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Review

Review

Workplace Measurements of Ultrafine Particles—A Literature Review

Anna-Kaisa Viitanen[1]*, Sanni Uuksulainen[1], Antti J. Koivisto[1,2], Kaarle Hämeri[3], and Timo Kauppinen[1]

[1]Finnish Institute of Occupational Health, PO Box 40, Helsinki FI-00251, Finland; [2]National Research Centre for the Working Environment, Lersø Parkallé 105, Copenhagen DK-2100, Denmark; [3]University of Helsinki, Department of Physics, PO Box 48, Helsinki FI-00014, Finland

*Author to whom correspondence should be addressed. Tel: +358438250672; e-mail: anna-kaisa.viitanen@ttl.fi

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Abstract

Workers are exposed to ultrafine particles (UFP) in a number of occupations. In order to summarize the current knowledge regarding occupational exposure to UFP (excluding engineered nanoparticles), we gathered information on UFP concentrations from published research articles. The aim of our study was to create a basis for future epidemiological studies that treat UFP as an exposure factor. The literature search found 72 publications regarding UFP measurements in work environments. These articles covered 314 measurement results and tabled concentrations. Mean concentrations were compared to typical urban UFP concentration level, which was considered non-occupational background concentration. Mean concentrations higher than the typical urban UFP concentration were reported in 240 workplace measurements. The results showed that workers' exposure to UFP may be significantly higher than their non-occupational exposure to background concentration alone. Mean concentrations of over 100 times the typical urban UFP concentration were reported in welding and metal industry. However, according to the results of the review, measurements of the UFP in work environments are, to date, too limited and reported too heterogeneous to allow us to draw general conclusions about workers' exposure. Harmonization of measurement strategies is essential if we are to generate more reliable and comparable data in the future.

Keywords: exposure assessment; incidental nanoparticles; indoor air; nanoparticles; occupational exposure; particle exposure; ultrafine particles; work environment; workplace; workplace measurement

Introduction

Ultrafine particles (UFP) are generally defined as the fraction of fine particles with a diameter of <100 nm. UFP are always present in the air, thus people are constantly exposed to variable concentrations of background UFP. These background concentration have significant spatial and temporal variations, and are influenced by, for example, the amount of traffic, seasons, and weather conditions. The typical urban UFP concentration is ~10 800 cm^{-3} (Morawska *et al.*, 2008).

The interest in UFP relates to their postulated negative health effects. Their nanometer size range allows UFP to relatively efficiently penetrate the deepest parts of the lungs (Oberdörster, 2001). Particles of the nanometre size range may penetrate blood circulation, affecting inner organs, and it is also possible that they can penetrate the brain (Donaldson *et al.*, 2005; Knol *et al.*, 2009). In addition, the UFP have a large effective surface area, which allows them to act as carriers of harmful chemicals (Wichmann and Peters, 2000; Oberdörster, 2001). It has also been postulated that particles that are not toxic in the µm-size range may indeed be so in the nm-size range (Kittelson, 1998).

Exposure to fine particulate air pollution has shown to lead to negative health effects (Pope and Dockery, 2006) and occupational exposure to fine particles has been associated with, for example, cardiovascular diseases and cancer (Fang *et al.*, 2010; Kile *et al.*, 2013; Costello *et al.*, 2014). The epidemiological evidence of the health effects of exposure to ultrafine particulate matter is still unclear. Epidemiological studies have associated UFP present in the atmosphere to total mortality, the respiratory and cardiovascular causes of mortality, acute airway inflammation, and impaired lung function (Wichmann and Peters, 2000; Strak *et al.*, 2012). Exposure to UFP has also been associated with increased asthma symptoms (Wichmann and Peters, 2000), although this connection is not completely undeniable (Andersen *et al.*, 2008).

Workers are exposed to UFP in various work environments, but this exposure is not currently regulated as a distinct part of current occupational exposure limits. In occupational hygiene, coarse and fine fractions of these particles have been routinely sampled for decades now, and different occupational exposure limits have been assessed. These exposure limits and regulations have been either mass based, or, in the case of fibres, number based (EC, 2000, 2006, 2009; ACGIH, 2016). The measurement of UFP based on mass using current technologies is challenging due to the extremely low mass of UFP. Thus, number and/or surface area metrics should be measured rather than mass concentration alone (Aitken *et al.*, 2004; Brouwer *et al.*, 2009; Hämeri *et al.*, 2009; Park *et al.*, 2010). However, for demonstration of compliance with regulatory requirements, measurements of particle number or surface area concentrations alone are not sufficient, because mass balance is neither preserved nor conveyed in either of the units alone.

Workers may be exposed to three different types of UFP: engineered nanoparticles (ENP); incidental particles originating from processes, vehicles and combustion sources; and environmental background particles from both natural and anthropogenic sources (van Broekhuizen *et al.*, 2012). In work environments, UFP are generated in processes involving high temperatures, in combustion, and in mechanical processes involving massive energies (Wake *et al.*, 2002; Biswas and Wu, 2005; Hämeri *et al.*, 2009). Typical examples of these are welding, engines, and grinding, respectively. Other indoor sources in occupational settings are, for example, cooking, office supplies, and building materials (e.g. Hämeri *et al.*, 2009). The formation and dynamics of indoor UFP are described e.g. in Hämeri *et al.* (2009) and it occurs typically through the nucleation of vaporized compounds or as primary particles from combustion sources. In addition, outside the work environment, UFP are formed in both natural and anthropogenic sources. UFP originating from outdoor sources may penetrate the work environment through ventilation, which in turn influences workers' overall exposure burden. Generally, exposure levels in occupational settings might be higher than environmental exposure levels and thus, the risk for some worker groups might be higher than the average risk of the general public.

In recent years, especially, the emerging industry around ENP has drawn attention to workers' exposure to particles in the ultrafine size range (i.e. nanoparticles). ENP have been measured in various workplace studies, and several review papers have been written on the topic (Aitken *et al.*, 2004; Brouwer *et al.*, 2009; Brouwer, 2010; O'Shaughnessy, 2013; Pietroiusti and Magrini, 2014). Thus, we excluded workplace measurements in facilities producing or utilizing ENP. Some of these reviews have also touched on UFP in settings other than related to ENP, i.e. particles originating from processes (Aitken *et al.*, 2004; Biswas and Wu, 2005), but comprehensive up-to-date reviews are lacking. This is despite the fact that the number of people working with ENP is relatively low compared to workers potentially exposed to incidental nanoparticles. The number of workers involved in ENP in 2008 was ~400 000 worldwide and it is estimated that this will grow to 6 million by 2020 (Roco, 2011). It is believed that over 1 million workers in the metal industry alone are potentially exposed to UFP originating from work processes in the UK (Aitken *et al.*, 2004). However, these figures do not cover the many millions of workers exposed to particles originating from, for example, combustion sources such as vehicle emissions and cooking.

UFP have also been measured from the perspective of the general public. In some cases, these studies may be connected to workers' exposure; for example, schools and commutation are the workplaces of teachers and professional drivers. Here, we excluded studies that focus on the exposure of the general public. A comprehensive summary of UFP concentrations measured in classrooms can be found in, for example, Fonseca *et al.* (2014); Rivas *et al.* (2014) and in the review paper by Lin and Peng (2010). UFP concentrations in commutation have been reviewed by Knibbs *et al.* (2011) and UFP concentrations measured in schools and residential homes by Morawska *et al.* (2013).

Here, we have gathered the publications regarding UFP-measured number based in work environments. The goal of our work was to gather the studies in which UFP have been measured in actual work environments. Based on this information, we show the relative UFP exposure levels in different work environments and occupations compared to the annual background exposure level. We also distinguish the occupations in which exposure to UFP is negligible compared to exposure to annual background levels. From the results of this study, we are able to distinguish possible gaps in the knowledge concerning exposure to UFP in work environments. The results of the study may be utilized in, for example, the job-exposure matrix (JEM) (e.g. Finnish JEM; Kauppinen *et al.*, 1998) and other exposure assessment tools. In the future, JEM, together with the information on UFP will allow us to identify worker groups potentially at high risk and enable large epidemiological studies on occupational exposure to UFP.

Methods

The systematic literature search of research papers relating to the occupational exposure to UFP was carried out on 19 April 2013. We used a Web of Science database with a search strategy that included the following terms or combinations of terms: ultrafine, fine, nano, respirable, PM0.1, PM1, PM2.5, PM10, particle, dust, aerosol, fume, mist, exhaust, smoke, exposure, emission, measure, inhalation, breathing zone, distribution, airborne, worker, occupation, workplace, work site, at work, and work-related. The original search was limited to articles published in or after 1980 and resulted in 2269 publications. We separated those that included the concentrations of UFP.

The original literature was later supplemented with articles from more targeted searches (using terms such as UFP, nanoparticles, workplace, occupational exposure) and from the authors' personal collections. The literature searches were limited to the end of 2015, and articles published after this were not included.

We only included peer-reviewed publications written in English. Conference proceedings were excluded. Publications concerning radio activity, asbestos, the 9/11 World Trade Center disaster, bacteria, and otherwise non-relevant topics (such as animal studies) as well as simulation studies were excluded on the basis of the title and/or abstract.

In order to compare the different measurement results, only the studies that reported the concentration of the UFP number based were included. Thus, publications that reported UFP concentrations in metrics other than number-based metrics, as well as cumulative concentrations, were excluded.

Publications included in the review were required to study workers' exposure, and studies focusing on the general public were excluded. The workplace concentrations of the ENPs have been reviewed widely, thus those were excluded here.

Here, the low end of the measured particle sizes in the studied articles were between 1 nm (modified electrical aerosol detector [MEAD]) and 20 nm (condensation particle counter [CPCs]) depending on the instrument type and model. UFP are typically defined as particles with a diameter of <100 nm. Still, in practice, UFP total number concentrations are reported on the basis of measurement results by instruments whose measurement ranges are not limited by the UFP definition. This is especially the case when using instruments other than size-separating instruments (e.g. CPCs, diffusion chargers). Although it is possible to separate the UFP-fraction with size-separating instruments, results limited to <100 nm are not systematically reported. Thus here, the upper limit for the measured particle diameter, the maximum criteria, was not fixed. This leads to the fact that the reviewed total number concentration values represent sub-micron particles rather than strictly UFP. The term UFP is widely used, even though the measured particle size range exceeds 100 nm. In most cases, the UF fraction dominates the total particle number concentration value but this cannot be generalized (Morawska *et al.*, 2008).

The main results of the publications are illustrated in the tables in the online supplementary material (available at *Annals of Work Exposures and Health*). When available, data was collected on exposure agents; measurement site and/or work task; the measurement range (Range) with the information on the used measurement instrument; minimum (min), maximum (max) and mean number concentration; the mean number concentration of the background reported in the study (BG); and the duration of the measurement (T). In the tables, the background value represents that reported in the cited publication, and may have been measured, for example, outdoors, in the far field, or at the workplace when there is no activity. Complete tables may be found in the online supplementary material (Supplementary Tables S1–S11, available at *Annals of Work Exposures and Health*).

The data were taken from the publications without any processing, except in cases in which the background concentration was subtracted from the reported values. In these cases, we added the background concentration reported in the paper to the exposure concentration reported in order to allow comparison between the studies. Here, the original reported value was given as additional information.

The articles reported UFP concentrations in different ways. The concentration range was reported as a minimum and maximum value, as a 5th and 95th percentile, and as an inter-quartile range, depending on the study. The mean concentration was reported as a geometric or arithmetic mean. In some cases, median concentrations were also reported.

Morawska *et al.*, (2008) reviewed measurements in different ambient background environments. According to their study, mean ambient background concentrations vary from 2610 cm^{-3} in rural conditions to 48 180 cm^{-3} at roadsides. Correspondingly, the mean concentration in urban conditions, reported in 24 different studies and measured in different locations around the world, was 10 760 cm^{-3} (Morawska *et al.*, 2008). The review by Morawska *et al.* presents by far the most extensive data on ambient particle number concentrations. It would be impossible to set one value to describe the non-occupational background exposure of people while particle number concentrations have strong spatial and temporal variability. The value presenting the number concentration in urban conditions was chosen to best describe the typical non-occupational background concentration in ambient conditions, and the concentration in different occupations and work environments were compared to this in order to distinguish the conditions in which UFP concentration is greater than typical non-occupational concentration to UFP in urban conditions.

Results and Discussion

The literature search found 72 articles about UFP concentrations in work environments, covering 314 different work tasks or sites. The measurement results were categorized on the basis of work environment and similar exposure agents. Table 1 shows the publications' categorization. Detailed tables are available in the online supplementary material (Supplementary Tables S1–S11, available at *Annals of Work Exposures and Health*).

UFP originating from the basic metal industry and welding were measured in 14 and 13 different publications, respectively. All the other sub-groups included 11 or less different publications (2–11). The relatively small amount of publications posed challenges when dividing the measurements into different groups to make them comparable. For instance, the 'Other industries' (Supplementary Table S4, available at *Annals of Work Exposures and Health*) and 'Service sector' (Supplementary Table S11, available at *Annals of Work Exposures and Health*) groups included individual measurements in quite different work environments that are not comparable with each other, for example, a pottery studio and a rubber manufacturing factory in 'Other industries' or Aroma therapy and indoor ice rinks in 'Service sec-

Table 1. Classification of workplace measurements, number of different measurements included in each class, and total number of publications

Work environment and exposure agent if available	Number of measurements	Number of publications	Supplementary material
Asphalt work/bitumen fumes	30	2	Table S1
Machine shops	12	5	Table S2
Basic metal industry	77	14	Table S3
Other industry	30	10	Table S4
Painting and coating	11	6	Table S5
Power plants	16	2	Table S6
Traffic/diesel engine exhaust and other traffic-related exposure agents	40	8	Table S7
Welding/welding fumes	33	13	Table S8
Office work	25	11	Table S9
Restaurants, etc./cooking fumes and environmental tobacco smoke (ETS)	31	9	Table S10
Services	9	8	Table S11

tor'. Measurements in similar work environments will be needed more in the future in order to be able to estimate workers' exposure in these work environments.

In 2005, Biswas and Wu tabled the publications on occupational exposure to nanoparticles, and found 12 publications, of which only a few included number-based workplace measurements. This review clearly shows that, since the review by Biswas and Wu, the number of publications about UFP measurements in work environments has increased substantially. The first studies presenting workplace measurements were published in 2000. Since 2008, the trend of the number of publications has been increasing (Fig. 1).

Fig. 2 shows a summary of the concentrations reported in every sub-group. The review revealed that UFP concentrations are higher than the typical urban background concentration in several fields of industry.

The highest mean concentrations were found in welding, machine shops, the basic metal industry, traffic, other industries, and restaurants (around 0.7–4.7 × 10^6 cm^{-3}), and were roughly 60–450 times higher than the background concentration in typical non-occupational urban conditions. This was expected, as hot processes, machine-tooling and engines are often used in these fields. The highest mean concentrations reported for the different sub-groups were all higher than the typical non-occupational urban background concentration. As regards individual measurements, the mean concentration reported in 240 measurements was higher than the typical urban background concentration, and that reported in 34 measurements was lower than the typical urban background concentration. In three measurements, the mean concentration reported varied between a lower and higher concentration, and 37 measurements did not report the mean concentration at all.

The issue of background concentration is one of the fundamental issues in measurements of particle number concentrations (Brouwer *et al.*, 2009; Ramachandran *et al.*, 2011). Our review showed that only 174 (roughly 55%) of the 314 measurements reported background concentration. In some measurements, the background concentration reported was already higher than that in typical urban conditions. The effect of reported background concentrations on reported workplace concentrations in different studies is difficult to compare, as there is currently no mutual understanding as to how background concentration should be measured, which means that many different methods are in use (Brouwer *et al.*, 2009). Background concentration is currently measured, for example, outdoors, at ventilation inlets, far from the emission sources, as well as in workplace air before or after the process or the work phase in question (e.g. Brouwer *et al.*, 2009; Koivisto *et al.*, 2014).

The highest maximum concentration was reported in the metal industry, i.e. in beryllium metal and alloy plants. A concentration of 1739 × 10^6 cm^{-3} was measured while studying a process which includes reducing magnesium in beryllium hydroxide in a fluoride furnace area. The concentration reported is extremely high, and according to the authors, the area in question was later prohibited from non-essential personnel (McCawley *et al.*, 2001). High maximum concentrations were also reported in welding and machine shops (~10 × 10^6 cm^{-3}), and were 1000 times the background concentration in typical non-occupational urban conditions (Fig. 2, Supplementary Tables S2 and S8, available at *Annals of*

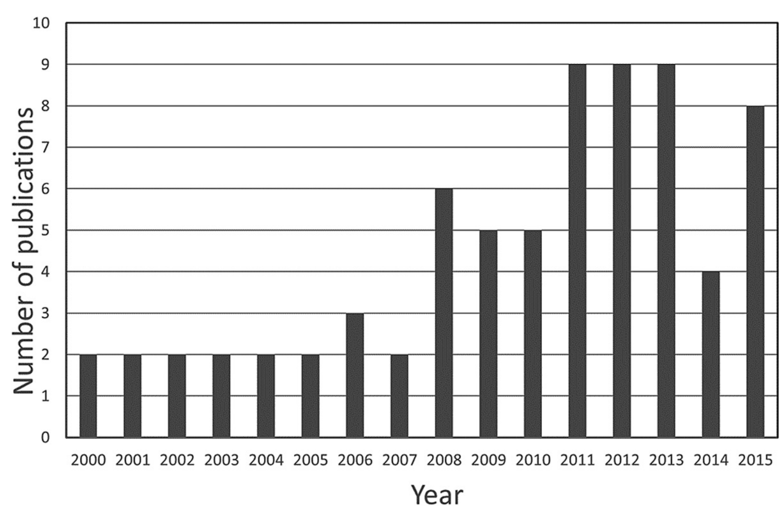

Figure 1. Number of published research papers on workplace measurements of UFP in 2000–2015.

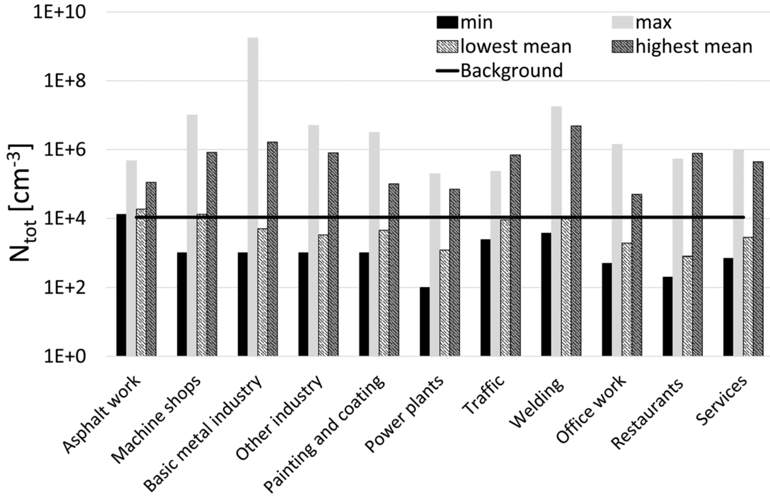

Figure 2. Minimum, maximum, lowest mean, and highest mean concentration for each group of exposure agents and work environments. The black horizontal line shows the value of typical urban background UFP concentration (10 760 cm^{-3}) as reported by Morawska et al. (2008).

Work Exposures and Health). Sanding of carbon- and glass-fibres resulted in maximum concentrations of 1–5 × 10^6 cm^{-3}, whereas sanding in plywood production was reported to generate a mean concentration of only 4400 cm^{-3} (Supplementary Table S4, available at *Annals of Work Exposures and Health*).

Workers in restaurants and bars are mainly exposed to cooking and tobacco smoking activities, which are both known to generate UFP. In studies in which the measurement site was sampled before and after the smoking ban, UFP concentrations were lower after the smoking ban than before, as expected. However, the mean concentrations in bars and restaurants remained higher than the background concentration in urban conditions. Thus, UFP most likely originate from cooking activities, but other sources such as traffic close to the measurement site may also influence the measured concentrations. In one publication, a mean UFP concentration as high as 773 × 10^3 cm^{-3} was reported during cooking activities. During non-cooking hours, this concentration was 9100 cm^{-3} (See *et al.*, 2006). The reported concentration is even higher than most of the mean concentrations reported in welding, which is well known to be a strong source of UFP (Aitken *et al.*, 2004). The other publications in which cooking fume concentrations were measured reported more moderate concentrations (mean concentrations of 800–290000 cm^{-3}). The amount of data is too small to enable us to draw conclusions about occupational exposure to cooking fumes but, based on the results, workers' exposure to UFP in restaurants and kitchens merits further study.

Even in the 'Office work' group (Supplementary Table S9, available at *Annals of Work Exposures and Health*), the highest mean concentration reported was above the background level of typical non-occupational urban conditions. In office environments, UFP concentrations without any indoor activities have been reported as being even lower than the typical non-occupational urban background, namely below 7100 cm^{-3} and 1800 cm^{-3} in spring and winter, respectively (Niu *et al.*, 2015). This shows that the influence of indoor sources on UFP is considerable and should be recognized. The reviewed studies reported that UFP in the offices originated mainly from copy machines, printers, and other office devices (Han *et al.*, 2011; Tang *et al.*, 2012).

To date, UFP are not routinely measured in occupational hygiene. In addition, measurement methods and instruments are not currently standardized, which means that measurement strategies and methods vary significantly. Some studies sampled workers' breathing zones, whereas others carried out stationary sampling. Sampling distance has a significant influence on measurement results, as the concentration of UFP becomes rapidly diluted after leaving the original exposure source (e.g. Biswas and Wu, 2005). The reproducibility of the measurements has been stated as one of the key issues of nanoparticle and UFP studies, and improved measurement methods and strategies are needed in order to determine exposure to UFP (Aitken *et al.*, 2004; Kumar *et al.*, 2010).

Kumar *et al.* (2010) reviewed the nanoparticles in the urban atmosphere that can be considered to also apply to workplace measurements. They pointed out several issues relating to the challenges in measurement: a lack of application guidelines and methods, instrument standardization, and measurements of particles below 3 nm. They also highlighted some practical measurement issues that should be considered when studying occupational settings as well; for example, what is the appropriate sampling frequency and how should the sampling tube losses of particles be corrected? The need for standardized methods for measuring occupational exposure was clearly shown here as well.

The measurement instruments used for measuring UFP concentrations have different operation principles and measurement ranges. A summary of the different instruments used to measure the particle concentrations in reviewed studies is illustrated in Fig. 3. More detailed information on the instruments along with the corresponding measurement ranges may be found in Supplementary Table S12 in the online supplementary material (available at *Annals of Work Exposures and Health*). The most typically used instrument in the reviewed articles was a CPC, which were used in 195 measurements. In this technique, particles are first grown by condensation and then optically counted (Hinds, 1999). Instruments based on diffusion charging (i.e. DiSCmini and NanoTracer, Hinds, 1999) were used in 17 studies. Different types of mobility particle sizers (SMPS, DMPS, SMPS+C) were used in 69 measurement, and instruments based on electrical measurement method (i.e. FMPS, MEAD, DMA, EAS, ELPI) in 33 measurements.

The low end of the measurement range for the instruments used in different studies varied from 1 nm to 20 nm. This limit is an essential factor when evaluating the comparability of different measurement studies. The amount of the particles in the size range of 1–20 nm may be significant in environments that contain nucleation mode particles (i.e. particles below 30 nm; Kumar *et al.*, 2010). UFP is defined as a fraction of particles with diameter smaller than 100 nm. Still, in most of the studies that reported UFP, the upper size limit was not fixed and the measured particle size range included particle sizes as high as 10 µm. Typically, the total particle number concentration is dominated by the UFPs, but this cannot be generalized and the influence of particles >100 nm cannot be automatically ignored (Morawska *et al.*, 2008). In their review of motor vehicle, UFP emissions Morawska *et al.*, (2008) also compared concentrations measured with CPCs to concentrations measured with SMPS/DMPS's. They reported that the mean and median concentrations measured with the CPCs were higher than concentrations measured with the SMPS/DMPS's. Morawska *et al.* also concluded that comparison of the results measured with different size ranges should be made with caution. Here, we do not have enough data for reliable comparison. However, in order to produce comparable data of the UFP-fraction, particles in the fixed size range should be reported.

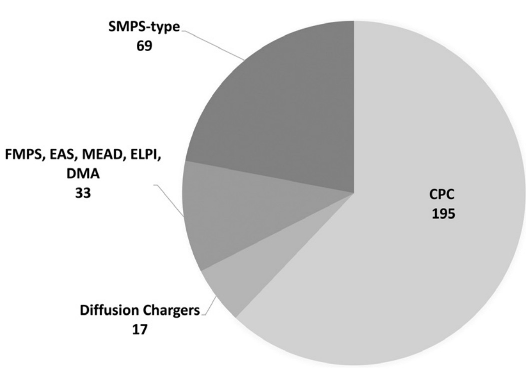

Figure 3. Different types of instruments used to measure particle concentrations among reviewed studies.

In work environments, UFP originated from atmospheric background, from processes or work, and from other indoor sources not related to actual work processes themselves, such as heaters or fork lifts etc. (Hämeri *et al.*, 2009). It is not always possible to exclude the additional particle sources, thus the measurement results may include other particles than those generated by the process or work. In addition, the measurement instruments suitable for measurements in work environments that are currently available online are not able to separate particles on the basis of their chemical composition (e.g. Brouwer *et al.*, 2009). Here, this means that a worker who is exposed to bitumen fumes, for instance, is actually exposed to traffic-related UFP from machines and traffic as well. A similar example would be restaurants in which workers might be exposed to cooking fumes, environmental tobacco smoke, and traffic emissions. In total number concentrations, the total exposure to particles measured is the sum of all the particles present in the air. Environmental tobacco smoke was only reported in the catering business, but smoking may also be prevalent in other work environments. If smoking is not forbidden during the measurements, this might lead to misrepresentations of the exposure data which could further complicate the epidemiological interpretation of the data.

When measuring workers' personal exposures, sampling of their breathing zone concentration is essential and suitable instruments are needed (Biswas and Wu, 2005). Instruments suitable for measuring breathing zone concentrations have been developed in recent years (Marra *et al.*, 2010; Fierz *et al.*, 2011; Asbach *et al.*, 2012). The data that can be achieved with personal instruments are not yet as accurate or comprehensive as the results provided by traditional instruments (Asbach *et al.*, 2012). A comparison study of different hand-held instruments showed an accuracy difference of 30% between a DiSCmini and a Hand-held CPC (TSI model 3007; Asbach *et al.*, 2012). The review revealed that in most of the studies, stationary sampling was used instead. Only 17 measurements (i.e. 5 different studies) were performed with instruments designed for personal breathing zone measurements (i.e. DiSCmini and NanoTracer) from which only in one study personal breathing zone concentration was reported. As UFP concentration has strong spatial and temporal variations, stationary sampling cannot reliably assess the personal exposure of the worker (Brouwer *et al.*, 2004). The air exchange rate also influences UFP concentration, thus the concentration in breathing zones differs to that at stationary sampling points, depending on the level of air exchange. Different air exchange rates may also cause identical emission sources to lead to different exposure levels.

The sampling durations vary significantly between reviewed studies. In order to determine the workers exposure, time-weighted average concentrations should be reported. For this, long enough sampling times are needed.

Based on the facts stated above, the particle number concentrations of different studies are not fully comparable. Even so, the results presented here may be considered general levels of UFP particles in different work environments.

According to the results of the review, the key factors for making relevant and reliable measurements and for improving the comparability of the measurements may be summarized as follows:

- Routine-based measurements of UFP in different work environments are needed. Today, the barriers to routine-based measurements are that exposure limits are lacking, state-of-the-art instrumentation suitable for occupational hygiene measurement is limited, and sampling standards and generalized practices are lacking (Brouwer *et al.*, 2009; Kumar *et al.*, 2010; Kuhlbusch *et al.*, 2011).
- Standardized measurement methods with fixed measurement range with low end below 20 nm and if possible down to 1 nm are needed. Parallel measurements using different techniques would improve the evaluation of the comparability of past studies.
- The temporal and spatial variation of particle concentrations, as well as the air exchange rate, have significant influence on measured concentrations and should be taken into account when measuring UFP concentrations and occupational exposure.
- The occupational background concentration should be measured. For this, a standardized method is needed. Also, the question whether or not the particle concentrations should be reported with or without the background should be resolved.
- The standardized method for reporting the concentrations should be stated.
- The influence of particles other than the relevant exposure agent should be recognized and eliminated if possible.
- The duration of the measurements should be long enough so that the time-weighted average typically used in work hygienic measurements could be calculated.

Conclusion

In this literature search, we reviewed 72 publications that reported UFP number concentrations in different work environments. The results showed that occupational exposure to UFP may be significantly higher than exposure to background concentration alone. However, the number of these articles is relatively low. Thus, the level and prevalence of occupational exposure are still relatively poorly known, and the amount of data currently available is not sufficient for reliable estimates to be used in job-based exposure matrix development. Based on the literature search, more studies are needed in order to better understand the levels of occupational exposure to UFP and to be able to determine an acceptable degree of exposure. Harmonization of the measurement instruments and strategies is essential in order to obtain comparable data in the future. Instrument development is also needed before occupational exposure limits or guidelines can be given. This would enable standardized work hygienic measurements in the future. The literature search serves as an example of how measurement results could be gathered in order to form job-exposure matrices for epidemiological studies on occupational exposure.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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