LIFE NANO HEALTH

DELIVERABLE A.1.1.: LIFE-NANOHEALTH BACKGROUND

Activity	Summary of literature review regarding INP (Incidental Nanoparticle) emissions
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INTRODUCTION

This document constitutes the deliverable D.A.1.1: “LIFE-NANOHEALTH background: scientific publication/report summarising the results from the A1.1. review”. This report describes an update of the most relevant information about industrial processes and NP legislation with regard to process-generated nanoparticle (PGNPs) emissions, including updates sampling and characterization. The initial steps of the review identified a shift in terminology, with the term “incidental nanoparticles” (INPs) being used frequently instead of PGNPs. As a result, both terms were included in the review.

RESULTS

Scientific publications dealing with each of the topics in Table 1 were identified. The design characteristics and key findings of each of the publications were then summarized and included in Tables 1 and 2 below.

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1. INDUSTRIAL PROCESSES

Even though thermal spraying processes have been employed for decades in the ceramic and metallurgical industrial sectors, further information about incidental nanoparticles (INPs) is required to evaluate the health risk of the workers. While all of the studies identified through the literature review confirmed that thermal spray coating processes generate incidental nanoparticles, the majority of them also concluded that there is a lack of information in this field. The global demand of ceramic products is in continuous growth due to the constant increase of the construction industry. In 2018 the global ceramics market had an estimated value of around $229.13 billion. Worldwide, ceramic tile production was approximately 13,500 million square meters, with China leading the market with over 45.7% of the world's total. In China alone, the annual production of ceramic tiles has exceeded 10 billion m2. The other key players are South America and the European Union (EU), producing 11% and 9%, respectively (Dylan D.Furszyfer Del Rio et al, 2022). To the authors' knowledge, no new information about incidental particle emissions during tile firing has been found. At present, the key interest of major international ceramics producers is found in the decarbonisation on this industry. The trend on the main producer countries is to legislate and encourage decarbonisation. Once this issue is accomplished, worker protection from incidental particle emissions has the potential to become the next priority for this industrial sector.

Table 1. Design characteristics and key findings of each of the publications regarding industrial processes.

YEAR	RELATED PROCESS	SUMMARY	REFERENCE
2022	Thermal Spraying	Design and development of an automated thermal spray coating generator and inhalation exposure system.	https://doi.org/10.1016/j.toxrep.2022.01.004
2022	Thermal Spraying	Investigation of four influencing factors of high-temperature particles. The transport characteristics and exposure risk of high-temperature fine particles generated in a transiently welding process with four influencing factors (i.e. 10 μm ≤ dp ≤ 20 μm, 293 K ≤ T0 ≤ 423 K, 0.2 m/s ≤ v0 ≤ 0.4 m/s, and 0.1 s ≤ t0 ≤ 0.2 s) were examined by numerical simulations.	https://doi.org/10.1016/j.ijheatmasstransfer.2021.121471
2021	Thermal Spraying	State of the art of particle emissions in thermal spraying and other high energy processes based on metal powders. They conclude that nanoparticles emission is crucial for processes based on metal powders and high energy such as thermal spraying, powder atomization and additive manufacturing. During processes, particles are in a liquid/vapor state in the thermal source. Generated nanoparticles are incidental. As a result, companies and operators must be aware of the risk and release into the environment. The different surveys on thermal spray activity demonstrate the lack of information and communication between the industry and scientific community.	https://doi.org/10.1016/j.jclepro.2021.126952
2021	Thermal Spraying	Review of the physicochemical properties and associated health effects of aerosols generated during thermal spray coating processes. Documented information about the health effects related to exposure during thermal spray coating is lacking, although workers in the industry may be exposed to a variety of potentially toxic metals.	https://doi.org/10.1177/0748233720977975

2022	Tile Firing	Identification of the NPs under real-world-operation circumstances in an artisanal ceramic production area. Description of the chemical and morphology of NPs. In general, inorganic particles larger than 100 nm did not contain toxic elements. The <100-nm particles contained elements such as Ti as a constituent of rutile and anatase (both detected in this study) to some Fe hydr/oxides contained minor portions of Cr and Se. The results of this study demonstrate a wide variety of particles both in terms of size, morphology, and composition.	https://doi.org/10.1016/j.gsf.2021.101151
2022	Tile Firing	Investigation of the decarbonization of the ceramics industry. They conclude that ceramics can be highly damaging to social and natural systems during their lifecycle. For instance, in the EU, the manufacture of ceramics emits around 19 Mt CO_2, bricks manufacturing is responsible for 2.7% of carbon emissions annually, and in Asia alone, it is estimated that the brick sector consumes more than 110 million tonnes of coal per year.	https://doi.org/10.1016/j.rser.2022.112081

2. INP SAMPLING AND CHARACTERISATION

Research on incidental nanoparticles is a growing field. According to Clarivate Analytics the publications on the topic “incidental nanoparticles” has increased by a factor of 5 since 2013 (Figure 1). Despite this, studies on incidental nanoparticles in actual workplaces are still considered to be scarce.

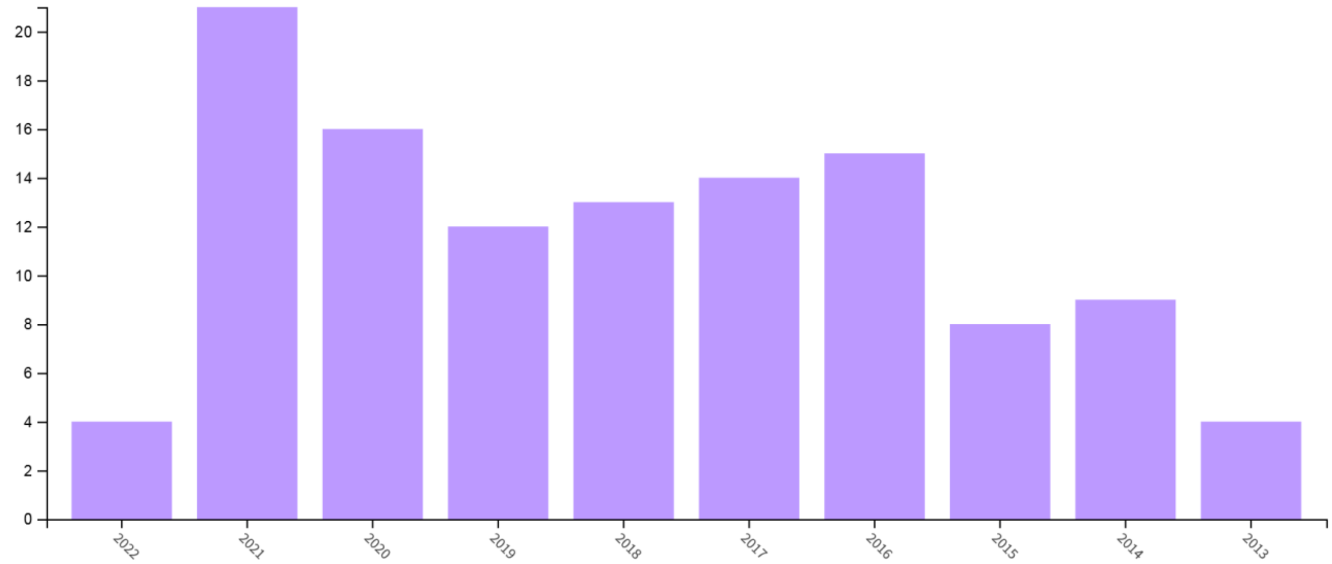

Figure 1. Number of publications per year dealing with “incidental nanoparticles” or “process-generated nanoparticles”.
Source: Clarivate Analytics, February 2022.

Table 2 reports on different studies which sampled and characterised nanoparticles in workplaces, as well as, new publications on nanoparticle characterisation technologies.

Table 2. Design characteristics and key findings of the publications regarding NP sampling and characterisation.

YEAR	SUMMARY	REFERENCE
2022	TD-GC/MS analysis of indoor air pollutants (VOCs, PM) in hair salons.	https://doi.org/10.1016/j.chemosphere.2022.133691
2022	Particle release from refit operations in shipyards: Exposure, toxicity and environmental implications	https://doi.org/10.1016/j.scitotenv.2021.150216
2022	Development of a thermal spray coating aerosol generator and inhalation exposure system	https://doi.org/10.1016/j.toxrep.2022.01.004
2022	Systematic control technologies for gaseous pollutants from non-ferrous metallurgy	https://doi.org/10.1016/j.jes.2022.01.035
2021	Analytical method using SEM-EDS for metal elements present in particulate matter generated from stainless steel flux-cored arc welding process.	https://doi.org/10.1016/j.jhazmat.2021.127412
2021	Occupational exposure to nanoparticles originating from welding – case studies from the Czech Republic	https://doi.org/10.13075/mp.5893.01058
2021	Characterization of Ultrafine Particles and VOCs Emitted from a 3D Printer	https://doi.org/10.3390/ijerph18030929
2021	Numerical investigation on transport characteristics of high-temperature fine particles generated in a transiently welding process	https://doi.org/10.1016/j.ijheatmasstransfer.2021.121471
2021	State of the art of particle emissions in thermal spraying and other high energy processes based on metal powders	https://doi.org/10.1016/j.jclepro.2021.126952
2021	A review of suitable analytical technology for physio-chemical characterisation of nanomaterials in the customs laboratory.	https://doi.org/10.1016/j.talo.2021.100069

Relatively few measurements of thermal spray incidental particles have been carried out: Afshari et al. (2022) developed a thermal spray coating aerosol generator and inhalation exposure system and Kato et al. (2021) characterized individual welding fumes (WFs) and welding slags (WSs) formed during CO_2 arc welding processes in order to evaluate the risk assessment. No new research has been found about incidental particles in tile firing process, based on the authors' research. Concerns of incidental nanoparticles in workplaces are focused on welding and metallurgy (see, e.g., Liu et al., 2022, Berger et al., 2021, Zhuang et al., 2021). Additional research on incidental nanoparticles in workplaces was also found. Kaikiti et al. (2022) monitored emissions of VOCs (volatile organic compounds) as well as of PM1, PM2.5, PM4 and PM10 in five different hair salons, Bernatikova et al. (2021) characterized ultrafine particles and VOCs emitted from a 3D printer, and López et al. (2022) monitored and sampled INPs in the Mallorca harbour (Spain) under real-world operating conditions during abrasion of coatings in the shipyard and in a workshop.

The most reported physical characteristics of nanoparticles in workplaces are particle mass concentration (μm/m^3), (see, e.g., Kaikiti et al., 2022, López et al., 2022, Afshari et al., 2022, Berger et al., 2021) particle number concentration (N particles/cm^3), (see, e.g. López et al., 2022, Kato et al., 2021, Berger et al., 2021, Bernatikova et al., 2021) and particle size distribution (PSD) (see, e.g., Afshari et al., 2022, Liu et al., 2022, Kato et al., 2021, Berger et al., 2021, Bernatikova et al., 2021).

The most frequently used techniques for the chemical characterisation of nanoparticles are ICP-MS, ICP-AES and ICP-OES (see, e.g., López et al., 2022, Afshari et al., 2022 Kato et al., 2021), while for morphology they are TEM (see, e.g., López et al., 2022) and SEM (see, e.g., Afshari et al., 2022, Kato et al., 2021, and Liu et al., 2022) These techniques were also recently reported by McCarron et al. (2021) as suitable analytical techniques for physico-chemical characterisation of nanomaterials.

3. LEGISLATION

No changes were identified in terms of legislation about particulate matter (coarse, fine or ultrafine) exposure in workplaces since 2021. In Spain, the current legislation is found in the document "Límites de exposición professional para agentes químicos en España, 2019" (https://www.insst.es/documents/94886/188493/L%C3%ADmites+de+exposici%C3%B3n+profesional+para+agentes+qu%C3%ADmicos+2019/7b0b9079-d6b5-4a66-9fac-5ebf4e4d83d1), published by the national institute for occupational health and safety (INSST).

4. COVID-19 WORK PROTOCOLS

Covid-19 work protocols are not supposed to affect the projects implementation since in work places where the use of PPE (Personal Protection Equipment) is implemented, protocols are not changed.

5. ANNEX

TD-GC/MS analysis of indoor air pollutants (VOCs, PM) in hair salons.
Kaikiti, C., Stylianou, M., & Agapiou, A. (2022).
Chemosphere, 294(January), 133691.
https://doi.org/10.1016/j.chemosphere.2022.133691

Kaikiti et al. (2022) monitored the emitted VOCs (volatile organic compounds) as well as the PM of 1, 2.5, 4 and 10 μm aerodynamic diameter. The sampling was carried out in 5 different saloons with similar conditions. Particulate matter was measured using a laser photometric instrument (DustTrack 11, Aerosol Monitor 8532) segregating particulate matter in 4 different aerodynamic diameters (PM1, PM2.5, PM4 and PM10). The sampler was placed in hairdressers breathing zones in parallel with the collection of the VOCs. Camp blank samples were performed at different places from the sampling rooms, without the impact of outdoor pollution. Finally, they are able to express the percentage contribution (%) of PM per specific activity and conclude that involuntary daily exposure to contaminated products for the employers.

Particle release from refit operations in shipyards: Exposure, toxicity and environmental implications.
López, M., López Lilao, A., Ribalta, C., Martínez, Y., Piña, N., Ballesteros, A., Fito, C., Koehler, K., Newton, A., Monfort, E., & Viana, M. (2022).
***Science of the Total Environment*, *804*.**
https://doi.org/10.1016/j.scitotenv.2021.150216

López et al. (2022) monitored and sampled in the Mallorca harbour (Spain) under real-world operating conditions during abrasion of coatings in the shipyard and in a workshop. Two monitoring locations were set up in each scenario in order to account for background concentrations in parallel with emissions from the activities: far field (FF) and near-field (NF) and background concentrations were also monitored during the midday lunch break, when activities were fully stopped. The characteristics monitored were:

- Particle number concentration:

  DiSCmini (TESTO AG)
  Mini-LAS 11-R (Grimm)

- Particle mass concentration:

  Mini-LAS 11-R (Grimm) between 0.25 and 32μm
  Mini-WRAS (Grimm) 10nm to 35 μm
  DustTrak TM DRX (TSI Model 8533) 3200 nm

- Mean particle diameter:

  DiSCmini (TESTO AG) between 10 and 700 nm

- PSD:

  NanoScan SMPS (TSI Model 3910) from10 to 420nm

Two different types of ultrafine particles were observed during mechanical abrasion of surface coatings: (1) regular (triangular, hexagonal) engineered nanoparticles (Ti-, Zr-, Fe-based) which were originally embedded as nanoadditives in the coatings, and (2) irregular, incidental particles emitted directly or formed during the abrasion activity Therefore, in order to ensure effective worker's protection in complex real-world scenarios, it is advisable that risk management protocols take a holistic view, with comprehensive protection protocols covering not only activity periods in the NF but also shutdowns and FF locations.

Development of a thermal spray coating aerosol generator and inhalation exposure system.

Afshari, A. A., McKinney, W., Cumpston, J. L., Leonard, H. D., Cumpston, J. B., Meighan, T. G., Jackson, M., Friend, S., Kodali, V., Lee, E. G., & Antonini, J. M. (2022).

***Toxicology Reports*, *9* (January), 126–135.**

https://doi.org/10.1016/j.toxrep.2022.01.004

Afshari et al. (2022) designed and constructed an automated, computer-controlled thermal spray coating particle generator and inhalation system to perform animal studies to mimic workplace exposures. The electric arc wire-thermal spray coating aerosol generation and exposure system is separated into two areas, the electric arc wire-thermal spray coating was performed in one room (A) and the aerosols transferred to an animal exposure chamber in a separate room (B) divided by shaded glass doors (Fig. 2).

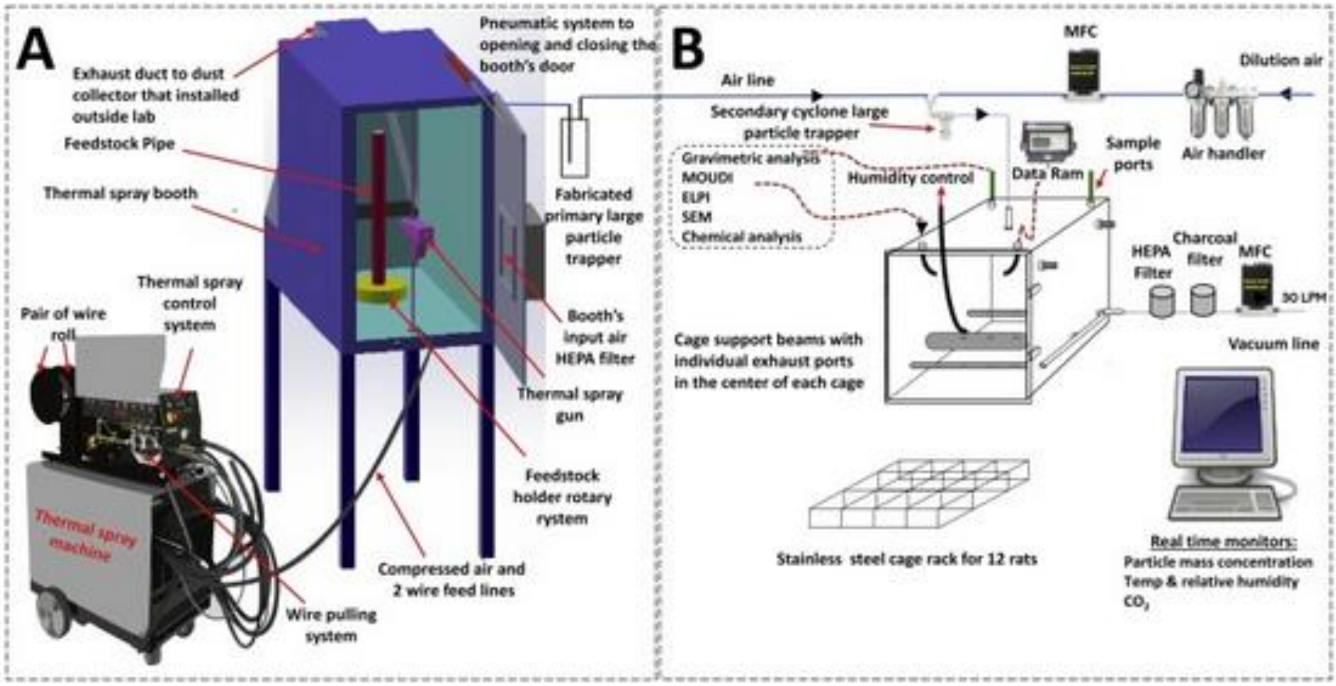

Figure. 2. Schematic diagram of the electric arc wire-thermal spray coating aerosol generator and exposure system. Abbreviations: Data Ram = real-time aerosol monitor; MOUDI = Micro Orifice Uniform Deposit Impactor; ELPI = electric low-pressure impactor; SEM = scanning electron microscopy; TEM = transmission electron microscopy; Temp = temperature; MFC = mass flow controller.

The mass concentration in the chamber was monitored by a real-time aerosol monitor (DataRAM, MIE, Inc. Bedford, MA). The sensors and measurement devices were managed and controlled through a custom computer software programed written in LabVIEW (National Instruments Corporation, Austin, TX). The size distribution of the different thermal spray coating aerosols inside the exposure chamber were determined by two methods. The first method assessed particle size distribution by mass and used a Micro-Orifice Uniform Deposit Impactor (MOUDI; MSP Model

110, MSP Corporation, Shoreview, MN). Particles were collected between the size ranges of 0.056–18 µm that were separated into 11 stages where each stage was loaded with a 47-mm aluminum foil filter except for the filter stage. The mass median aerodynamic diameter (MMAD) and geometric standard deviation (GSD) of the aerosols were determined from gravimetric measurements. The second method assessed particle size distribution by number and used an electrical low-pressure impactor (Dekati ELPI; Particle Instruments, Vadnais Heights, MN) that measured airborne particle size distribution in real time in the size range of 6 nm - 10 µm at 10 Hz sampling rate. The count median aerodynamic diameter (CMAD) and particle surface area were determined by ELPI.

To assess particle morphology, the aerosolized particles from thermal spray coating were collected using 47-mm cassettes loaded with polycarbonate filters (0.2 µm pore size; Whatman, Clinton, PA). The filters loaded with particles were mounted onto aluminum stubs using double-stick carbon tape and viewed using a Hitachi S4800 field emission scanning electron microscope (SEM; Hitachi High-Tech America, Boston, MA). Elemental profiles of collected thermal spray coating particles were determined by energy dispersive X-ray spectroscopy analysis (EDX; Bruker Madison, WI) at 20 kV to map specific metal components of the particle samples.

They conclude that the metal composition of the generated particles during electric arc wire-thermal spray coating was completely derived from the wire that was consumed during the process and that stainless-steel thermal spray coating aerosols may pose a risk to the respiratory health of exposed workers arguing that the lung responses are comparable to the respiratory effects observed in the study of other metal particles that have similar physical and chemical characteristics in terms of size and metal composition to thermal spray coating aerosols.

Systematic control technologies for gaseous pollutants from non-ferrous metallurgy.

Liu, H., Shen, F., Li, Q., Wen, M., Zhang, H., Jiang, L., Zheng, C., Liu, Y., Liu, T., & Chai, L. (2022).

***Journal of Environmental Sciences*, 1–19.**

https://doi.org/10.1016/j.jes.2022.01.035

Liu et al. (2022) developed high-efficiency and low-cost purification technologies for typical gaseous pollutants from non-ferrous smelting. The generation and transformation mechanisms of pollutants were studied and control technologies for particles generated during the whole smelting process were designed. Finally, collaborative control technologies for different pollutants were developed for aluminum electrolysis. (Fig. 3)

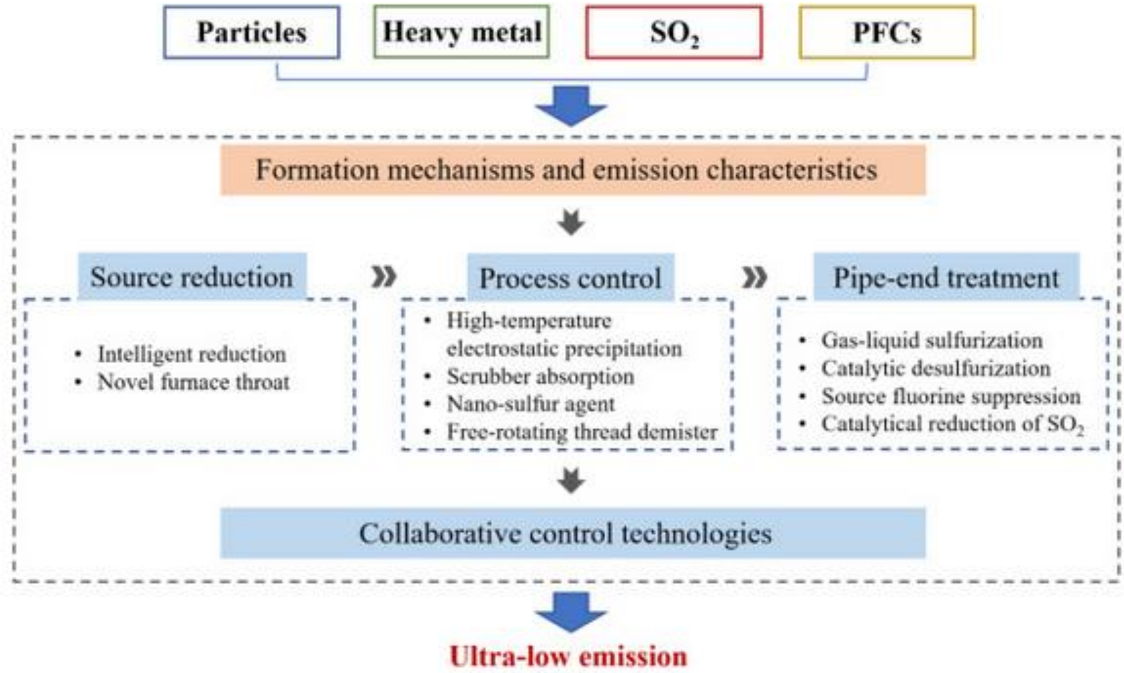

Figure 3. Design of purification technologies for air pollutants from non-ferrous smelting.

They investigated the formation mechanisms and emission characteristics of typical air pollutants derived from smelting processes, including heavy metal particles (Cu, Pb, Zn and Al), mercury, sulfur oxides and fluoride. A fine particle control technology was developed for heavy metal smelting, namely "source dust control, high temperature electro-filtration coupled with dust removal and turbulence-enhanced dust capture", which realized emission levels far superior to current particle emission limits. The coupled SO_2/nano-sulfur technology is able to effectively capture gaseous Hg° from flue gas, which significantly improves the mercury pollution control capability of non-ferrous industries. Source abatement and terminal treatment technologies for fluorine-sulfur pollutants achieved ultra-low emission levels of sulfur dioxide and fluoride from aluminum electrolysis.

Analytical method using SEM-EDS for metal elements present in particulate matter generated from stainless steel flux-cored arc welding process.
Kato, N., Yamada, M., Ojima, J., & Takaya, M. (2022).
***Journal of Hazardous Materials*, *424*(PB), 127412.**
https://doi.org/10.1016/j.jhazmat.2021.127412

Kato et al. (2022) analyzed metal elements present in particulate matter generated from stainless steel flux-cored arc welding process since welding fumes (WFs) can cause occupational pneumonoconiosis and other diseases in workers. They characterized individual WFs and welding slags (WSs) forming during CO_2 arc welding processes for knowledge acquisition of risk assessment.

WFs generated through semiautomatic CO2 gas arc welding were supplied automatically through a welding wire using a welding machineSampling was performed using a Sioutas Cascade Impactor (225–370; SKC hereinafter referred to as the Sioutas sampler, USA) and an IOM sampler (225–70 A; SKC, USA) The filters were also used for WF sampling for metal analysis by ICP-AES. The three WF samples were collected on Isopore filters using Sioutas and IOM samplers. WFs were generated for 20 s for SEM observation.

Their conclusions were:

- Some micron-sized SPs grew by incorporating primary particles composed of hazardous metal species such as Ni.
- Fluxing agents formed elemental distribution patterns on the surface.
- Each of the elements in stainless metals (Cr and Fe) was distributed on a divided surface.
- The BSE results obtained for the agglomerate showed that Bi were dotted in the WF agglomerate after the primary particles of Bi coagulated. For WS, it was revealed that the Mn amount in WS depends on the amount of Mn estimated to be present in the WFs.

Occupational exposure to nanoparticles originating from welding – case studies from the Czech Republic. Berger, F., Bernatíková, Š., Kocůrková, L., Přichystalová, R., & Schreiberová, L. (2021). *Medycyna Pracy*, *72*(3), 219–230.
https://doi.org/10.13075/mp.5893.01058

Berger et al. (2021) studied the occupational exposure to nanoparticles originating from welding in 3 companies engaged in the manufacture and machining of metal structures, fabricated metal products, machinery and equipment or motor vehicle components. Measurements were taken in 3 companies engaged in the manufacture and machining of metal structures, fabricated metal products, machinery and equipment or motor vehicle components located in the Czech Republic. The measurements consisted of determining the particle number concentration of particles in the size range of 20–1000 nm/cm^3 of air, and the particle number size distribution of particles in the size range of 10–10 000 nm/cm^3 of air. In order to archive it they used the instruments listed on table 3.

Table 3. Specification of measuring instruments.

Measuring instrument	Measured value and output	Aerosol concentration range	Particle size range
P-TRAK 8525 (TSI)	particle number concentration	1–10^5 particles/cm^3	0.02–1 µm
DustTrak DRX 8534 (TSI)	particle mass concentration – PM_1, $PM_{2.5}$, PM_4, PM_{10} and total fraction	0.001–150 mg/m^3	0.1–15 µm
NanoScan SMPS 3910 (TSI)	particle number concentration, particle size distribution, 13 size channels	1–10^6 particles/cm^3	10–350 nm
OPS 3330 (TSI)	particle number concentration and particle size distribution, 16 size channels	1–3000 particles/cm^3	0.3–10 µm
Defender 510M Flow Meter & Calibrator (Mesa Labs)	flow rate	50–5000 ml/min	
Hygro-/Thermo-/Barometer	temperature, atmospheric pressure and relative humidity	temperature: –25.0–70.0°C relative humidity: 0.0–100.0%	
Anemometer GREISINGER TA 88 N (GREISINGER)	air velocity	0.1–15 m/s spread: 0.01 m/s	

The average particle number concentrations of particles in the size range of 20–1000 nm were between 83×10^3–179×10^3 #/cm^3 which exceeded 4-8 times the recommended preliminary OEL (occupational exposure limits) for iron and iron oxides nanoparticles what leads them to recommend exposure risk controls, workplace ventilation and personal respiratory protective equipment, such respirators with FFP2 or FFP3 particle filters.

Characterization of ultrafine particles and VOCs emitted from a 3D printer.
Bernatikova, S., Dudacek, A., Prichystalova, R., Klecka, V., & Kocurkova, L. (2021).
***International Journal of Environmental Research and Public Health*, *18*(3), 1–15.**
https://doi.org/10.3390/ijerph18030929

Bernatikova et al. (2021) evaluated UFPs and VOCs emissions when printing on a commercially available 3D printer with PETG which is used in a variety of signage, packaging, industrial, and medical applications, for example, medical braces, bottles, and electronics, and NGEN the printer was placed in an enclosed glass box measuring 0.70 × 0.59 × 0.70 m with an internal volume of 0.29 m3, without forced air exchange, in order to determine the maximum values of emissions released into the environment during printing and a particle concentration monitor was placed next to the 3D printer, as can be seen in figure 4.

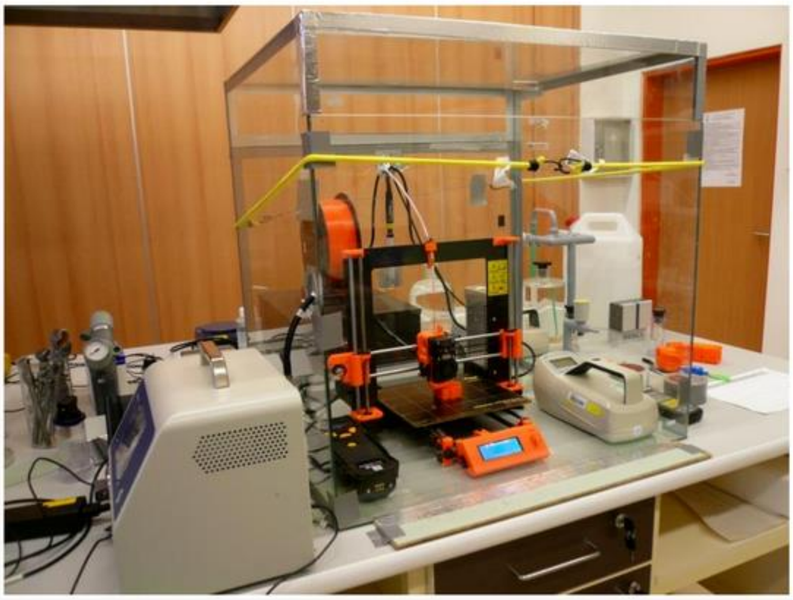

Figure 4. Glass box with printer and measuring instruments.

Before printing, the background value was measured for 15 min, then, the printer was turned on and warm-up was set. The nozzle and the base plate heating temperatures, t, were 245/75 °C and 230/85 °C, when using PETG filament and NGEN filament, respectively, as recommended by the manufacturer. Once the heating phase was completed, printing was started, and the glass box shut. Particle number measurements were performed at 1 s intervals using a condensation particle counter (CPC model 3007, TSI Inc., USA). The CPC 3007 measures the total particle number concentration with a size of 10–1000 nm and has a concentration range of 105 particles per cm^3. During printing, particle size distribution was also measured using a scanning mobility particle sizer spectrometer (SMPS model 3910, TSI Inc., USA). The SMPS can sort and count particles measuring in the size range 10–420 nm into 13 size channels.

Particle emission rates (PER) and total particle emissions (TP) were calculated based on the UL2904, the Standard Method for Testing and Assessing Particle and Chemical Emissions from 3D Printers. Particle concentrations (Cp) were calculated and particle number concentrations reported by the CPC ($D_p > 7$ nm) were averaged over nominally 1 min to smooth the data.

During printing, VOC emissions using both filaments were very low; the total VOC concentrations in the test chamber were in the order of hundreds of ppb after one hour of printing The UFP sampling was performed with a CPC 3007 instrument for particle sizes in the range of 10–1000 nm. UFP concentrations, increasing UFP concentrations to ~146,000 cm^{-3} could be a value many times higher than that usually observed in indoor air in office and laboratory environments. Although the measurements showed that VOCs were present in the indoor air, the concentration was low for short-term exposure. Nevertheless, caution should be taken in the case of exposure to carcinogens such as no threshold substances.

Numerical investigation on transport characteristics of high-temperature fine particles generated in a transiently welding process.

Zhuang, J., Diao, Y., & Shen, H. (2021). *International Journal of Heat and Mass Transfer*, *176*, 121471.
https://doi.org/10.1016/j.ijheatmasstransfer.2021.121471

Zhuang et al., (2021) investigated four influencing factors on the transport of high temperature particles: particle diameter (dp), release temperature (T_0), release velocity (v_0), and operation time (t_0).

Table 4. Influencing factors on the transport of high temperature particles.

Parameters (Units)	Low level	Middle level	High level	Environment temperature
Particle diameter, d_p (μm)	10	15	20	293K
Release temperature, T_0 (K)	323	373	423	
Release velocity, v_0 (m/s)	0.2	0.3	0.4	
Operation time, t_0 (s)	0.1	0.15	0.2	

To study transport characteristics of high-temperature fine particles generated in the welding process, a large enough modeling space with a dimension of 50 m × 30 m × 30 m (length × width × height) was adopted. A total of 24 measuring points were arranged above the nozzle. Among them, 12 measuring points taken every 0.1 m along the Z axis were used to monitor the temperature and velocity variation of the flow field. Meanwhile, the remaining 12 test points on the X and Y axes were only adopted to measure velocity, and they were placed symmetrically about the Z axis.

The unsteady solution method was used to simulate the movement of two-phase flow. A two-phase Eulerian-Lagrangian method was employed to simulate airflow and particle motion. The dynamic mechanics of two-phase flow motion was well revealed through Newton's second law and conservation of energy. Dynamic variations of particle temperature and the maximum horizontal diffusion distance of particles (ΔRmax) were quantitatively estimated for four different factors.

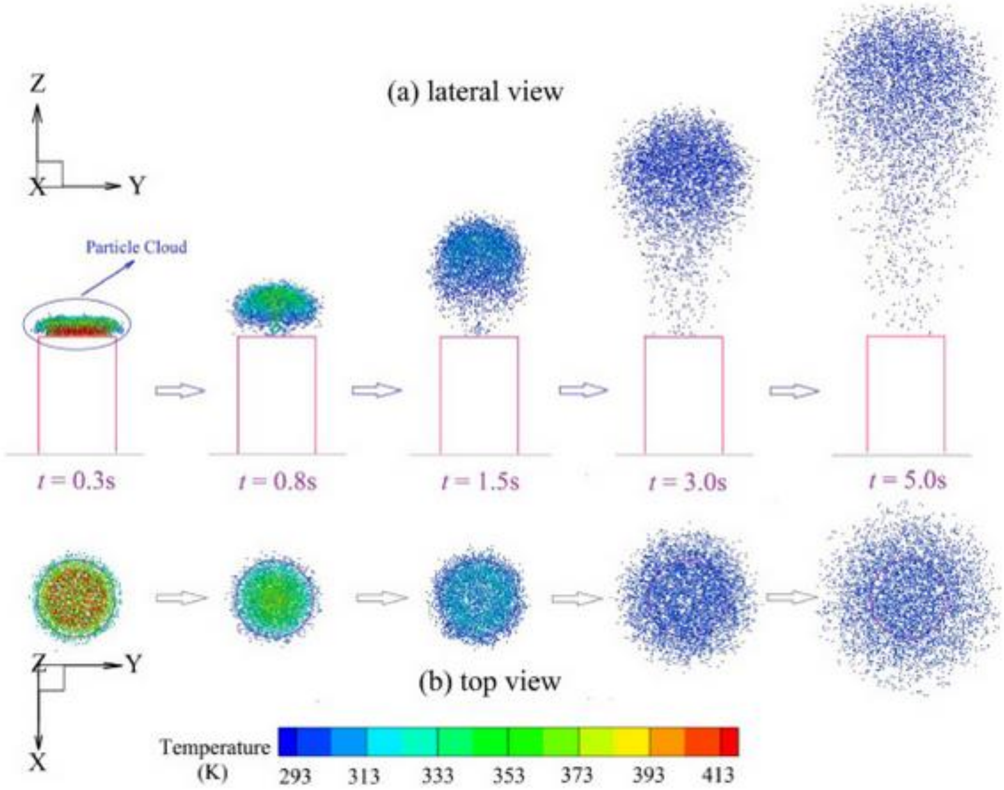

Figure 5. Particle distribution into indoor environment.

Figure 5 illustrate that high-temperature particles with the same particle size will show different temperature distributions after released into the indoor environment, although they have the same initial temperature and velocity. In the beginning, the temperature of aerosol particles decreases rapidly and eventually reaches the ambient temperature at t = 5.0 s, because of the large amount of heat exchange between particles and the surrounding environment. Compared with the particles away from the axis, particles in the core region might decay more slowly and keep a higher temperature. This phenomenon can be explained that, particles are sucked up by surrounding air during the rising process, and this effect is significantly related to the distance from the core.

State of the art of particle emissions in thermal spraying and other high energy processes based on metal powders.

Darut, G., Dieu, S., Schnuriger, B., Vignes, A., Morgeneyer, M., Lezzier, F., Devestel, F., Vion, A., Berguery, C., Roquette, J., & Le Bihan, O. (2021). ***Journal of Cleaner Production*****,** ***303*****, 126952.**
https://doi.org/10.1016/j.jclepro.2021.126952

Darut et al. (2021) updated the knowledge on thermal spraying and to a lesser degree on powder atomization and additive manufacturing technology. They conclude that nanoparticles emission is crucial for processes based on metal powders and high energy such as thermal spraying, powder atomization and additive manufacturing. During processes, particles are in a liquid/vapor state in the thermal source. Generated nanoparticles are incidental. As a result, companies and operators must be aware of the risk and release into the environment. The different surveys on thermal spray activity demonstrate the lack of information and communication between the industry and scientific community.

This review presents a brief overview of the potential suitability of some of the more commonly recommended analytical technologies of relevance for the physio-chemical characterisation of nanomaterials, for regulatory authorities, or indeed for use by EU customs laboratories. They perform a table including nanomaterial property, instrumentation and performance criteria.

Table 5. Overview of the more commonly recommended analytical technologies of relevance for the physio-chemical characterization of nanoparticles.

Priority property	Instrument Technology	Nanoparticle (NP) Property	Typical Materials	Sample Preparation	Detection Limit/Range	Type of Technique
Composition	AAS	Mass concentration, elemental composition.	Metals/Metal Oxides	Suspended in a liquid, as a solution or dispersion.	ppm-ppb	Destructive
	ICP OES	Elemental composition,mass concentration.	Metals/Metal Oxides	Suspended in a liquid as a solution or dispersion.	ppm - ppb	Destructive
	ICP-MS	Elemental composition,mass concentration.	Metals/Metal Oxides	Suspended in a liquid as a solution or dispersion.	ppm – ppt	Destructive
	UV–VIS	Elemental composition,size, shape,mass concentration, agglomeration state, and refractive index.	Metals, coloured compounds (dyes or pigments). Organic compounds or biological materials.	Suspended in a liquid as a solution or dispersion.	ppm-ppb	Destructive
	XRF	Elemental composition,mass concentration.	Solids	Minimal sample preparation (e.g. grinding, pellet formation, or 'as received')	ppm-ppb	Non-destructive
	EDX	Mass concentration, elemental composition. Identification of precipitates in alloys, elemental segregation at grain boundaries, and quantitative result. Composition of multi-component phases.	Metals/Metal Oxides	Solids	0.1ppm- 1 ppm	Non-destructive
Particle Size and Size DistributionParticle size and Size Distribution	Electron MicroscopySEM/ TEM	Elemental composition,mass concentration.Topography: surface features. Morphology: shape and size of the particles. Crystallinity, arrangement of atoms.	Particles deposited onto substrates or embedded in an electron-transparent medium.	Sample must be prepared on substrates or as thin films, etc.	SEM:7 nm - 1000 µmTEM:1 nm –1000 µm	Destructive
	XRD	(Refer to Crystallinity Priority Property)				
	DLS	Intensity of scattered light.	Inorganic, carbon based. Organic, particulate and non-particulate biological samples.	Suspended particles	1 nm –10µm	Non destructive
Crystallinity	XRD	Crystal/crystallite size, shape, crystal form and phase.	Liquid materials, powders, solids, and thin films.	Suspended as a homogenous material in a suitable sample holder.	2–100nm	Non destructive
	STEM	Chemical composition, structural and morphological information.	Particles deposited on substrates or particles embedded in an electron-transparent medium.	Sample must be prepared on substrates or as thin films, etc.	10 nm –100 µm	Destructive
	Raman	Chemical composition, physical and structural properties. Identification of surface interactions at molecular level.	Organic and inorganic samples; can be solid, liquid, gas, solution or emulsion.	Minimal sample prep. Can often be used on samples 'as received').	Sample and/or application dependant.	Non destructive

	AFM	Particle height above the level of a substrate provides info. on particle number, particle size, size distribution and structural information at molecular level.	Organic, inorganic, carbon based biological, core/shell materials and mixtures of different shapes and coatings.	Immobilized particles on a substrate i.e. solids or liquids.	1 nm >1 μm	Destructive
	spICP-MS	Particle number concentration, mass concentration. Calculated from mass, provides information on individual particles, particle number, size distribution, primary particles in non-aggregated and non-agglomerated samples.	Metals/Metal Oxides	Suspended particles	Different depending on the element analysed e. g.Au approx. 15–1000 nmAg approx. 20–1000 nmTiO_2 approx. 50–1000nm	Destructive
	UV–Vis	(Refer to Composition Priority Property)				
Particle Shape	TEM	(Refer to Particle size and Size Distribution Priority Property)				
	AFM	(Refer to Particle size and Size Distribution Priority Property)				
Surface area&Specific Surface Area (SSA)	BET	Specific surface area of a material.Inorganic, carbon based, organic particulate and non-particulate and composite samples.	Inorganic, carbon based, organic, particulate and non-particulate and composite samples.	The BET method is used to determine the amount of gas 'adsorbed' as a single or multi molecular layer, on a dry powder or solid material.	Sample dependant and/or experimental conditions dependant.	Non destructive