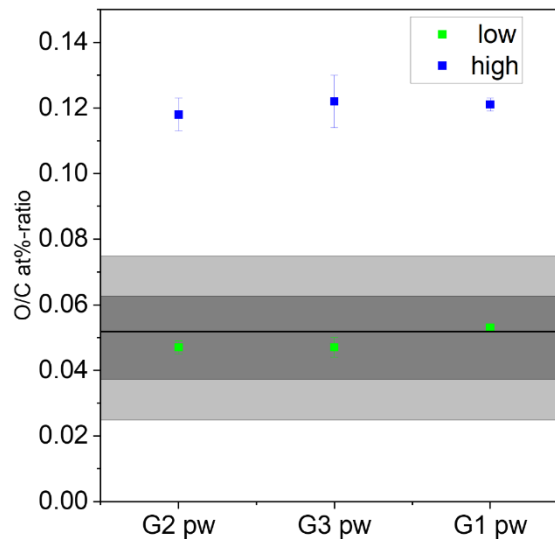


Validation: O/C ratio with XPS

Sample preparation



Humidity

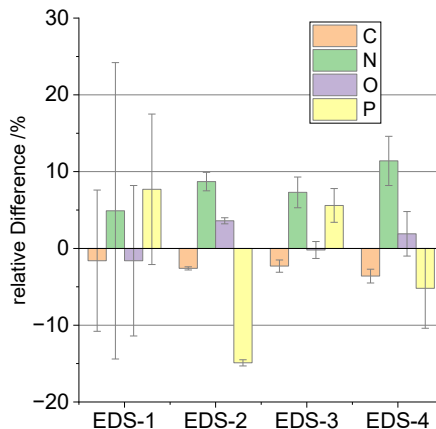
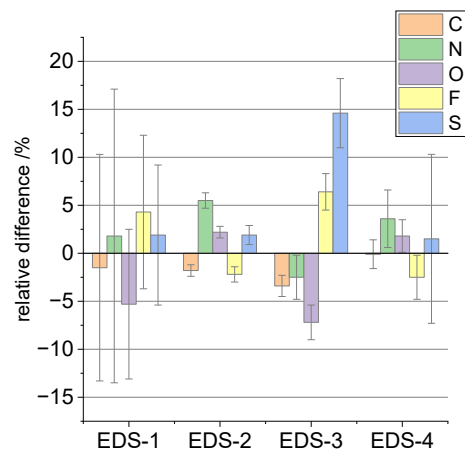


Crucial influence of

- Humidity
 - Sample preparation
- on the results

Validation: Ionic Liquids

Ongoing ILC (CCQM P230): preliminary results



First results for EDS are promising

- Further participants are interested.
- Great interest of the manufacturers.

- EDS at functionalized graphene flakes.
- Fitting of high-resolution spectra for functional group analysis.

- EDS@SEM is suitable for the quantitative analysis of light elements.
- Reliable workflows for the quantification of functionalized graphene flakes and GNPs are available.
- First steps on the path to standards are done.

Acknowledgements



- Mario Sahre, Jörg Manfred Stockmann (BAM)
- Elena Corrao, Francesco Pellgrino (University of Torino)
- Beatriz Alonso, Amaia Zurathuza (Graphenea)
- Charles Clifford, Andrew Pollard, Benjamin Reed (NPL)



UNIVERSITÀ
DI TORINO

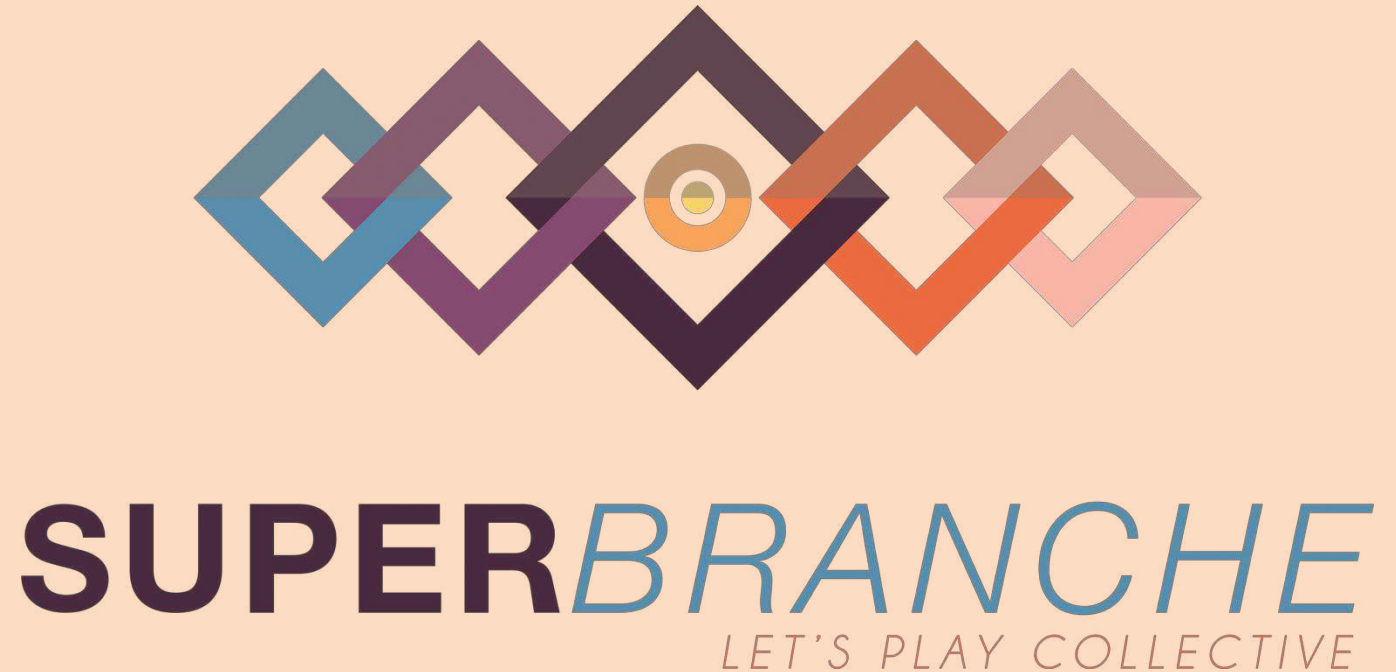


Funding:



Surface chemistry in nanomedicine : The (simple) case of SuperSPIO20

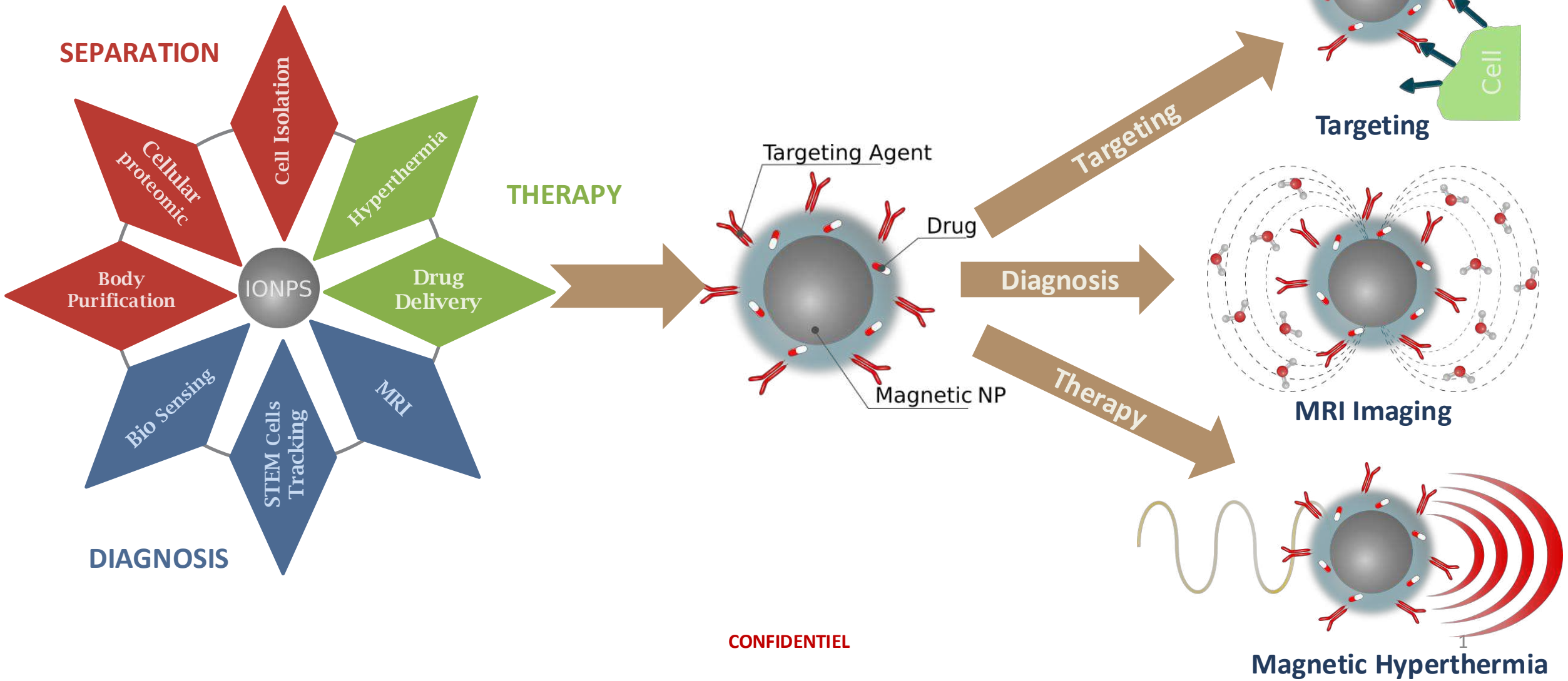
Geoffrey Cotin, CTO



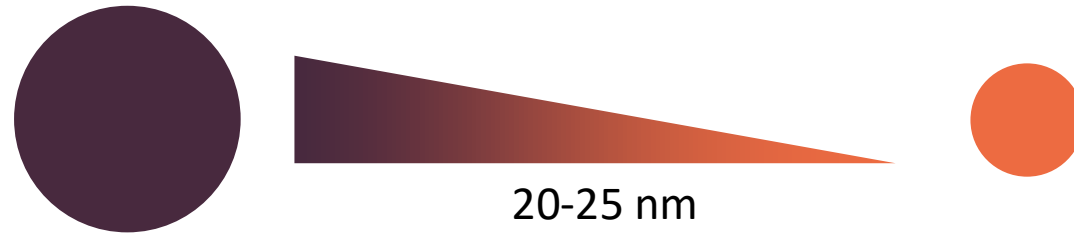
Theranostic



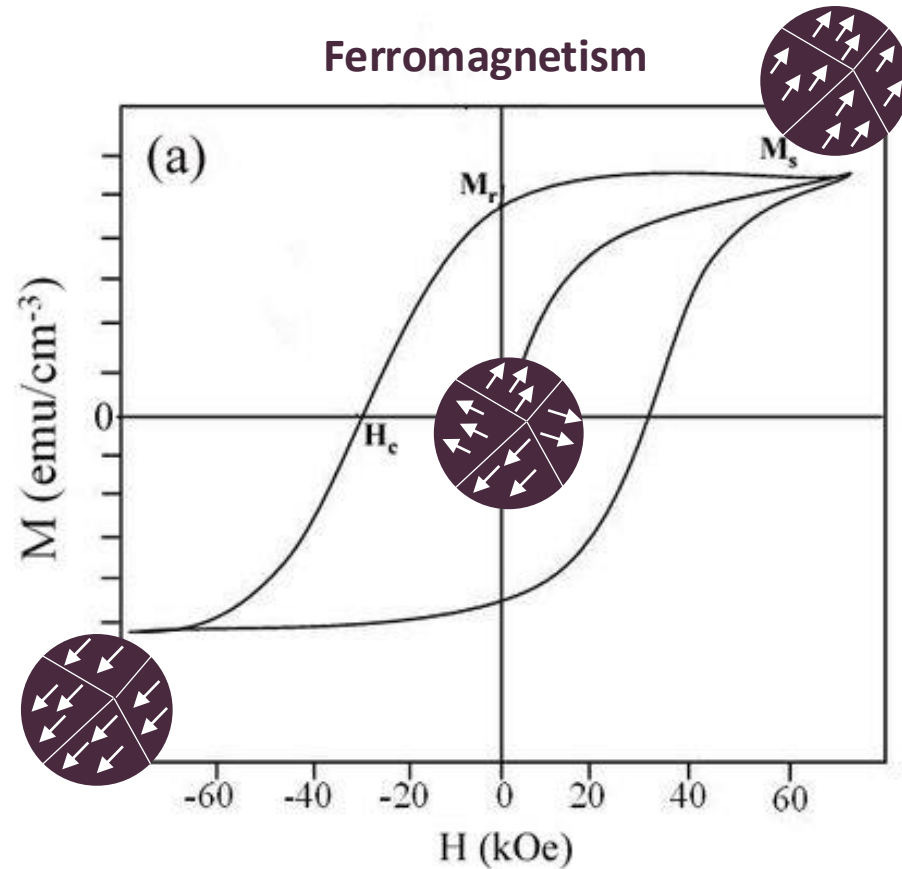
SUPERBRANCHE
LET'S PLAY COLLECTIVE



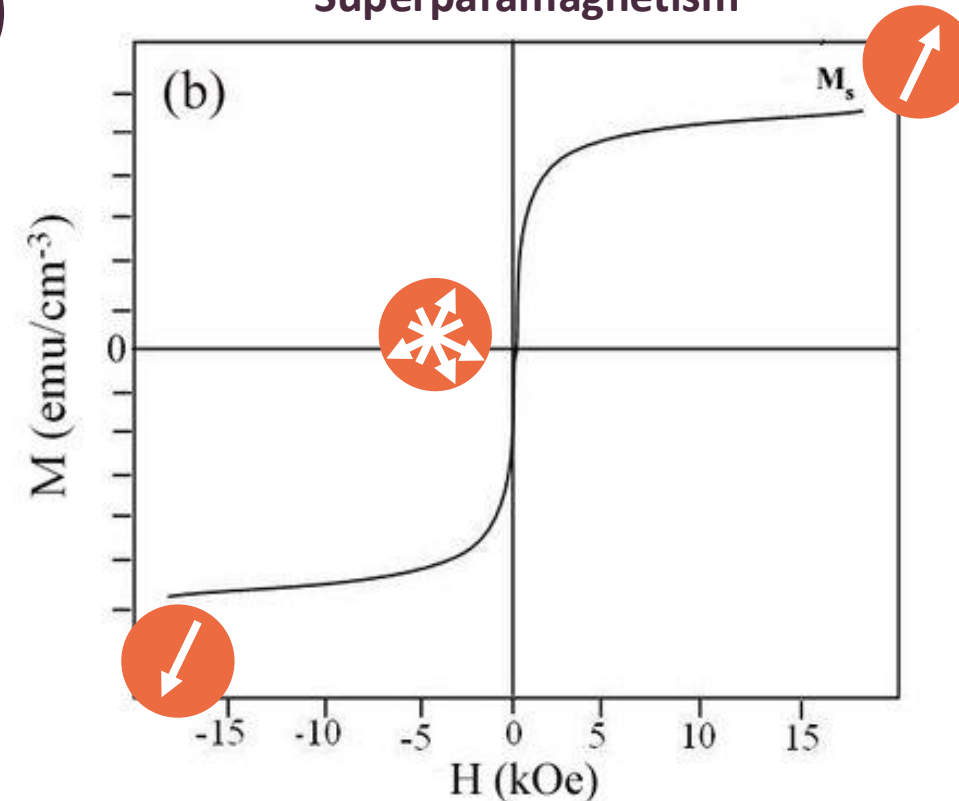
Superparamagnetism



Ferromagnetism



Superparamagnetism

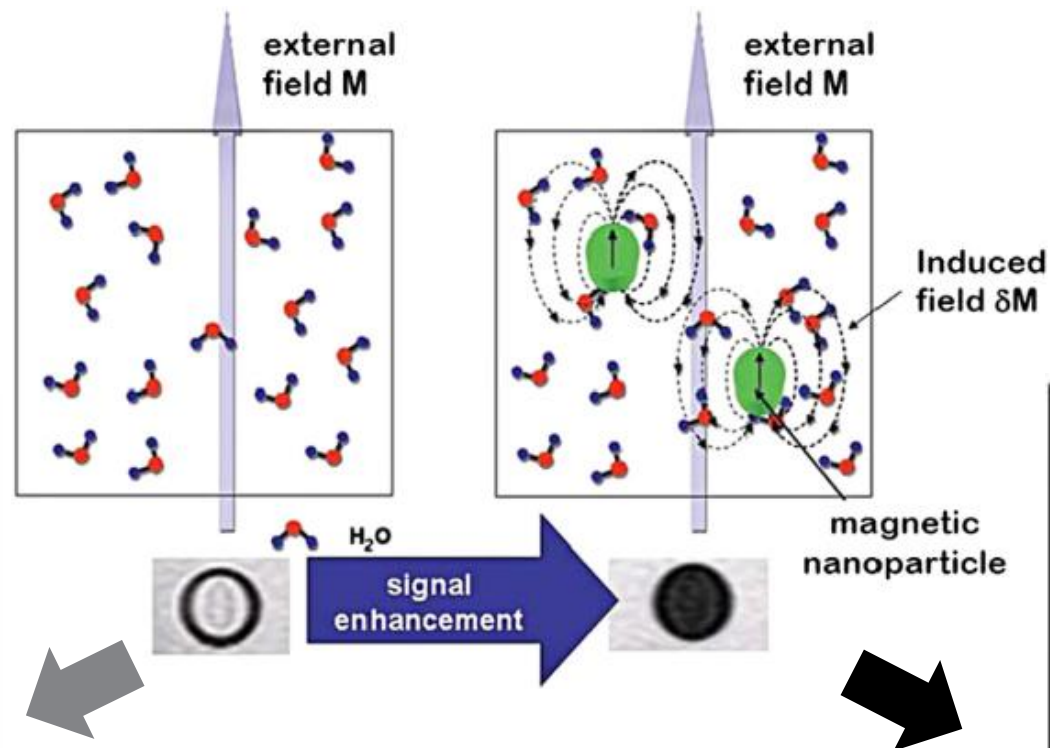


Once NPs have been presented a magnetic field, they present a magnetization

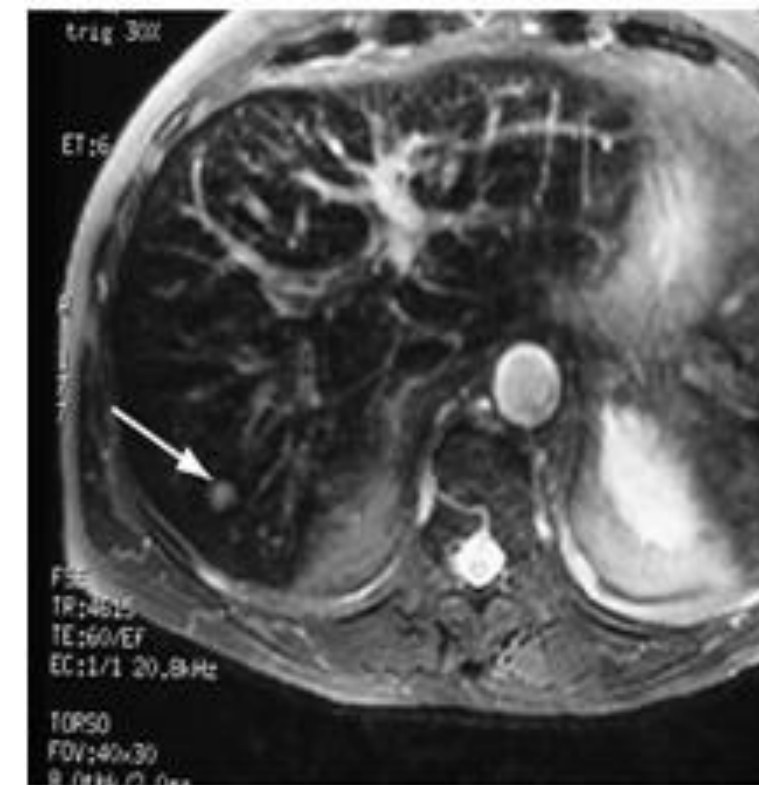
NPs present a magnetization only in presence of a magnetic field

IONPs as MRI contrast agent

No contrast



Darker contrast



CONFIDENTIEL

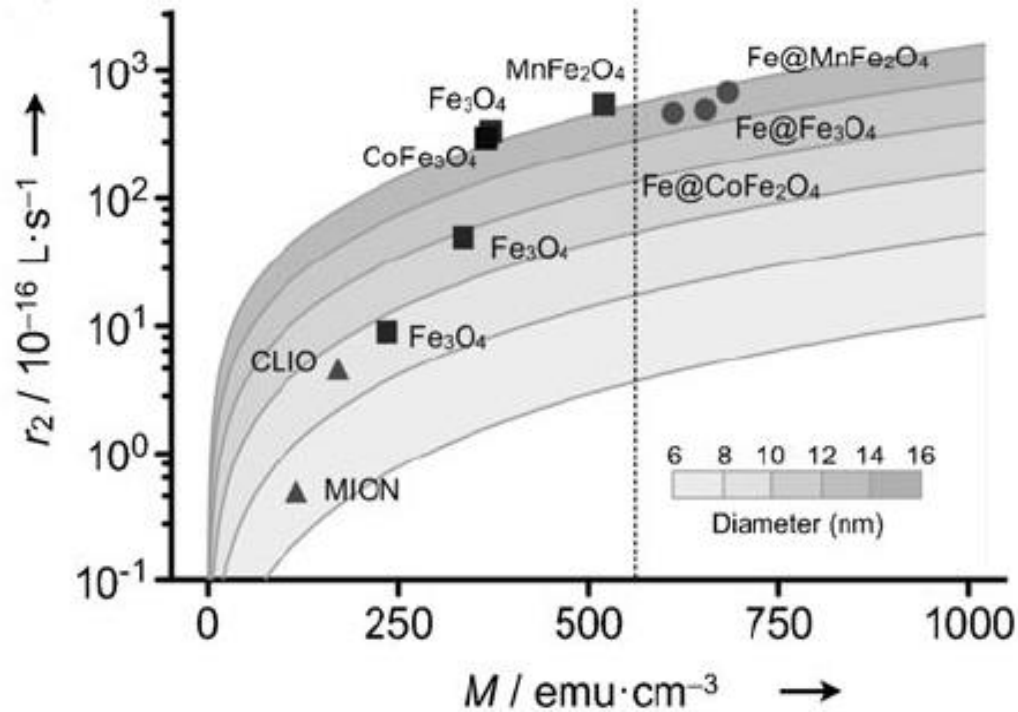
IONPs as MRI contrast agent

Good T2 contrast agent (dark contrast) :

High r_2 & High r_2/r_1

Saturation magnetization M_s

$$r_2 \propto M_s$$



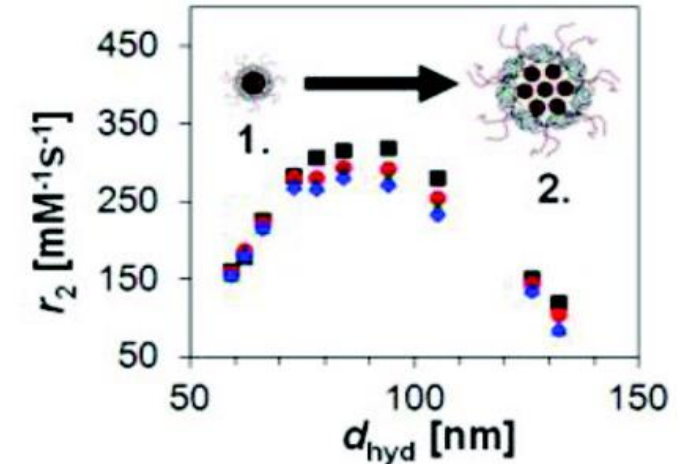
Yoon, T.-J., et al., Angew. Chem. Int Ed., 2011. **50**, 20, 4663-4666.



SUPERBRANCHE
LET'S PLAY COLLECTIVE

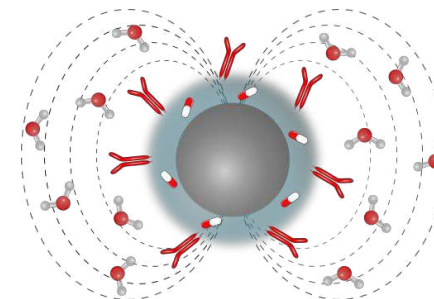
Agregation state

Mean hydrodynamic size in suspension



Pösel E, Kloust H, Tromsdorf U *et al*, ACS Nano 6(2), 1619–1624 (2012).

Water diffusion

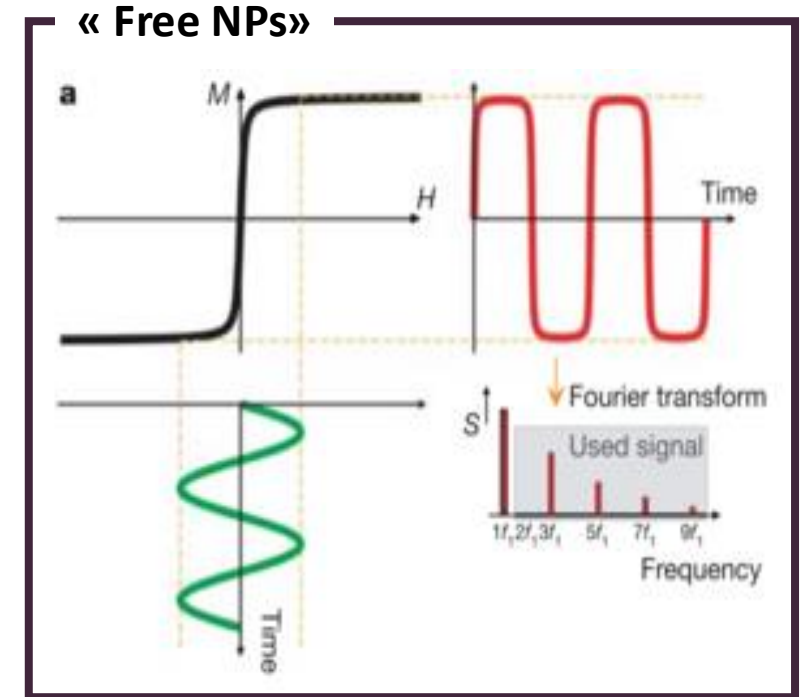
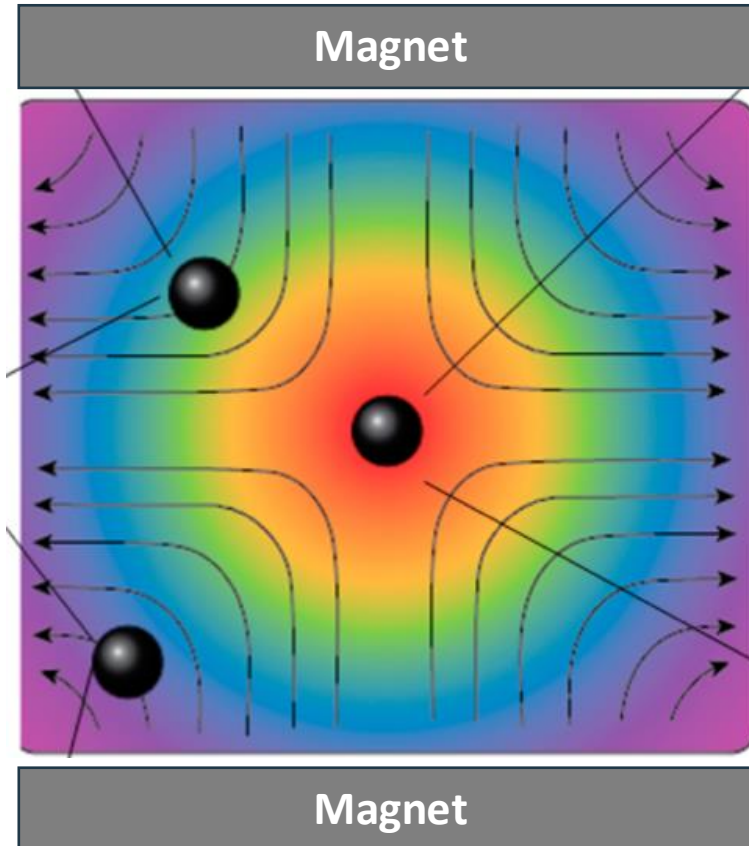
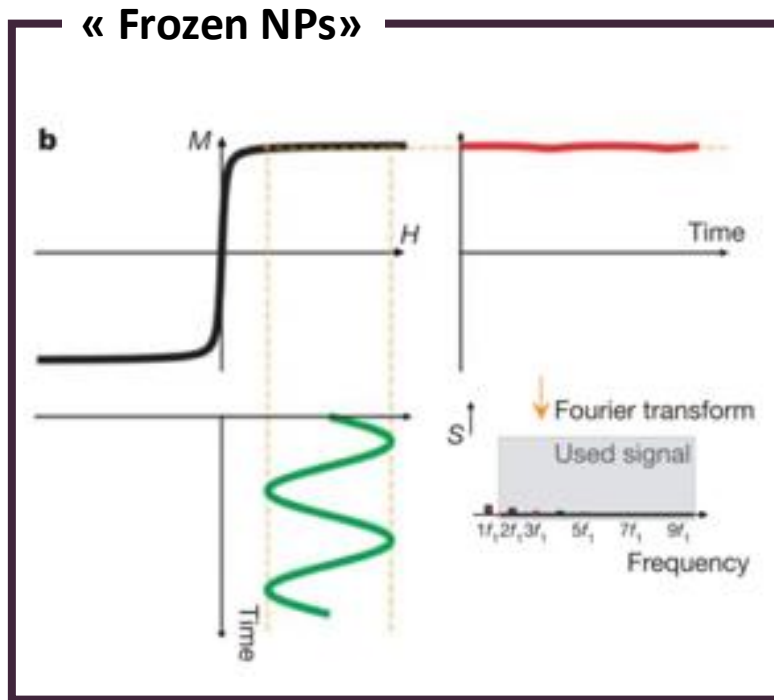


CONFIDENTIEL

IONPs as MPI contrast agent



SUPERBRANCHE
LET'S PLAY COLLECTIVE



→ Signal measurement in a single point in space

IONPs as MPI contrast agent

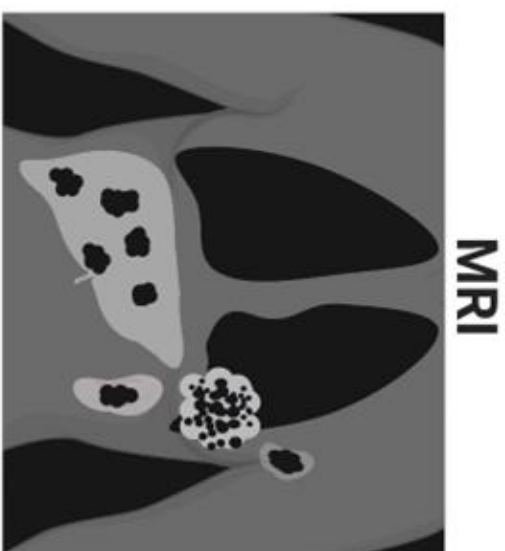
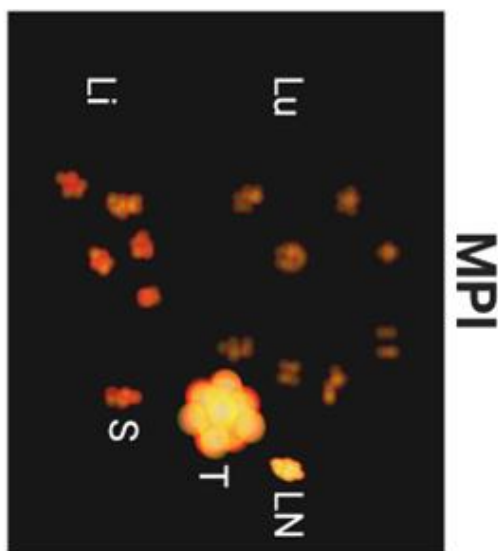
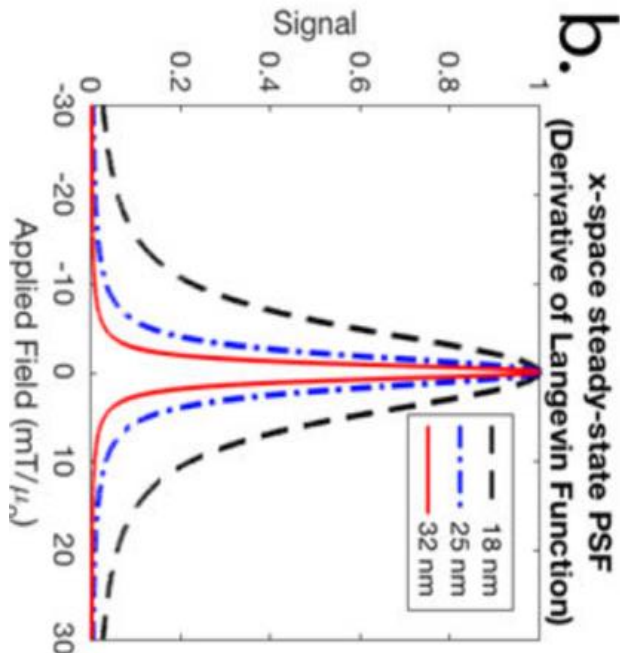
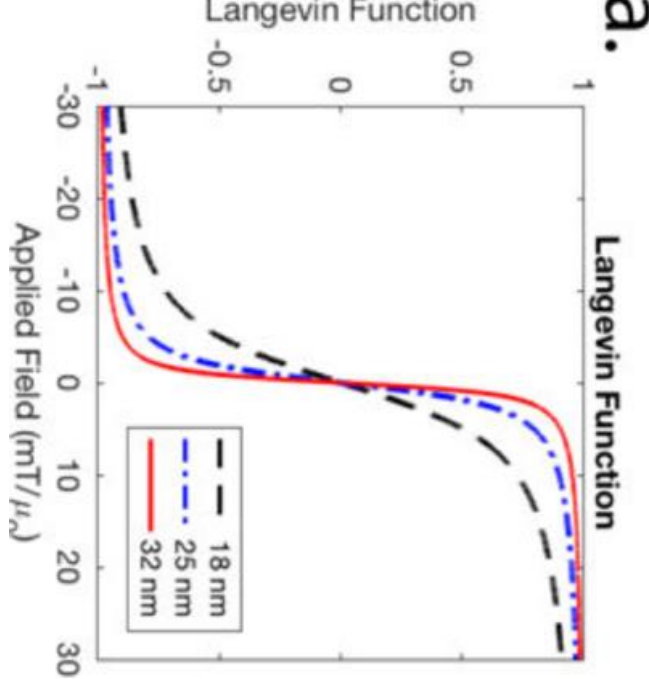


SUPERBRANCHE
LET'S PLAY COLLECTIVE

Measure

Signal treatment

Image



→ Need a fast reversal of magnetization

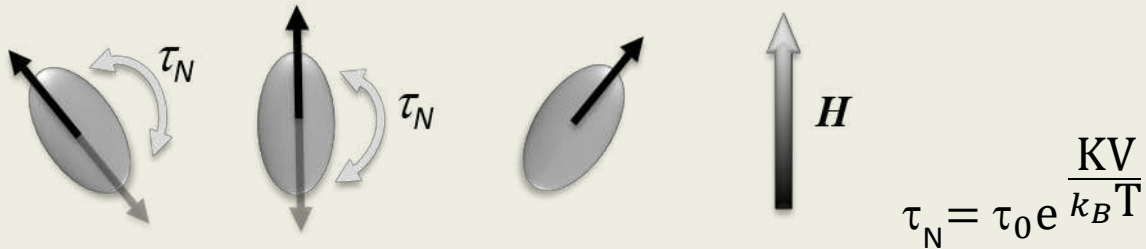
CONFIDENTIEL

Magnetic Hyperthermia

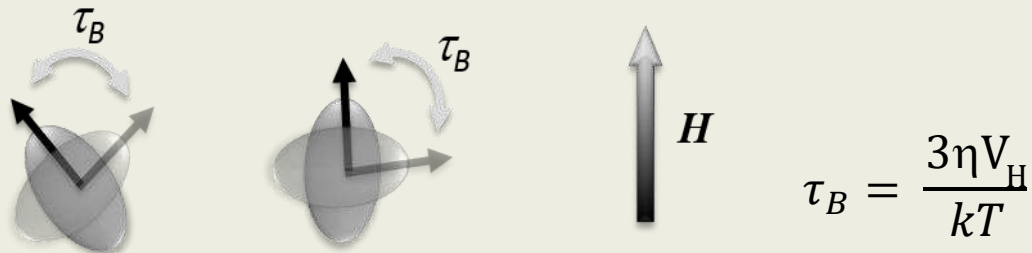
Higher temperature sensitivity of tumoral cells ($T > 42^{\circ}\text{C}$)

- **Improvements** : Reducing the dose to a minimum level.

Neel relaxation



Brownian relaxation



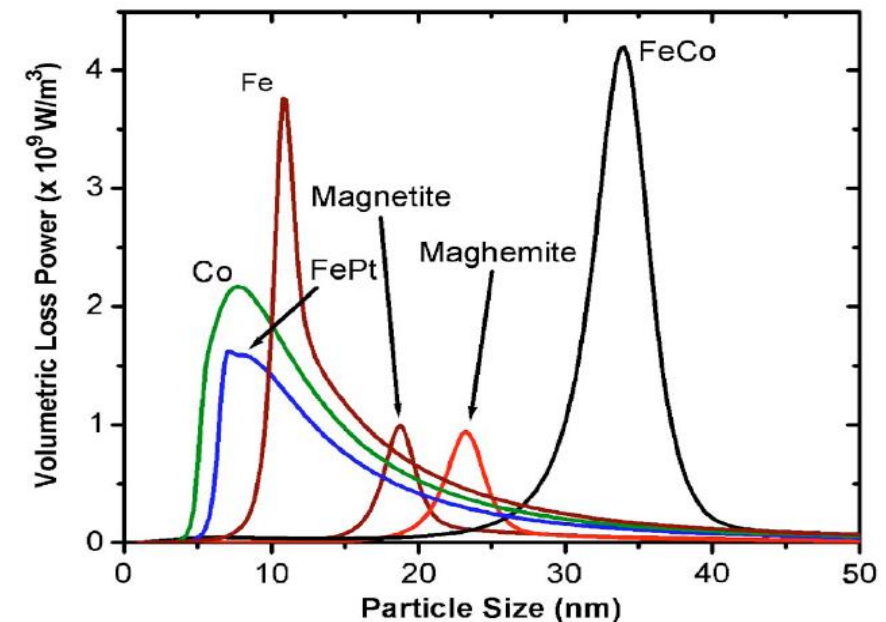
$$\text{Specific absorption rate (SAR)} = \frac{C_{MNP}}{m_{MNP}} * \frac{dT}{dt} \text{ (W/g MNP)}$$

Extrinsic parameters :

- Frequency
- Magnetic field amplitude
- $H * f < 4.5 * 10^5$
- Viscosity of media

Intrinsic parameters :

- **NPs size**
- **NPs anisotropy**
- Concentration
- Collective interactions (dipolar interactions)

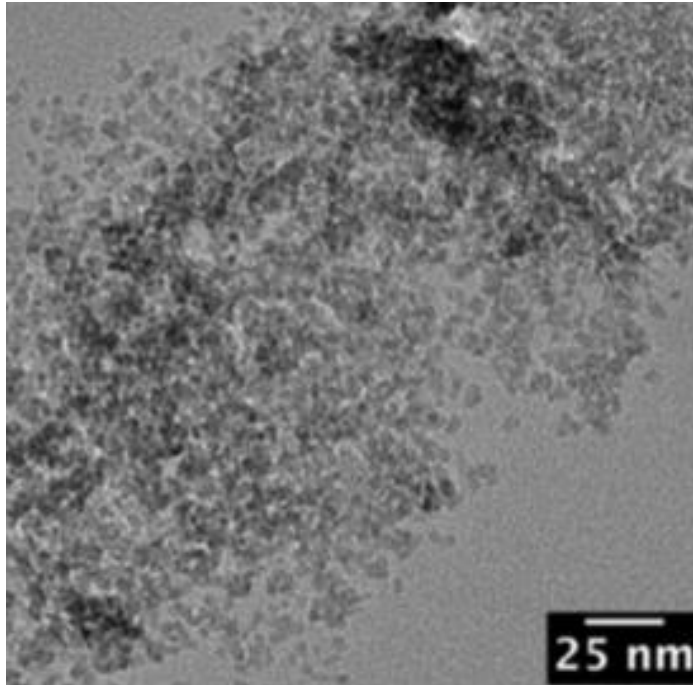


The SuperSpio platform

T₂ MRI

Magnetic Particle Imaging

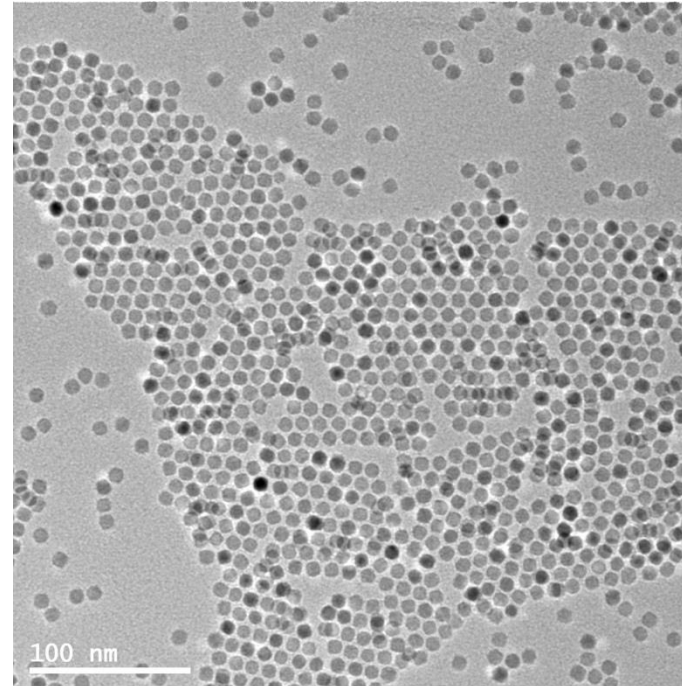
Magnetic Hyperthermia



Resovist

D_{TEM} : 3-5 nm

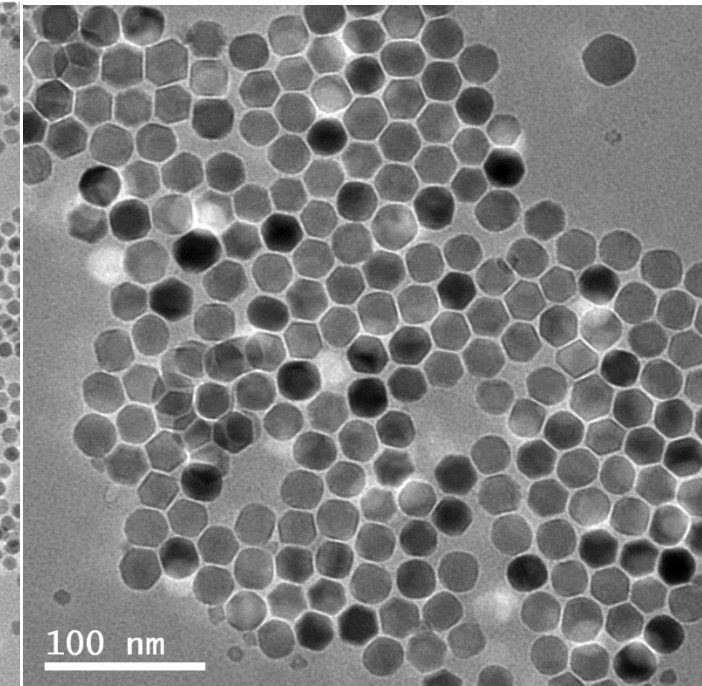
$D_{\text{hydrodynamic}}$: 62 nm



SuperSpio10

D_{TEM} : 10 nm

CONFIDENTIEL $D_{\text{hydrodynamic}}$: 20 nm



SuperSpio20

D_{TEM} : 20 nm

$D_{\text{hydrodynamic}}$: 40 nm

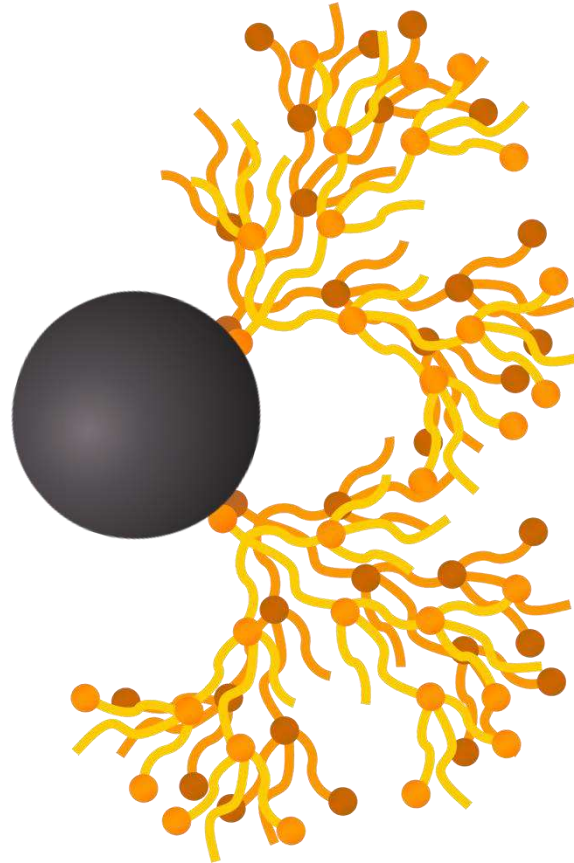
The SUPERSPIO Platform

Iron Oxide Core

Optimized magnetic properties

Eligible for :

MRI or MPI diagnostic
Magnetic Hyperthermia therapy



Customizable for a specific indication

CONFIDENTIEL

Dendritic Coating

Provides colloidal stability,
biocompatibility, stealthiness

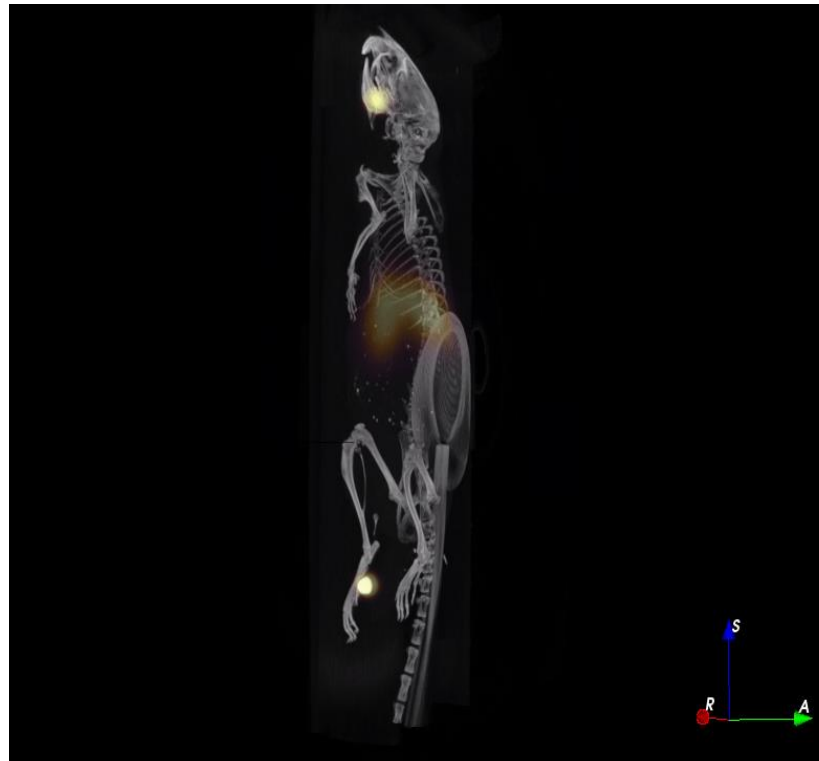
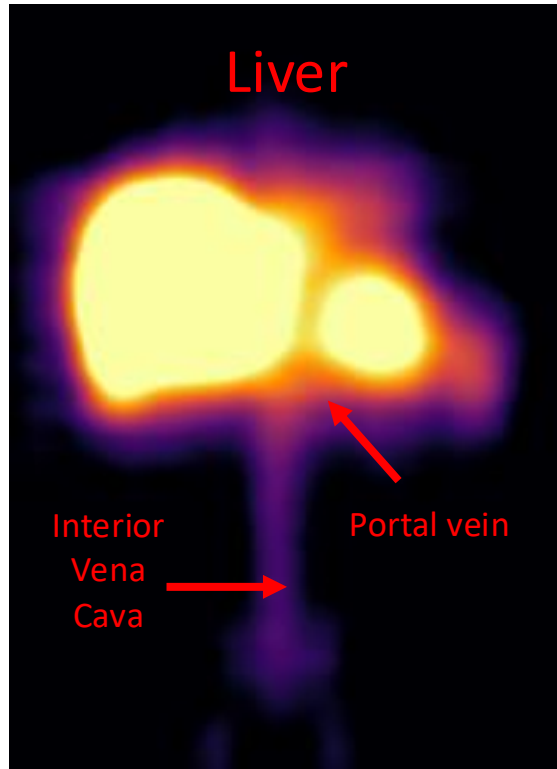
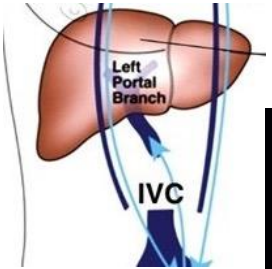
Can be further functionalized with :

Fluorophores
Chelates
Targeting agents

...

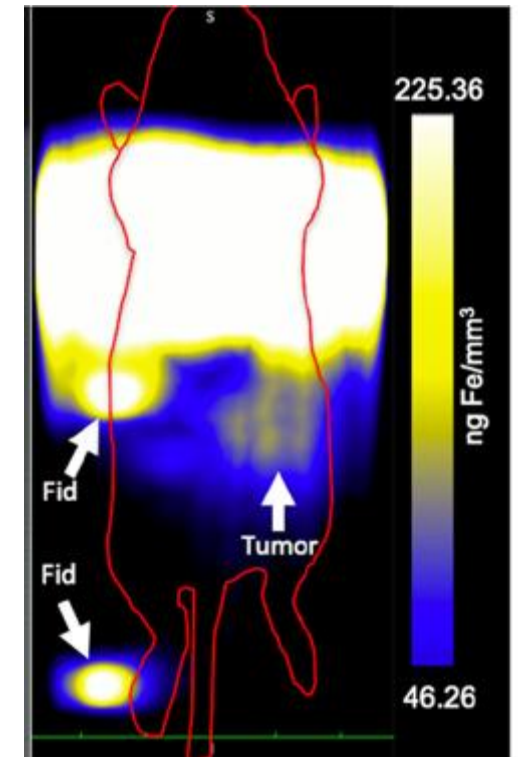
SuperSpio20





Drs. Jeff W.M. Bulte, A. Bibic, A. Shakeri-Zadeh
Johns Hopkins University School of Medicine

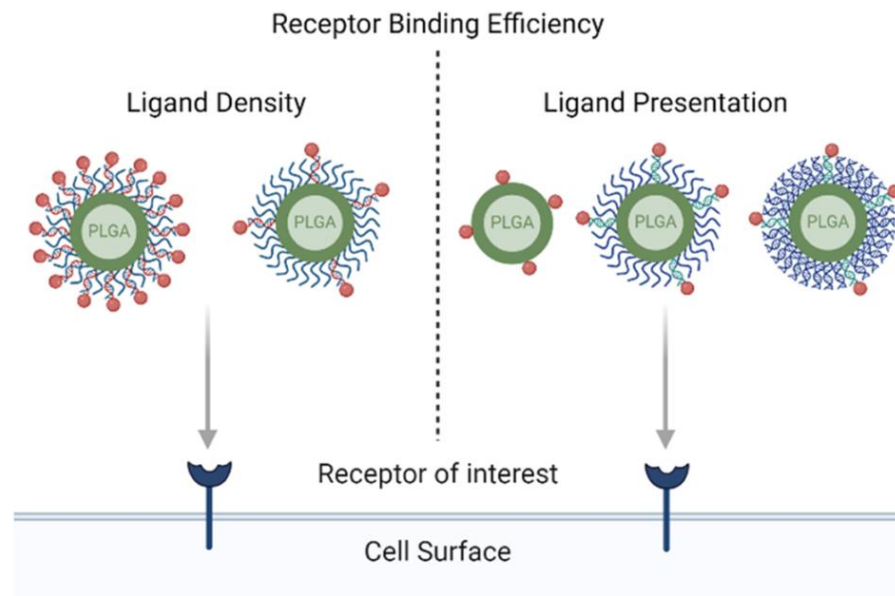
Ferumoxytol



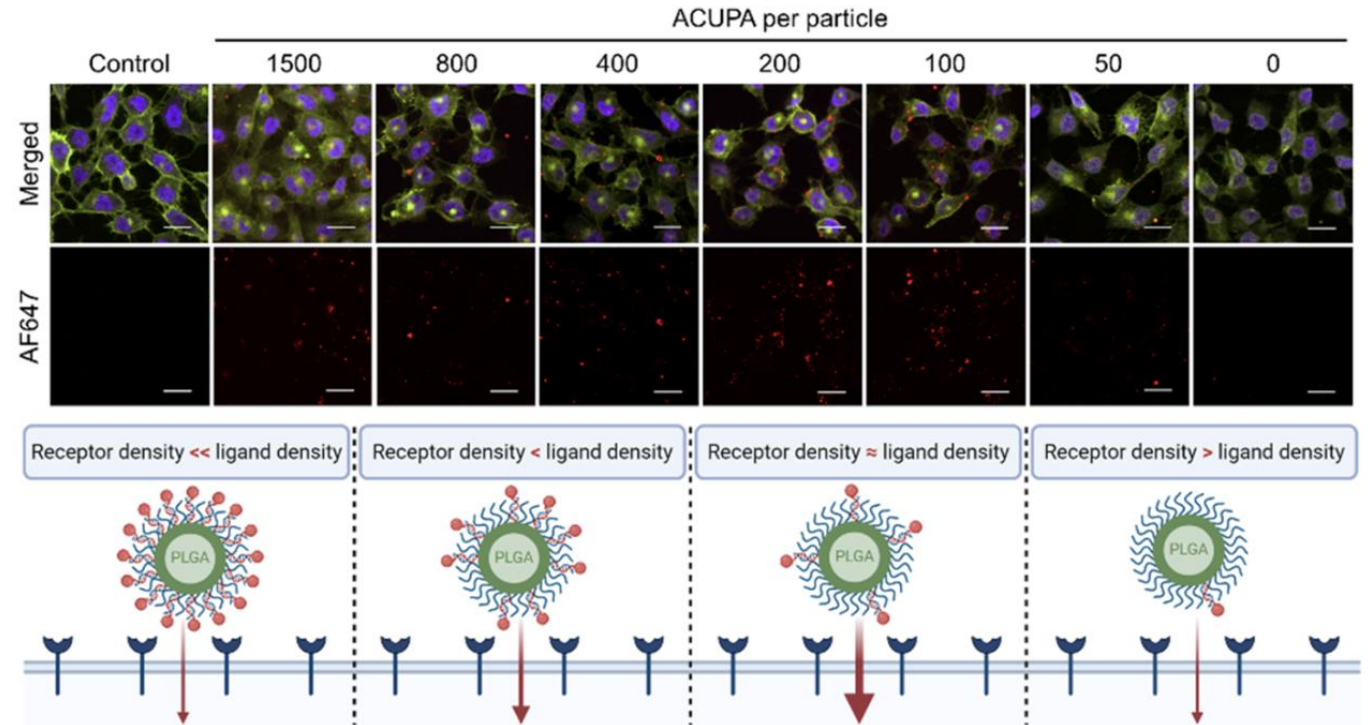
A.V. Makela et al.,
Mol. Im. Biol. 22, 958-968 (2020).

Active tumor targeting

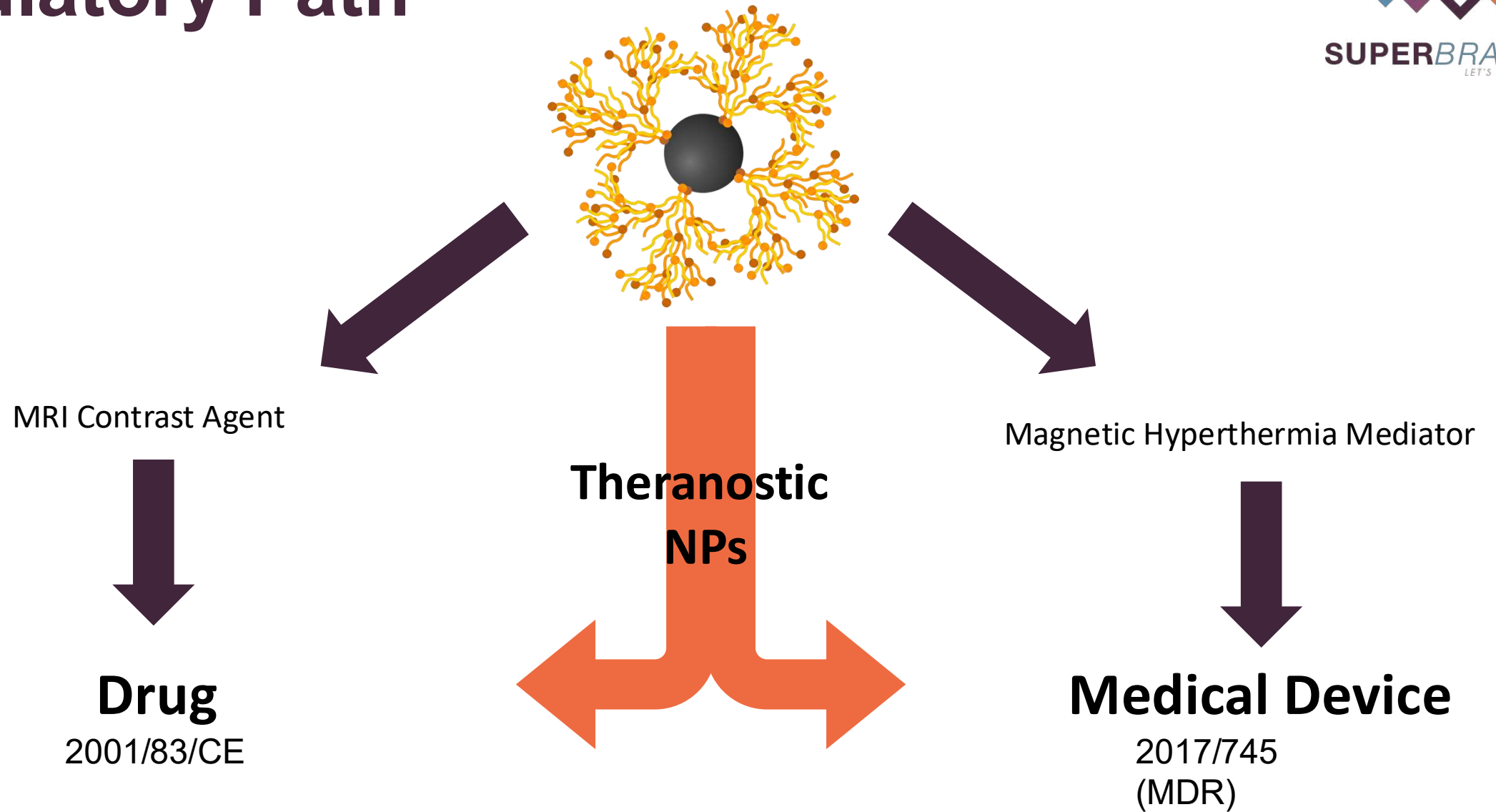
For an identified receptor, the antagonist molecule has to be grafted at the surface of the NPs in a way that fits perfectly the conformation of that receptor



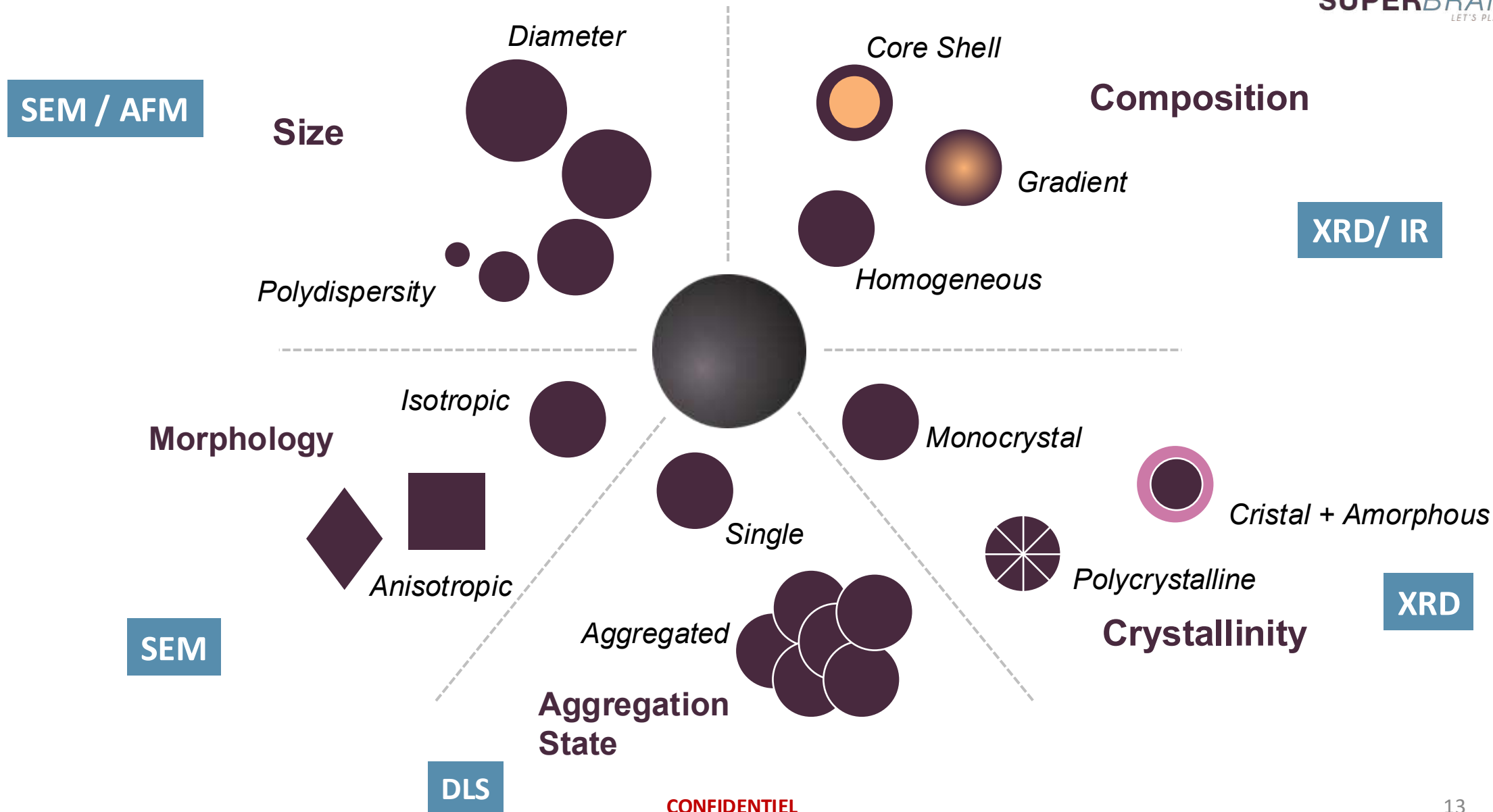
Jana et al. ACS Nano 2024, 18, 16674–16683



Regulatory Path



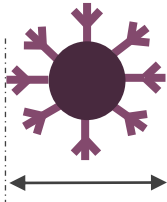
Analytics of the inorganic core



Analytics of the dendronized NPs

DLS

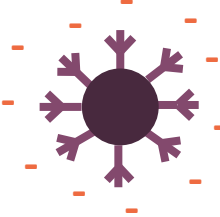
Size



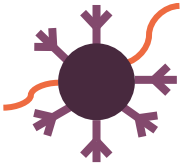
Hydrodynamic diameter

Zeta Potential

Surface charge



HRMAS ?



Replacement

Surface molecule
quantification

?

Aggregation
State



DLS

CONFIDENTIEL

Conclusion

- Analytics of inorganic core characteristics : well described and normalized (Gap analysis, nanomedicine work group)
- Characterization of the quality of the organic coating and the grafting of interest molecules : still looking for simple (to be integrated in QC), robust, versatile and precise techniques for routine surface characterization

Thank you for your attention





From metrology to industry: Addressing challenges in nanomaterial characterization

*Dr. Loïc Crouzier, R&I Research Scientist,
L'Oréal, Aulnay-sous-Bois, France*

2026-06-17

Exploring new inorganic UV filters

TARGET



Transparent in visible light



Isoperformance



Naturally occurring

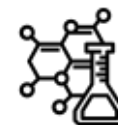
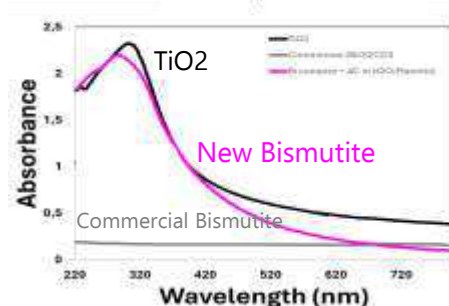
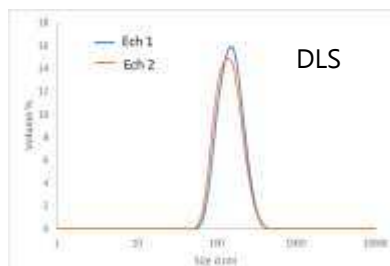
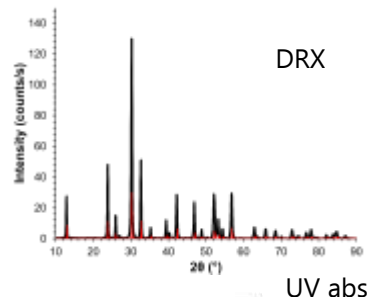
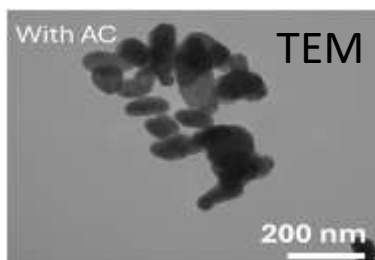
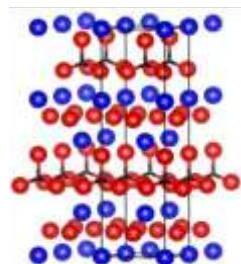
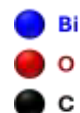


Regulatory compliant



Safe for human and environment

Bismutite or bismuth subcarbonate - naturally occurring oxide mineral with a chemical formula of $\text{Bi}_2\text{O}_2\text{CO}_3$



Formulation



Despite a potZ value favorable to stabilization there is agglomeration

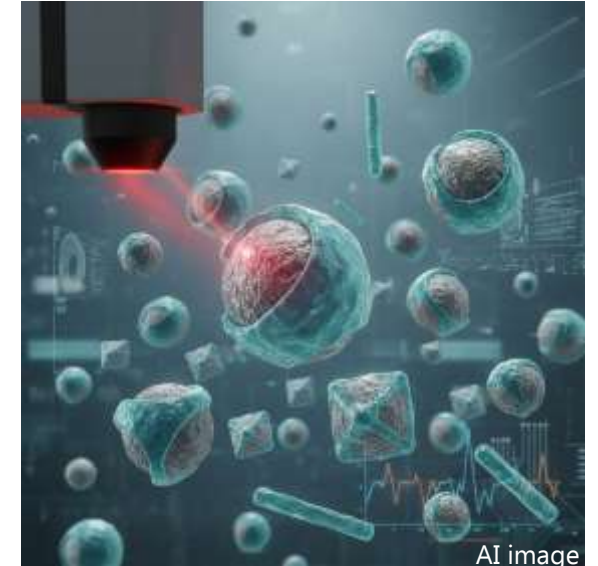
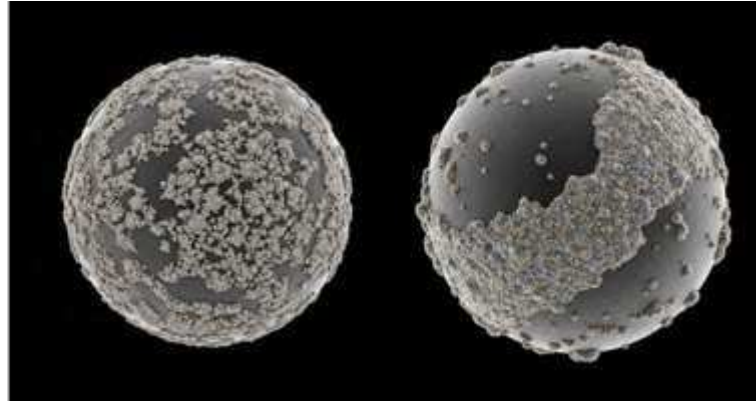
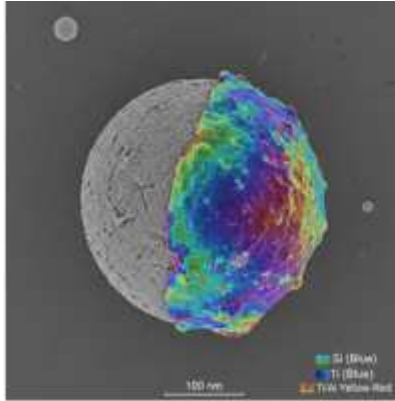
- Need to improve the particle dispersibility in green formula
- Need to develop and characterize bismutite particle coatings

Local surface chemistry & state of particles.

INNOVATION



- Support dev. of new fla. with new UV filter.
- Understanding properties of particle in fla linked with surface properties (agglomeration)



AI image



IDENTIFICATION

What is the particle / coating bonding ?
(covalent or adsorption)



STATISTICS

What is the proportion of coated
particles or agglomerates?



HIGH RESOLUTION

Is the coating homogeneous on each
particle? What is its thickness? What is its
coverage rate?

Why Nanomaterial Characterization Matters ?

2011 - currently valid

'Nanomaterial' → insoluble or bio-persistent and **intentionally manufactured** material with one or more external dimensions, or an internal structure, on the scale from **1 to 100 nm**



2022 – to be implemented

'Nanomaterial' → **natural, incidental or manufactured material** consisting of **solid** particles, present either on their own or as **identifiable constituent particles in aggregates or agglomerates**, **50 % or more** of these particles **in numbers** of the size distribution [have] one or more external dimensions [...] in the size range **1 to 100 nm**;

Few
existing
nanos

Main existing provisions

- **[Nano] labelling**
- **Ban/restriction** of nano-forms of regulated ingredients,
- **Nano notification** (EU, France, REACH)

Main estimated provisions

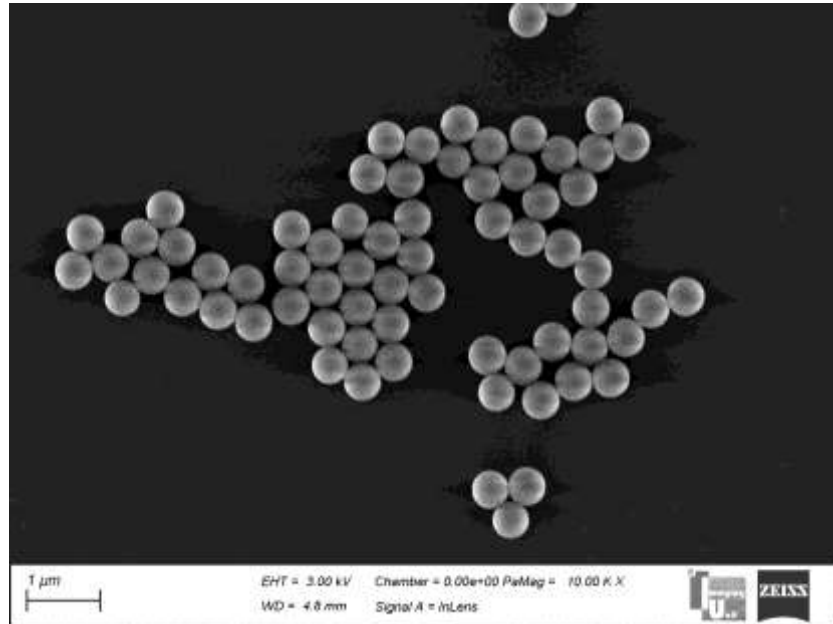
- **Increase +++** of **[Nano] labelling**
- **Increase +++** of **nano notifications**
- Nano-Substances which have not been submitted may be banned

✈ **ANTICIPATING THE TRANSITION:**

- *Assess the nano-status of numerous and diverse samples*
- *Metrology support required to support accuracy of the results*

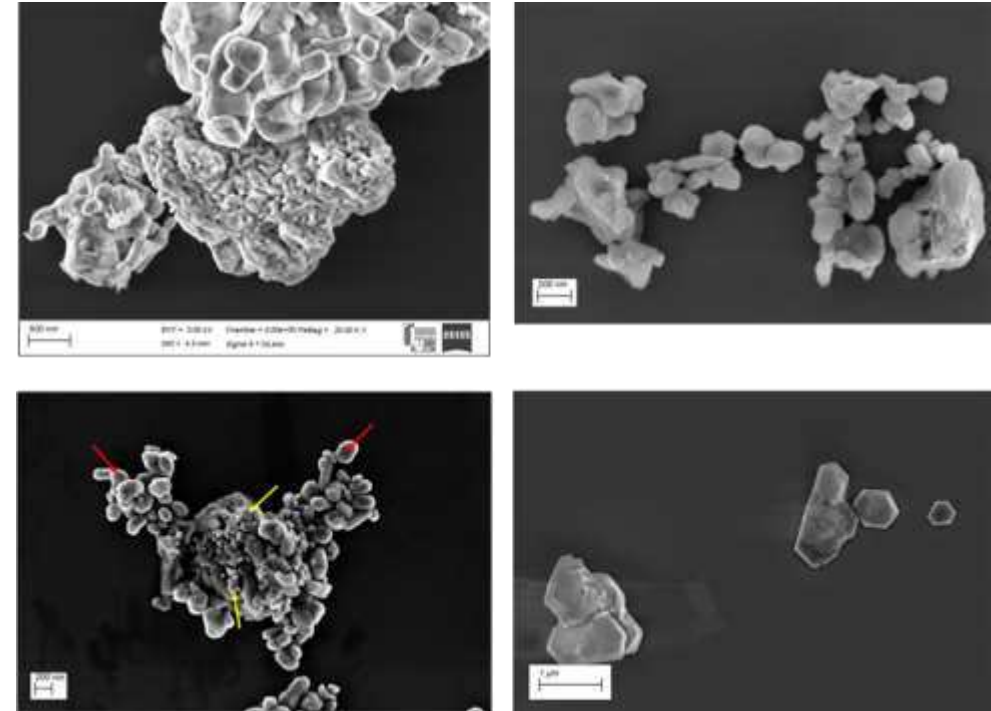
The Reality Gap: reference materials vs. Industrial samples.

REFERENCE MATERIALS



- Monodisperse
- Simple shape
- Stable in suspension

INDUSTRIAL RAW MATERIALS



- Highly Polydisperse
- Multi-shape - Mixtures
- Agglomerates / aggregates

TECHNICAL LIMITATIONS OF REQUESTED APPROACH

Today's understanding of « inconclusive samples »

JRC recommendation (2023)¹

- Surface area (VSSA) : low weight
- Quantitative Electron Microscopy (EM) : high weight

BUT

Samples characteristics (e. g. composition, shape) can prevent accurate measurement of particle size
➔ **no conclusion on Nano status**



Specific adaptations required for quantitative EM
(e. g. sample preparation, imaging conditions)

Platelets



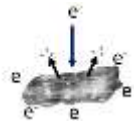
Measuring thickness is challenging in 2D images

Polydisperse materials



Limited image resolution
Agglomeration concerns

Beam-sensitive materials



Measurement conditions influences size and shape

Agglomerates



Difficult to distinguish particles in agglomerates
"Hidden" particles

Aggregates



Difficult to distinguish particles in aggregates

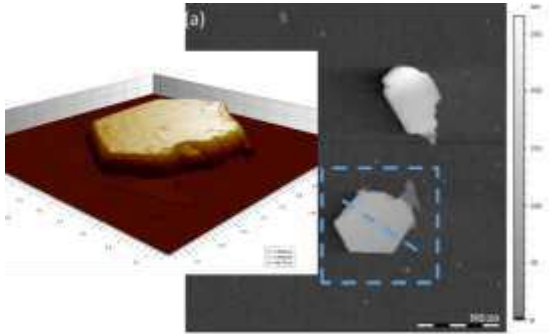
Multicomponents (composites, mixtures)



Need to discriminate each ingredient within samples

Pragmatic Solutions: Case study of platelet-like nanomaterials

Recommended method – Thickness measurement using AFM



- Time-consuming, High Cost
- Need for a perfect deposition with no particle overlapping
- Statistical distribution is difficult to obtain (minimum of 300 particles required).

Alternative and pragmatic solution: thickness measurement by EM after resin embedding and cross-sectioning



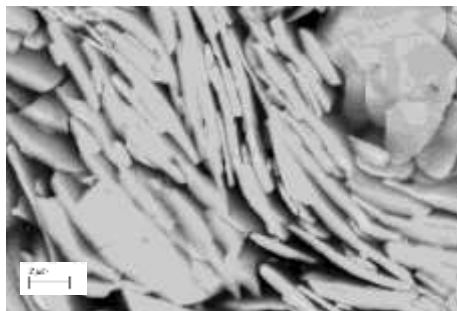
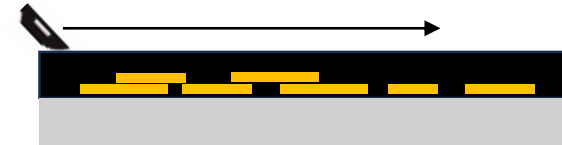
1 PLATLET ALIGNMENT ON SUBSTRATE



2 RESIN EMBEDDING

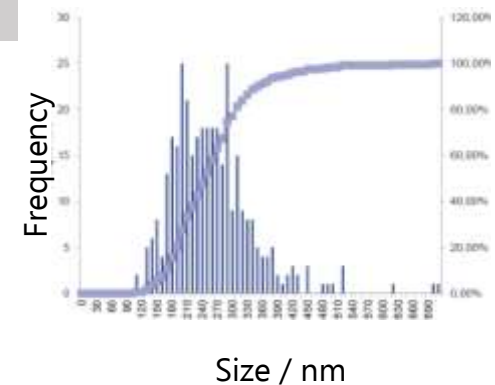


3 CROSS SECTIONING



Avoid hot mounting resins cured under pressure

- Risk of platelet bending, cracking, and fracturing



TECHNICAL LIMITATIONS OF REQUESTED APPROACH

Today's understanding of « inconclusive samples »

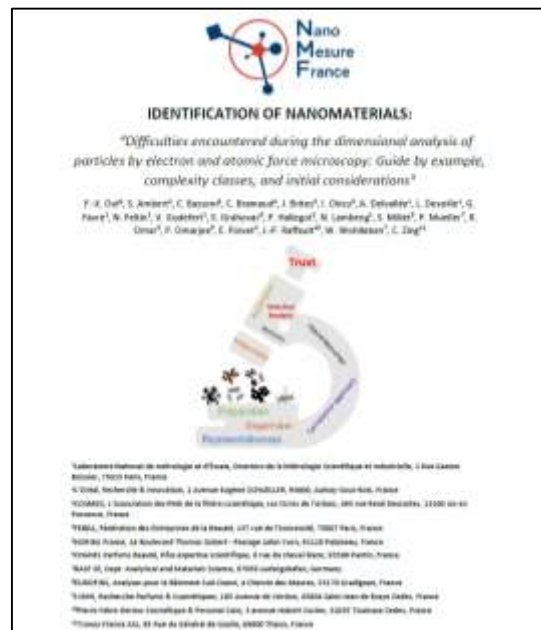
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(e. g. sample preparation, imaging conditions)

Platelets



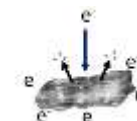
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Limited image resolution
Agglomeration concerns

Beam-sensitive materials



Measurement conditions
influences size and shape

Agglomerates



Difficult to distinguish
particles in agglomerates
"Hidden" particles

Aggregates

Difficult to distinguish
particles in aggregates

Multicomponents

(composites, mixtures)



Need to discriminate each ingredient within samples

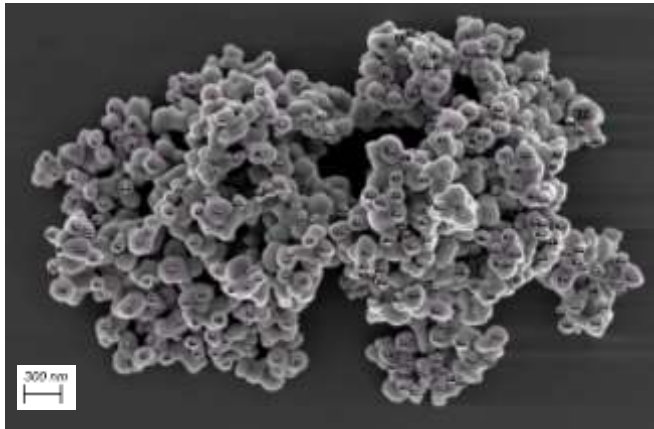
Borderline samples



Measured size close to threshold (D_{50} : 80-120 nm)
Nano status variable due to measurement uncertainty

Borderline values: Critical questions for the industry

Example : Inorganic Ingredient



Operator	Nbr of particles measured	D50 / nm
1	238	109.8
2	417	104.7
3	155	107.5
4	168	111.3

7 nm peak to peak (Same image)

- Need to consider also :
- Image processing effect
 - Image acquisition effect
 - Sample preparation effect

Small ILC on inorganic ingredient by EM

Same sample, measurement by EM, flexible sample preparation



Need to harmonize analytical methods and develop CRMs to address the challenges associated with industrial sample analysis.

Conclusion & Perspectives

🌐 Bridge the Reality Gap

- Transition from ideal, monodisperse reference materials to **complex, polydisperse industrial raw materials by actively managing measurement uncertainty.**

🔬 Adopt Pragmatic & Innovative Methods

- Overcome technical limitations of "inconclusive samples" (platelets, aggregates) through alternative quantitative workflows

🔒 Secure Regulatory Compliance

- Strengthen **metrological support** to proactively address the upcoming, stricter European nano-definitions, ensuring robust labeling, notifications, and safety compliance.

🤝 Drive Industry Harmonization

- Collaborate to standardize sample preparation and analysis protocols while co-developing CRMs tailored to real industrial samples.

THANK YOU



L'ORÉAL
RESEARCH
& INNOVATION