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Field Study

Research and development—where people are exposed to nanomaterials

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Abstract: Research and development—where people are exposed to nanomaterials: Chantal IMHOF, *et al*. Institute for Work and Health, Universities of Lausanne and Geneva, Switzerland—Objectives: Many nanomaterials (materials with structures smaller than 100 nm) have chemical, physical and bioactive characteristics of interest for novel applications. Considerable research efforts have been launched in this field. This study aimed to study exposure scenarios commonly encountered in research settings. **Methods:** We studied one of the leading Swiss universities and first identified all research units dealing with nanomaterials. After a preliminary evaluation of quantities and process types used, a detailed analysis was conducted in units where more than a few micrograms were used per week. **Results:** In the investigated laboratories, background levels were usually low and in the range of a few thousand particles per cubic centimeter. Powder applications resulted in concentrations of 10,000 to 100,000 particles/cm^3 when measured inside fume hoods, but there were no or mostly minimal increases in the breathing zone of researchers. Mostly low exposures were observed for activities involving liquid applications. However, centrifugation and lyophilization of nanoparticle-containing solutions resulted in high particle number levels (up to 300,000 particles/cm^3) in work spaces where researchers did not always wear respiratory protection. No significant increases were found for processes involving nanoparticles bound to surfaces, nor were they found in laboratories that were visualizing properties and structure of small amounts of nanomaterials. **Conclusions:** Research activities in modern laboratories equipped with control techniques were associated with minimal releases of nanomaterials into the working space. However, the focus should not only be on processes involving nanopowders but should also be on processes involving nanoparticle-containing liquids, especially if the work involves physical agitation, aerosolization or drying of the liquids.
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Clark—wrote the manuscript on the basis of Imhof's master's thesis, which included analyzing the original data and developing several conclusions that are presented in this manuscript. Meyer—helped organize the field campaign, supported the data interpretation, and contributed to the manuscript writing. Schmid—assisted in preparatory phase of experimental work, including training on devices and data analysis, and planning and execution of the pilot test of the experimental plan, and contributed to the manuscript review. Riediker—conceived of the study, supervised the field campaign, evaluated and interpreted data, and contributed to the manuscript writing.

Technological advances allow the targeted production of objects and materials with structures at the nanoscale, which is the size range between 1 and 100 nm[1)]. Materials at this scale often display chemical and physical properties that are distinct from their counterparts on a larger scale. By controlling the size and chemical constituents of these substances, materials with novel and tunable properties can be created. There is great enthusiasm surrounding the potential for nanotechnology to improve upon existing products or contribute to the development of new products in a

wide range of sectors. Globally, government investment into the research of nanotechnologies was estimated to be over US$10 billion per year in 2011[2], and the number of products on the market claiming to contain nanomaterials is growing rapidly[3].

The properties that lend nanomaterials their unique and desirable applications may also be hazardous for human health. The small size of the particles may translate to penetration to deeper regions of the lungs and increased uptake[4]. Small particles (<2.5 μm), as found in combustion-related air pollution, are associated with adverse cardiovascular and pulmonary health effects[5]. The smallest particles (<100 nm) dominate this fraction of air pollution in terms of number and are thought to be potent in terms of health effects[6]. Despite the concerns regarding the toxicity of nanomaterials, there is very little consensus on the hazard these materials pose to human or environmental health. In recent years, there has been a large increase in the number of studies published on the human health risks of nanomaterials[7], however, the broad range of nanomaterials and their potential uses make it difficult to establish conclusions concerning their risk.

One of the key inputs in a risk assessment is the potential exposure to a substance, yet evaluation of nanomaterial exposure is a particularly challenging endeavor. Nanomaterials have a negligible mass, such that the more commonly used mass-based methods for exposure assessment of other substances are not optimal. Methods based on real-time particle counting are better for detecting the particles; however, the resulting data must be interpreted with caution, as these instruments cannot distinguish between different particle sources (i.e., engineered and ambient particles). Complementary techniques, such as electron microscopy, elemental analysis and surface area measurements are routinely used in nanomaterial exposure assessment; however, these are expensive and are most informative when conducted in conjunction with particle counting methods and/or mass-based methods[8].

The objective of this study was to evaluate different nanoparticle exposure scenarios in academic research settings in Switzerland. The laboratory is the site of research and development of nanomaterial applications, and by extension, the employees who work in the laboratories in which the research is performed are among the first individuals to be exposed to nanomaterials. Research and development activities can be particularly difficult to monitor for exposure. Research units tend to have their own processes, conducted by a relatively small number of people, and these processes continually change in response to previous results and new research needs[9].

In this study, task-based evaluations of particle concentrations and particle emissions were conducted during activities commonly conducted in nanomaterial research settings, such as centrifugation, weighing, lyophilization, and synthesis of engineered nanomaterials. Particle number concentration and size distribution were measured in real time, and activity-based concentrations were compared with background concentrations. The results of the study were informative, indicating which commonly conducted activities may yield greater exposures than others.

Methods

All laboratory evaluations were conducted in 2008 at a Swiss university. The evaluations of the particle concentrations in the research units were conducted in the following four steps:

1) Work process analysis
2) Definition of measurement strategy
3) Measurements
4) Analysis of data

Work process analysis

Within the university, approximately 30 research units were identified that use nanomaterials. Each was visited, and the principal investigators were asked if they would answer a series of questions about their work with nanomaterials. Those who agreed to participate were asked questions from a questionnaire (see annex 1 in the online supplement for example questionnaire provided to research labs) to determine the following:

- Aim of nanomaterial use
- A detailed description of nanomaterial-related processes performed in the laboratory
- Characteristics of the nanomaterials (i.e., chemical composition, size)
- Frequency of use
- Quantities of nanomaterials presently stored on-site
- Safety measures employed by the research unit (e.g., use of PPE, specific handling recommendations)
- Additional questions about other risks (chemical, physical and biological)

The results of the questionnaires were used to select research units for a more detailed exposure analysis. Provided consent was given by the principle investigator, research units having frequent or relatively high volumes of nanomaterial use were further investigated, with a focus on activities that are representative of the range of handling processes present in the unit.

Measurement strategy

Measurements were collected using two P-Traks

(model 8525, TSI, Shoreview, MN, USA) and one Wide Range Aerosol Spectrometer (WRAS) (Grimm, Ainring, Germany). The P-Trak is a portable condensation particle counter that measures total particle number concentration in the range of 20 to 1,000 nm. The WRAS is a two-part system consisting of a Scanning Mobility Particle Sizer (SMPS) and a Portable Aerosol Spectrometer (PAS). When combined, these instruments measure particle number concentration as a function of particle size in the range of 5 to 40,000 nm, thus providing a particle size distribution in addition to total particle number concentration. The WRAS is mobile and battery powered but nevertheless heavy and bulky; to make it more easily moved within the laboratories, it was placed on a rolling cart (Fig. 1).

The purpose of this study was to measure task-based particle exposure and emission during various commonly performed laboratory activities. Appointments were scheduled with participating labs on days when activities of interest were planned. Baseline concentrations were typically measured for at least 15 minutes within a room before an activity or series of activities took place in the room. As far as possible, activities or processes were measured for a minimum of 15 minutes. In many cases, peak concentrations were observed for short time periods and noted.

For each activity characterized, the WRAS and at least one of the P-Traks were located near the worker or where a worker might be standing during the process (e.g., right outside the fume hood for processes in the fume hood or on the table next to the scale during weighing). The second P-Trak did not have a specific function and was placed where it was thought to be most beneficial for the task at hand. During all measurements, detailed observational data were collected on worker activities, the processes being conducted, and worker protection strategies in place.

Fig. 1. Transport system used to make the WRAS (consisting of an SMPS, portable aerosol spectrometer, and laptop computer) more mobile.

The measurements collected were not considered personal samples, as they were not collected in the worker's breathing zone and did not precisely track the worker's movements; however, they are representative of the magnitude of exposure a worker could experience. When appropriate, one of the P-Traks was placed directly next to the nanoparticle emission source for comparison of concentrations at the source to those where the worker may be standing, such as for operations in a fume hood.

Analysis

The measurements from the WRAS were transferred to an accompanying laptop in real time, while the data from the P-Traks were stored on the instrument during measurements and transferred to the laptop at the end of the day. The time stamps on the data from each instrument were corrected to match those in the daily activity log.

The data were plotted as concentration versus time and linked to the observational data to identify activities associated with increases or spikes in particle exposure. Particle concentrations were averaged over time by activity. Depending on the activity and data available, background concentrations were either taken as the baseline concentration measured before the activity started, as the concentration in the same room but far from the process or as the concentration for the same activity conducted without the use of nanomaterials. The WRAS data did not have enough temporal resolution to capture short peaks in concentration (<~3 minutes duration); therefore, particle number size distribution was compared between baseline and activity only when feasible (i.e., for activities of sufficient duration to span several WRAS cycles).

Results

Of the 30 initially identified laboratories involved in some type of activity with nanomaterials, four of the research units were approached for a more detailed analysis. A description of these laboratories and their activities, including room size, number of people typically working in the room where the activity was taking place, the frequency and duration of exposure and the protective measures in place, is provided in Table 1.

Research Unit A

In this research unit, doctoral students synthesize

Table 1. Characteristics of the laboratories selected for detailed particle exposure analysis, including room size, particle characteristics, and frequency and duration of activities of interest

Research unit	Process involving MNMs	Activities of interest	Particle properties[1]	Room vol. (m^3)	No. of people in room[2]	Frequency of activity	Duration of activity	Personal protective measures[3]	Engineering protective measures
A	Manufacture and characterization of CNTs	Lyophilization of catalyst nanoparticles	Fe1-xCox supported by CaCO3 Diameter : <10 nm	126	3	2/wk	8 hr	None	None
		Synthesis of MWCNTs by CVD (incl. cleaning furnace tube)	Diameter: 20 nm Length: several μms Traces of Co or Fe	150	2	1/wk	8 hr	FFP3 mask, woven overall, glasses, gloves[4]	Local exhaust ventilation over furnace
B	Assessment of the properties of BiVO4 nanoparticles	Weighing BiVO4 nanopowders	Diameter: 5–100 nm BET: 20–300 m^2/g	200	4	5/wk	20 min	Woven overall, glasses, gloves[4]	None
C	Synthesis of TiO_2 by hydrolysis of $TiCl_4$	Preparation of TiO_2 colloid by adding $TiCl_4$ drop by drop to H_2O	Anatase TiO_2 Diameter: 10 nm	74	4	1/wk	2.5 hr	Woven overall, glasses, gloves[4]	Process conducted in fume hood
D	Synthesis of inorganic NPs	Formation of NPs by attrition	nr	96	nr[5]	2/wk	3 hr	Nonwoven overall, glasses, gloves, mask	Low pressure rooms
		Centrifugation	nr	60	nr[5]	3/day	5 min	Nonwoven overall, glasses, gloves, mask	None

1 Particles were not coated unless otherwise stated. 2 Number of people typically working in the same room or vicinity of processes, and not necessarily handling nanomaterials themselves. 3 Only personal protective measures that were observed are reported, regardless of written policies. 4 Only worn by workers involved in activities. 5 25 workers in research unit overall, working in 11 laboratories. CNTs - carbon nanotubes; MWCNTs - multi-walled carbon nanotubes; CVD - carbon vapor deposition; NPs - nanoparticles.

carbon nanotubes (CNTs) by catalytic chemical vapor deposition in the "furnace" room (150 m^3). A preliminary step in producing CNTs is the synthesis of catalyst metal nanoparticles in a chemical laboratory (150 m^3). For the synthesis of catalysts, a colloidal suspension is frozen, and then the water is removed from the frozen dispersion by lyophilization.

Nanoparticle concentrations were measured during lyophilization of catalysts and synthesis of CNTs.

1) Lyophilization

Airborne nanoparticle concentrations were measured twice when a frozen dispersion was lyophilized to form a nanopowder, once in the initial phase and again in the final phase. In total, lyophilization can take several hours. No increased particle concentrations were measured during the initial phases of lyophilization; however, towards the end of the process, particle concentrations were significantly higher in the area immediately surrounding the lyophilizer. During this assessment, neither of the two P-Traks had sufficient memory to complete the sampling. Therefore, the data from the WRAS are presented in Fig. 2. Concentrations increased by about 40,000 particles/cm^3 within about 1 m of the lyophilizer as measured by the WRAS, with peaks as high as 300,000 particle/cm^3 detected by the P-Trak placed directly at the exhaust port of the lyophilizer. The WRAS was too bulky to be placed at the exhaust port. Particle size distributions were unimodal and were similar compared with a distant point in the room, at the source and in the neighboring hallway. Normally, the exhaust port of the lyophilizer should be connected to an exhaust tube that leads to the outside of the building; however, it was not connected on the day of sampling for an unknown reason, emitting directly into the laboratory.

2) CNT synthesis by CVD

Synthesis of CNTs by CVD is a multistep process. On the first day of sampling, the worker loaded the catalysts into the rotary tube oven and started the furnace, which was equipped with local exhaust ventilation. The following day, observation continued as the same worker removed the CNTs, poured them into a beaker, transported them to a chemical lab and cleaned the quartz tube in which they had been synthesized.

In general, the particle number concentrations were highest when the door of the laboratory was opened. The baseline concentration in the room before any activities was about 7,000 particles/cm^3, whereas that in the hallway was about 25,000 particles/cm^3. Overall, particle concentrations, as measured 1 meter

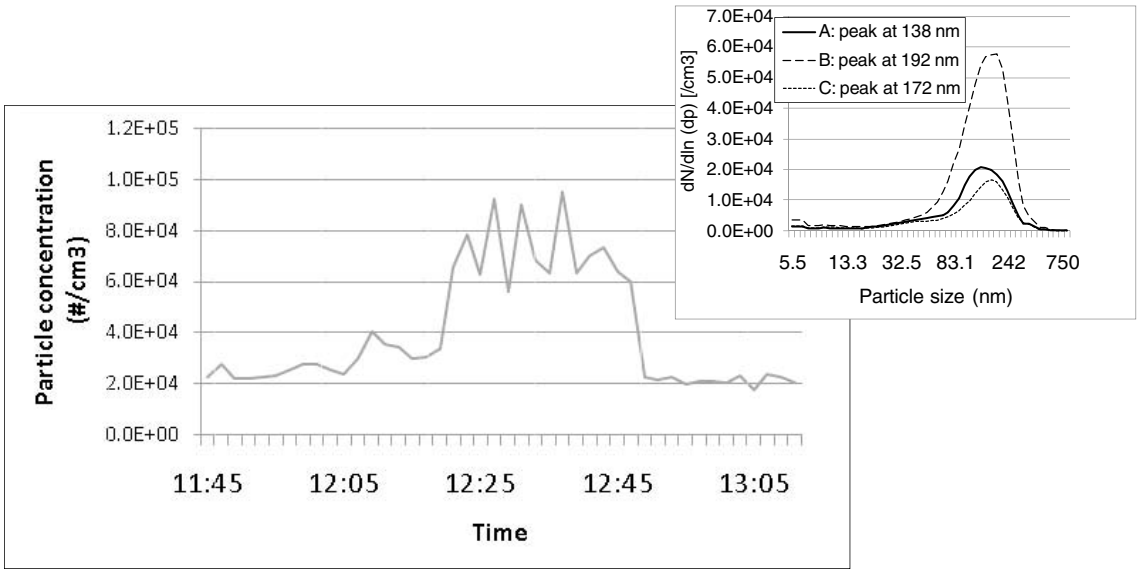

Fig. 2. Real-time particle concentration (5 nm to 1000 nm) during the final stages of lyophilization as measured by the WRAS (SMPS + OPC) in the general room area approximately 2 meters from the lyophilizer exhaust port (A), 1 meters from the lyophilizer exhaust port (B), and in the corridor outside of the room that housed the lyophilizer (C).

from the reactor, decreased during CNT synthesis. This was probably due to the activated exhaust ventilation. Particle size distributions were highly variable during the sampling period and were not further characterized.

Research Unit B

In this research unit, BiVO4 nanoparticles were weighed in powder form before putting them into solution. Airborne particle concentrations were assessed before, during and after weighing out 4 grams of the BiVO4 powder. The scale was not under a fume hood, and there was no local ventilation present. The particle concentrations increased by about 400 particles/cm^3 during weighing compared with concentrations before and after weighing (Fig. 4), as measured by the P-Ttraks adjacent to the scale. The concentrations during weighing were subjected to pair-wise comparisons by the Wilcoxon Rank Sum test with those before and after weighing and found to be statistically significantly different (p<0.05). The particle size distributions did not change appreciably during weighing compared with before or after weighing.

Research Unit C

Nano-TiO_2 colloids were prepared by hydrolysis of $TiCl_4$. The $TiCl_4$ was added drop by drop into a beaker of water, forming TiO_2 particles of 5 nm. Hydrolysis can also occur in humid air, creating a mist of particles above the beaker.

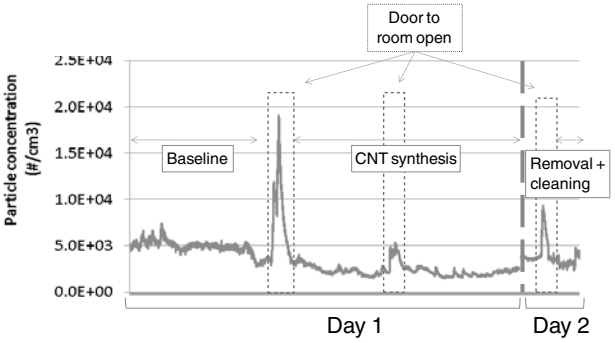

Fig. 3. Particle concentrations during CNT synthesis and handling as measured by the P-Trak. Measurements peaked when the doors to the room were opened. The local exhaust ventilation used during CNT synthesis probably explains the lower concentration during synthesis than before.

The above process took place in a fume hood. The WRAS was placed next to the fume hood; on P-Trak (P-Trak 1) was just below it at a height of 15 cm, and the other (P-Trak 2) was mostly next to the fume hood but was moved around to follow particular events.

Four instructive observations were made during this activity, with the average concentration during the process being about 5,000 particles/cm^3. This concentration during the activity was initially more variable than during the baseline period. P-Trak 2 measured a concentration of about 50,000 particles/cm^3 when it was moved into the hood and over the beaker. A

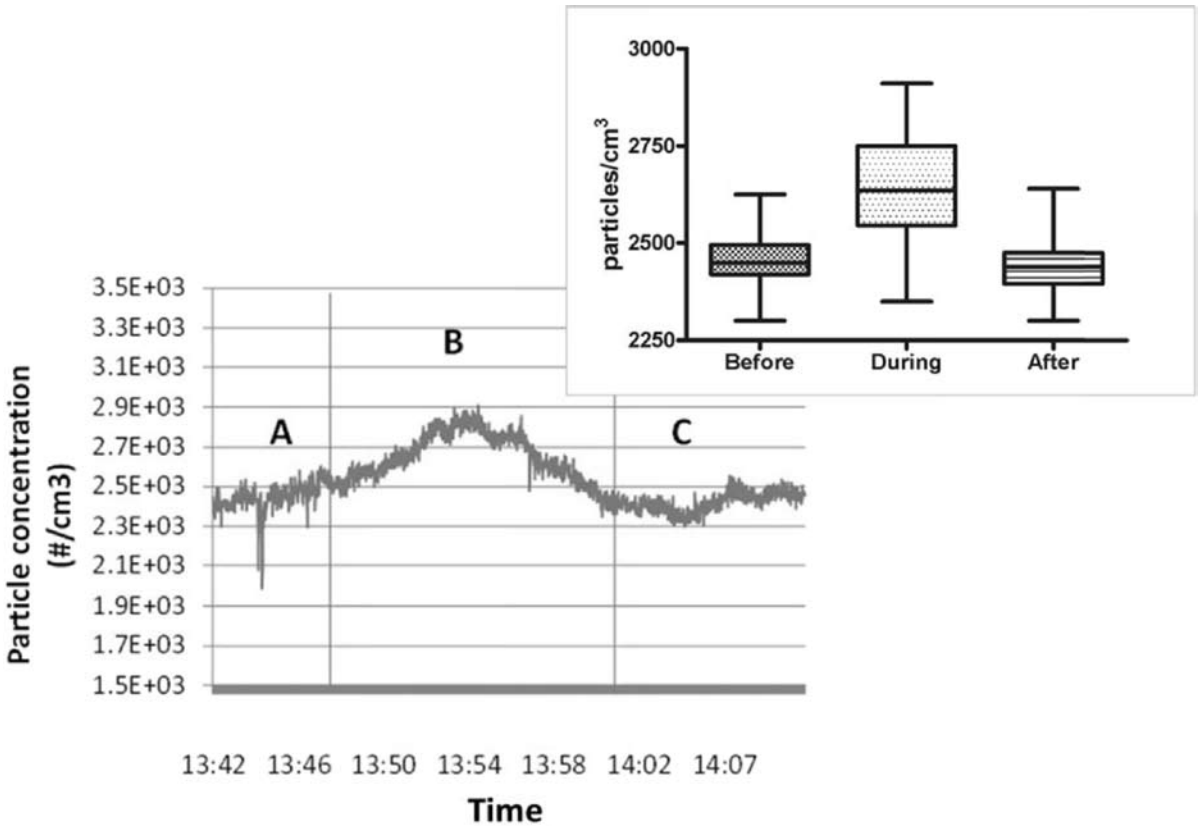

Fig. 4. Average number of particles measured by the two P-Traks, which were placed equal distances from the process, as a function of time. A, before weighing; B, weighing of BiVO4; C, after weighing.

drop of $TiCl_4$ subsequently fell on the ground outside the hood, resulting in peaks in all instruments, with the highest concentration, 100,000 particles/cm^3, measured by P-Trak 1. Finally, the researchers blew on the liquid to check the status of the liquid in the beaker, resulting in a peak of 18,000 particles/cm^3 outside the hood according to P-Trak 2 (Fig. 4). The peaks were too short-lived to measure the size distribution with the WRAS.

Research Unit D

Research Unit D is a large unit that conducts research on inorganic nanoparticles (metals, oxides and sulfides). Two processes were followed in this exposure analysis: the attrition of microparticles and centrifugation of nanoparticle suspensions.

1) Attrition

Attrition is used to mechanically decrease the size of particles. This activity was conducted in a fume hood on zirconium oxide micoparticles in solvent for about 15 minutes. The sampling instruments were placed both inside and directly outside the fume hood during preparation and operation of the attritor. No particle concentration increased to above the baseline level (data not shown).

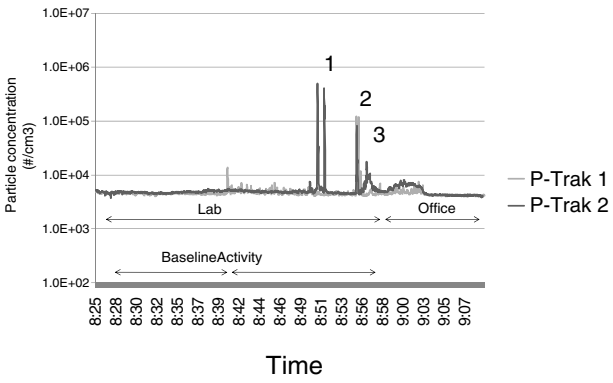

Fig. 5. Particle concentration as a function of time. Peak 1 - concentration at the source (in the hood over the beaker); peak 2 - concentration measured outside the fume hood when one drop of $TiCl_4$ fell onto the ground; peak 3 - blowing into the beaker.

2) Centrifugation

The centrifuge room was 60 m^3 and without artificial ventilation. Three solutions were centrifuged in a compact high-speed centrifuge on the day of sampling: one in the morning (after baseline sampling) and two in the afternoon. Figure 6 shows the measurements

done during centrifugation.

The first sample contained 10–20 nm gold nanoparticles and was centrifuged for about 50 minutes, the second contained 10–20 nm iron oxide nanoparticles and was centrifuged about 15 minutes, and the third was a medical product that did not contain nanoparticles. It was centrifuged for about 15 minutes. The rotation speed of the centrifuge was not noted, and no filter sampling was done. All measurements were taken within about 50 cm of the centrifuge.

The centrifugation of nanoparticle-containing solutions led to large increases in particle concentrations (particularly in the nano-size range); however, particle concentrations decreased continuously and were closer to baseline when the medical product without nanoparticles was centrifuged (Fig. 6).

Environmental release

At the time of air sampling, each laboratory had their own method for handling waste from their processes:

- Research Unit A rinsed materials contaminated with CNTs with water, which flowed down a drain. Gloves and other contaminated objects were disposed of with municipal solid waste, while residues of nano-objects were sent to the waste treatment facility of the university.
- Research Unit B filtered all nanoparticle-containing solutions; the filters were disposed of with municipal solid waste.
- Research Unit C disposed of aqueous TiO_2 colloids in a sink. If the TiO_2 particles were in a solvent, the suspension was disposed of with other solvents. Films containing TiO_2 on glass were sent for standard glass recycling.
- Research Unit D placed all items in contact with nanomaterials into a sealed plastic bin that was normally stored in a fume hood and was disposed of as hazardous waste. Iron oxide nanoparticles were disposed of by dissolving them in HCl. Titanium oxides and aluminium oxides were immobilized in cement. Other powders were aggregated by thermal treatment to create micro-sized particles.

Building air was filtered by the global air filtration unit of the building before being exhausted.

Discussion

The results of this study demonstrate that some of the activities commonly conducted during nanomaterial research and development may release nanomaterials into the breathing zone of workers. It is generally assumed that handling nanoparticles in liquid suspensions is relatively unlikely to release airborne nanoparticles, yet some of the activities in which increased particle concentrations were measured in this study involved liquid-handling operations.

Particle concentrations

During centrifugation of nanoparticle-containing solutions at Research Unit D, relatively high particle concentrations were measured compared with during centrifugation of solutions that did not contain nanoparticles. This comparison suggests that the

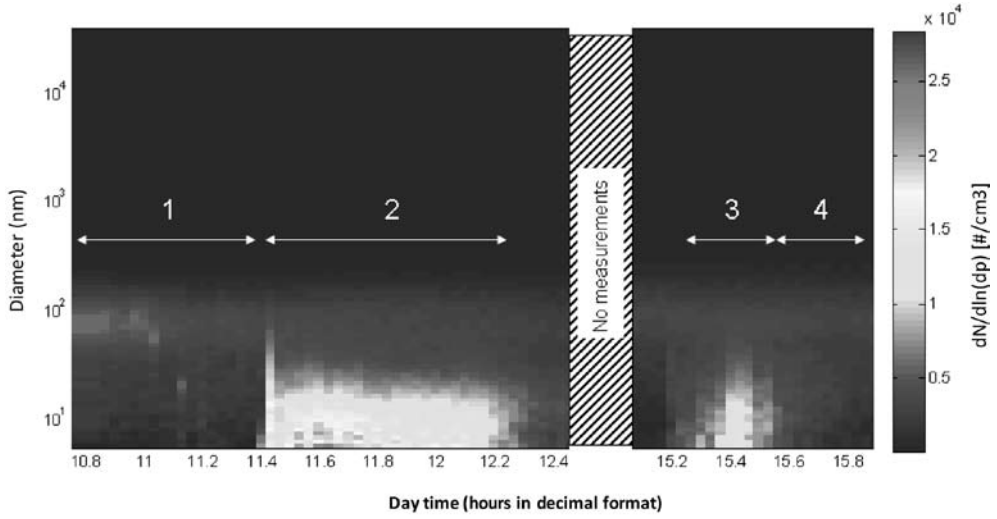

Fig. 6. Particle concentrations measured in the centrifugation room. Time range 1 corresponds to baseline (decreasing probably because the door is closed). Time range 2 corresponds to centrifugation of a solution containing 10–20 nm Au particles. Time range 3 corresponds to centrifugation of 10–20 nm Fe_2O_3, and time range 4 corresponds to centrifugation of a medical product not containing any nanoparticles.

Table 2. Summary of the concentrations measured during specific steps in various processes

Research unit	Activity	Distance from source (cm)	Measured concentration (#/cm3)[1]	Baseline (#/cm3)[1]
Activity-related concentrations				
A	Lyophilization - initial stage	100	4,000	4,000
	Lyophilization - initial stage	100	20,100	4,000[2]
	Introduce catalysts to CVD furnace	50	5,300	5,300
B	Weighing nanopowders (BiVO4)	10	2,700	2,500
C	Preparation of TiO_2 colloids (measured outside fume hood)	30	5,500[3]	4,600
D	Centrifugation	10	9,500[4]	4,800[5]
Peak concentrations				
A	Lyophilization - final stage	1	300,000	4,000
B	Preparation of TiO_2 colloids (in hood)	5	500,000	—[6]
D	Attrition (in hood)	10	4,500	4,500

1 Concentration as measured by P-Traks (one or average of both). 2 Baseline measured on a different day. 3 Includes peaks. When peaks are excluded, the concentration is the same as the baseline. 4 From the first centrifugation activity measured. 5 The baseline was assumed to be the lowest concentration prior to the start of centrifugation. 6 Not measured.

measured nanoparticles were not generated by the centrifuge's motor. Centrifugation has been shown to release microbiological particles in biotech laboratories[2]. In this study, it was noted that the centrifuge vibrated strongly during operation and that the caps on some samples were broken after centrifugation. The size distribution shows an increase in particles mostly in the very small size range that corresponds to the size range of the nanoparticles contained in the solutions. It is thus likely that this increase in nanoparticle concentration reflects nanoparticles released into the air. However, it cannot be fully excluded that some of them are suspended water droplets. As centrifugation is a standard method for isolating nanoparticles and other constituents of heterogeneous samples, laboratories should enact strict policies on centrifuge use, including policies concerning properly maintaining and balancing the rotors, having a backup method to keep samples closed (i.e., parafilm) and providing ventilation for centrifuges.

The use of a lyophilizer to dry a frozen nanoparticle suspension at Research Unit A without appropriate exhaust ventilation was perhaps the most extreme source of airborne nanoparticles. It not only released large numbers of nanoparticles but also did so for several hours. In contrast, the lyophilizer at Research Unit D was used under a fume hood and did not result in measurable particle concentration increases outside the hood. This result underscores the need to assess the proper setup and maintenance of laboratory equipment used to handle potentially dangerous substances.

The weighing of particles did lead to small but seemingly real increases in particle concentration that are not readily explained by other activities. Scales used in nanomaterial research should therefore be placed in hoods or otherwise provided with exhaust ventilation.

Not all activities that were expected to result in increased particle concentrations were found to do so. For example, the removal of CNTs and cleaning of the CVD furnace used to make CNTs in Research Unit A did not result in increased particle concentrations. It is possible that relatively few CNTs were aerosolized during these processes, which would not be detectable by the methods used. Note that it is unclear how the measurement units used perform with airborne CNTs, both as single particles and as larger bundles.

Control measures

In general, this study demonstrated that the use of standard engineering controls were effective. The processes conducted in a fume hood generally did

not produce detectable increases in particle concentrations outside of the hood, and no increased particle concentrations were measured in the vicinity of the CVD furnace, even when opening and removing the contents. In contrast, use of the lyophilizer without a proper exhaust system demonstrated how important the proper use of engineering controls can be in reducing exposure.

The use of personal protective equipment (PPE) among laboratory workers was often not adequate for handling nanomaterials. For example, in all but one laboratory, the workers wore woven lab coats or coveralls, through which nanoparticles can pass. Other protective measures, such as a mask, gloves or eye protection, were also inconsistently worn.

Measurement devices

This study primarily relied on handheld condensation particle counters (P-Traks) to assess exposure to nanoparticles. These results were supplemented with particle size distribution information from the WRAS for certain activities. However, the slow stepwise scanning of the WRAS made it impossible to characterize the size distribution of short-lived peaks, such as those measured by the P-Traks during hydrolysis of $TiCl_4$ or the opening of doors in Research Unit A during CNT synthesis. The use of a handheld device is advantageous, making it relatively easy to take samples in the breathing zones of workers or at the source, and analysis of the data is relatively straightforward. Therefore, it is a useful tool for hygienists who need to be able to quickly measure particle concentrations in the workplace, particularly when assessing the effectiveness of control measures such as fume hoods. However, a particle counter like the P-Trak used in this study cannot distinguish particle types or particle sizes: in areas of relatively high or unstable background particle concentrations, relatively small particle emissions will not be distinguishable from the background. There have been some recent improvements in hand-held measurement devices that provide the particle concentration and mean particle size in real time.

In this study, efforts were made to observe and account for potential alternative sources of particles, such as the opening of doors and the use of motors and other equipment. However, there could be any number of factors that could affect the particle number concentration; elemental analysis and electron microscopy would be needed to confirm the size and chemical composition of the measured particles.

Conclusions

Laboratories are the first sites where nanomaterials are used yet are notoriously difficult sites in which to implement health and safety measures. The nature of research lends to varying and novel methods, making it challenging to identify specific and enduring exposure control measures.

The results of this study provide a better understanding of potential particle releases during commonly conducted laboratory activities. The methods employed here, using primarily handheld devices, could easily be adopted for a preliminary hazard assessment in similar settings. The results of this study have already led to the implementation of a university-wide protection strategy[9].

The study evidenced again the need to precisely describe the measurement setup to allow for distinguishing between concentrations measured inside a process (e.g., under a fume hood) and concentrations measured in the workplace or for personal exposure (where people are exposed).

High concentrations of nanoparticles were found for processes that a priori do not seem to emit nanoparticles. For instance, nanoparticle emission from the centrifugation of liquid suspensions was not expected. Consequently, no safety measures were taken for this process. The study showed that nanoparticles can not only be emitted from a dry phase (powder) but can also escape from liquid suspensions. Further investigation is necessary to find out under which conditions nanoparticles can become airborne (e.g., as a function of the energy applied).

At several research units, the possible technological and organizational protection measures were unexploited. Personal protection is not effective when it is only worn by the people working with nanoparticles, leaving those working in the background unprotected. Technological and organizational protection measures might be more effective under these conditions.

Only few publications about exposure to nanoparticles in occupational settings exist, and they use different metadata. For further development of the knowledge in the field of occupational exposure to nanomaterials, the use of standardized measurement protocols and methods is crucial.

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