MULTI-FUN

ENABLING MULTI-FUNCTIONAL PERFORMANCE THROUGH MULTI-MATERIAL ADDITIVE MANUFACTURING

Emerging occupational risks with innovative (nano)technology

- Towards responsible R&Di in metal additive manufacturing-

SpeedTech Forum, 17th March 2023

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862617 – MULTI-FUN

Overview

1. Responsible innovation in (nano)technology
2. Nanomaterials definition
3. Challenges in innovative (nano)technology to determine the risks
4. Routes of exposure
5. Life cycle thinking – Ensure safety at all stages
6. MULTI-FUN – safety concerns in metal additive manufacturing
7. Methodology to assess the risks in MULTI-FUN project
8. Strategy to mitigate the inhalation exposure to nanoparticles
9. Lessons learned

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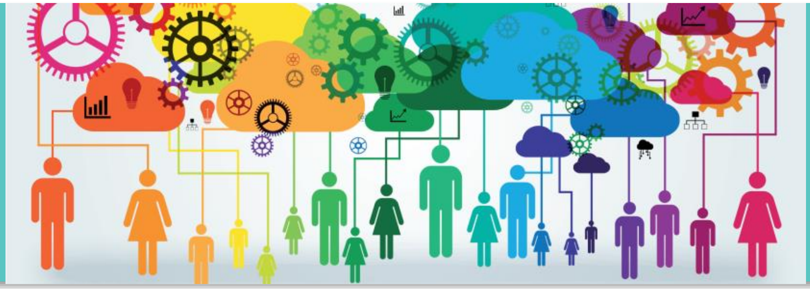
Responsible innovation in (nano)technology



Determine the appropriate governance to balance the associated risks and benefits of the adoption of the new technology.

Nanotechnology

Engineered nanomaterials are being developed for renewable energy capture and battery storage, water purification, food packaging, environmental sensors and remediation, as well as greener engineering and manufacturing processes.

- Design of safer nanomaterials
- Design for reduced environmental impact
- Design for waste reduction
- Design for process safety
- Design for materials efficiency
- Design for energy efficiency

Assessments: human and Environmental risks, life cycle analysis, socio-economic life cycle analysis

How effective the new (nano)technologies can deliver benefits to society (i.e end-users, stakeholders)?

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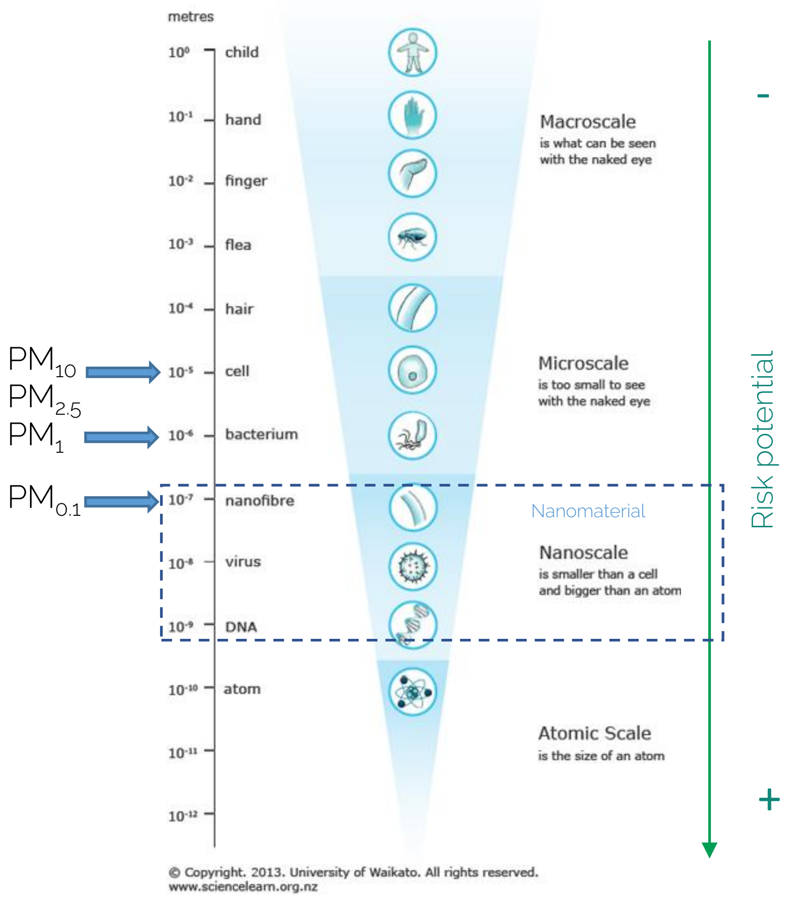
What is a Nanomaterial?



https://www.sciencelearn.org.nz/images/2063-scale-ladder-from-macro-to-atomic

PM10: particles Ø < 10 µm – coarse particulate matter

PM2.5: particles Ø < 2.5 µm – fine particulate matter

PM0.1: particles Ø < 100 nm – ultrafine particulate matter

Nanomaterial means a **natural**, **incidental** or **manufactured material** consisting of solid particles that are present, either on their own or as identifiable constituent particles in aggregates or agglomerates, and where 50 % or more of these particles in the number-based size distribution fulfil at least one of the following conditions:

(a) one or more external dimensions of the particle are in the size range **1 nm to 100 nm**;

(b) the particle has **an elongated shape, such as a rod, fibre or tube**, where two external dimensions are smaller than 1 nm and the other dimension is larger than 100 nm;

(c) the particle has a **plate-like shape**, where one external dimension is smaller than 1 nm and the other dimensions are larger than 100 nm

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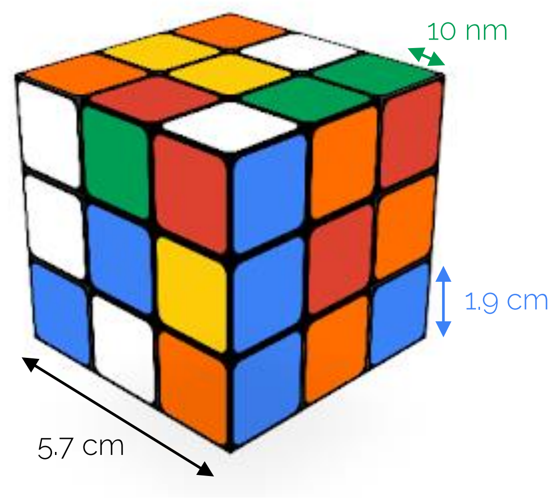
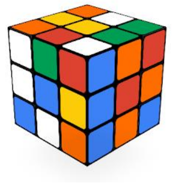
What is a Nanomaterial?

Specific surface area

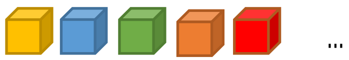


What is the Rubik's cube area?



195 cm²

What is the Rubik's cube area?



585 cm²   3× more

What is the Rubik's cube area?

5.7×10^6 cm² = 570 m²

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Risk-related challenges specific to nanotechnology R&D

Physical risks of nanomaterials

Occupational exposure and exposure limits to NMs

NMs adverse health effects (toxicology)

Enviromental fate

Enviromental risks

Synergies of NMs

Standardization

NMs used in a wide range of industries

Exposure mitigation

Rapid pace of NMs generation

Exposure characterization

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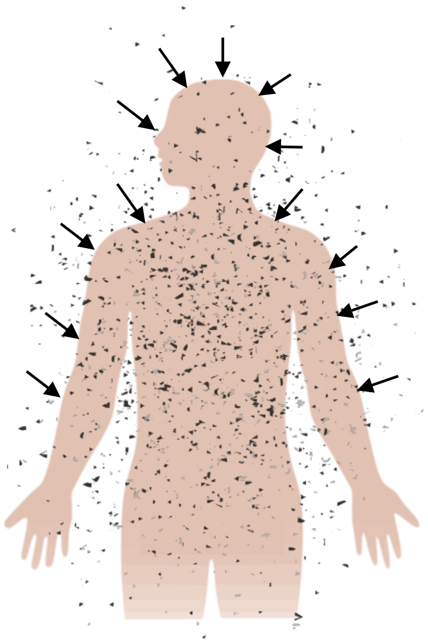
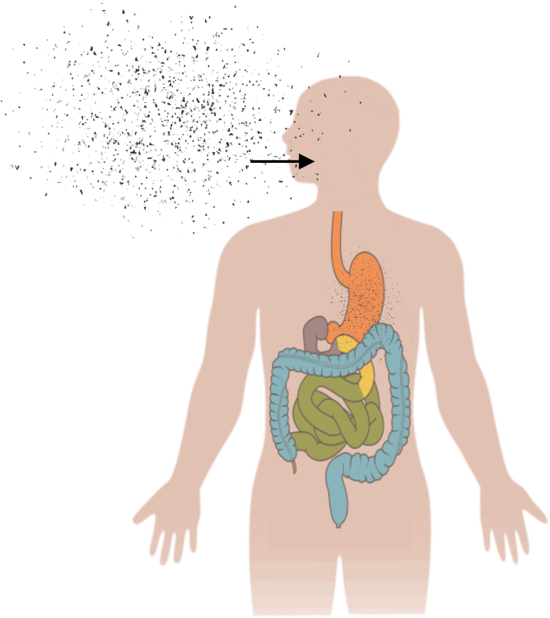
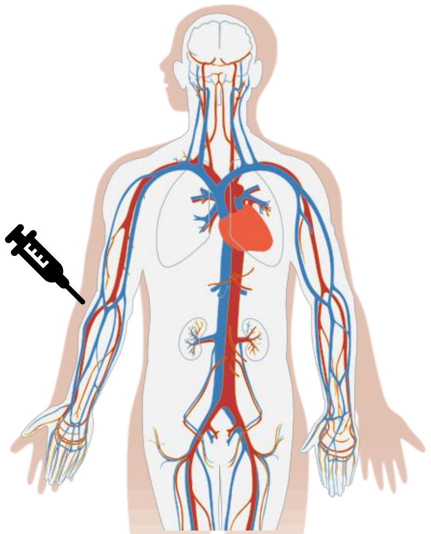
Potential routes of human exposure to nanoparticles



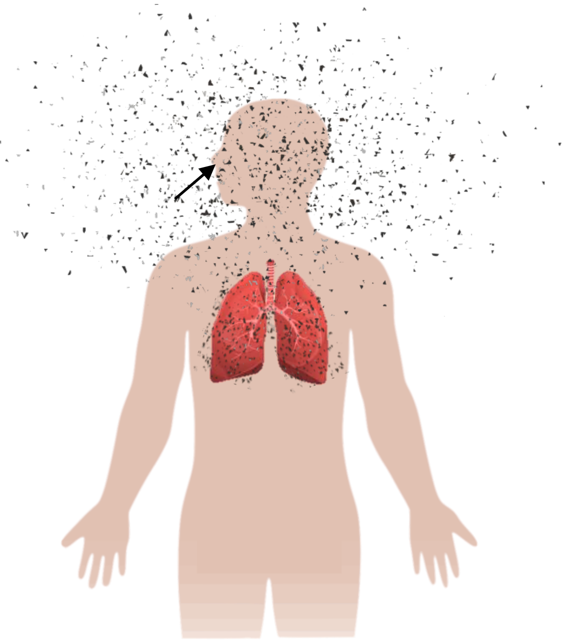
Dermal contact



Ingestion



Injection
Blood circulation



Inhalation

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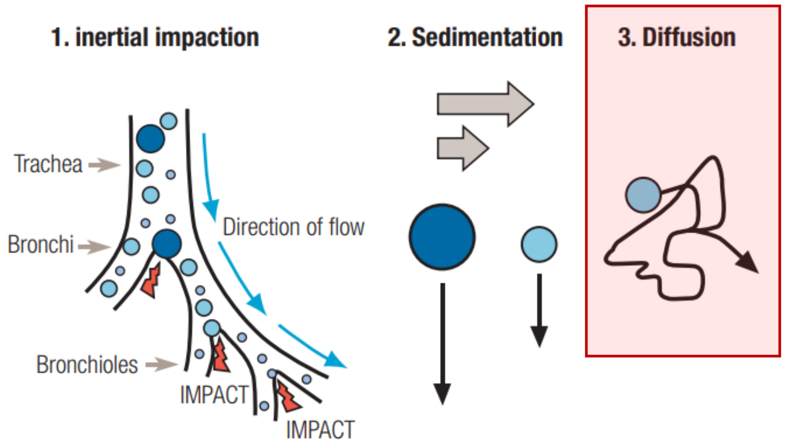
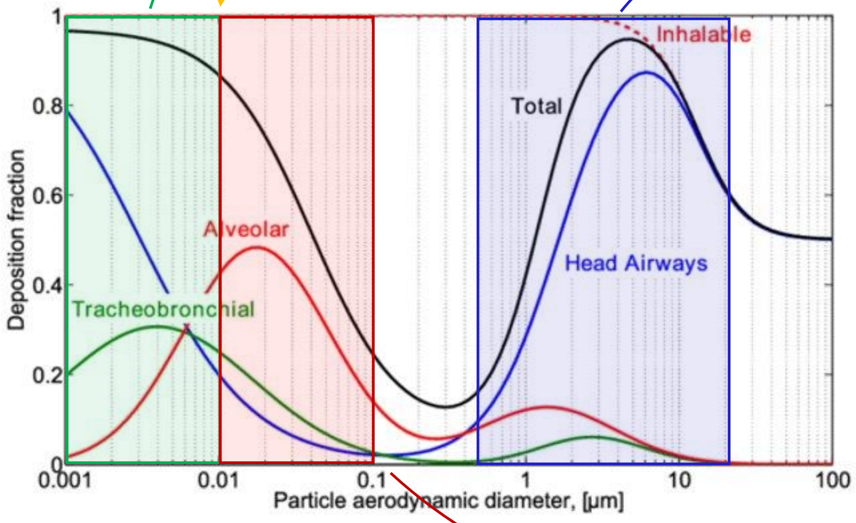
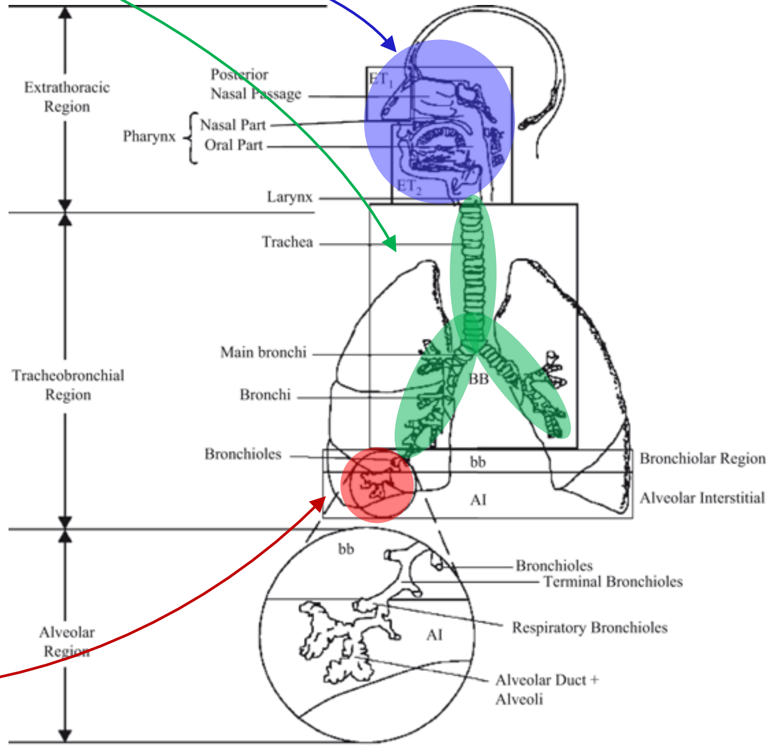
Potential routes of human exposure to nanoparticles

(Nano)particles deposition mechanisms in the respiratory tract



Higher prominence of Nanoparticles deposition





Higher potential to cause harm

Decrease in particle size means reduced efficiency of sedimentation but increased intensity of Brownian diffusion

Ka-Man Kei et al., From Aerodynamics to Inhalation Technique - More about Inhaled Medications, Hong Kong Pharmaceutical Journal, 2015, Vol. 22 (3)
Antti Koivisto, Source Specific Risk Assessment Of Indoor Aerosol Particles, Academic dissertation, University of Helsinki, 2013

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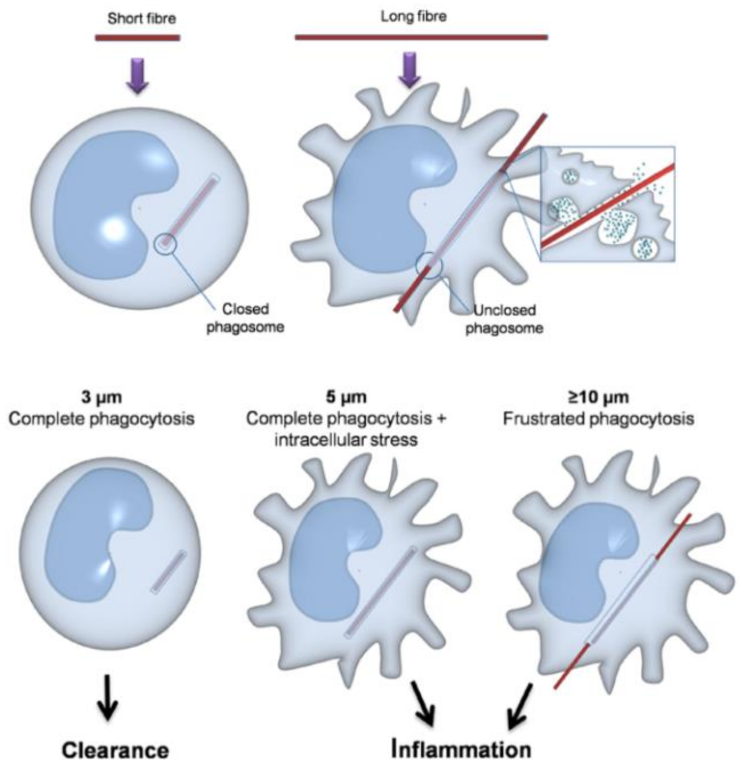
Potential routes of human exposure to nanoparticles

Inhalation toxicity of nanoparticles

Frustrated phagocytosis of macrophages



The **inhalation toxicity** of nanoparticles can be influenced by:

- Particle number and size
- Surface coating of NPs
- Degree of aggregation/agglomeration – aging during suspension in air (before inhalation)
- Shape/ Morphology
- Method of synthesis (wet or dry)
- Solubility
- Bio-persistency and bioaccumulation

Schinwald, A., Donaldson, K. Use of back-scatter electron signals to visualise cell/nanowires interactions in vitro and in vivo; frustrated phagocytosis of long fibres in macrophages and compartmentalisation in mesothelial cells in vivo. Part Fibre Toxicol 9, 34 (2012). https://doi.org/10.1186/1743-8977-9-34

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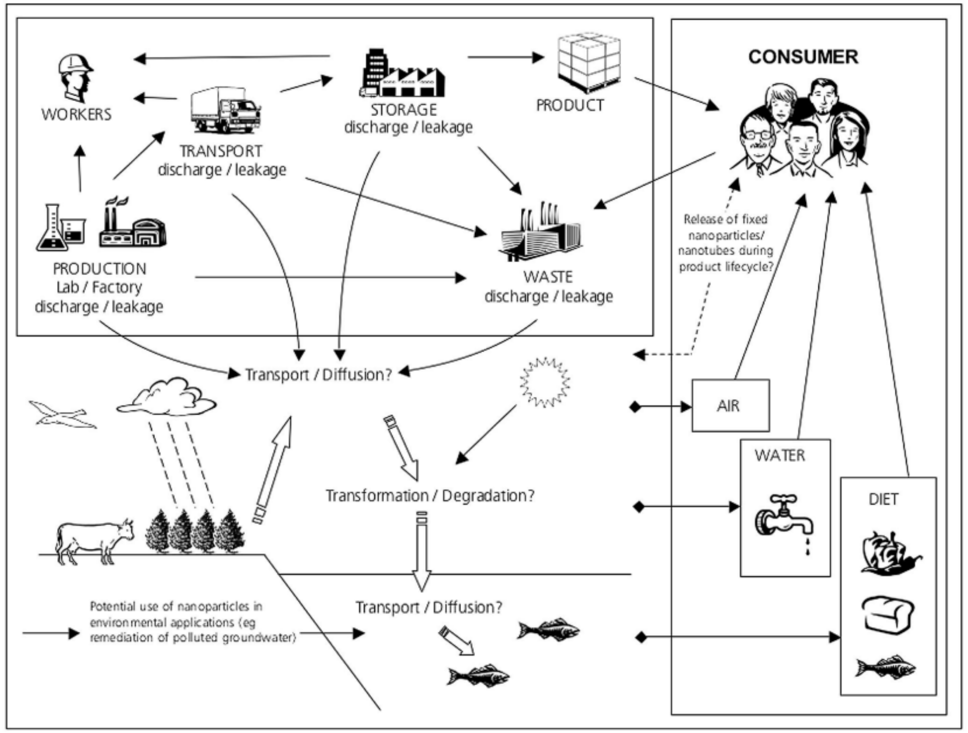
Potential routes of human exposure to nanoparticles

Direct and indirect exposure may occur throughout the nanomaterial life cycle

$$Risk = Hazard \times Exposure$$



Aitken R., RS Report Nanoscience and nanotechnologie, (2004)

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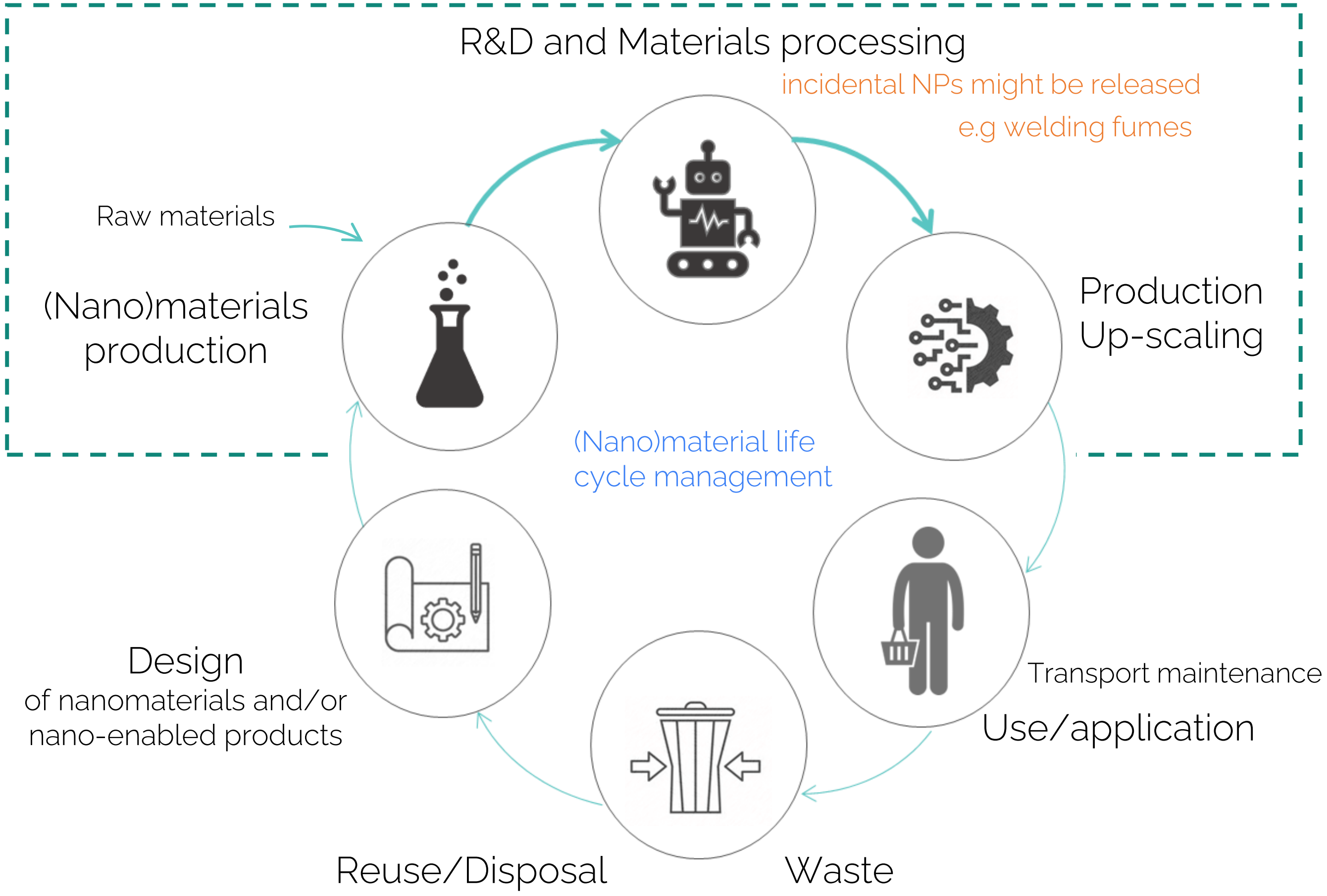
Life cycle thinking – Ensure safety and sustainability at all stages



Exposure
- Workers
- Public via releases to environemnt

- *Identify emission sources*
- *Characterise exposure*
- *Evaluate the efficiency of implemented measures in the workplaces*
- *Recommend control measures (hierarchy of controls, collective and indivual)*

MULTI-FUN: Focus on materials development and innovative DED processes – building the demonstrators

Source: ISO 31000:2018

MULTI-FUN – safety concerns in metal additive manufacturing

$$Risk = Hazard \times Exposure$$

0 0

Whatever the hazard, the risk may be maintained acceptable if no exposure exists

Safe materials

Assess toxicity (*in vitro*)

- Aluminium composite powders with TiC or TiB2 nanoparticles
- FeCrAl nanostructured powder

Safe processes

Assess the exposure

- Plasma metal deposition
- Wire arc additive manufacturing
- Wire-laser additive manufacturing
- Atmospheric pressure plasma deposition

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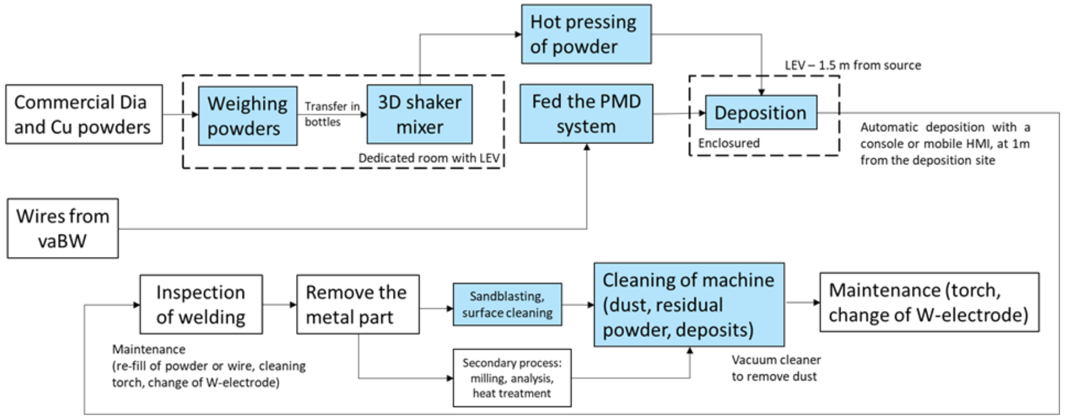
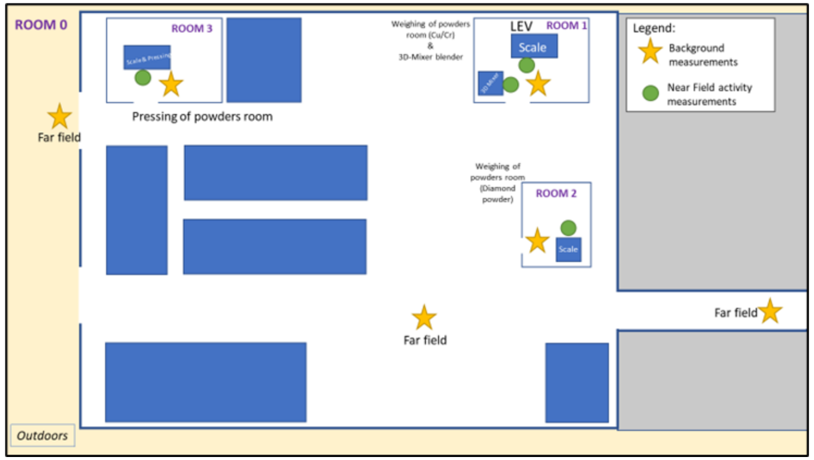
Methodology to assess the risks in MULTI-FUN project

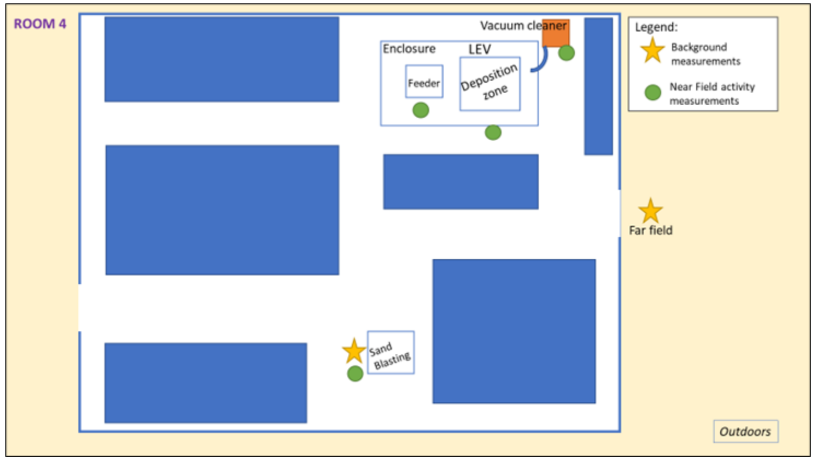
Planning

Collect information:

- Processes flowchart
- Chemicals used
- Work procedures
- Possible sources of release
- Implemented control measures
- Number of workers
- …







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Methodology to assess the risks in MULTI-FUN project

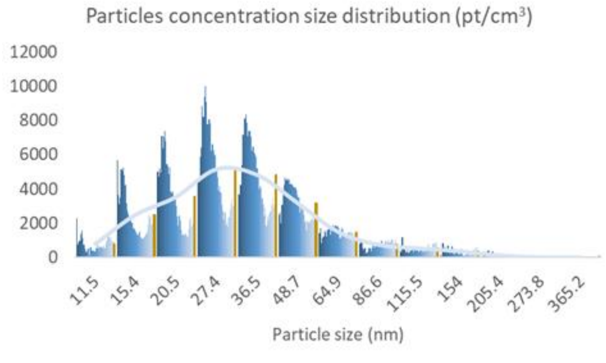
Monitoring equipment

NanoScan

Stationary equipment

SMPS – Scanning mobility particle sizer

- *Metrics:*
  - Particles concentration
  - Mass concentration
  - Surface area
  - Size distribution



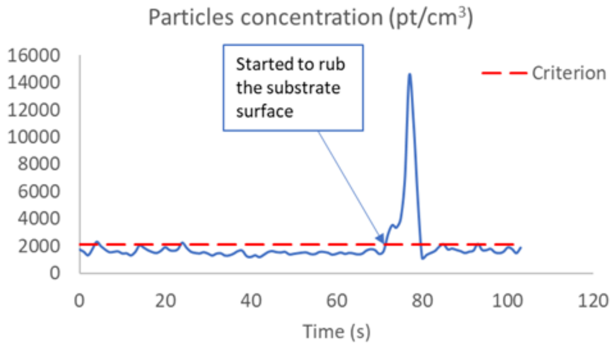
DISCmini

Personal monitor

High time resolution (1 s)

Diffusion charger

- *Metrics:*
  - Average **particles concentration**
  - Lung deposited surface area (LDSA)
  - Average particle diameter



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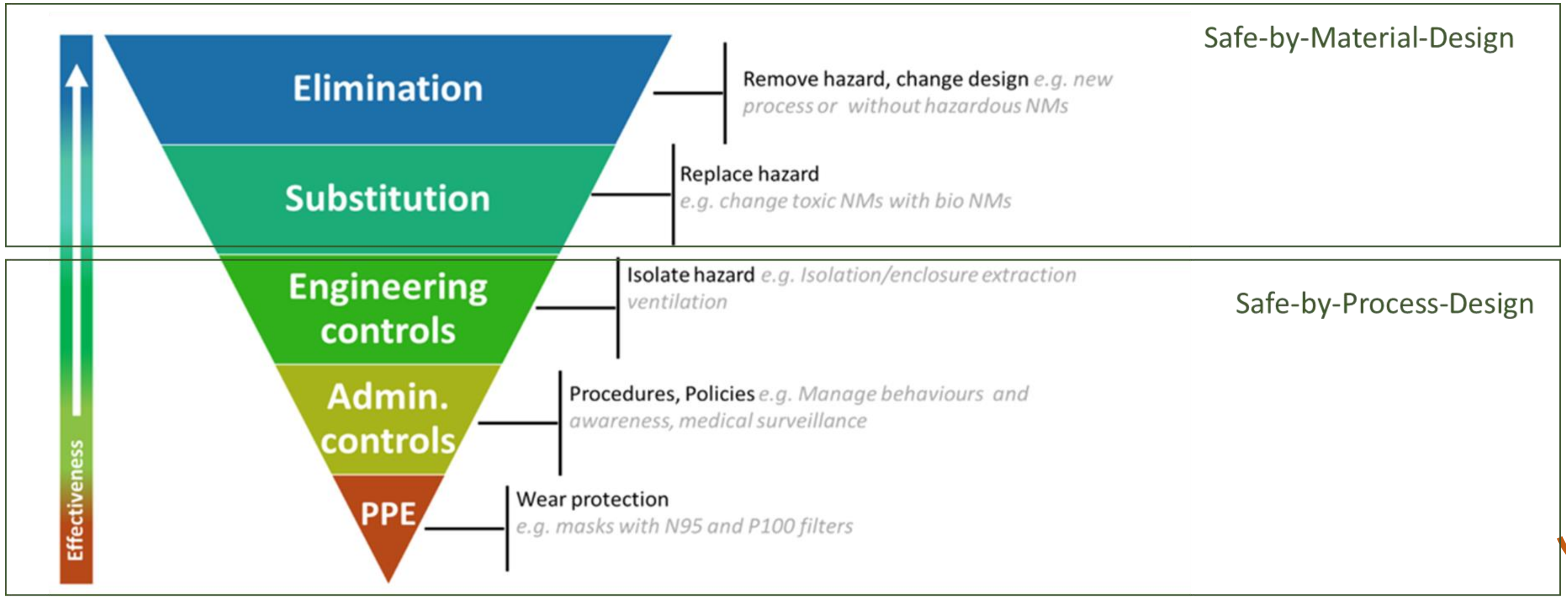
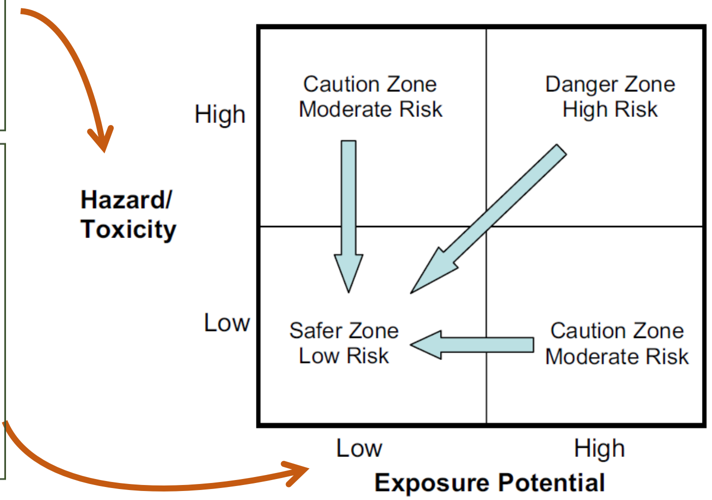
Strategy to mitigate the inhalation exposure to nanoparticles



Plog et al. 2002; NIOSH 1990.

Risk mitigation matrix



The 5 principles of "Design for Safer Nanotechnology" Gregory Morose

If the potential hazard cannot be eliminated or replaced with a less hazardous or non-hazardous substance, engineering controls must be installed and adapted to the process or task.

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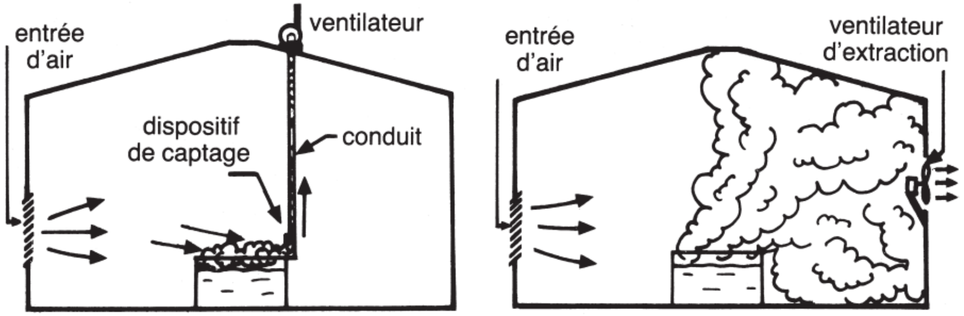
Strategy to mitigate the inhalation exposure to nanoparticles

Engineering controls

ISO/TS 12901 P2 - Nanotechnologies - Occupational risk management applied to engineered nanomaterials



a) Ventilation locale : assainissement par captage des polluants.

b) Ventilation générale : dispersion des polluants dans le local.

https://www.inrs.fr/media.html?refINRS=ED%20695

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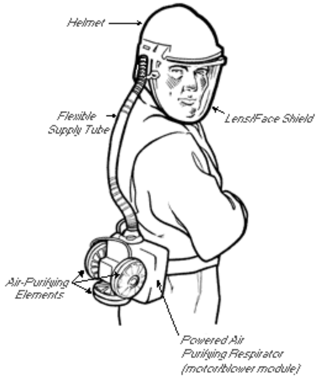
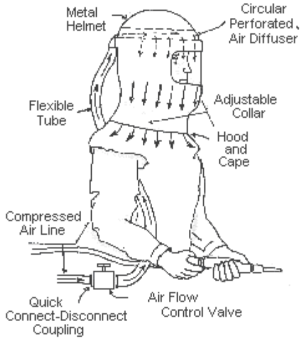
Strategy to mitigate the inhalation exposure to nanoparticles

Respiratory protection

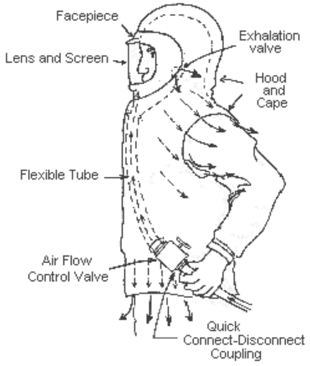
Breathing apparatus



Loose-Fitting Facepiece



Abrasive Blasting Respirator (Hood Respirator)



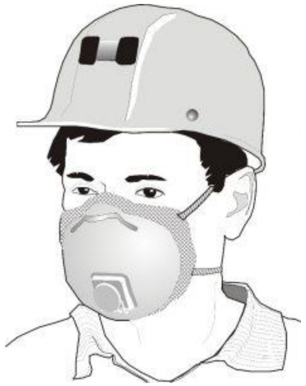
Loose-Fitting Hood with Blouse

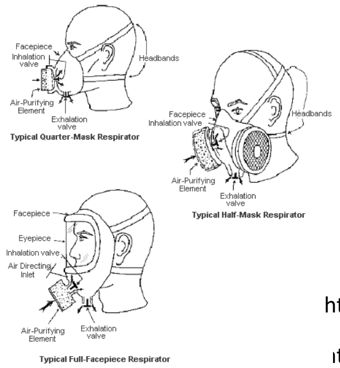
Powered Air-Purifying Respirators

Filtering devices

Reusable Half-Masks

Filtering Facepiece Respirators





EN 529 specifies the procedures required to set up a suitable RPE Program.

https://www.osha.gov/otm/section-8-ppe/chapter-2

ıttps://blogs.cdc.gov/niosh-science-blog/2020/08/17/respirators-construction/

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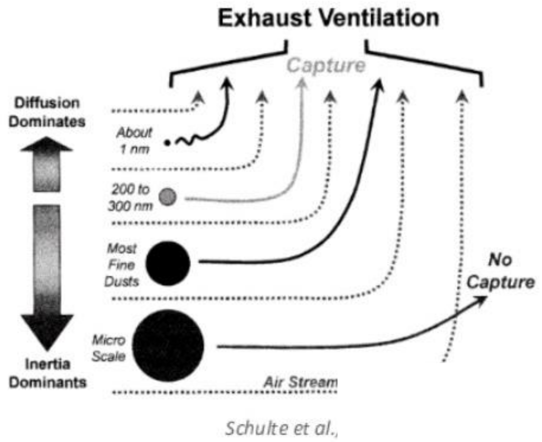
Lessons learned

The evaluation of engineering controls in the nanomaterial production and innovation DED processes showed varying levels of control effectiveness to anthropogenic nanoparticles,



Nanoparticles transport in the air is mainly accomplished through convection. Airborne nanoparticles behave very differently from coarser particles, affecting the effectiveness of control measures

Glove boxes and containment enclosures can be used effectively in facilities that require worker protection during small-scale material handling operations.

Risk assessment must be tailored for each case.

Protection measures must be designed for each process and procedures, taking into account the levels of exposure, frequency of the tasks, number of workers, …

To efficiently manage the occupational risks, through exposure mitigation, is essential a strong engagement from the stakeholders,

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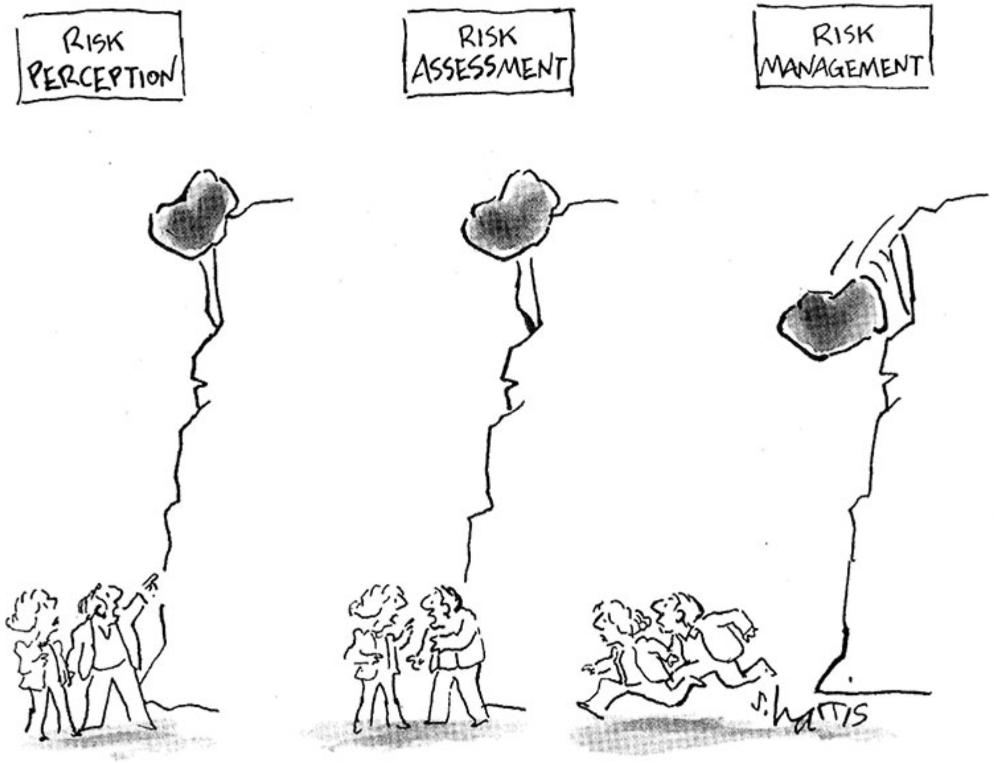
Take home message



Design and development of new nanomaterials

Safety and regulation

"Not all nanomaterials necessarily have a toxic effect, however, and a case-by-case approach is necessary while ongoing research continues" EU-OSHA

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Thank You!

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