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POTENTIAL OCCUPATIONAL HEALTH RISK FROM EXPOSURE TO NANO-SCALE PARTICLES FROM PHOTOCOPIERS - A PILOT STUDY

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ABSTRACT

This work aimed to characterize and quantify the nanoscale particles emitted by a typical heavy duty industrial photocopier and printer to assess the long term effect of these particles on occupational health. The measured data showed that the nanoscale particle count in the room increased by about 5 times when the photocopier was in use as compared to when there was no activity in the room. The size distribution showed a correlation with the size distribution of the photocopier toner, suggesting the photocopier as the probable main source for the increased nanoparticle count in the room. This study also identified the settling time for the nanoscale aerosol in the work environment as twelve hours with the existing ventilation system. The potential health risk related to toner particles is also explored.

1. INTRODUCTION

The effect of ultrafine and airborne particles on health has long been an area of immense interest because of its direct link with adverse human health. Recently the ultrafine particles emitted from various sources such as internal combustion engines and combustion devices, manufactured nanoparticles such as carbon nanotubes and nanoparticles generated from welding process have received more attention because of their ability to penetrate deep inside the human organ systems [1]. Recent advances in measurement techniques have enabled researchers to measure the ultra fine particles of nanoscale range and have provided evidence that the smaller particles typically emitted from sources such as internal combustion engines may have more severe impact on the human respiratory system than the bigger particles. However, the growing importance of nanotechnology due to its promised benefits warrants a thorough assessment of the risks involved in the manufacturing plants and at the site of the end users.

Exposure assessment of nanoparticles is still in its infant stage compared to the exposure assessment of other airborne pollutants [1,2,3]. Recently, various aspects of these have been studied by various researchers: the number of nanoscale airborne particles, size distribution of these particles, chemical composition of particles and exposure time [4,5,6,7,8,9,10,11]. However, only limited information can be drawn from the available literature in certain areas because of the relative newness of the subject itself. One such area is the contribution of laser toners used in photocopiers and printers to the nanoparticles in the ambient air in a typical work place setting.

There is growing evidence that nanoparticles are produced when office equipment such as printers are in use [12, 13]. Also, the size distribution, total number of particles, chemical composition of the particles, the residence time of the particles in suspended stage and the health implications related to these particles are yet to be ascertained.

He *et al* [12] and Morawska *et al* [13] studied particle emission characteristics of the office printers , focused on the emission characteristics of submicron particles emitted from the office printers. One of the main aims of their work was to classify the printers as high, low or zero emitters. They also showed that even with a fairly adequate ventilation system, accumulation of moisture and dust can provide a good medium for microbial growth that may subsequently lead to further contamination of work environment. A similar study done by Wang and Morawska (2008) [14], who used computational fluids dynamics (CFD) method to determine ultrafine particle concentrations found that particle concentration increased close to the printer.

The results of He *et al* [12] suggested that there is potential harm to human beings because of breathed in toner particles. A recent study by Gatti [15] using in-vitro and in-vivo experiments with 5 types of nanoparticles found chemical evidence of particulate matter in human pathological tissues from patients who had suffered diseases of unknown origin. It was pointed out in this study that inhaled and ingested nanoparticles can penetrate through the alveolar as well as the digestive walls to enter the blood system and subsequently be transported to any organ in the body. In contrast, Wensing *et al* [16] claimed that as the chemicals released from laser printers are of high volatility, they are evaporated as soon as they are released. This study, however, was confined to paraffin and silicon and did not go further to explain other chemical components of toner.

Printers and photocopiers are capable of emitting ozone as well as volatile organic compounds (VOCs) [18]. This adds to contaminants from office furniture that also contributes to the VOCs concentration. It is a known fact that where there are high concentrations of indoor contaminants, problems may arise ranging from skin irritation to serious respiratory conditions. Perira *et al*'s [17] study on particle concentration and thermal parameters in four types of ventilation systems found no correlation in terms of size of particles and efficiency of each ventilation system in the breathing zone.

A review of the various components of the toner by Banerjee and Wimpenny [18], suggested that the standard toner consists of the following components: polymer, colorant or carbon black, charge control agent, flow control additives such as fumed silica (titanium oxide, organometallic salts) and wax. Some have iron –oxide additives up to 30%. Examining some of these components reveals links with health hazards. For example, Polymer is clay that contains polyvinyl chloride (PVC) that is mixed with a substance known as phthalate. This has potential harmful effects on health and may be associated with birth defects, reproductive anomalies and damage to nervous system [1].

In order to assess the risk related to manufactured nanoparticles on adverse human health, the knowledge of the effect induced by nanoparticles on respiratory organs and or dermal contact is essential. One of the most important aspects to be considered is the dose or exposure rate. This requires a comprehensive and quantitative assessment of nanoparticles emitted from photocopiers and printers including particle size, particle count, residence time of these particles in a suspended state and size distribution with respect to residence time. This is the aim of this pilot study. It aims at quantifying the amount of particles emitted by photocopiers when in use constantly or intermittently and when at rest. It will also examine the settling time of particles to room base level after use. This information along with mean diameter of the nanoparticles will provide sufficient information to examine any potential link with the health hazards of the components of the toner.

2. EXPERIMENTS

A room (approx 4 x 5 x 3 m) with an industrial heavy duty Photocopier was chosen for investigating nanoparticles emitted from the photocopier. No forced ventilation systems used during the measurement. However, the door to the experimental rooms were opened and closed often by the users whenever they entered the room to use the equipment. The sampling point was positioned at 1160 mm above the floor level, 180 mm away from the photocopier and 200 mm above the photo copier. A real time fast particle spectrometer (DMS 500) was used to measure the total number and size distribution of aerosol particles ranging from 5 to 1000 nm. The sample flow rate was 8 litres per minute. The working principle of the instruments and the scheme of experiments are explained in the subsequent sections.

2.1 Instrumentation

The particulate number count and size distributions were measured using a DMS 500 fast particle spectrometer. The measurements were based on the particle's electrical mobility. Electrical mobility is a measure of the ease with which a charged particle will be deflected by an electric field and is a function of both the charge on the particle and its aerodynamic drag. Both of these parameters are in turn functions of particle diameter, so by knowing a particle's electrical mobility, its size can be determined [19]. The schematic diagram of DMS 500 is shown in Figure 1.

Particles which enter the particle spectrometer are diffusion charged, made to collide with air ions to charge them, and are then carried down the central column as shown in Figure 1. The electrode in the middle repels the particles, which are deflected according to their electrical mobility. Particles with a high electrical mobility will be repelled sooner than those with lower electrical mobility. Twenty-two electron rings run around the outside of the column and detect particles landing on them, and a size density spectrum is built up as shown in Figure 2. The minimum diameter the instrument can detect is 5 nm.

It is impossible to state that all particles emitted from the photocopier will be spherical in shape. For non-spherical particles, appropriate compensation has been applied by the instrument's in-built functions to determine the electrical diameter mobility diameter.

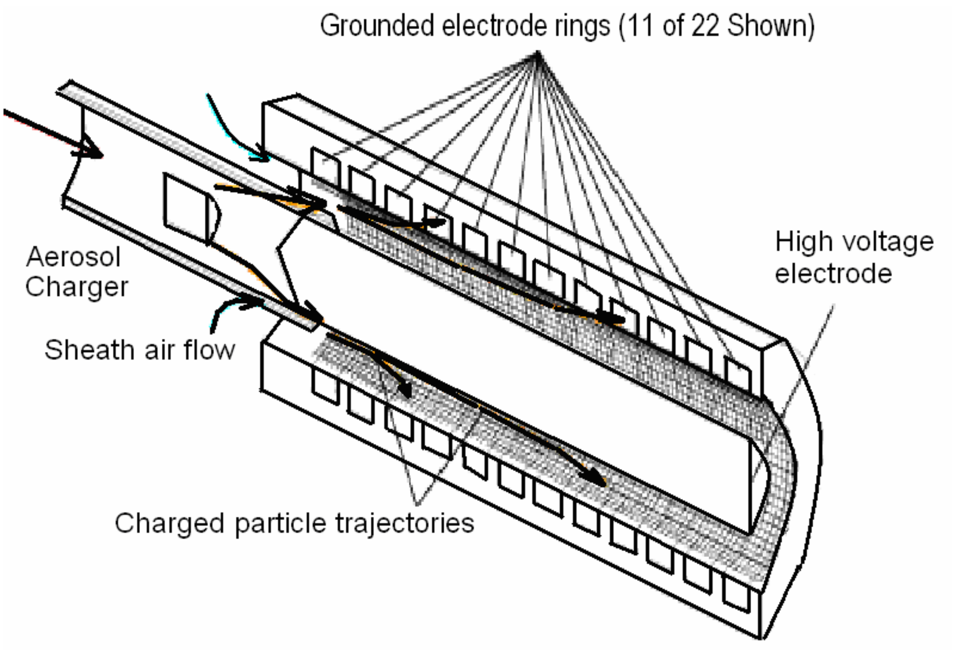

Figure 1 DMS Classification Column -schematic reproduced from [11]

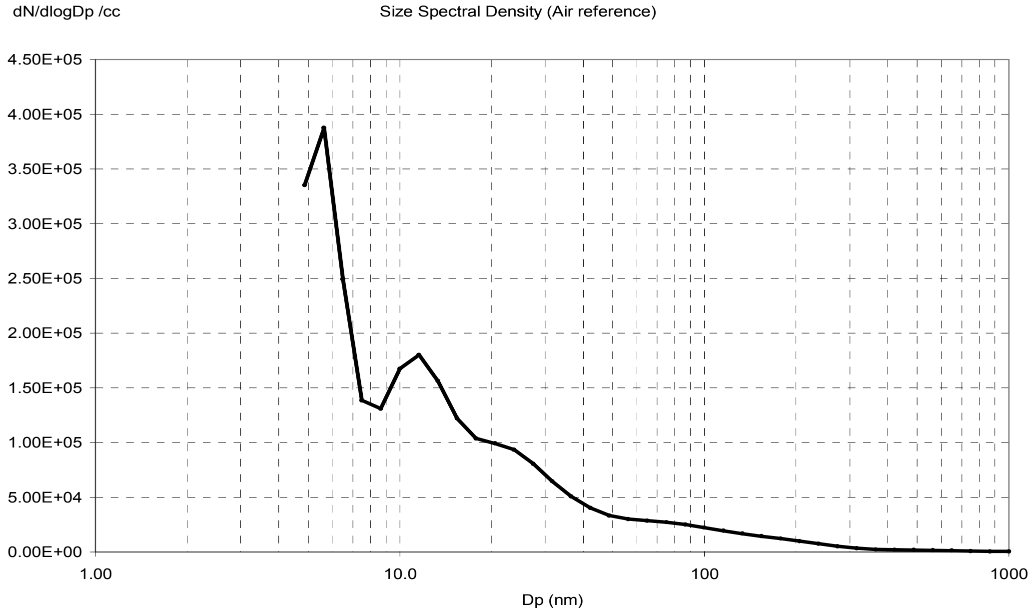

Figure 2 Typical Spectral densities of particles in ambient air

2.2 Scheme of experiments

Continuous measurements were taken at the breathing height of an average person standing close to the photocopier. To establish a base value, measurements were taken overnight (12 hours) when there was no activity in the photocopier room. Other measurements were then carried out during the day over 5 working days continuously. The data related to various events (photocopier in use) were obtained from the continuous measurements. These were then compared with the base value taken during the night and with the size distribution of the toner.

2.3 Characterization of printer toner

The size distribution of the toner was measured using DMS 500 by injecting the toner in the air stream close to the sampling point. It was identified that the geometric mean diameter of the laser toner was 22 nm. In addition the measurement also revealed that most of the toner particles are in the size range of 10 to 40 nm. The particle size spectral density map for the laser toner used in this work is shown in Figure 3.

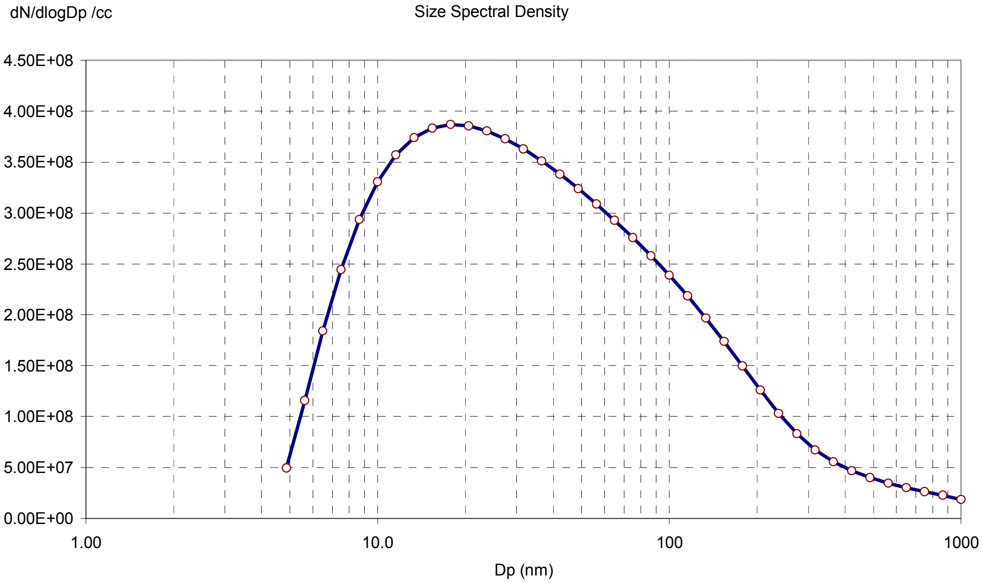

Figure 3 Spectral density of the laser toner used in experimental photocopier

3. RESULTS AND DISCUSSION

The data collected were analyzed to identify the relationship between the activity in the experimental space and the particle spectral density and total particle count as well as settling time for the measured particles. The results derived from these data are discussed in the subsequent sections.

3.1 Spectral Density

Figure 2 shows the spectral density for the air sample when the photocopier was not in use. A typical spectral density for air sample collected while the photocopier was in use for about 30 minutes is shown in Figure 4. It could be seen from Figure 4 that the spectral density has been influenced by the particles emitted from the photocopier. The additional peak seems to occur between 20 and 30 nm. The characteristics of the toner shown in Figure 3 suggest that this peak is due to particles emitted by the photocopier. The spectral density of air borne particle measured in the room show that only a certain size range identified from the toner spectral density contributes to the aerosol emitted from the photocopier. Figure 5 shows the spectral density of the air sample collected when the photocopier was in use intermittently – in use for 30 minutes, in use for 5 minutes, inactive for 10 minutes and inactive for 30 minutes. The particle count for the size ranges of the ambient air (base value) remains constant irrespective of the activity in the room. However, the particle size ranges related to the particles emitted from photocopier vary depending upon the duration of activity or duration of no activity in the room. The size distribution does not change with the duration of the photocopier use. However, the particle count related to particles from the photocopier drops if the photocopier is not in use. The characteristics of the toner are clearly seen in Figure 5. The main contribution from the photocopier seems to be between 15 and 200 nm.

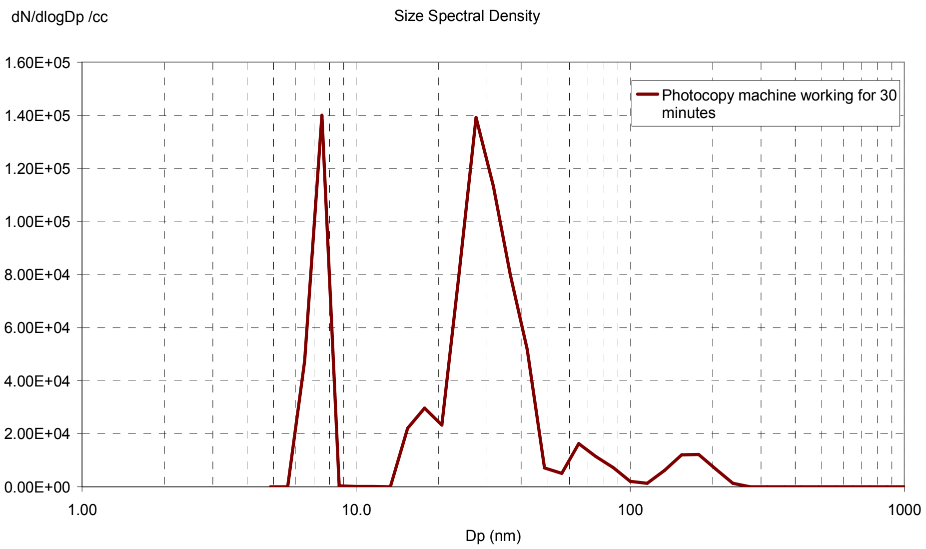

Figure 4 Spectral densities for the air sample when the photocopier is in use

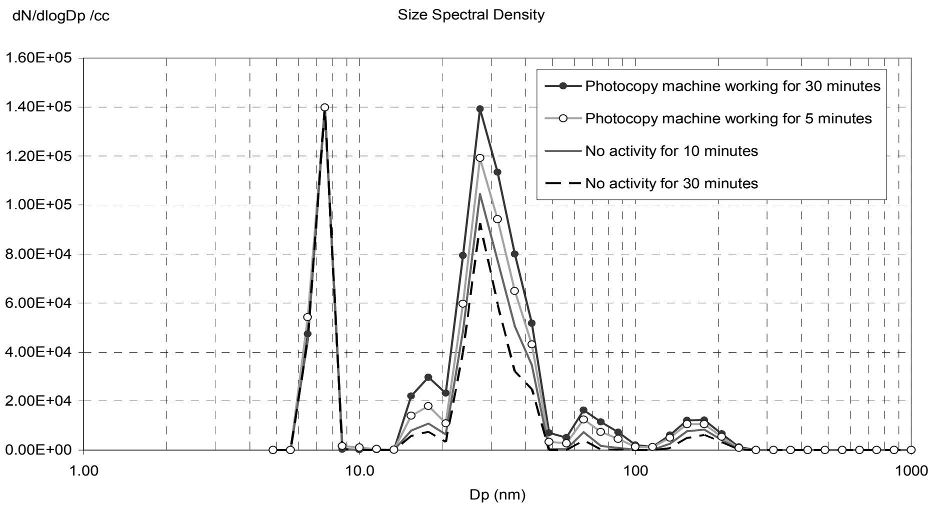

Figure 5 Spectral densities for the air sample when the photocopier is in use intermittently

3.2 Total particle count

The total particle count was estimated for all four conditions and is shown in Figure 6. The total number of particles in a cubic centimeter (cc) of air sample was about 50,000 when the photocopier was in use for 30 minutes and 44,000 when the photocopier was used for 5 minutes. Similarly, if the photocopier was not in use the total number of particles in a cc of air dropped to 35,000 when there was no activity for 10 minutes and to 30,000 when there was no activity for 30 minutes. This shows that the main contributors to the increased levels of aerosol in the room were the particles emitted from the photocopier.

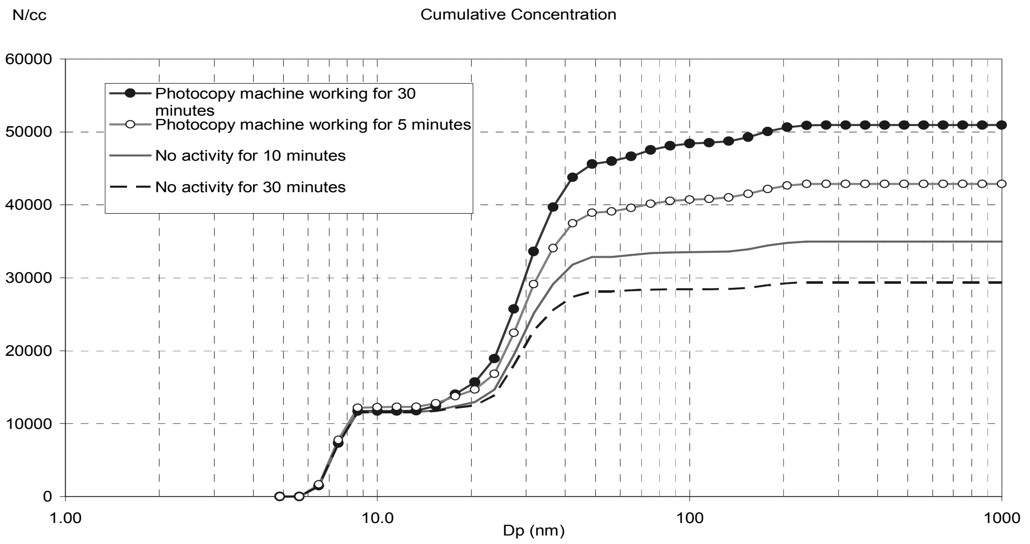

Figure 6 Total particle counts in a cubic centimeter of air

3.3 Settling time

Settling time for the particles emitted from the photocopier was analyzed from the overnight measurement. The photocopier was not in use from 6.00 pm till 7.00 am during the period of measurements reported in this study Data were logged every 10 seconds. The total particle count in a cubic centimeter of air was estimated for every hour and is shown in Figure 7. Activity resumed at 8.00 am the next day. Hence, the settling time of the particles could be estimated using the data from 6.00 pm to 7 am. It can be seen that the total particle count dropped to low levels over 8 hours and then remained constant when there was no movement of air in the room. Figure 8 shows that the settling characteristic of particles emitted from the photocopier follows a power law. The effect of ventilation on the settling characteristic particle has been studied since it is outside the scope of the current study.

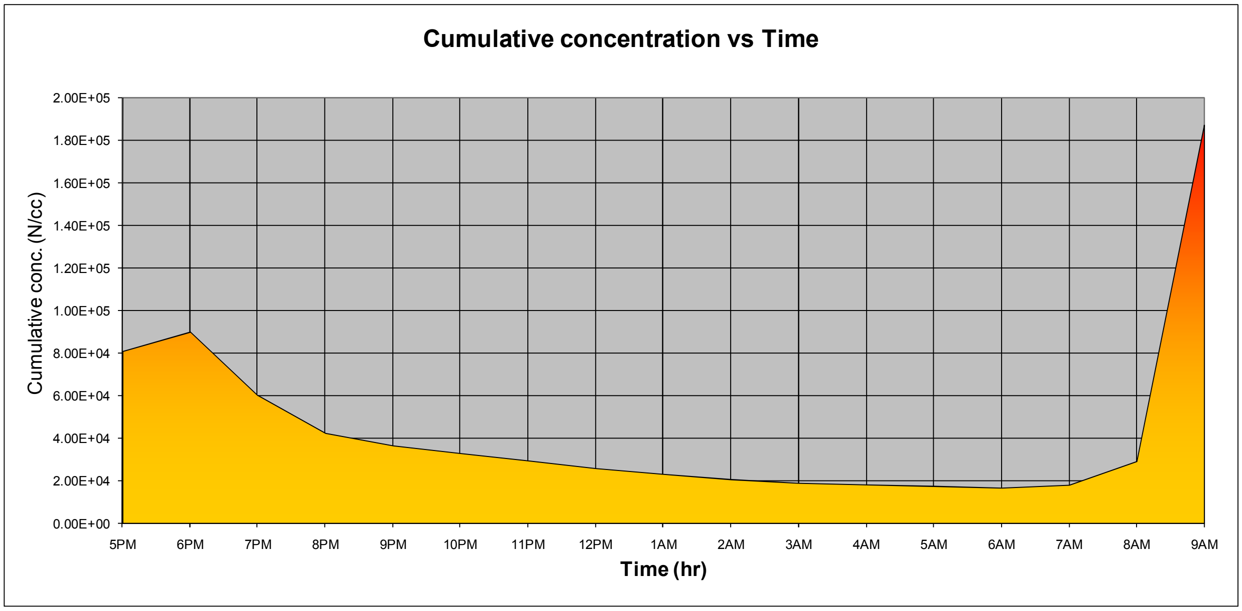

Figure 7 Aerosol particles emitted from photocopier - settling characteristic

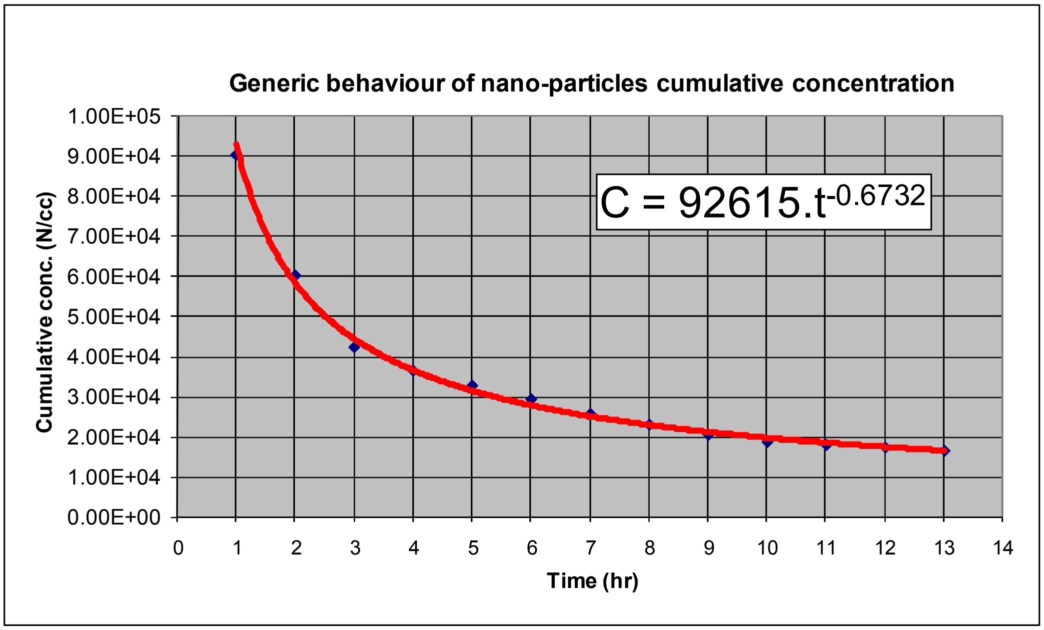

Figure 8 Aerosol particles settling characteristic

4. POSSIBLE HEALTH IMPLICATION

In order to assess the possible occupational health impacts, a worst case scenario was considered along with a reference case scenario based on the measured data and are shown in Tables 1 and 2 respectively. A scenario of average possible inhalation of the particles is presented. Data used in the tables were from this study and figures from the literature. Maximum numbers of particles value (NC) in table 1 = 90,000 and in table 2 = 16600 nano per cubic centimeter (see figure 6). Tidal volume (TV) – the amount of air breathes in and out during normal respiration = 500 cubic centimeter per breath [20] in both tables 1 and 2.

Number of breaths in a minute = 15-20 breaths per minute [21] 18 was used as an average breaths in both tables 1 and 2.

The present work shows that a total of 810,000,000 particles per minute can possibly be inhaled when the photocopier machine has been used. This is against 149,400,000 particles in the room air when photocopier machine is not used (an additional 660,600,000 particles inhaled). Higher number of nano-scale particles will have larger surface area per mass unit capable of carrying larger concentrations of adsorbed or condensed toxic air pollutants and size-specific deposition rate [1, 22] when inhaled.

Many studies documented the link between ultrafine particles exposure and adverse health effects such as cardiovascular diseases, respiratory morbidity and mortality in the populations that are susceptible [23, 24, 25]. Pereira et al [18] suggested that printers and photocopiers are capable of releasing ozone and VOCs which have been associated with adverse health effects. In general, it has been shown that engineered nanoparticles can penetrate the human body via many routes such as inhalation; ingestion; skin; and injection. Inhalation of ultrafine particles in certain sizes can be deposited in all parts of the respiratory tract [26]. Nanoparticles can cross epithelia and endothelial to get into blood circulation and from there have potential to reach any part of the body including bone marrow, lymph nodes, spleen and even the heart [1].

In relation to the results of this pilot study, there are nano-toxicological studies that have shown association between some of the chemical components of toner and adverse health effects. For instance, ultrafine and fine Titaniumdioxide (TiO_2) particles (of 20 nm diameter) when instilled are able to induce pulmonary inflammation in rats and mice [27]. Gardiner *et al* [28] demonstrated that carbon black has association with adverse respiratory symptoms and decreased lung function. Borm [1] also documented that nano-particles, TiO_2 and carbon black are capable of inducing lung tumors in rats. Gardiner et al's study [28] in rats involving instillation of 4 different types of ultrafine particles namely carbon black, cobalt, nickel and TiO_2, produced evidence of inflammatory response, while found association with TiO_2 and increased lung cancer without link with exposure. This pilot study highlights the need for evaluating long term effects of exposure to toner particles since these are yet to be fully understood.

Table 1 data for worst case scenario

Description	**notation**	**value**	**unit**
maximum number of particles in air	NC	90000	n/cc
tidal volume	TV	500	cc/breath
number of breaths in a minute	NB	18	
total amount of particles inhaled	**810,000,000**		

Table 2 data for reference case scenario

Description	**notation**	**value**	**unit**
maximum number of particles in air	RNC	16600	n/cc
tidal volume	TV	500	cc/breath
number of breaths in a minute	NB	18	
total amount of particles inhaled	**149,400,000**		

5. CONCLUSION

This experimental investigation characterized the size distribution and geometric mean diameter of the nano-scale particles emitted by a typical heavy duty industrial photocopier and printer. This investigation showed that the nano-scale particle count in the room increased by approximately 5 times when the photocopier was in use as compared to when there was no activity in the room. The size distribution showed a probable correlation with the size distribution of the photo copier toner, suggesting the photo copier as the main source for the increased nano-particle count in the room. This study also identified the settling time for the nano-scale aerosol in the work environment as 12 hours.

Even though this pilot study is not aimed at actual measuring of health effects of exposure to engineered nano-particles from photocopier or printer as such, it has capacity to point out the potential health risk for the purpose of taking appropriate preventive actions to reduce exposure. This has been possible from the closer study of effects of hazards that toner components are capable of causing to workers exposed to photocopier or printer at work as pointed out above.

Due to evidences shown from previous studies that link all the components of toner to one health hazard or the other, this study concludes that particles emitted by photocopier and printer used in this study can be potential risk to health. Further studies are recommended to measure the direct adverse effects of these particles to human health.

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