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Exposure to process-generated nanoparticles during thermal spraying

A. Salmatonidis, C. Ribalta, S. Bezantakos, G. Biskos, V. Sanfelix, E. Monfort and M. Viana

Introduction

FRAMEWORK: CERASAFE

- **CERASAFE** is a European project which addresses the issue of **"Safe production and use of nanomaterials in the ceramic industry.** It proposes an integrated approach to occupational and environmental health and safety in this specific industrial sector :
  - Characterize **NP release scenarios** in this sector and **assess exposure** by addressing the **release mechanisms**, toxicity, **NP characterization**, as well as propose **mitigation** measures.
  - Establish a set of Good Manufacturing and Use Practices for nanoceramic materials, including risk assessment and recommendations.

PRESENTATION OUTLINE

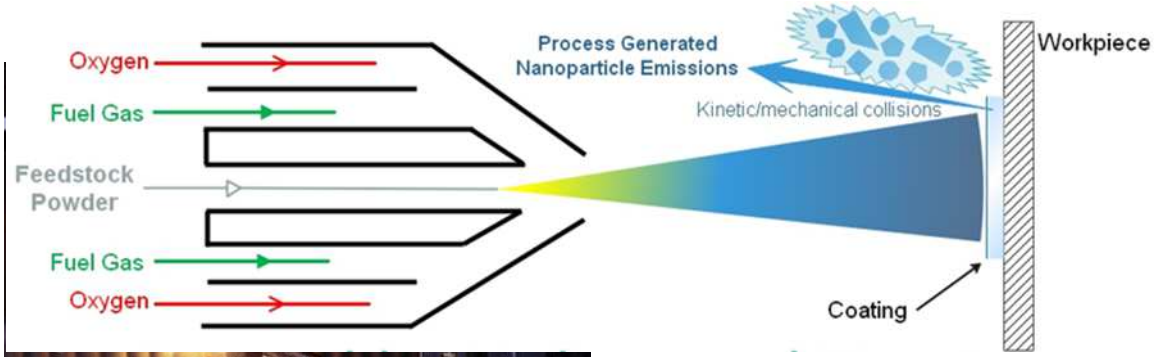
- Process-generated nanoparticles (**PGNP**) are unintentionally produced and released from different processes applied in the ceramic sector – e .g., traditional (pottery[1]), conventional (kiln firing[2]) and **novel methods** (laser sintering[3]).
- The workers in diverse fields of the ceramic industry can potentially be **exposed** to PGNP.
- We address the occupational exposure to **PGNP emissions** during thermal spraying processes:
  - Atmospheric Plasma Spraying (**APS**)
  - High Velocity Oxy-Fuel spraying (**HVOF**)

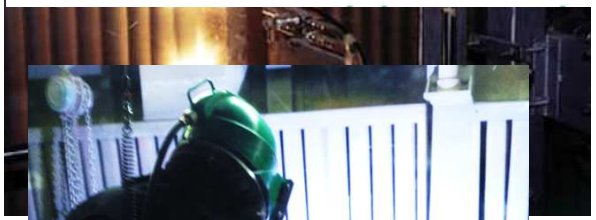
[1] *Voliotis et al., 2014, Environ. Sci.: Process Impacts, 16,* 1489-1494 [2] *Monfort et al., 2008, CFI, 85, 12* [3] *Fonseca et al., 2016, STOTEN,* 565, 922-932

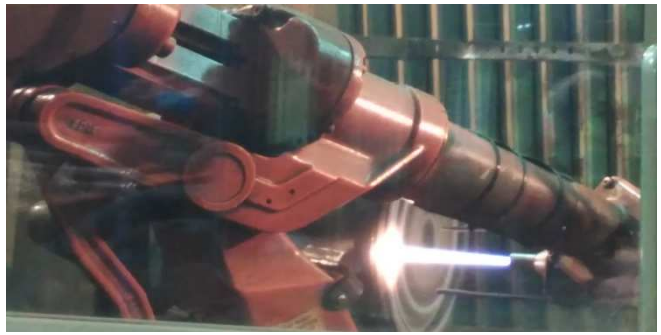
Thermal Spraying Techniques

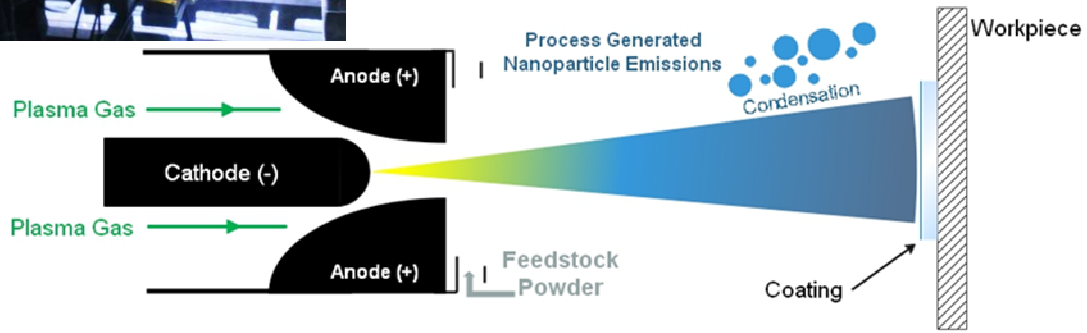
- Application of high-performance coatings (e.g. wear and corrosion resistant, thermal barriers)
- Micron-scaled powder feedstock material spayed on the substrate
- **A**tmospheric **P**lasma **S**praying (APS) : 5-20×10^3 ˚C, 200-500 m/s
- **H**igh **V**elocity **O**xygen-**F**uel spraying (HVOF) : 2.9×10^3 ˚C, 425-1500 m/s
- High energy process → High potential for NP formation and release[1]
- APS impacted exposure in a pilot-plant scale[2]

[1]A.S. Fonseca et al., 2015, JAEROSCI, 88, 48–57;
[2]M. Viana et al., 2017, STOTEN, 599–600, 2065–2073



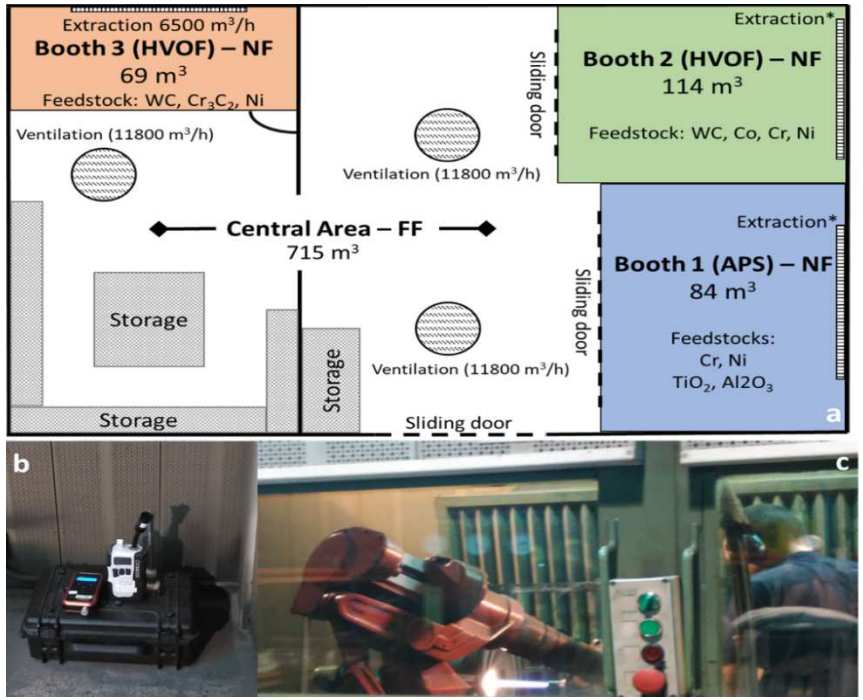






Motivation and Methods

- **Aim**: assess **nanoparticle emissions** during thermal spraying and their impact on inhalation **exposure**, under actual operating conditions in a real-world industrial setting
- A Near Field (**NF**) / Far Field (**FF**) approach was applied
- **NF:** inside the spraying booth – emission source
- **FF**: at the worker area, with inlets 0.7-1.5 m above ground



Koivisto et al., 2015, Environ. Sci. Process Impacts, 17, 62–73

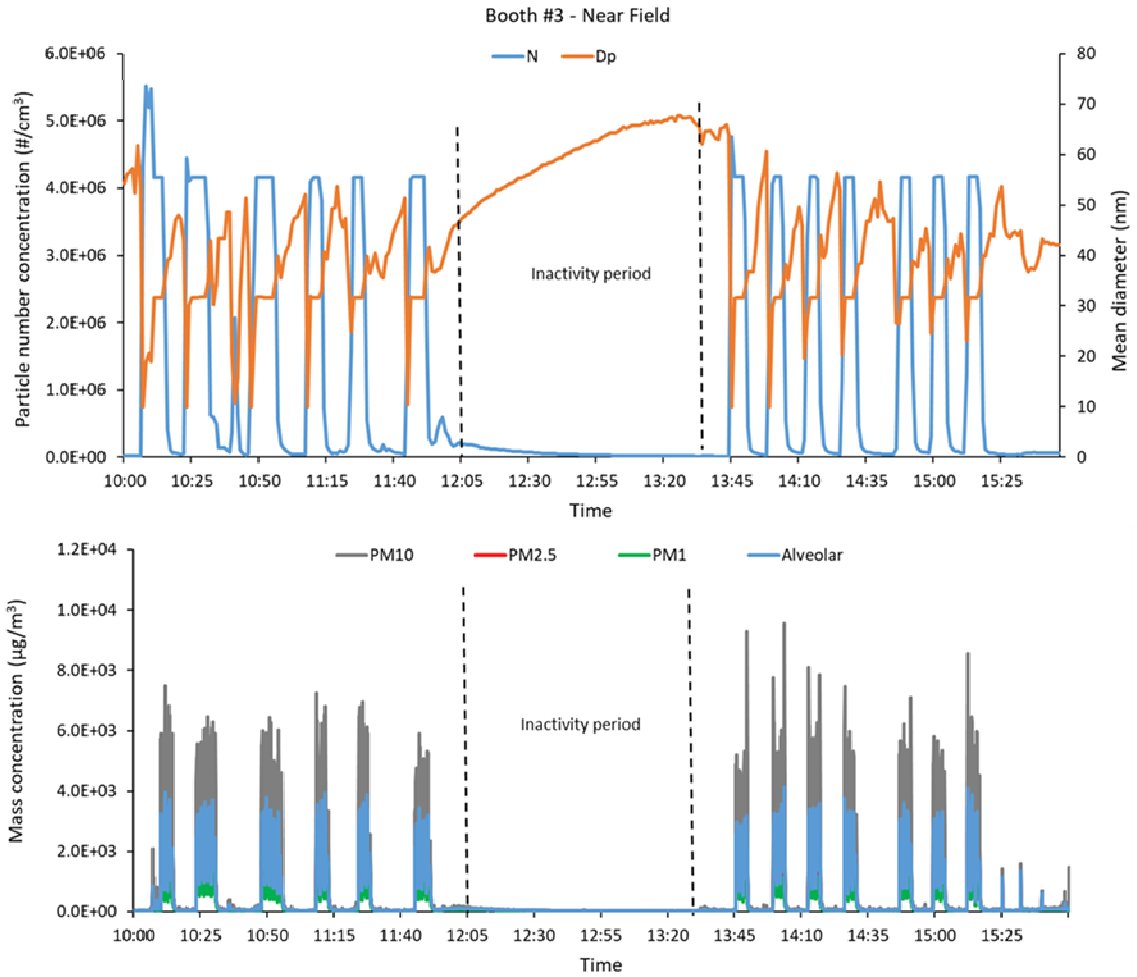
Near Field

- DiSCmini (TESTO AG): particle number (N), mean particle diameter (Dp) and lung deposited surface area (LDSA), 10-700 nm;
- Mini-LAS 11-R (GRIMM): total and size-segregated particle mass concentrations, 0.25-32 µm
- TEM/EDX: samples collected on microscopy grids

Far Field

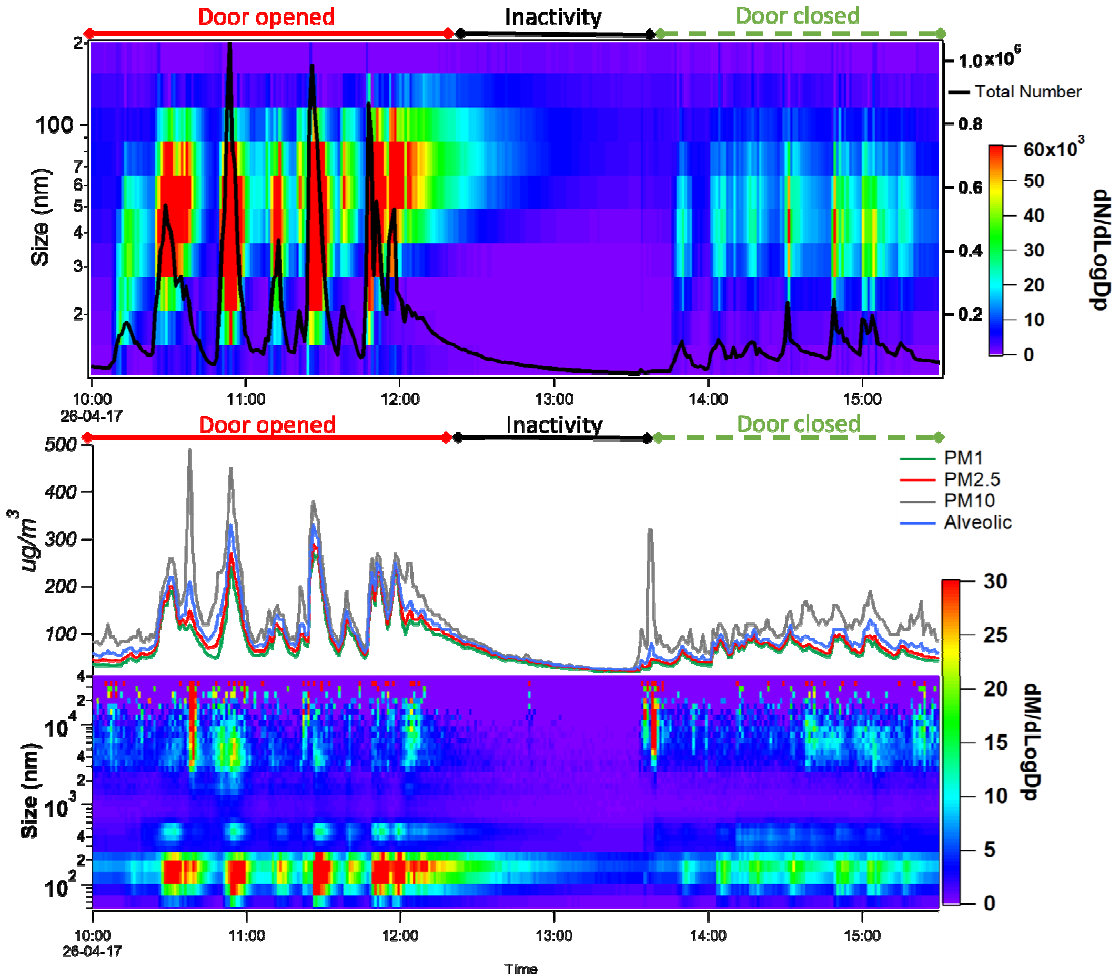
- Nanoscan-SMPS (TSI model 3910): particle mobility size distributions, 10-420 nm
- Mini-WRAS (GRIMM):size and mass distribution, 10 nm-35 µm
- DiSCmini

HVOF-Booth #3- Near Field



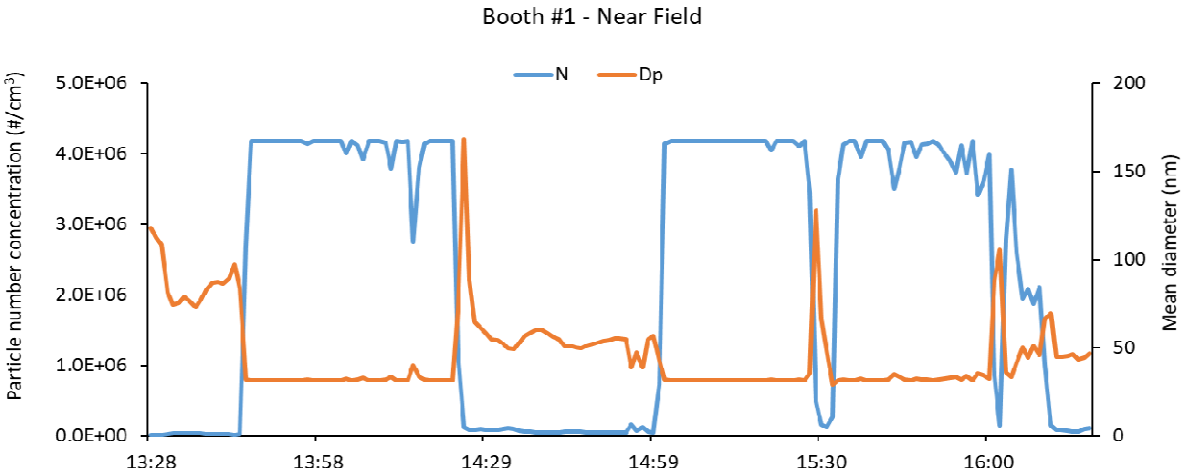
- Spraying duration: 7-9 min
- # of repetitions/session: 6-7
- PPE: FFP3 respirator
- Door: opened

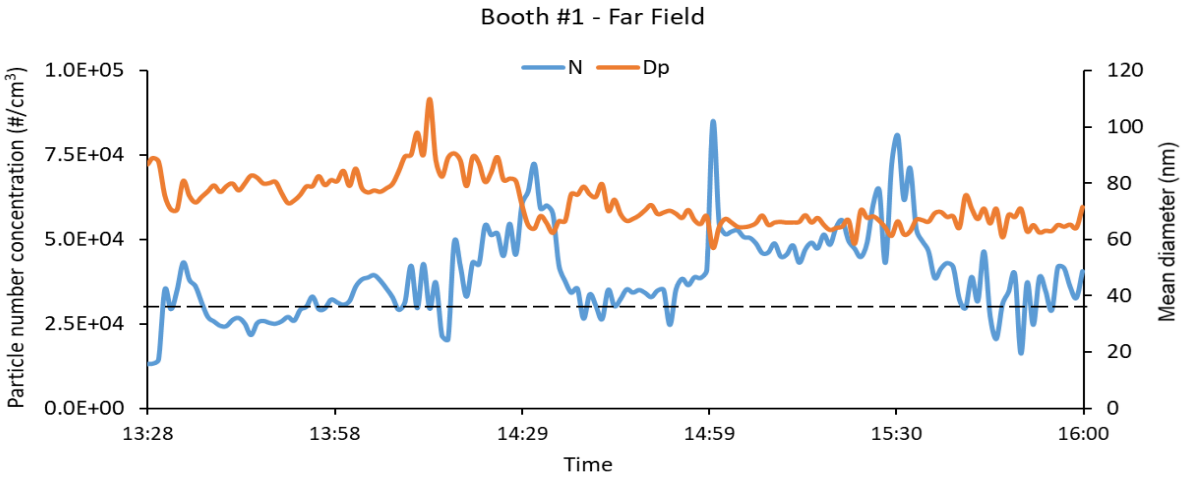
HVOF-Booth #3- Far Field

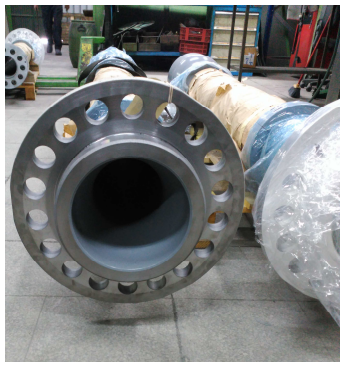


Door	N (cm^{-3})	D_p (nm)	PM_1 ($\mu g/m^3$)
Opened	3.6×10^5	33.2	1.0×10^2
Closed	1.1×10^5	36.6	6.3×10^1
Inactivity	3.0×10^4	57.5	2.9×10^1

APS – Booth #1- NF *vs* FF

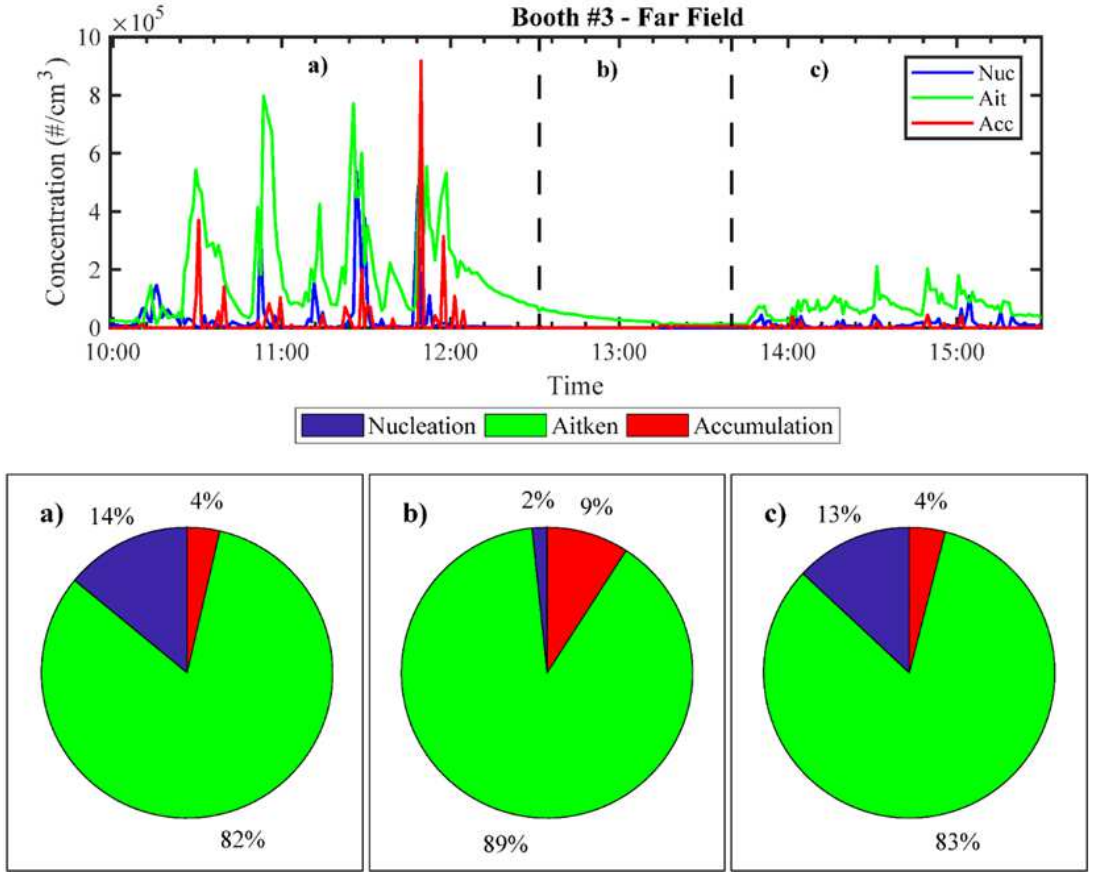






- Spraying duration: 30-40 min
- # of repetitions/session: 3
- PPE: Pressurized helmet and FFP3 respirator
- Door: Closed

Modal Analysis-Far Field



- Modal analysis assumes that particle number concentrations are log-normally distributed across the size space, and that their distribution can be analysed as three lognormal modes
  - Nucleation mode: 10 - 25 nm
  - Aitken mode: 26 - 90 nm
  - Accumulation mode: 91 - 660 nm
- Particle number concentrations for particles in each of the modes
- Relative contribution of each mode for each time interval
- Aitken was the dominant mode (82.5%)
- Increased contribution from nucleation mode during thermal spraying periods (13.5%)

Hussein et al., (2005); BORENV;10; 337–355

Conclusions

- Inside the thermal spraying booths (NF): **high** particle **number** (>10^6/cm^3) and **mass** (up to 600 µgPM_1/m^3) **concentrations**
- In the worker area (FF): 10^4-10^5/cm^3 and 44-87 µgPM_1/m^3
- Correlation between particle number concentrations in the **NF** and **FF** suggest that worker **exposure** was strongly impacted by process generated nanoparticles

- The proper sealing of the spraying booths was a key element for **exposure reduction**, in spite of the continuously working local extraction systems
- **Reduction in exposure** in terms of number concentrations
  - by a **factor of 3.3** due to closed doors for Booth #3 (HVOF)
  - **one order of magnitude** due to better overall booth sealing Booth #1 (APS)

- Aitken mode particles (26 - 90 nm) were dominating the PGNPs emissions, to witch worker are exposed

- Optimising the production routine could limit nanoparticle transport and consequently **minimise impacts on exposure** in adjacent worker areas

Salmatonidis et al., (2018); ANNWEH; article in press; DOI: 10.1093/annweh/wxy094

Acknowledgments

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www.tmcomas.com

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Safe Implementation of Innovative Nanoscience and Nanotechnology

Thank you for your attention!

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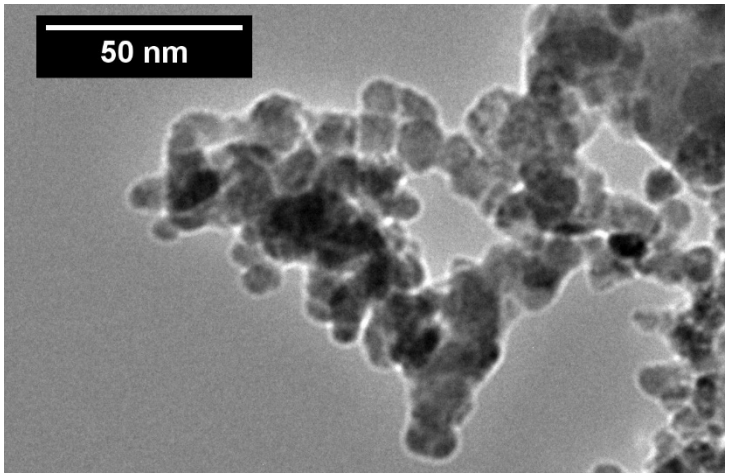
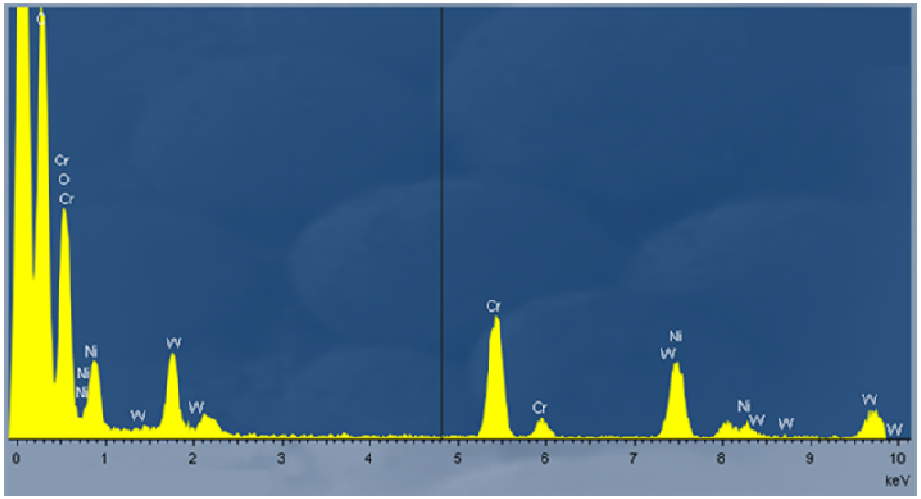
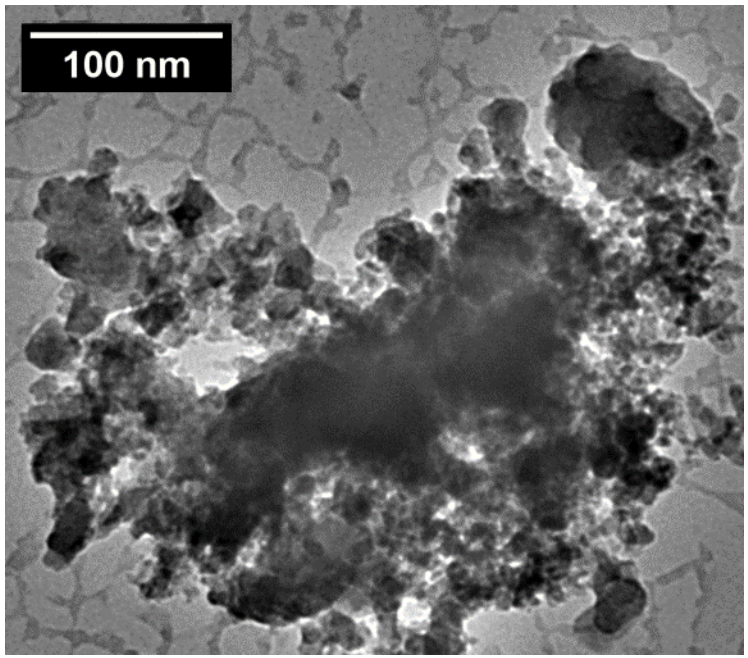
TEM/EDX



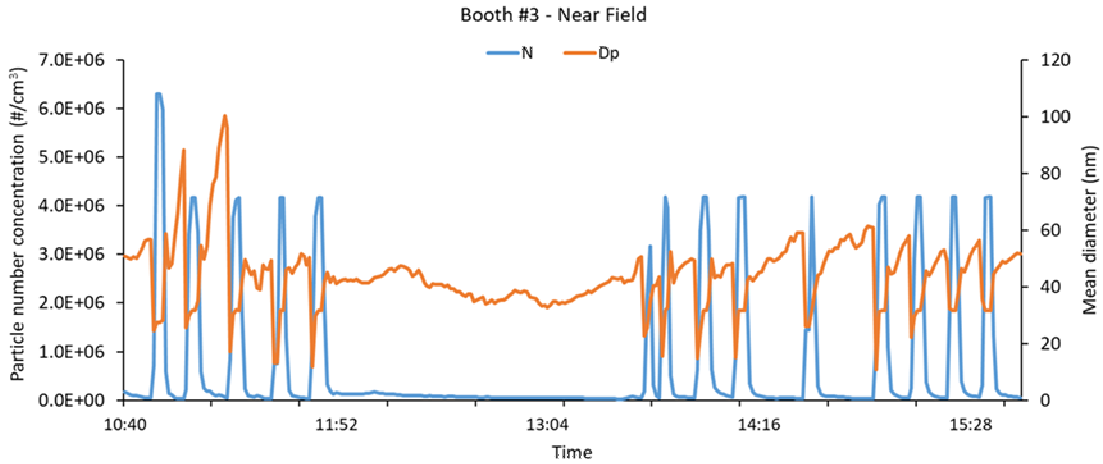


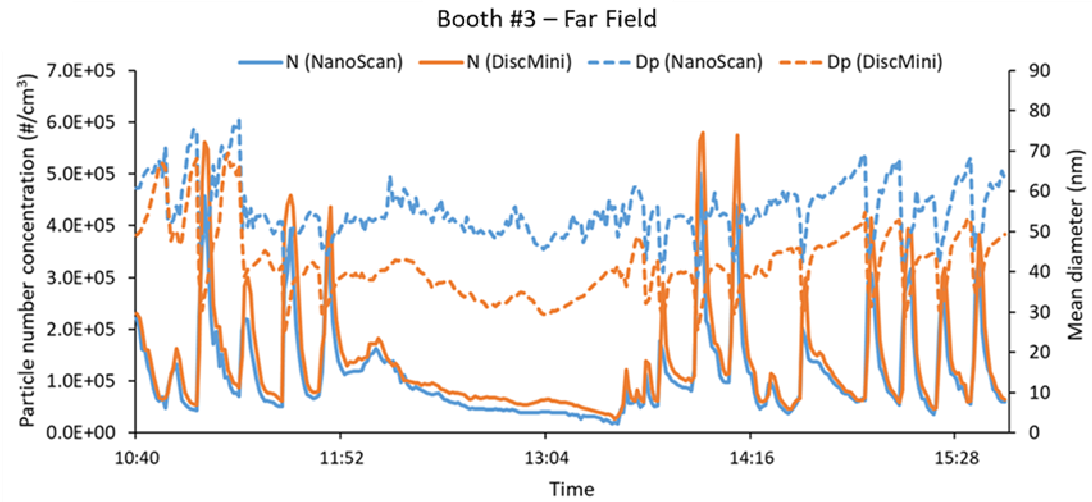


Feedstock

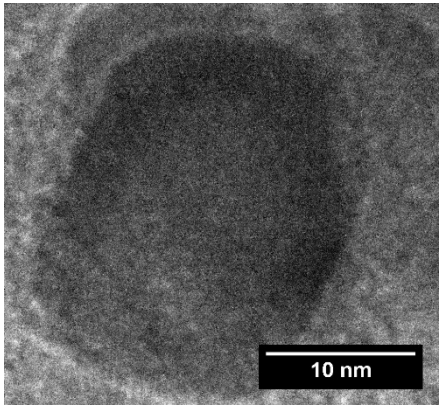
Booth	Composition (Blend)	Aggregate Size (µm)
#3	WC, Cr_3C_2, Ni	34.3

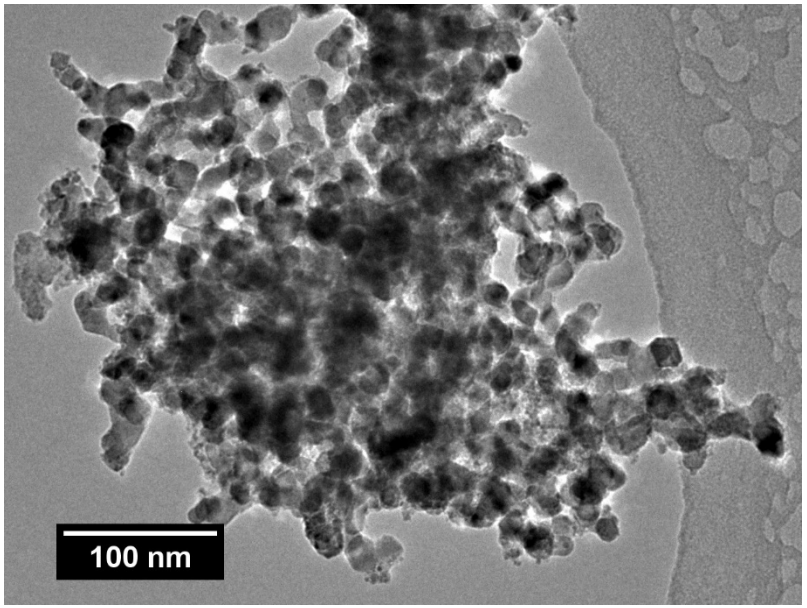
HVOF – Booth #3 – NF *vs* FF

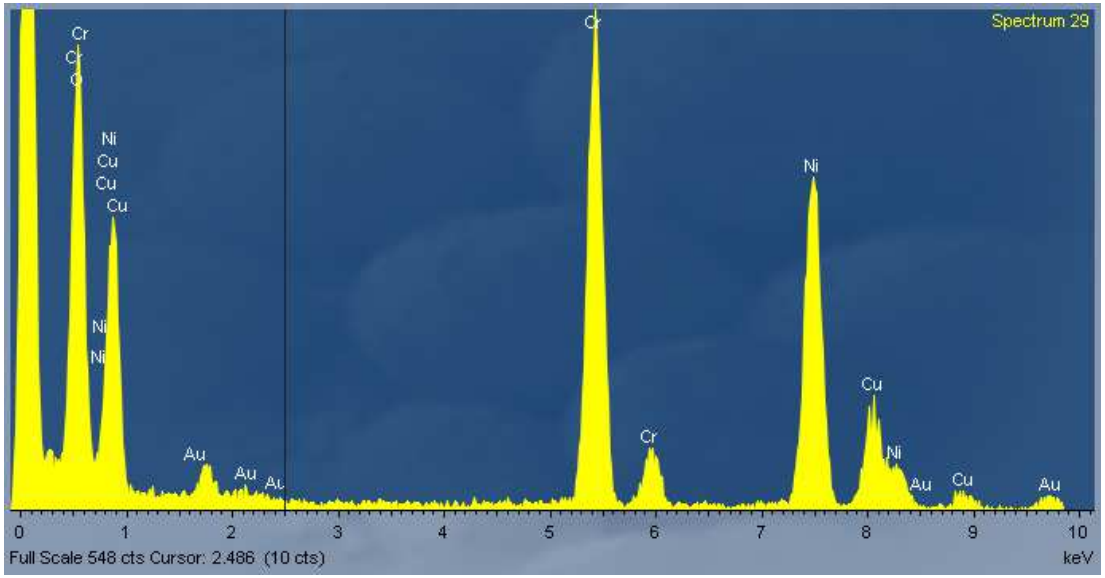




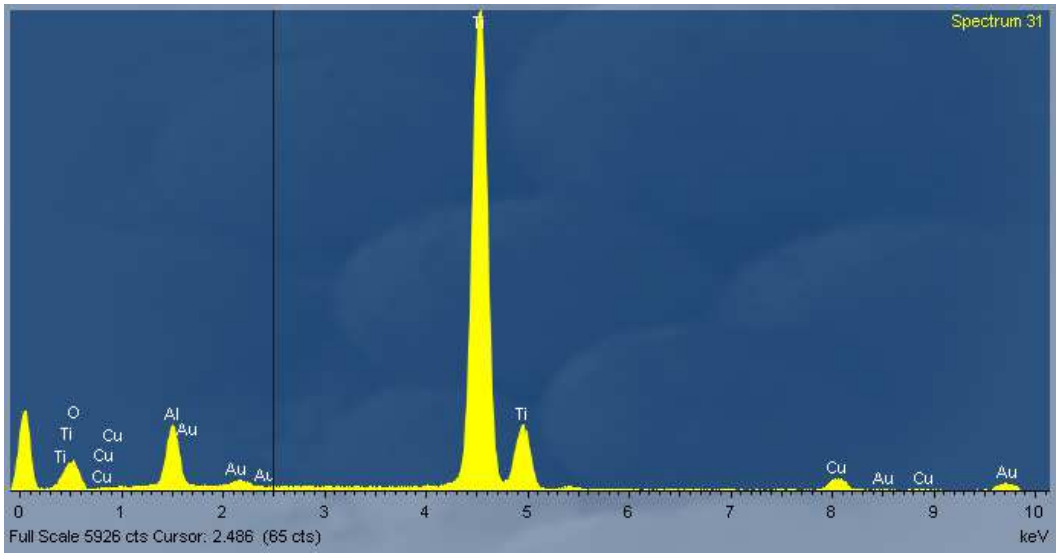
APS – TEM/EDX

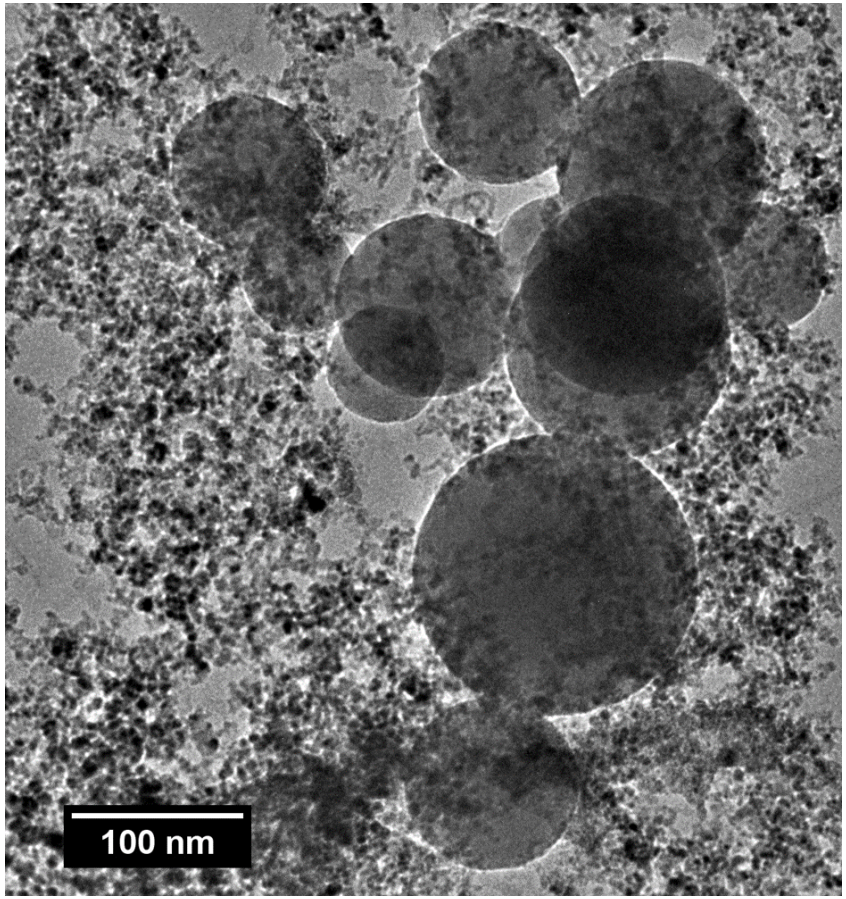

10 nm


100 nm


Spectrum 29
Cr
Cr
O
Ni
Cu
Cu
Cu
Ni
Ni
Au
Au
Au
Cr
Cr
Ni
Cu
Ni
Au
Cu
Au
0
1
2
3
4
5
6
7
8
9
10
Full Scale 548 cts Cursor: 2.486 (10 cts)
keV

APS – TEM/EDX


Spectrum 31
O
Ti
Ti
Cu
Cu
Cu
Al
Au
Au
Au
Ti
Ti
Cu
Au
Cu
Au
0
1
2
3
4
5
6
7
8
9
10
Full Scale 5926 cts Cursor: 2.486 (65 cts)
keV


100 nm