nano SAFE'18
5-9 November 2018
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6th international conference on HEALTH and SAFETY issues related to NANOMATERIALS for a socially responsible approach

Nanomaterials as an occupational risk in metal additive manufacturing

Marta Sousa[1,2], Pedro Arezes[1], Francisco Silva[1,3]

[1] *ALGORITMI Research Center, School of Engineering, University of Minho*
[2] *Technological Center for the Metal Working Industry*
[3] *CTCV – Technological Center for Ceramics and Glass*

Grenoble, 9th November 2018

catim centro de apoio tecnológico à indústria metalomecânica

CTCV

Universidade do Minho
Escola de Engenharia

AGENDA

- Wide approach to Additive Manufacturing (AM)
- Occupational exposure to nanomaterials during AM processes
- Risk assessment of occupational exposure to nanomaterials
- Risk assessment of exposure to nanomaterials during AM processes
- Conclusions
- Next steps

ADDITIVE MANUFACTURING

Source: ConceptLaser

Additive Manufacturing

"Process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies."

(ISO/ASTM 52900:2015)

- **Goal**: create three-dimensional parts by successive additions of materials

ADDITIVE MANUFACTURING

Source: ConceptLaser

Benefits

- Variety of raw materials and applications;
- Single machine for all process, no need to use additional dies;
- Less waste;
- Customized parts;
- …

Disadvantages

- Inability to mass production;
- Often time-consuming process and high investment;
- Risks not yet sufficiently known;
- …

ADDITIVE MANUFACTURING

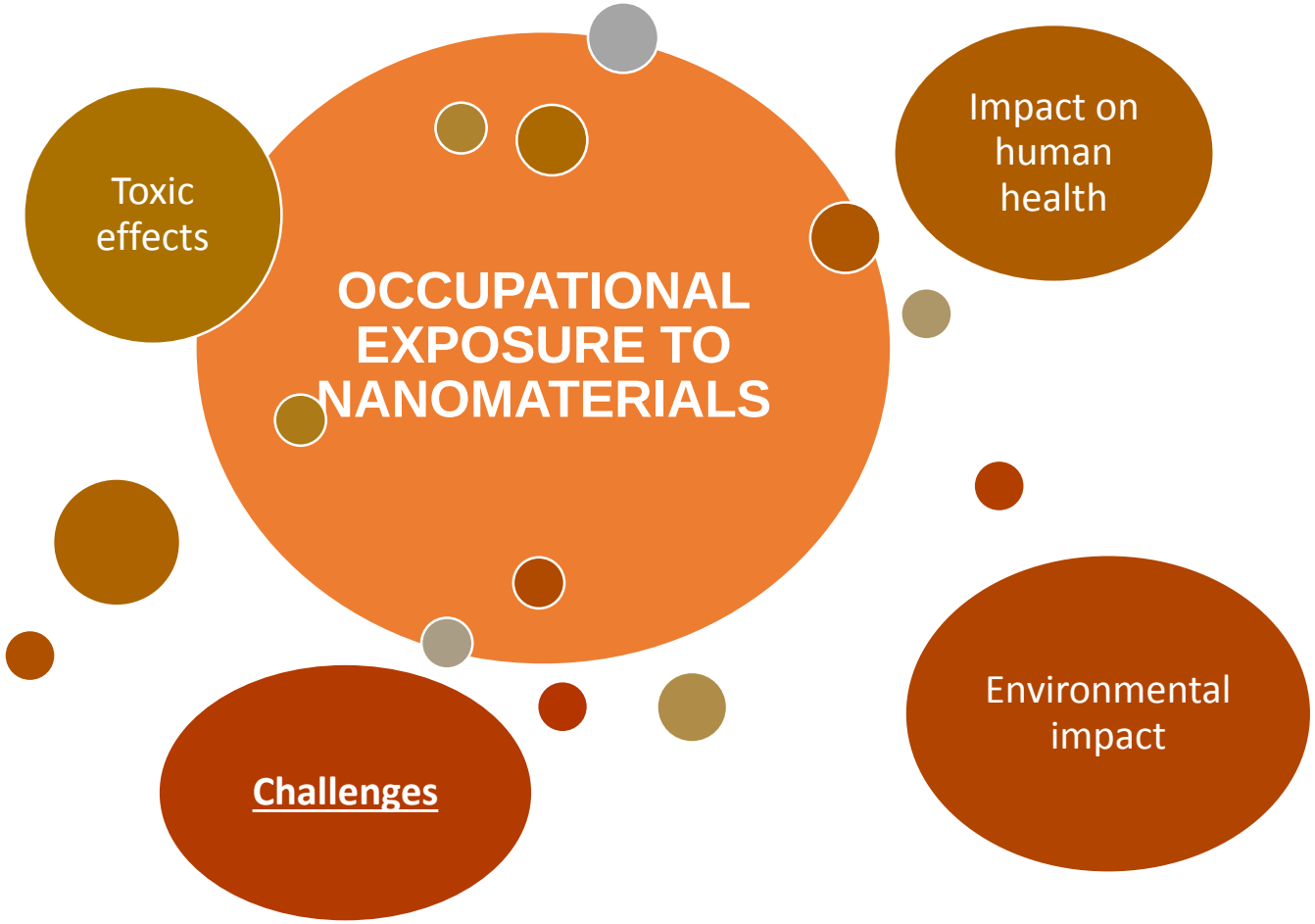
Metal additive manufacturing

- **Different raw materials;**
- **Impact on health and safety related mainly to particulate emissions**: coarse, fine and ultrafine;
- **Health effects of metal nanoparticles** are well-known hazards in other metal processing activities such as welding.

Source: ConceptLaser

AND SO RESEARCH BEGINS

EXPOSURE TO NANOMATERIALS

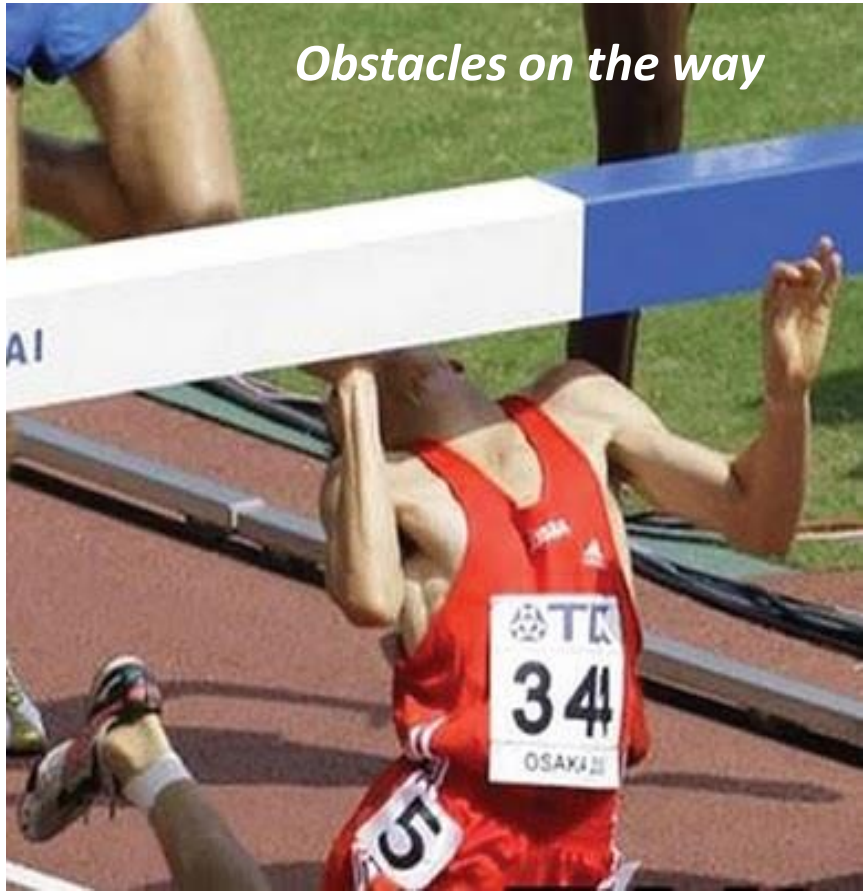


RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS

Quantitative methods

- Several alternatives to assess exposure, based on:
  - Number concentration;
  - Mass concentration;
  - Morphology;
  - Chemical composition;
  - ...

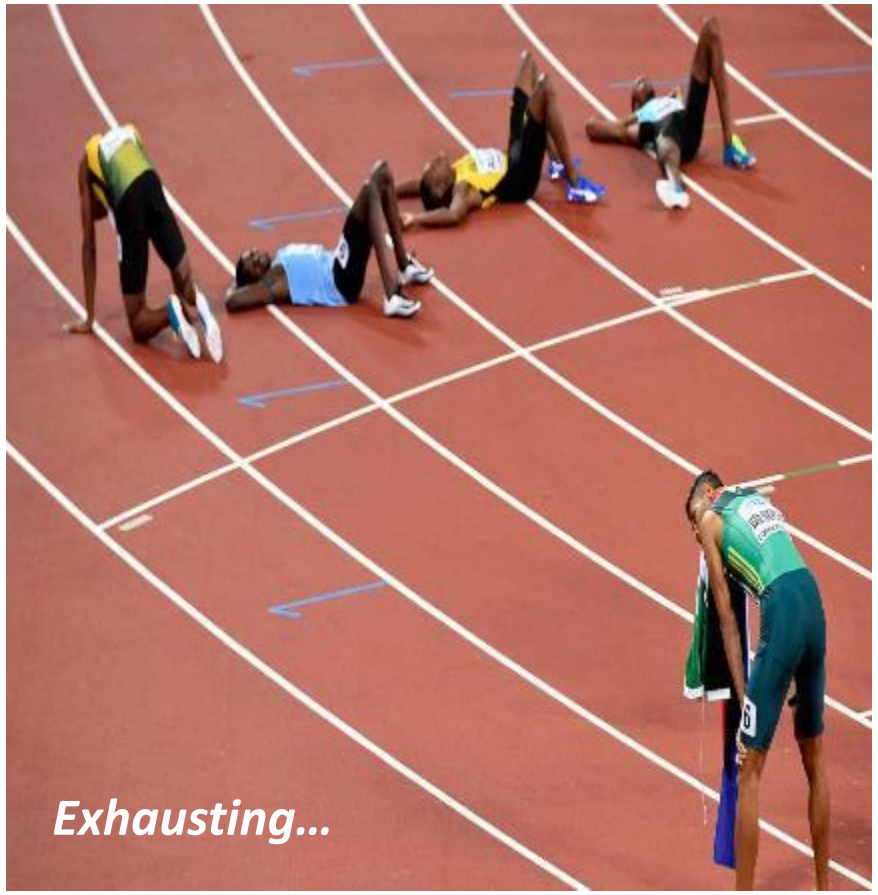
RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS



Quantitative methods

- Difficult to choose the most **appropriate methods**;
- Difficult to choose the most proper **sampling techniques;**
- **Specific equipment** is required and has some limitations;
- **OELs are not defined** for all nanomaterials;
- ....

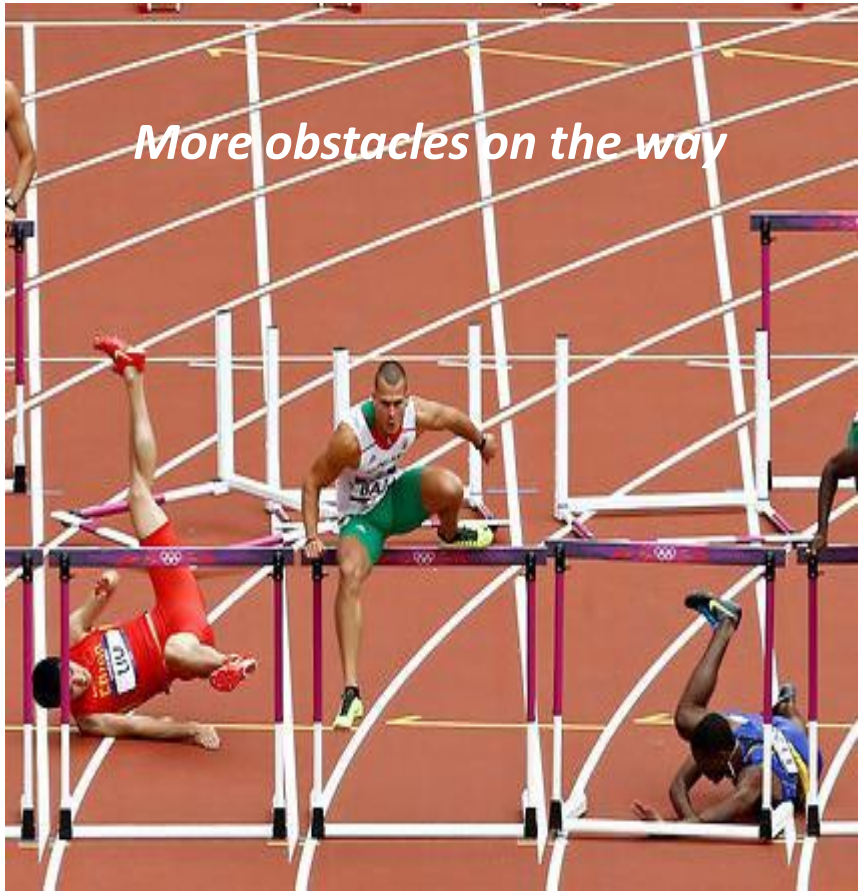
RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS



Qualitative and semiquantitative methods

- Control Banding Nanotool
- Stoffenmanager Nano
- Anses Tool
- NanoSafer CB
- Precautionary Matrix for Synthetic Nanomaterials
- Monte Carlo Simulation Model
- Decision Tree Analysis, Multicriteria Decision Analysis
- Bayesian Analysis
- Systematic Design Analysis Approach
- …

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS



Qualitative and semiquantitative methods

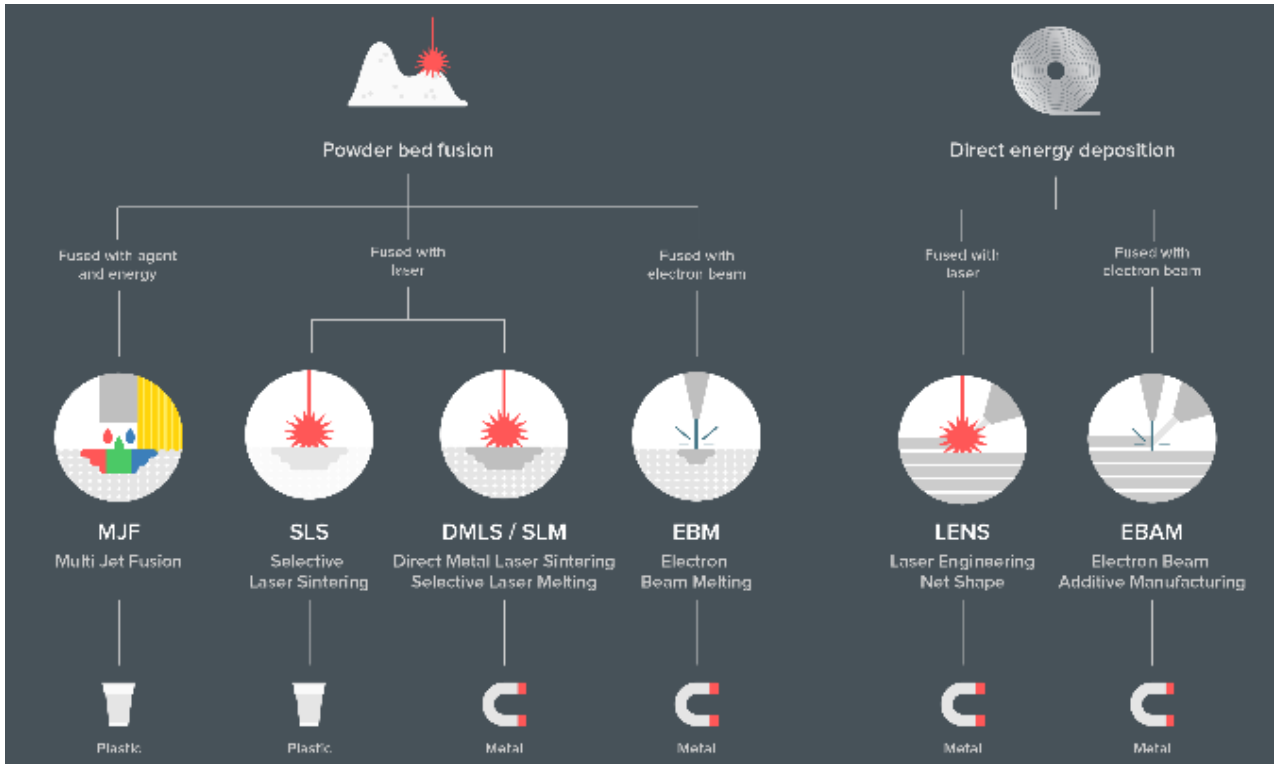
- **Difficult to choose** the most appropriate method;
- Applications are often **specific;**
- Difficult to gather some **input data;**
- **Not yet validated.**

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS

Focus on metal additive manufacturing and find out what´s already been done…

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM

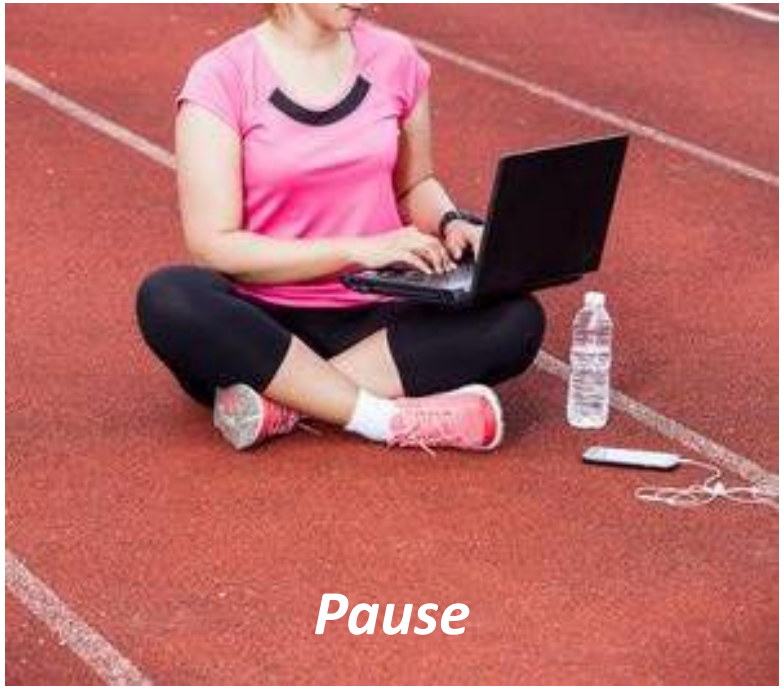


Source: 3D Hubs

Occupational exposure to nanomaterials during metal additive manufacturing

- Diversity of raw materials and technologies;
- Most common processes: Power Bed Fusion and Direct Energy Deposition;
- Tasks that require direct contact with metal powder.

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM



Literature review

- Published between 1990 – 2018;
- Peer reviewed publications;
- Written in English;
- Regarding emissions during metal AM;
- Real occupational conditions.

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM

Literature review

- Graff, P., Ståhlbom, B., Nordenberg, E., Graichen, A., Johansson, P., & Karlsson, H. (2017). ***Evaluating Measuring Techniques for Occupational Exposure during Additive Manufacturing of Metals: A Pilot Study***. Journal of Industrial Ecology, 21, 120–S129.

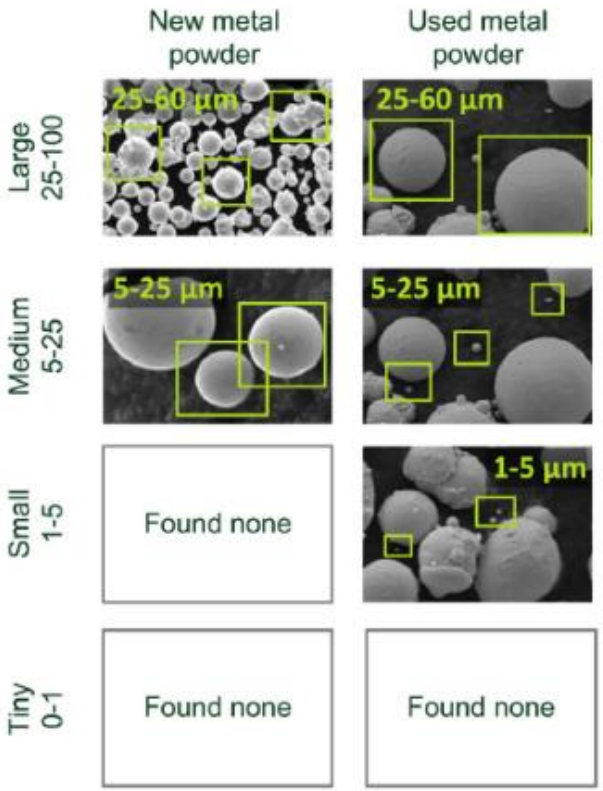
- Mellin, P., Jönsson, C., Åkermo, M., Fernberg, P., Nordenberg, E., Brodin, H., & Strondl, A. (2016). ***Nano-sized by-products from metal 3D printing, composite manufacturing and fabric production***. Journal of Cleaner Production, 139, 1224–1233.

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM

	STUDY #1	STUDY #2
	Evaluating Measuring Techniques for Occupational Exposure during Additive Manufacturing of Metals A Pilot Study *Pål Graff, Bengt Ståhlbom, Eva Nordenberg, Andreas Graichen, Pontus Johansson, and Helen Karlsson*	Nano-sized by-products from metal 3D printing, composite manufacturing and fabric production Pelle Mellin [a, b, *], Christina Jönsson [a, c], Malin Åkermo [a, d], Patrik Fernberg [e, f], Eva Nordenberg [g], Håkan Brodin [g], Annika Strondl [a, b]
AIM	To use measuring techniques optimized for different particle sizes while analyzing numbers, sizes, masses and identities of metal particle emissions	To examine metal 3D printing, composite manufacturing and fabric production in terms of generated nano-sized by-products during production
MATERIAL	**Chromium, nickel and cobalt alloy** (both virgin and used powder)	**Nickel-base Inconel 939** (both virgin and used powder)
AM TECHNIQUE	Selective laser melting (**SLM**)	
QUANTITATIVE ANALYSIS	• **Nanotracer** (10 to 300 nm); • **Lighthouse** (300 nm to 10 µm); • **Traditional filter-based** particle mass estimation **+** inductively coupled **plasma mass spectrometry**	• Scanning electron microscopy (**SEM**) • Energy Dispersive Spectrometer (**EDS**)

RISK ASSESSMENT OF EXPOSURE TO NANOMATERIALS DURING METAL AM

	STUDY #1	STUDY #2
RESULTS	• Nanosized particles are generated during metal AM; • Operators are exposed mainly while handling powder; • Particle sizes tended to be smaller in recycled powder.	• Nanosized particles are generated during metal AM; • Presence of nanosized particles in samples with recycled powder.
RECOMMEN-DATIONS	• Improve powder handling systems; • Measurement techniques for nanosized particles; • Work environment regulations; • Personal protective equipment; • Regular metal analyses of urine.	• Powder handling in a confined space; • Personal protective equipment; • Good ventilation with HEPA filters; • Include information in the safety data sheet for powder intended to be used in metal 3D printing; • Training for workers.



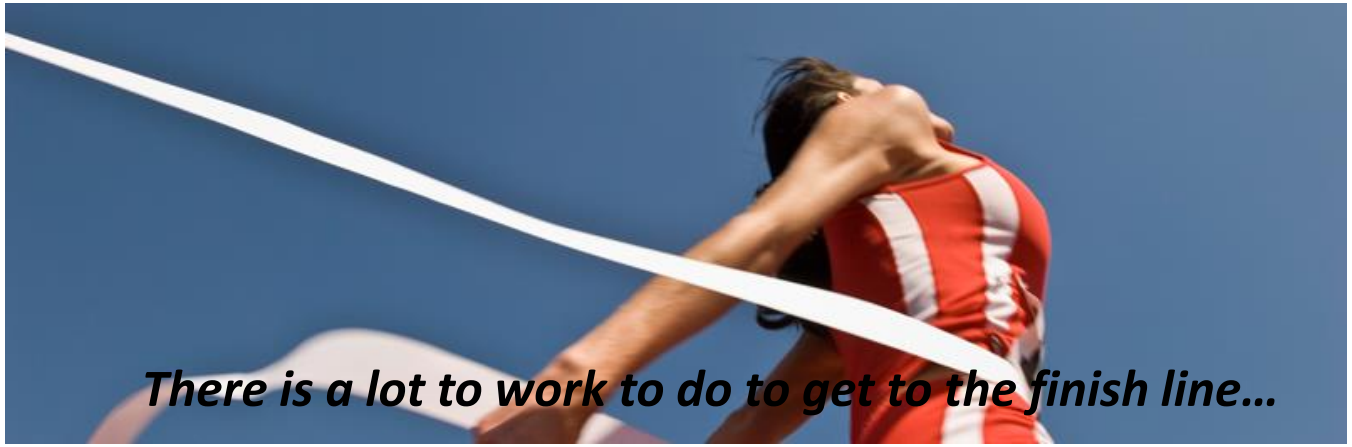
CONCLUSIONS

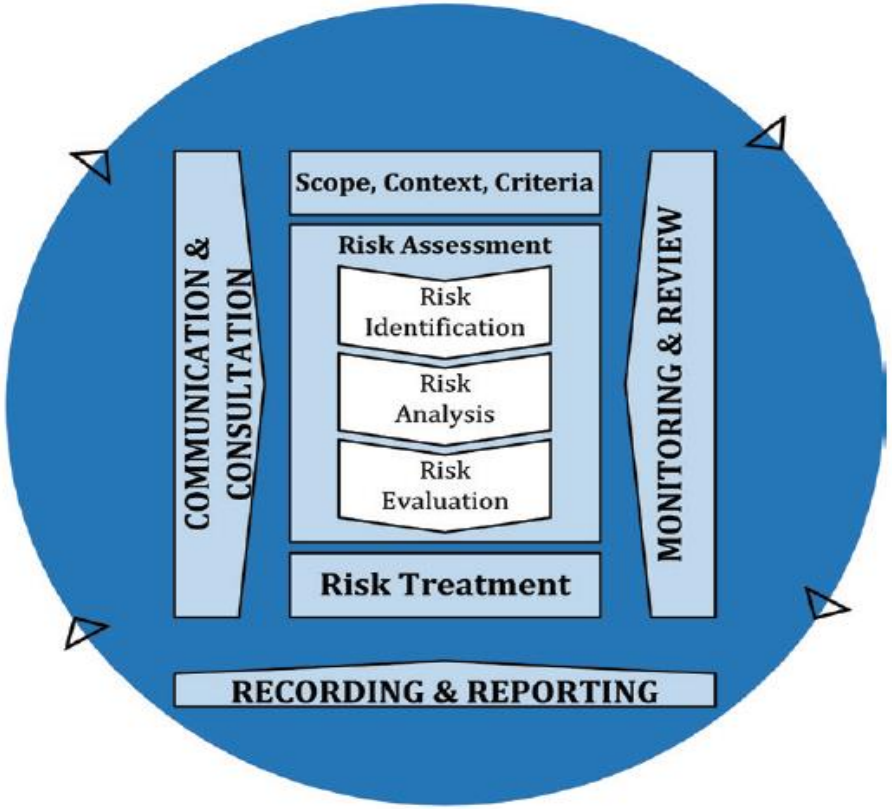
- Studies prove that **there is occupational exposure to nanomaterials** during metal additive manufacturing;
- **Not many studies are available** in this field, although AM is a promising and emergent technology;
- **Opportunity:**
  - Explore and improve occupational risk management in metal AM;
  - Collect new relevant data to the scientific community;
  - Provide a contribution to the protection of workers that are working with this recent technology in the metalworking field.

NEXT STEPS

GOAL

Development of a risk management framework regarding the occupational risk of exposure to nanomaterials emitted during metal additive manufacturing processes.





Source: EN ISO 31000:2018 – Risk Management

NEXT STEPS

- **Data collection (case study):** raw materials, products generated, all tasks performed, ... ;
- **Qualitative approach** (Control Banding & Systematic Design Analysis Approach*);
- **Quantitative approach** (CPC; SEM; …);
- **Definition of control actions** to be implemented based on results;
- **Design of a risk management framework** for occupational risk of exposure to nanomaterials emitted during metal AM.

* Silva, Francisco, Arezes, Pedro, & Swuste, Paul (2015

Thank you for your attention!

Marta Sousa
marta.sousa@catim.pt