INDUSTRY · TECHNOLOGY · INNOVATION

Risk assessment in additive manufacturing: From materials design to Industrial Innovation

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Presentation Outline

1. ISQ – Introduction of the company
2. Nanomaterials in Additive Manufacturing
3. Evaluation of risk in Nanotechnology
4. Risk management: Approach, Tools & Monitoring
5. Case study: H2020 Project | **Multi-Fun**
6. Conclusions

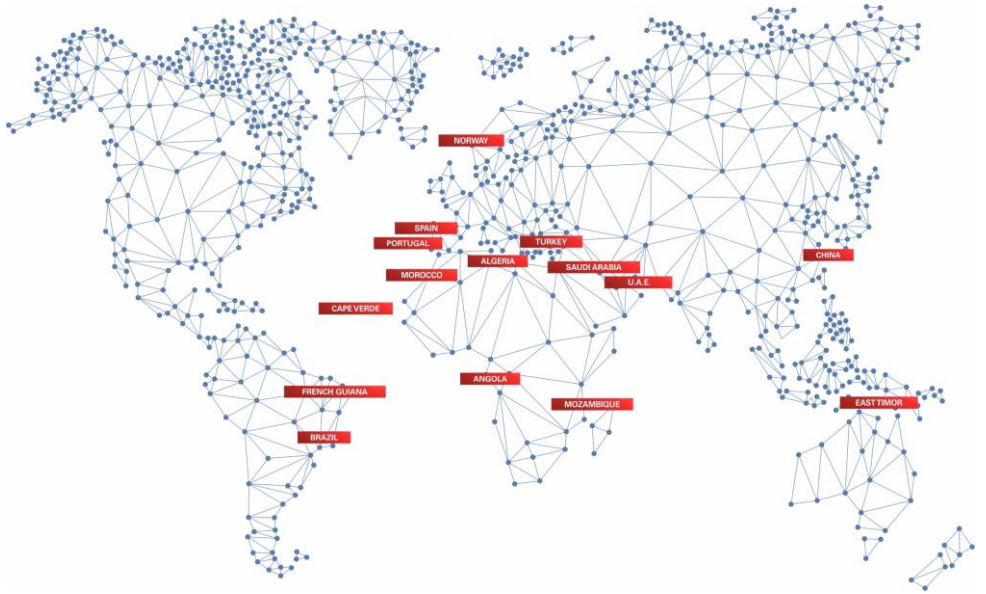
headquarters in **Portugal**

Founded in **1965**

30 + AFFILIATES

250 SPECIALIZED SERVICES

- ENGINEERING & CONSULTANCY
- VERIFICATION & REGULATORY
- METROLOGY
- TESTING
- TRAINING
- INSPECTION
- R&D + I



CUSTOMIZED SOLUTIONS

16 accredited laboratories

145 000 + trainees

13 500 + training courses

Promote **R&D**

400 + R&D international projects

1.200 + partners

1.600 employees

800 in Portugal

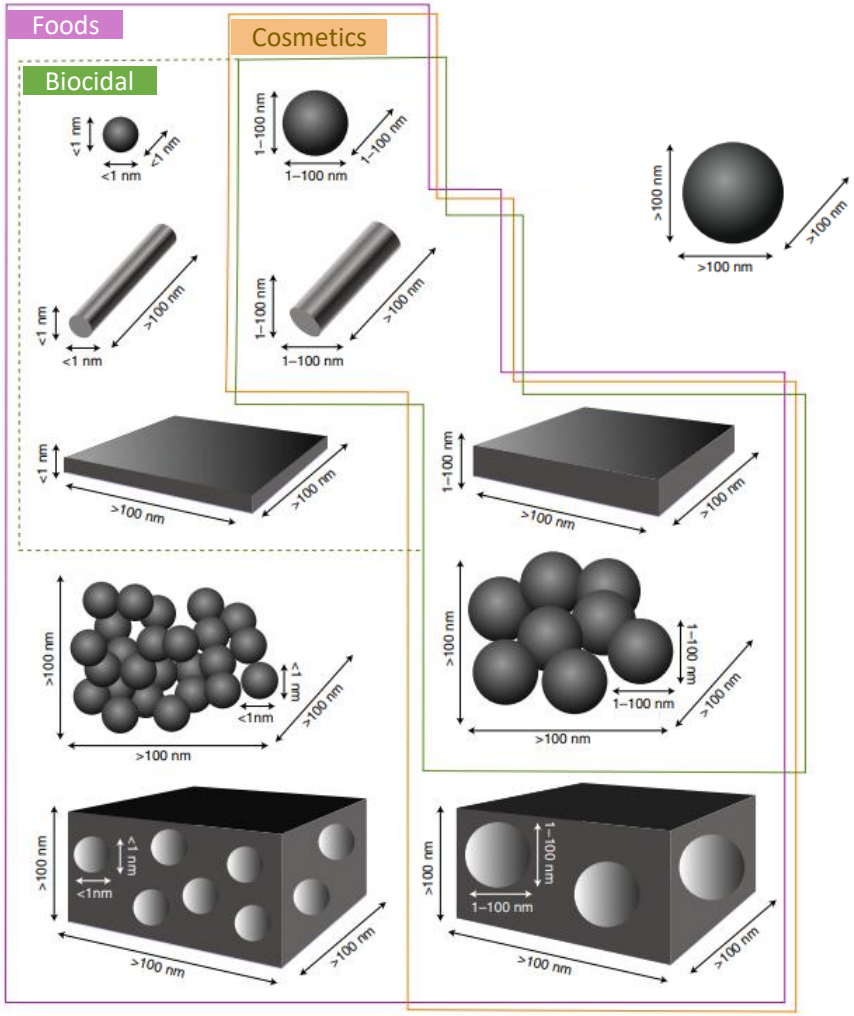
55% + with degrees

CLIENT ORIENTED
10 000 + clients worldwide

Build long lasting partnerships

More information available at www.isq.pt

What is a nanomaterial?



Martin Miernicki et al, *Legal and practical challenges in classifying nanomaterials according to regulatory definitions*, Nature Nanotechnology, Vol.14, 2019, 208-2016

EU Recommendation 2011/696/EU

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

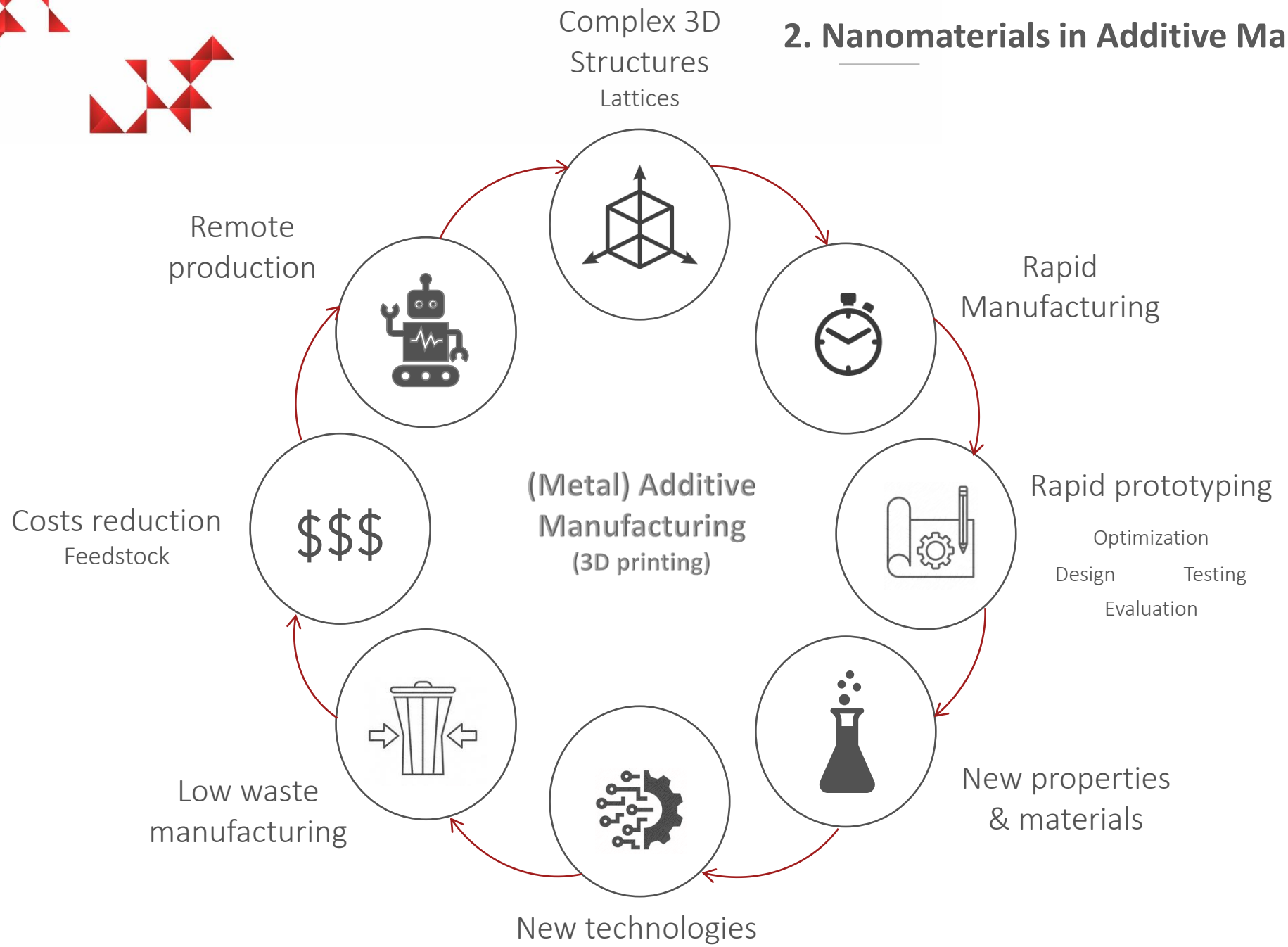
- Cosmetics, Novel Foods and Biocidal Regulations have their own nanomaterial definition

Other definition

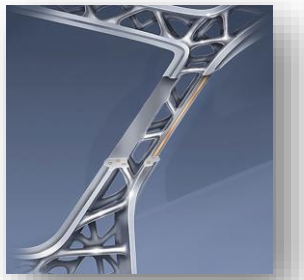
Material with any external dimension in the nanoscale (length range approximately from 1 nm to 100 nm) or having internal structure or surface structure in the nanoscale.

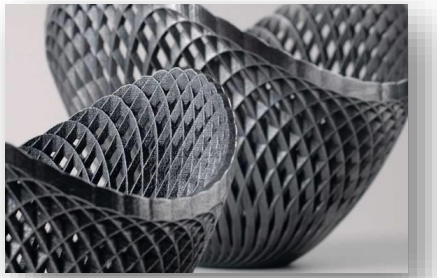
- ISO – International Organization for Standardization ISO/TS 80004-1:2015
- CEN – European Committee for Standardization DNP CEN ISO/TS 80004-1:2016

2. Nanomaterials in Additive Manufacturing



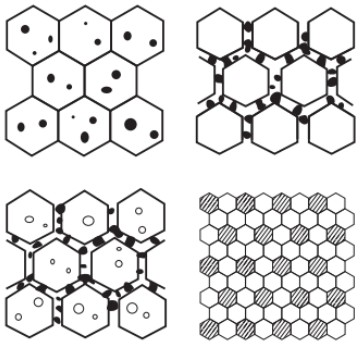
2. Nanomaterials in (Metal) Additive Manufacturing





Integration of multi-materials - **inclusion of nanoparticles (NPs)**

- ✓ Increase **mechanical properties** (strength, elasticity)
- ✓ Improved **electric and thermal conductivities**
- ✓ **Thermodynamic stability**
- ✓ Reinforcement of light metals, structures
- ✓ Preventing of solidification cracking
- ✓ Strong **interfacial bonding** in metallic matrices
- ✓ Lower sintering temperatures of printed parts, improving the quality of the final product



The introdution of NPs break property limits for new application fields and new developments

Mantilaka et al, *13 - Current review on the utilization of nanoparticles for ceramic matrix reinforcement*, Composites Science and Engineering, Interfaces in Particle and Fibre Reinforced Composites, Woodhead Publishing, 2020, Pages 345-367

2. Nanomaterials in (Metal) Additive Manufacturing

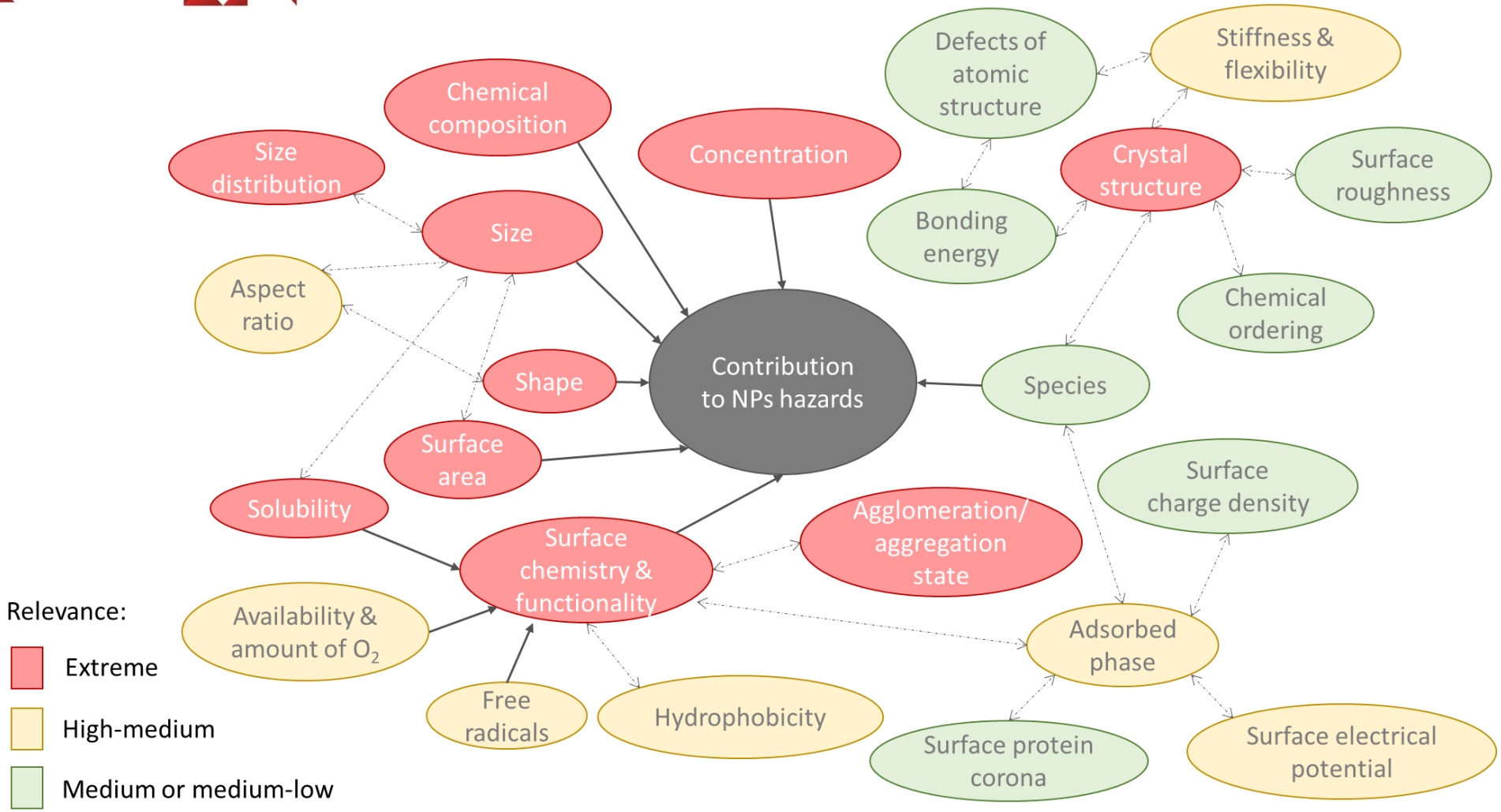
"Studies thus far show that **during 3D printing processes nanomaterials are emitted**, with diverse emission rates, depending on the experimental design, modelling, temperature applied, and materials used. Judging from studies carried out previously, **concerning possible impacts of human exposure to metal nanomaterials**, for example during welding, it becomes clear that it is of extreme relevance to **study deeply the risk of occupational exposure to nanomaterials** during metal 3D printing, including both incidental and engineered nanomaterials."

PAPER • OPEN ACCESS

Nanomaterials exposure as an occupational risk in metal additive manufacturing

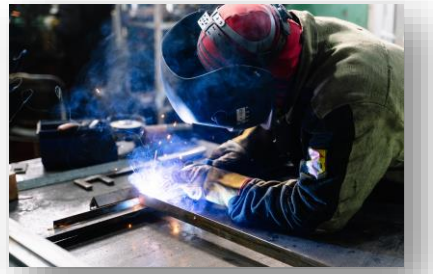
To cite this article: M Sousa *et al* 2019 *J. Phys.: Conf. Ser.* **1323** 012013

3. Evaluation of Risk in Nanotechnology



Adapted from: Guilherme Lenz e Silva and Camila Viana and Danieli Domingues and Fernanda Vieira, *Risk Assessment and Health, Safety, and Environmental Management of Carbon Nanomaterials*, Nanomaterials, 2020

Exposure to NPs



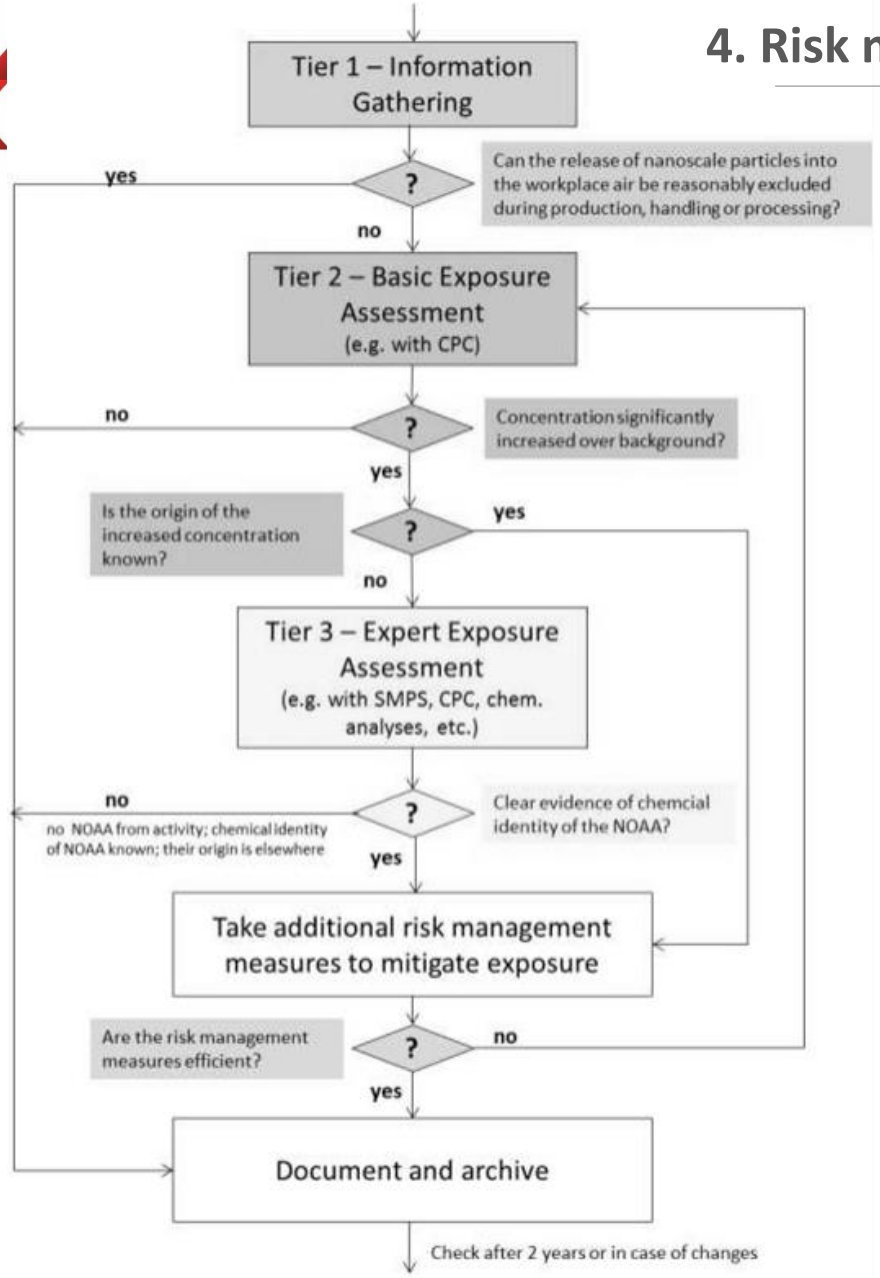
- Occupational exposure - workers can be exposed to NPs in:
  - NPs manufacturing
  - Formulation
  - Additive manufacturing
  - Transport, packaging, storage
  - Cleaning procedures
  - Recycling
  - Etc.

Inhalation

- The NPs can be absorbed *via* inhalation, skin contact and ingestion
  - Associated to pulmonary, cardiovascular and nervous system issues
  - Low solubility or insoluble NPs, possess higher probability to deposit in the human body, leading to increased health risks

The framework

Tiered approach



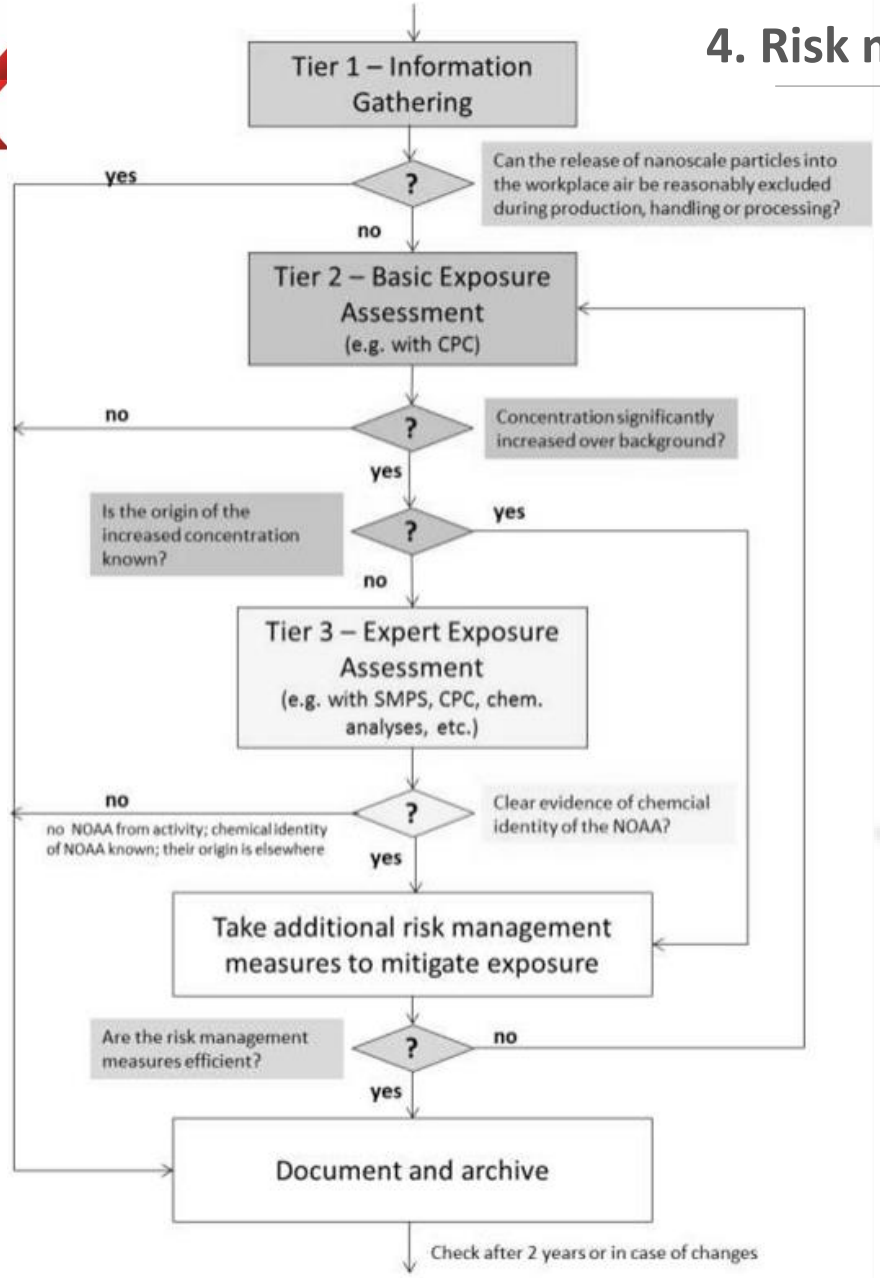
Key elements

- Workplace conditions
- Activities/Sources – production, handling, processing, quantity, duration, frequency
- Number of workers exposed
- NPs characterization – powder, liquid, gel, vapor, dust, fume, shape, free or embedded
- Confirmation of NPs exposure

OECD (2015), *Harmonized Tiered Approach To Measure And Assess The Potential Exposure To Airborne Emissions Of Engineered Nano-objects And Their Agglomerates And Aggregates At Workplaces*

The framework

Tiered approach



Exposure concentration is significantly above background if:

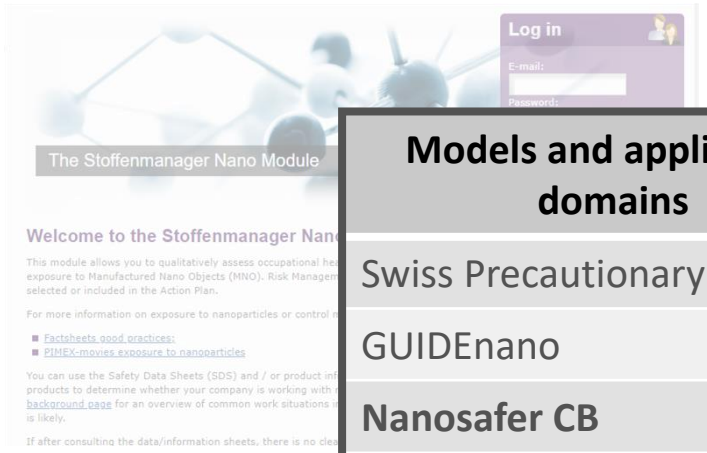
$$WA - BG > 3\sigma_{BG}$$

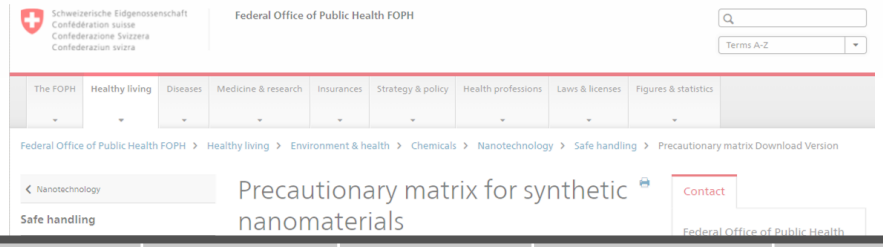
OECD (2015), *Harmonized Tiered Approach To Measure And Assess The Potential Exposure To Airborne Emissions Of Engineered Nano-objects And Their Agglomerates And Aggregates At Workplaces*

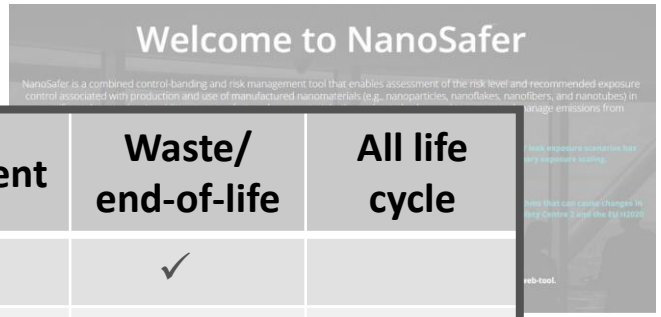
4. Risk management: Approach, Tools & Monitoring

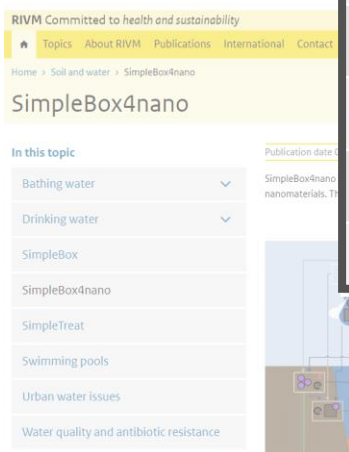
Control Banding Tools

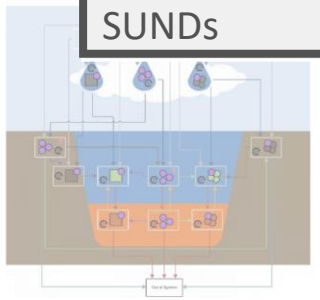
Models and application domains	Workers (labs)	Workers (all)	Users & Consumers	Environment	Waste/ end-of-life	All life cycle
Swiss Precautionary Matrix		✓	✓	✓	✓	
GUIDEnano		✓	✓	✓		✓
Nanosafer CB		✓				
Control banding nanotool	✓	✓				
Stoffenmanager nano		✓				
LICARA nanoscan		✓	✓	✓		✓
SimpleBox4Nano				✓	✓	✓
SUNDs		✓	✓	✓		✓

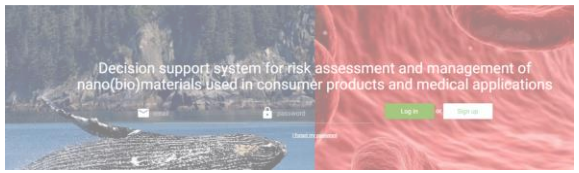








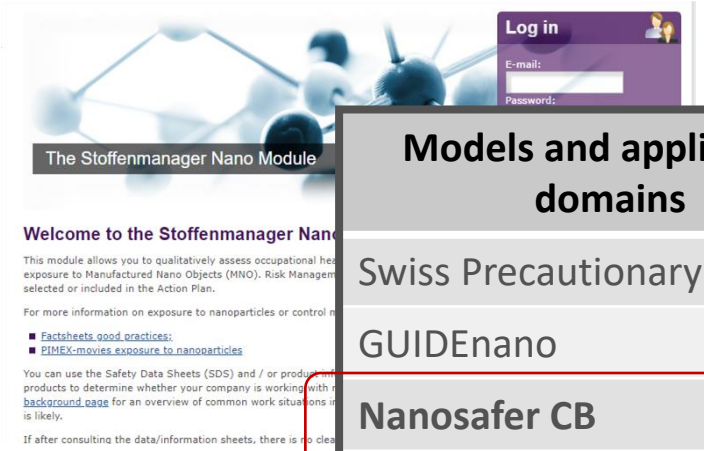


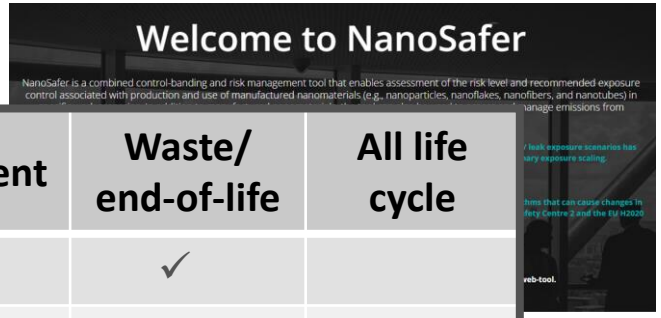


Liguori et al, *Control banding tools for occupational exposure assessment of nanomaterials — Ready for use in a regulatory context?*, NanoImpact, Volume 2, 2016, Pages 1-17

4. Risk management: Approach, Tools & Monitoring

Control Banding Tools





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Nanosafer CB		✓				
Control banding nanotool	✓	✓				
Stoffenmanager nano		✓				
LICARA nanoscan		✓	✓	✓		✓
SimpleBox4Nano				✓	✓	✓
SUNDs		✓	✓	✓		✓

Liguori et al, *Control banding tools for occupational exposure assessment of nanomaterials — Ready for use in a regulatory context?*, NanoImpact, Volume 2, 2016, Pages 1-17

Monitoring

Online

	Metric	Size range
Diffusion Charger (DISCmini)	PN, LDSA or Dp	10-700 nm
Handheld CPC (TSI, model 3007)	PN	10 - 1000 nm
CPC (TSI)	PN	2.5 - 3000 nm
SMPS (TSI) - NanoScan	PN, PSD	5 - 1000 nm
Aerosol photometers	PM	100 - 15000 nm 0.001 - 150 mg.m^{-3}

PN – particle number (#.cm^{-3}); LDSA – Lung deposited surface area concentration (µm^2.cm^{-3}); Dp – particle size diameter (nm); PSD – Particle size distribution (cm^{-3}); PM – particle mass concentration (µg.m^{-3})

Offline

To characterize chemical and physical properties of particles

Personal sampling cyclones

Aerosol sampler (NAS, TSI) or Micro Inertial Impactor

ICP-AES or ICP-MS

Microscope
SEM or TEM-EDX

Monitoring

Which exposure metrics to use?

Mass concentration ($mg.m^{-3}$)

Particle number concentration ($\#.cm^{-3}$)

Surface area ($m^2.cm^{-3}$)

Monitoring

Which exposure metrics to use?

Mass concentration (mg.m^{-3})

Particle number concentration (#.cm^{-3})

Surface area (m^2.cm^{-3})

Inhalation exposure is usually expressed based on the inhaled mass that are believed not to lead to adverse health effects

"For nanomaterials, it has been shown that similar mass doses of particles with different geometry may induce very different levels of effect in test animals. Therefore, mass does not seem to be an appropriate metric to base the risk characterization on."

Source: The Dutch National Institute for Public Health and the Environmenthttps://www.rivm.nl/en/dose-metrics

Monitoring

Which exposure metrics to use?

Mass concentration ($mg.m^{-3}$)

Particle number concentration ($\#.cm^{-3}$)

Surface area ($m^2.cm^{-3}$)

"Agglomeration can influence the deposited dose since the particle size determines the deposition efficiency in the respiratory tract."

Source: Kuempel et al, *Risk Assessment and Risk Management of Nanomaterials in the Workplace: Translating Research to Practice*, The Annals of Occupational Hygiene, Volume 56, Issue 5, July 2012, Pages 491–505

Consensus on a common metric was not achieved yet!
A combination of metrics must be used.

4. Risk management: Approach, Tools & Monitoring

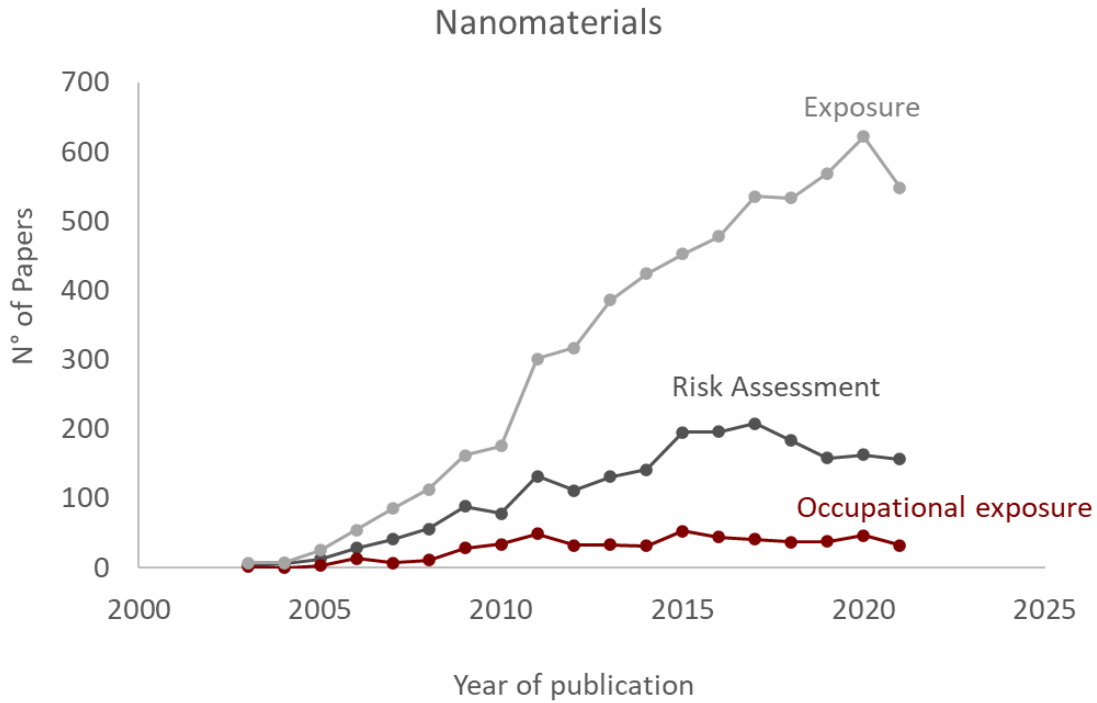
A lot of research in the last years!

Total n° of papers published (2003 – 2021)

Exposure – 5793
Risk Assessment – 2086
Occupational exposure - 533

Scopus® results

Exposure AND Nanomaterials
"Risk Assessment" AND Nanomaterials
"Occupational Exposure" AND Nanomaterials



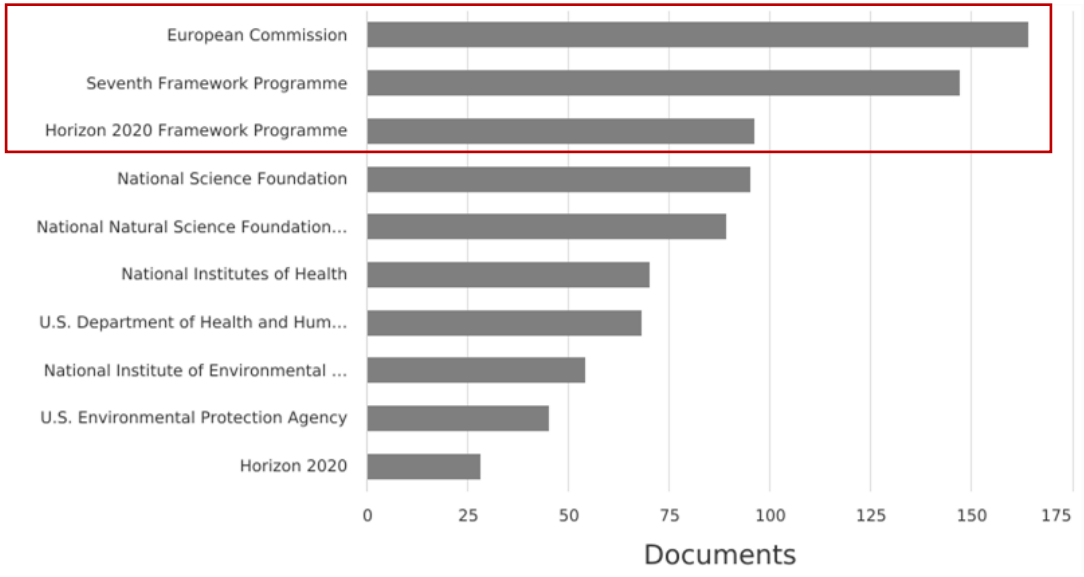
4. Risk management: Approach, Tools & Monitoring

A lot of research in the last years!

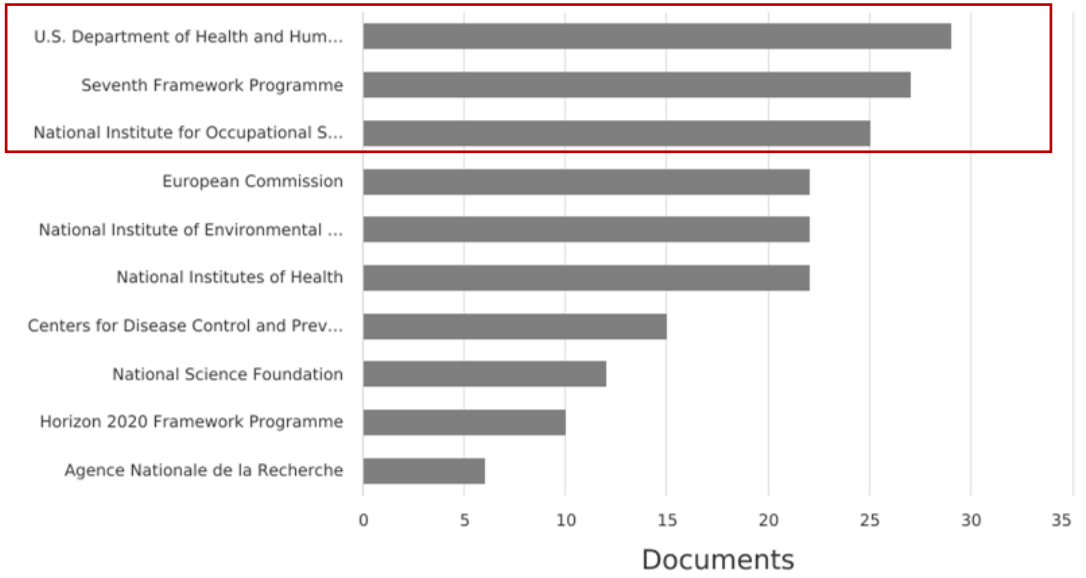
Scopus® results

Exposure AND Nanomaterials
"Risk Assessment" AND Nanomaterials
"Occupational Exposure" AND Nanomaterials

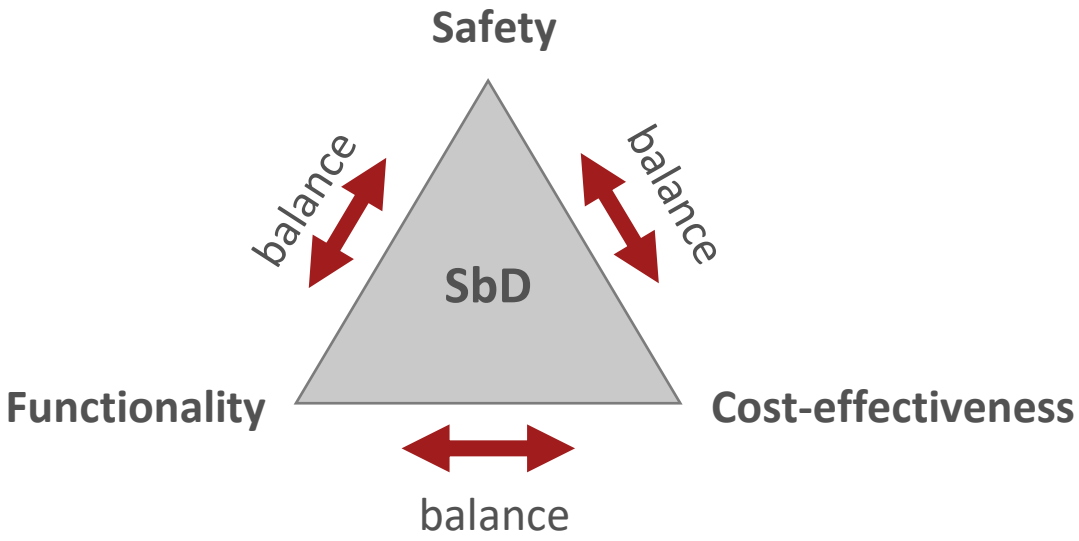
Funding sponsors – "Risk Assessment"



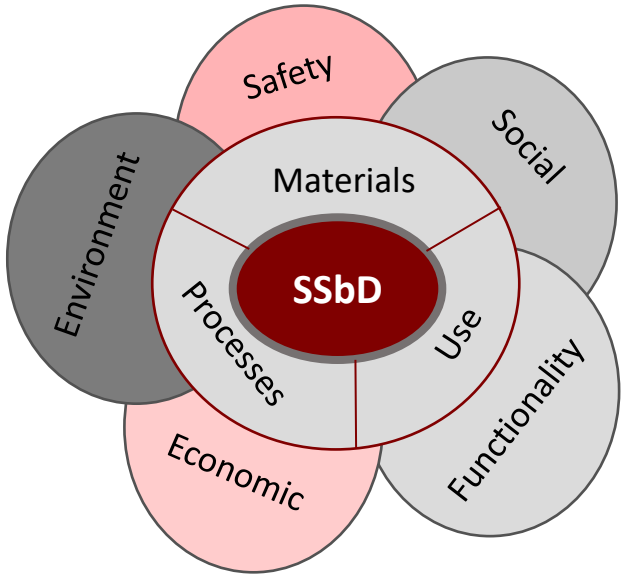
Funding sponsors – "Occupational exposure"



Safe-by-Design (SbD)

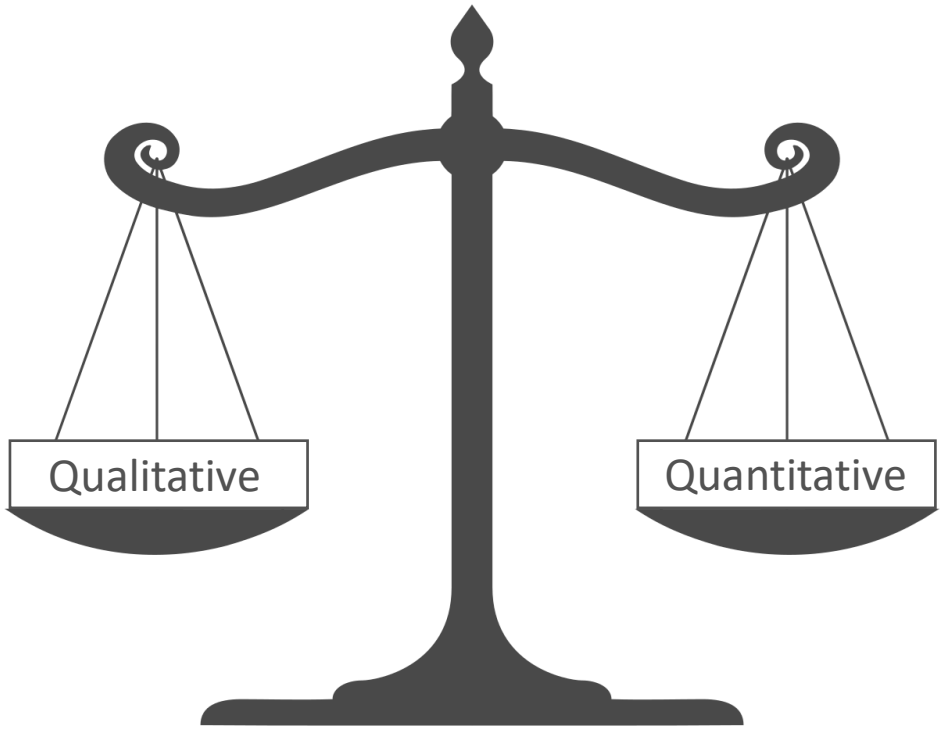


Safe- and Sustainable-by-Design (SSbD)



4. Risk management: Approach, Tools & Monitoring

Risk Assessment



Control banding tools

Questionnaires

Tiered approach (Tier 1)

Risk management strategies

Dose-response

Surface area

Monitoring

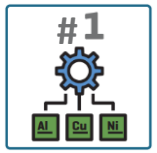
Number concentration

Toxicology

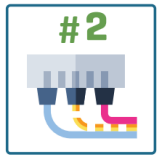
Tiered approach (Tier 2 and 3)

Multi-Fun | Enabling MULTI-FUNctional performance through multi-material additive manufacturing

Objectives



Development of 5 new materials customized for additive manufacturing, 3 of them using **nanotechnology**



Development of AM equipment and software to produce the requested material compositions during the layer build-up

Manufacture and evaluate 7 physical demonstrators with multi-material design and integrated multi-functionalities: 3 use cases (structural parts, molds, test equipment) and 4 different markets (automotive, aviation, space and production industry)

Supervising the significant reduction of environmental and economic impact by Life Cycle Assessment

Multi-Fun | Enabling MULTI-FUNctional performance through multi-material additive manufacturing

MULTI-FUN
ENABLING MULTI-FUNCTIONAL PERFORMANCE THROUGH MULTI-MATERIAL ADDITIVE MANUFACTURING

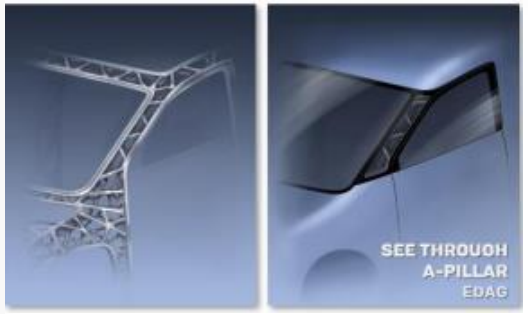
FEATURES ALLOWED BY INCLUSION OF NANO-MATERIALS

HEAT SINK MATERIALS with the highest thermal conductivity

A **HIGH DEGREE OF INTEGRAL DESIGN** that makes possible to embed electrical conductors in complex shaped metal structures

Addition of **SENSING AND DATA TRANSFER CAPABILITIES** to the equipment and software development

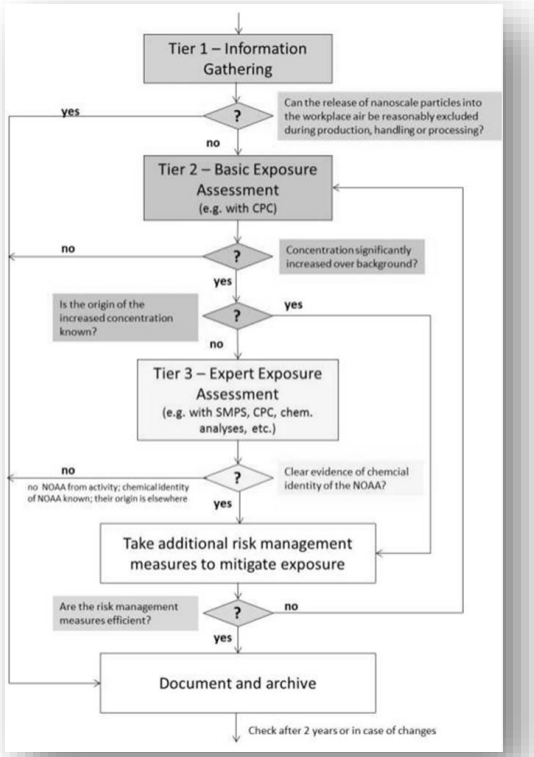
The integration of **TAILORED OPTICAL FIBRES** will enable bringing advanced thorough sensing capabilities to the manufactured parts to perform **STRUCTURAL HEALTH MONITORING (SHM)**



✓ Multi-Fun will allow for the creation of new products by maximizing thermal conductivity, minimizing electrical conductivity and/or improving wear resistance of metals

5. Case study: H2020 Project | Multi-Fun

Multi-Fun | Enabling MULTI-FUNctional performance through multi-material additive manufacturing



- ❑ Identification of potential hazards – chemical hazard assessment and risks
- ❑ Exposure routes identification
- ❑ Particles' emission monitoring
- ❑ Risks mitigation/Control measures
  - Safety handling of nanomaterials
- ❑ Report

6. Conclusions

Challenges

- High heterogeneity of nanomaterials
- Currently, mass concentration is the metric generally used in hazard reference values
- Exposure limits are being developed – dose response metrics need to be defined

Resources

- Portable monitoring is an additional resource to complement risk assessment
- Conceptual approaches for qualitative risk assessment outweigh time- and resources-consuming characterization analysis

Acknowledgements

This work has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant agreement N° 862617

Enabling MULTI-FUNctional performance through multi-material additive manufacturing | MULTI-FUN |

www.multi-fun.eu

Thank you

For your attention

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