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A Pilot Study of Nanoparticle Levels and Field Evaluation of N95 Filtering Facepiece Respirators on Construction Sites

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CPWR Small Study Final Report

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FINAL REPORT

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Abstract

Little attention has been paid to the generated submicron ultrafine and nanoparticles and their exposure levels on construction jobsites. This information is needed because cytotoxicity of nanoparticles is well known now. In addition, the performance of particulate respirators generally used by construction workers has never been evaluated in field conditions against ultrafine and nano-sized particles. We hypothesized that workers on construction jobsites are exposed to high levels of nanoparticles and current NIOSH-recommended N95 respirators may not provide them adequate protection against aerosolized nanoparticles. Our exposure assessments of ultrafine and nanoparticles on several construction sites using SMPS nanoparticle counters showed that particle mass concentrations ranged between 1.41 and 99.96 μg/m^3. The real-time filtration efficiency of N95 respirators against nanoparticles greater than 20.5 nm in aerodynamic diameter was often less than 95%. When surface electrostatic charge was removed in N95 respirators by isopropanol treatment, the filtration efficiency of larger nanoparticles dropped compared to smaller nanoparticles of <27.5 nm sizes.

Key findings

- Different construction tasks can release different levels of airborne nanoparticles and ultrafine particles of 11.5 – 365.2 nm sizes ranging from 10^3 to 10^5 particles/cm^3 (number concentration) and 1.41 to 99.96 μg/m^3 (mass concentrations).
- The field experiments in this study showed that concrete blasting and grinding activities can release more nanoparticles than wood building framework construction and soil moving activities on construction sites.
- N95 respirators may not provide 95% protection for all categories of nanoparticles and generally 95% protection is achievable for particles of 11.5 to 20.5 nm sizes.
- Foldable N95 respirators were found to be less efficient than pleated N95 respirators in filtering nanoparticles mostly in the soil moving site and the wooden building framework construction site. This trend was, however, not observed on the concrete blasting/grinding site possibly due to different electrostatic and physical properties of nanoparticles generated in this site.
- When electrostatic charges were removed from mask fibers by isopropanol treatment, filtration efficiency dropped, but mostly for larger nanoparticles rather than smaller ones.
- Morphology of nanoparticles differed by task. Porous silicious nanoparticles, however, were not prevalent in the outdoor concrete blasting and grinding site as anticipated.

Introduction

Generation of respirable dust is common during various construction activities, including blasting, cutting, grinding, chipping, and drilling of concrete and wood. Moving soil and demolishing concrete structures and buildings also create respirable dust. Cutting concrete can produce elevated concentrations of respirable dust, a portion of which is composed of quartz [1, 2]. A significant portion of the respirable dust could be nanoparticles. Previous laboratory -based study conducted by NIOSH researchers demonstrated potential generation of nanoparticles of 3 – 500 nm sizes during simulated grinding activity [3]. These observations warrant further study on exposure assessment of ultrafine and nanoparticles in construction jobsites because according to the 2016 U.S. Bureau of Labor Statistics, approx. 6.7 million workers are employed in the U.S. construction industry [4].

Submicron ultrafine particles and nanoparticles are respirable deeper into our alveoli beyond our body's natural respiratory cleaning mechanisms such as cilia and mucous membranes, and are likely to be retained in the lower airways. These particles have the potential to cause serious diseases, such as respiratory symptoms, lung cancer, and silicosis. Exposure to respirable fine and ultrafine dust containing crystalline silica can occur in many construction activities, including chipping, hammering, and drilling in rock, concrete or brick; crushing, loading, hauling, and dumping of rock and concrete; abrasive blasting using silica sand or from the materials being blasted (concrete); sawing, hammering, drilling, grinding, and/or chipping on masonry or concrete; demolition of brick, concrete, or masonry; dry sweeping concrete, sand, or rock dust; trenching and excavation; sheetrock activities, and tile and grout work. Nanoparticles of both crystalline and amorphous silica may stimulate and suppress the immune system and cause injury to cells of several organs [5-10]. They are thought to have different toxic effects depending on their surface characteristics [11]. A recent study suggested that the high surface area of silica and TiO_2 nanoparticles may aggravate airway inflammation and may have adverse effects on human health [12, 13, 14]. Surface area and morphology of airborne nanoparticles present on construction jobsites are mostly unknown and electron microscopic analysis of nanoparticles collected from field sites can provide this vital information.

The mechanisms by which the above-described construction tasks release nanoparticles and ultrafine particles are largely unknown and previous studies mostly focused on course dust, $PM_{2.5}$, and PM_{10}. Understanding the mechanisms is, however, critically important because recent laboratory studies have demonstrated cytotoxicity of silica nanoparticles on lung epithelial cells [15]. Furthermore, because nanoparticles have a much greater surface area, they can absorb airborne NO_2, SO_2, and other pollutants released from machines on construction jobsites. Therefore, exposure assessment of nanoparticles in construction sites is important.

General belief is that the dust generated during mechanical processes on construction jobsites is mostly large particles formed through crushing, drilling, grinding, or sawing. Consequently, little attention has been paid to the generated submicron ultrafine and nanoparticles and their exposure levels. These data are, however, important because recent laboratory studies have suggested adverse health effects of nanoparticles as described above.

Concrete grinding and cutting are very dusty jobs in the construction industry, which may pose a serious health risk to masons. Masonry bricks, blocks, and concrete slabs contain significant amounts of crystalline silica. Silica-containing dust can be released into the workers' breathing zone when these materials are dry-cut. The exposure levels are often above the Occupational Safety and Health Administration's recently revised Permissible Exposure Limit (PEL) for silica, which is 50 $\mu g/m^3$ [16]. Continuous chronic exposure to these hazardous dust levels can lead to the development of silicosis among workers.

Building construction in the United States involves numerous wooden structures. Wood is routinely used in framing walls, floors, stairs, and landings in new building construction. Numerous workers are involved in timber-based construction and wood dust is one of their most common occupational exposures. Exposure to wood dust is associated with a variety of adverse health effects among workers, including dermatitis, allergic respiratory effects, mucosal and non-allergic respiratory effects, and occupational asthma. The amount and size of particles released as wood dust differ according to the operations performed.

Engineering controls, respiratory protection, and work practices must be in place to prevent exposure to respirable particles including nanoparticles. The effectiveness of control measures on exposure to dust in the construction industry has only been described in very few studies and for a limited number of tools and techniques. Common ways to reduce dust exposure in the construction industry are by the use of local exhaust ventilation systems, wet dust suppression, use of personal protective equipment, and influencing worker behavior by training and education. In this pilot research project we have evaluated simulated workplace protection factors offered by NIOSH-approved N95 particulate filtering facepiece respirators. Respiratory protection appears to be the most widely used preventive measure in the construction industry [17]. For workers performing heavy labor, however, it is often inconvenient to work with respirators and their effectiveness might be questioned. They provide insufficient protection when the protection factor is too low for a specific situation and when not used or maintained properly. Because practically no data are available on the nanoparticle exposure levels among construction workers, obviously, the performance of particulate respirators generally used by construction workers (commonly N-series particulate respirators) was never evaluated in field conditions against particles of nano-sized range. People currently concerned about protection against engineered nanoparticles generally refer to structures approximately 1-100 nanometers in size, that have novel properties and functions because of their nanometer scale dimensions. At this time there are no enforceable U.S. exposure limits for engineered nanoparticles, only recommended exposure limits from NIOSH. Furthermore, the performances of filtering facepiece respirators on real construction jobsites can be significantly different from results in laboratory conditions because of the: (a) huge loading of dust particles on mask surfaces that may change pressure drop and affect penetration, and (b) ambient charged particles settled on surfaces of masks that may interfere with the filtration efficiency of nanoparticles.

A recent NIOSH study [18] showed that the filtration media in N95 and N100 respirators can capture nanoparticles at acceptable levels, but also that in leakage tests, nanoparticles are able to differentially enter respirators in higher numbers. Researchers have also shown that there are marked differences in filtration efficiency among specific brands of N95 respirators. In another study from the same research group [19] the authors found that the shift in the most penetrating particle size from 45 to 150 nm for respirator filters with charge removed indicates that mechanical filters without charge may perform better against nanoparticles than electrostatic filters rated for the same filter efficiency. These laboratory studies, however, were conducted using NaCl particles. The efficiency of charge-removed N95 respirators to provide protection against nanoparticles on construction jobsites is currently unknown. To address the first issue we have examined filtration efficiency of two different pleated and foldable models of N95 respirators.

Because the filtration mechanism for N95 respirators relies heavily on electrical charges, charged particles in ambient air in construction can affect the charge of the respirators, which could definitely affect the capture of nanoparticles. To better understand the interaction between filtration and leakage processes without interference from electrostatic charge we also conducted a few pilot measurements where respiratory protection against nanoparticles was tested for N95 masks that have their electrostatic charge removed by isopropanol immersion as described previously [19].

In this pilot research project we have conducted nanoparticle exposure assessment during (1) concrete grinding and drilling; (2) wood cutting and shattering during a new wooden building framework construction; and (3) soil moving in a large construction site. Additional experiments were also conducted in a concrete parking lot and building demolition sites, but we are not reporting those data in this report. The main purposes of our study were (a) to evaluate nanoparticle exposure levels in three construction jobsites by using a newest model of commercially available nanoparticle counters; (b) to characterize silica nanoparticles by electron microscopy; and (c) to evaluate the real-time filtration efficiency of N95 respirators with highest and lowest fit test rates against nanoparticles by simultaneously measuring nanoparticle levels inside and outside of the respirators fitted onto a manikin and creating leakage probes (two different sizes) on the surfaces of the masks.

Objectives

The study hypothesis was: "***workers on construction jobsites are exposed to high levels of nanoparticles and current NIOSH-recommended N-series respirators may not provide them adequate protection against aerosolized nanoparticles during various construction related jobs***".

To address and test this hypothesis we proposed three specific aims: ***Specific Aim 1:*** Measurement of airborne nanoparticles in construction jobsites and background control sites away from the construction locations. ***Specific Aim 2:*** Characterization of airborne nanoparticle morphology collected from construction jobsites. ***Specific Aim 3:*** Assessment of respiratory protection factors against airborne nanoparticles during construction jobs by using a manikin donned with N95 filtering facepiece respirators.

Methods

Figure 1. Collection of air samples by a NanoScan SMPS sampler during concrete blasting works.

Exposure assessment of nanoparticles on construction sites

To assess and measure the exposure levels of airborne nanoparticles associated with various construction operations, three construction jobsites were selected. We targeted three common construction related tasks: (1) concrete blasting and grinding; (2) wood cutting and other tasks during framing of wooden side walls, inner partition walls, and landings in a new building construction site; and (3) Soil moving by bulldozers in a large construction site. Ten one-minute samples were collected at three different distances (5, 10, 15 meters) from the worksite in all three construction sites (see Figure 1 below). Thus, altogether $n = 3 \times 10 \times 3 = 90$ air samples were collected. We also collected 10 air samples for nanoparticle levels in offsite control locations ($3 \times 10 = 30$ air samples).

Nanoparticles in construction worksites were measured by a SMPS (Scanning Mobility Particle Sizing) nanoparticle counter (Model 3910; TSI, Inc.). We rented two instruments from the manufacturer. This instrument measures a size distribution for particles ranging from 10 nm to 400 nm in diameter in 13 logarithmically-spaced size bins. The instrument offers battery-powered, portable operation. During each air sampling experiment we also recorded temperature, relative humidity, and air velocity. NanoScan Manager Software (available from TSI) was used for the analysis of nanoparticle sizes and concentration levels. Nanoparticle number concentration data were converted to mass considering the density of concrete, wood, and soil in three different sites.

Characterization of airborne nanoparticle morphology collected from construction jobsites

We collected ultrafine and nanoparticles on filter surfaces by another sampler - Sioutas Cascade Impactor (SKC, Inc.). We used this sampler for area sampling (30 min) in the construction jobsites by mounting the impactor to a sampling tripod at approximately 1.5 m height. This sampler consists of four impaction stages and an after-filter that allows the separation and collection of airborne particles in five size ranges. Air samples were collected at a constant flow rate of 9 L/min for 15 min. Particles above each cut-point were collected on a 25-mm PTFE filter in the appropriate stage. Particles below the 0.25 μm cut-point (including submicron ultrafine and nanoparticles) of the last stage are collected on a 37-mm PTFE after-filter. These filters ($n = 3$ per sampling location) were analyzed by electron microscopy. The surface morphologies of nanoparticles methanol-extracted from filters were investigated by means of a JEOL JSM 7600F scanning transmission electron microscope with resolution of 1.5 nm (1 kV) in GB mode, 1.0 nm (15 kV) in TEM mode.

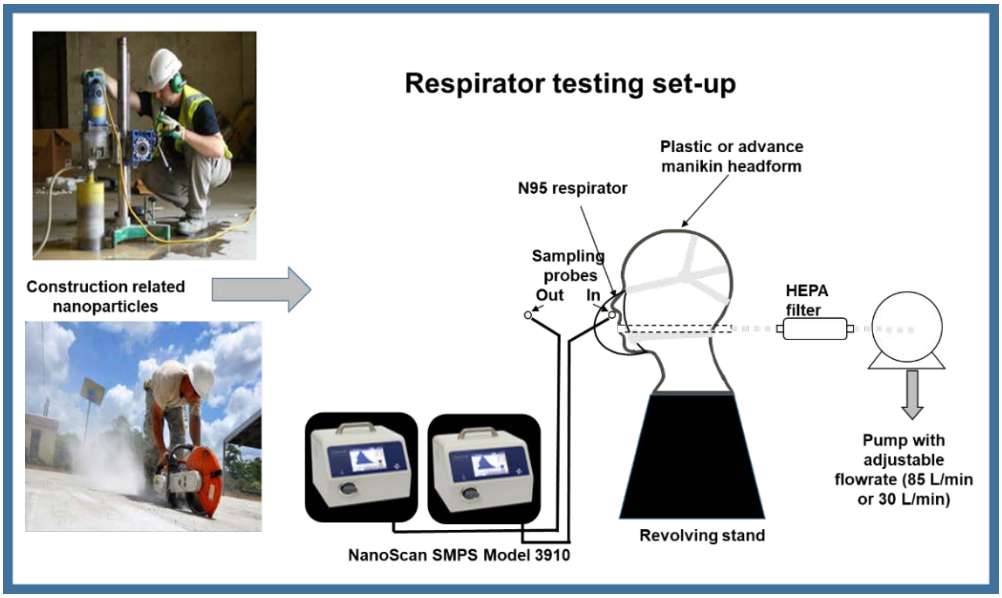


Figure 2. Schematic of the nanoparticle sampling system for assessing protection factors offered by N-series respirators in construction jobsites.

Assessment of respiratory protection factors against airborne nanoparticles during construction jobs by using a manikin fitted with N95 filtering facepiece respirators

In this specific task we used two NanoScan SMPS nanoparticle counters to monitor nanoparticle levels in two sampling lines as shown in the Figures 2 and 3 - inside (Sampling probe – In) and outside (Sampling probe – Out) of a respirator mask. In this experiment, we examined protection levels offered by N95 disposable particulate respirator against nanoparticles in three different construction jobsites as described above.

Two types of NIOSH approved N95 masks were tested in all experiments: (1) pleated N95 mask and (2) foldable N95 mask. N95 respirators are certified under NIOSH 42 CFR 84 regulations after passing the tests performed using charge-neutralized sodium chloride aerosol with the particle size of approximately 0.3 µm or 300 nm in diameter. The certification criterion for N95 half-facepiece respirators says that the total momentary particle penetration (P = Concentration inside mask/Concentration outside mask × 100) through the respirator filter cannot exceed 5% at 85 L/min, i.e., the filtration efficiency, defined as E=100%-P, must be at least 95%. Therefore, we conducted our experiments at a simulated inhalation air flow rate of 85L/min. Respiratory protection devices with less efficient filtration characteristics are not NIOSH-certified. The value of 300 nm is presently accepted as the most penetrating particle size (MPPS) and fraction for particulate filters. However, numerous investigations have demonstrated that the MPPS can vary considerably from one filter model to another and is dependent on the operational conditions. For non-charged fibers, while the MPPS increases with increasing fiber diameter and decreasing flow rate, it lies primarily within the range of 100 to 300 nm. The data collected by Brown [20] indicated that the MPPS may be even as high as 700 nm for very low (0.001 m/s) air velocity through the filter. For pre-treated respirator filter media, the MPPS may depend on the fiber charge [21]. Most of these experiments, however, were laboratory-based experiments and real time data in construction work environments are inadequate.

The N95 particulate respirators were placed on manikin faces and sealed so that no leakage occurs on the faceseal between the face and the inner lining of mask surfaces (see Fig. 3). We concurrently collected nanoparticle and ultrafine particle samples in real time from inside and outside of the respirator masks and particle penetration percentages were calculated (see below the results section) for 13 particle sizes: 11.5, 15.4, 20.5, 27.4, 36.5, 48.7, 64.9, 86.6, 115.5, 154, 205.4, 273.8, and 365.2 nm (median sizes of the particles collected in 13 collection bins). Ten data points were collected for each experiment. We have conducted some experiments with two leakage probes which were mounted on respirator surfaces simulating potential faceseal leakages expected during actual work. However, these probes were probably partially blocked in outdoor dusty environments and we did not receive consistent data. Therefore, this part of the study is not included in this report. We also excluded presenting penetration data for 205.4, 273.8, and 365.2 nm particles because often some bins for these size ranges showed zero values.

Accomplishments, results, including their relevance and practical application

The results of the study are presented below in figures. As shown in Figures 4, 5, and 6, total particle mass concentration in the size range between 11.5 and 365.2 nm were considerably higher in concrete blasting/grinding site (6.71 – 99.96 μg/m3) than other two sites (2.51 – 6.29 μg/m3 - in a building framework construction site and a soil moving location in a large construction site (1.41 – 2.76 μg/m^3). Nanoparticle levels during concrete blasting/grinding activity significantly differed with distances (see below the statistical analysis section). We also found that penetration of nanoparticles differed with respect to particle sizes as well as type of N95 masks. These penetration percentages are described below in the statistical analysis section. Overall, our data showed that different construction tasks can release different levels of airborne nanoparticles ranging from 10^3 to 10^5 particles/cm^3.

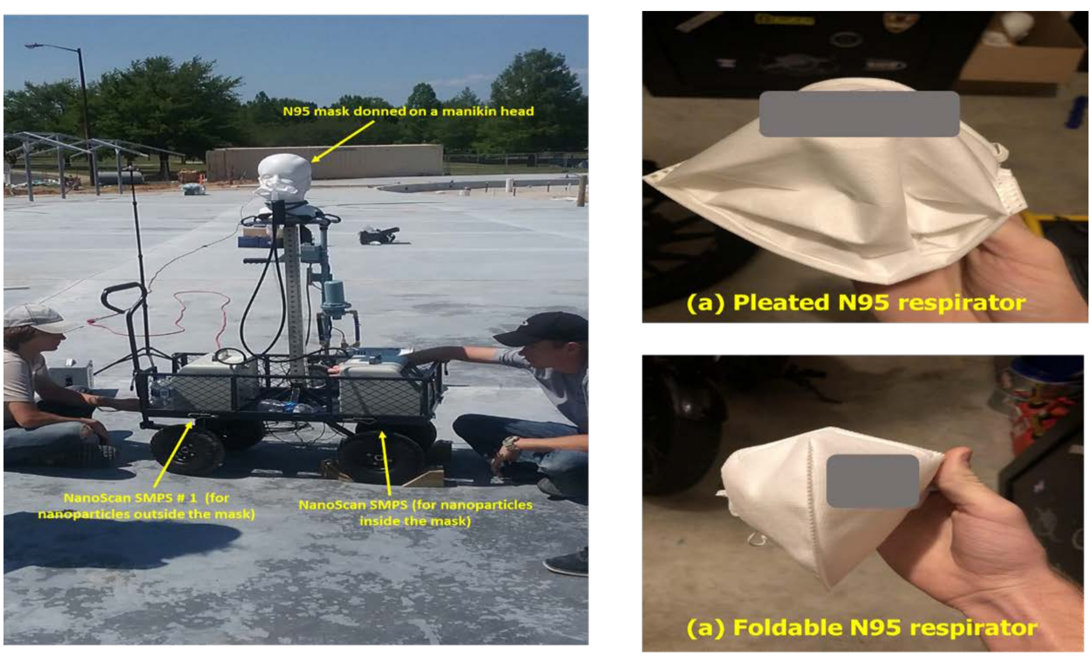


Figure 3. Manikin based N95 respirator evaluation system and respirators used in field experiments.

N95 respirators may not provide 95% protection for all categories of nanoparticles. We found that nanoparticles of <36.5 nm size generally penetrated least through both types of respirator models when compared with other particle sizes.

Foldable N95 filtering facepiece respirators were found to be less efficient than pleated N95 respirators in filtering nanoparticles mostly at the soil moving site and the wooden building frameworks construction site. Filtration efficiency of foldable N95 masks were generally lower for nanoparticles of medium size range. Filtration efficiencies of N95 masks differed in different construction operations likely due to different environmental conditions and/or physical properties of nanoparticles. Upon isopropanol treatment, the particles of larger sizes penetrated more compared to particles of smaller sizes.

Airborne nanoparticles have a diverse range of shapes and morphologies, ranging from spherical nano-titanium dioxide to inhomogeneous aggregates of spheres, such as welding fume and particle agglomerates such as those composed of fiber-like carbon nanotubes. The morphology of nanoparticles and their size distributions in electron microscopy are largely unknown, particularly in construction jobsites. Furthermore, how these nanoparticles exist in real field conditions – spheres, chains, or clustered aggregates – are also relatively unknown. Our electron microscopic analysis of samples collected by the Sioutas impactor showed presence of nanoparticles of examined size ranges (11.5 - 365.2 nm) in all sites. We also found large agglomerates of nanoparticles. Previous laboratory studies reported porous morphology for silica nanoparticles. However, we did not find significant amount of porous nanoparticles in the concrete blasting/grinding site. Two SEM photographs are presented below in the Fig. 12.

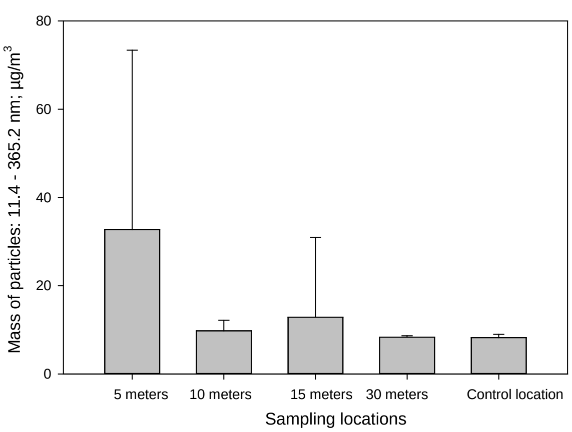


Figure 4. Mass concentration of total particles of 11.4 – 365.2 nm size range at concrete blasting and grinding site.

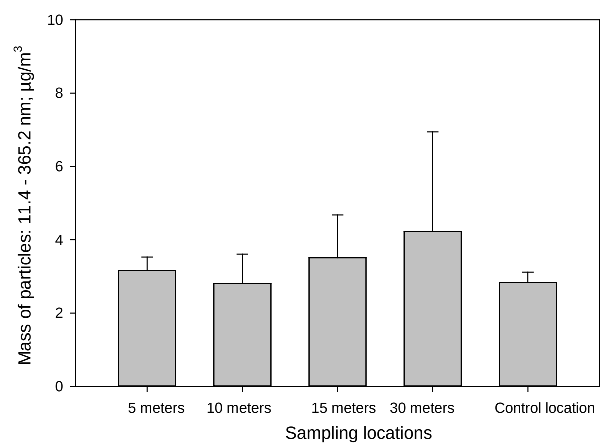


Figure 5. Mass concentration of total particles of 11.4 – 365.2 nm size range during wooden building frameworks construction.

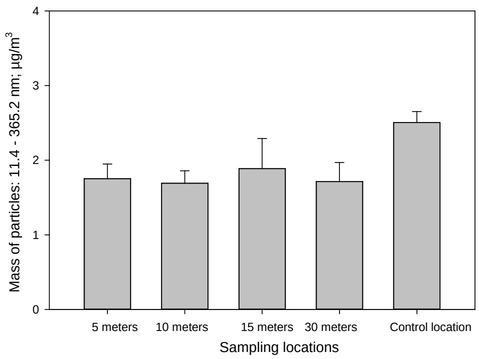


Figure 6. Mass concentration of total particles of 11.4 – 365.2 nm size range during soil moving at a large construction site.

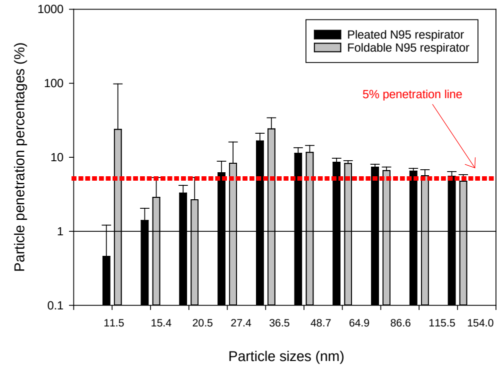


Figure 7. Penetration percentages of particles of 11.4 – 154.0 nm size range during concrete blasting and grinding.

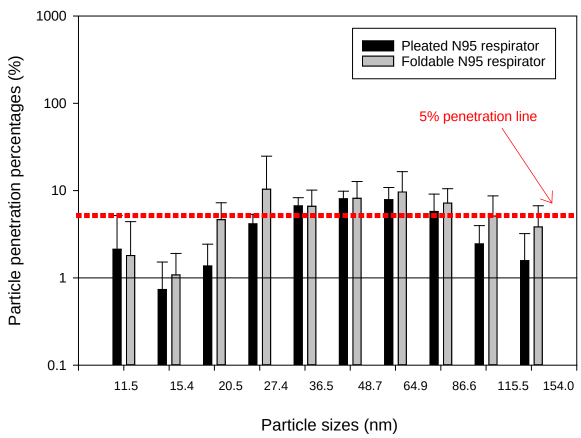


Figure 8. Penetration percentages of particles of 11.4 – 154.0 nm size range during wooden building frameworks construction.

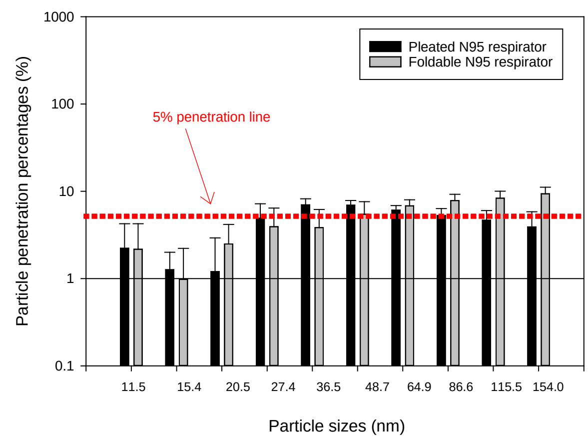
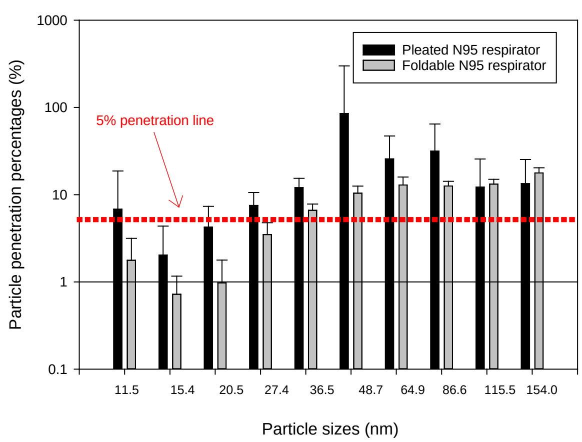


Figure 9. Penetration percentages of particles of 11.4 – 154.0 nm size range during soil moving by bulldozers in a large construction site.



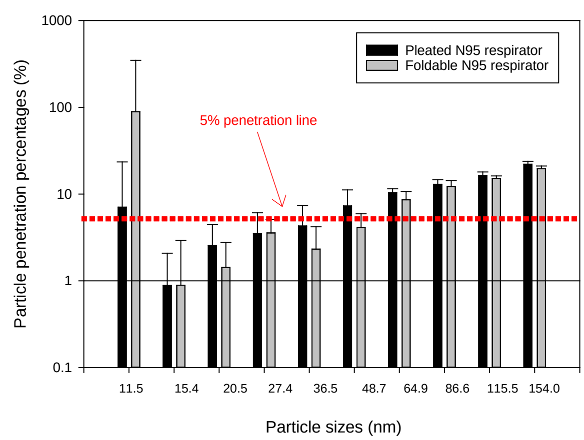


Figure 10. Penetration percentages of particles of 11.4 – 154.0 nm size range in isopropanol treated N95 masks during wooden building frameworks construction.

Figure 11. Penetration percentages of particles of 11.4 – 154.0 nm size range in isopropanol treated N95 masks during soil moving in a large construction site.

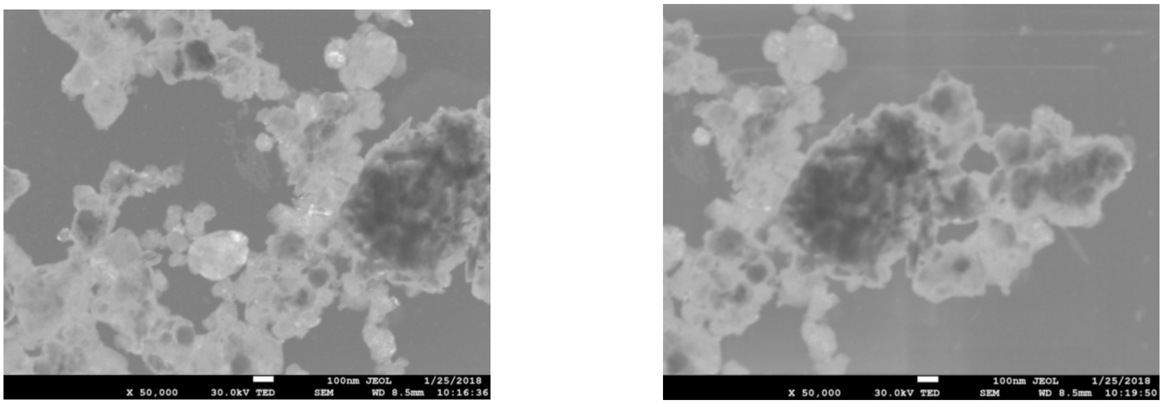


Figure 12. Scanning transmission electron micrographs of nanoparticles and agglomerates collected by the Sioutas impactor at construction sites.

Statistical analyses of data

We have compared mass concentration of total particles at four different distances (5, 10, 15, and 30 m) for all three sites. Because data were not normally or log-normally distributed we have used an independent sample Kruskal-Wallis test for these comparisons and found that data sets are significantly different for the concrete blasting-grinding site ($p = 0.002$) and the wooden building frameworks construction site ($p = 0.046$) but not for the soil moving site ($p = 0.595$). Although high concentration levels of nanoparticles were observed in the investigated construction sites the levels were not always significantly different from the control sites, probably due to other interfering sources because all these control sites were located outdoors.

We have compared particle penetration percentages between pleated and foldable N95 respirators by independent sample t-tests (Q-Q plots showed that most datasets were normally distributed). We found that penetration of particles differ according to particle sizes as well as type of construction activity. For instances, in concrete blasting/grinding site we found greater penetrations of 36.5 nm particle in foldable mask ($p = 0.042$) than pleated mask whereas 86.6 and 115.5 nm particles penetrated more ($p <0.05$) in the pleated mask. 20.5, 115.5, and 154.0 nm particles penetrated more ($p <0.05$) in foldable mask in the wooden building frameworks construction site whereas 36.5, 86.6, 115.5, and 154.0 nm particles penetrated more ($p <0.005$) in foldable mask in soil moving site. Upon isopropanol treatment significantly higher ($p <0.005$) penetrations were observed for pleated masks than foldable masks (20.5, 27.4, and 36.5 nm particles in the wooden building frameworks construction site and 48.7, 64.9, and 154.0 nm particles in soil moving site; concrete blasting site was not tested for this experiment).

Because individual particle penetration datasets were mostly normally distributed (in Q-Q plots), we conducted independent sample ANOVAs for understanding the differences between penetrations of different categories of particles. Except for the foldable mask in the concrete blasting/grinding site all other comparisons showed significant differences between penetration percent levels for different particles ($p <0.005$). In post hoc Scheffe tests, particles subset of 27.4, 36.5, 48.7, 64.9, and 86.6 nm showed significantly different ($p <0.05$) penetration than other particles in the wooden building frameworks construction site for pleated masks whereas particles subset of 11.5, 27.5, 86.6, 115.5, and 154.0 nm sizes showed significantly different ($p <0.05$) penetration trend from other particles in soil moving site in pleated masks. No such significant trends were observed for foldable masks in these two sites and for both pleated and foldable masks in the concrete blasting/grinding site. Interestingly, similar trends were not observed in the isopropanol treated pleated and foldable masks when post hoc Scheffe tests were conducted.

Practical applications

In summary, the completed project addresses the need in methods and techniques for the quantification of protection levels against nanoparticles on various construction jobsites offered by N95 particulate respirators. The scientific data generated over the grant period and the presentations at international, national, and regional conferences, which resulted from the study, will significantly advance the public, workers' and policymakers' knowledge about airborne nanoparticle levels in various construction sites. Our data will also provide new information on most penetrating nanoparticle sizes through N95 masks in field conditions (construction sites), which may be relevant for NIOSH and OSHA for future research and recommendations on appropriate respiratory protections against nanoparticles. The unique findings in this study and challenges are believed to be useful for workers' safety and health issues pertinent to nanoparticle exposures and establishing the linkage between exposure to nanoparticles in work environments and potential respiratory and inflammatory health effects among workers.

Changes/problems that resulted in deviation from the methods

Our purchasing of supplies and initial preparation took longer because we had some problems in finding N95 respirator vendors. In original application, we proposed testing of N95 masks from two manufacturers: (1) AOSafety Pleats Plus, TC 84A-2630, Aero Corporation (previously showed highest fit test rate and reduced 95% infection risk from *Mycobacterium*); (2) Model FR200 Affinity Foldable, TC 84A-3156, Mine Safety Appliance Company (lowest fit test rate and reduced 70% infection risk from *Mycobacterium*). Pleats Plus respirator with NIOSH approval number TC-84A-2630 was not available anymore from the manufacturer and we used a substitute item with NIOSH approval number TC-84A-0007 according to the suggestion of Dr. Bruce Lippy. The second type of N95 mask (FR200) was also unavailable, backordered for several weeks, and we decided to purchase another model of foldable masks, which was also vertically foldable, 42CFR84 approved, and N95 type. In some cases, there was no access to electricity and power within some earthmoving jobsites, especially those located out of town. In those cases, the only available option was switching to other jobsites.

One common problem with conducting experiments at construction jobsites was that in some cases contractors were reluctant to provide access to the jobsite to students due to potential safety hazards and liability issues. We had to deal with this problem in two jobsites. We could solve the issue for one site by speaking with the upper management and simply ignored the other jobsite and switched to other available options. Due to budget restrictions and limited rental duration for the NanoScan (two weeks only), timing and proper scheduling for jobsite visits was challenging for this project. That was the main reason we had to switch to some other construction operations as the operations mentioned in the proposal were not always available then.

One other unexpected issue was the inconsistency between the results obtained from different NanoScan. The PIs discussed this issue with TSI, Inc. and conducted some calibration experiments to modify the results. Calibration data revealed that one scanner was measuring 75% of the other one over a wide spectrum of the particle sizes from the same location when running in parallel. Considering a scanner can deviate between ±20%, a middle ground was chosen. Hence, the particle count in the low measuring scanner was increased by 16.67% and higher measuring particle count was decreased by 12.5%. That is how we generated normalized data which were comparable to each other. Because the limited rental duration of TSI NanoScan forced us to consider available jobsites only we had to change some sites. Three jobsites and two construction activities proposed in the original grant application were changed. During isopropanol treatment experiments, to avoid any adverse effect on mask fiber binders we reduced the immersion time to one minute only (following another paper from NIOSH researchers). All these modifications did not affect the overall objectives of the project. The major goals on data collection, analysis, and interpretation, which were specified in the grant work plan, were achieved, and the project was brought to a successful completion in a time- and cost-effective way within one year. The results were presented at regional, national, and international meetings as scheduled and we are expecting two journal publications later.

Future plans

The current CPWR small study showed that construction workers are often exposed to respirable nanoparticles while involved in tasks as demolition of concrete structures, crushing, drilling, grinding, or sawing concrete, wood or similar material, and during shoveling or soil moving. We found that different construction tasks can release different levels of airborne nanoparticles ranging from 10^3 to 10^5 particles/cm^3. Our field experiments showed that N95 respirators may not provide 95% protection for nanoparticles and foldable N95 respirator masks were found to be less efficient than pleated N95 respirator masks for filtering airborne nanoparticles released at construction sites. Interestingly, we found that filtration efficiency of foldable N95 masks were generally lower for nanoparticles of medium size range unlike smaller sized nanoparticles. This interesting observation stimulated our thought that filtration efficiencies of N95 masks may differ in different construction operations likely due to different environmental conditions and/or physical properties of nanoparticles.

We are interested to follow-up these two research topics in a second CPWR small grant proposal. Electrostatic charge of ions present in work environments may influence penetration of particles. Many previous laboratory studies have shown that ionization can improve filtration for fine and ultrafine particles and some microorganisms, but this was not demonstrated for nanoparticles present at construction worksites. Ionization leads to charging of the particles. In this proposed new small scale study out hypothesis will be: "environmental ions and electrostatic charge and surface electrostatic charge on N95 masks significantly influence protection against aerosolized nanoparticles during various construction related jobs". To address this hypothesis we will propose three specific aims:

Aim 1: Monitoring of airborne nanoparticles and other particles and airborne positive and negative ions during various construction activities at three construction sites.

Aim 2: Measurement of surface electrostatic charge on N95 masks during various construction tasks and also at various environmental conditions (relative humidity, temperature and wind levels) and evaluation of penetration levels of nanoparticles.

Aim 3: Analysis of the statistical associations between penetration of nanoparticles/submicron particles and surface electrostatic charge and airborne positive/negative ion levels.

In our current study we found that foldable N95 respirators were less efficient than pleated N95 respirators in filtering nanoparticles and ultrafine particles mostly in the soil moving site and the wooden building framework construction site. This trend was, however, not observed on the concrete blasting/grinding site possibly due to different electrostatic and physical properties of nanoparticles generated in this site. We believe the data collected through this new proposed research will enable us to explain these differences in nanoparticle filtration efficiencies between different respirator models when those are used in actual jobsites. This data will be valuable for designing improved respirator masks for protecting construction workers from airborne nanoparticles at different adverse environmental (e.g., heat stresses) conditions in constructions jobsites.

In the current pilot study we did not find consistent significant differences between nanoparticle levels in work sites versus control sites possibly due to multiple sources of nano-aerosols in outdoors. Therefore, disaggregating the task-specific nanoparticle exposures is a challenging issue. To address this inherent problem we may conduct simulated laboratory experiments where similar tasks will be repeated in the GSU Soil mechanics and Construction Technology Laboratory and release of nanoparticles can be analyzed separately in control experiments. Comparison of these data should resolve this problem as much as possible. Additional respirator laboratory testing under these controlled lab conditions will provide better understanding of the multiple potential interferences present in actual work sites.

List of presentations/publications

As of now, the data collected through this project were presented at two national and regional conferences and one international conference. The list of these presentations are provided below:

1. Adhikari A, Rashidi A, Schwartz J, Ekpo I, Pawlak A, Doehling J, Lewis S, Mitra A. A pilot study on nanoparticle levels and field evaluation of N95 respirator masks in construction sites. National Conference on Worker Safety & Health (COSHCON17), 2017, Baltimore, Maryland.

2. Ekpo I, Doehling J, Rashidi A, Mitra A, Pawlak A, Lewis S, Schwartz J, Adhikari A. Exposure to nanoparticles including submicron silica dust in a construction site during concrete blasting. 2017. The Society of Environmental Toxicology and Chemistry (SETAC) Southeastern Region 15th Annual Meeting, Brunswick, Georgia.

3. Adhikari A, Mitra A, Rashidi A, Ekpo I, Doehling J, Pawlak A, Lewis S, Schwartz J. Wood dust and nanoparticle exposure among workers during a new building construction. ICOHS 2018: 20th International Conference on Occupational Health and Safety, Miami, Florida, March, 2018.

4. Mitra A, Rashidi A, Lewis S, Doehling J, Pawlak A, Schwartz J, Ekpo I, Adhikari A. Nanoparticle exposure levels in indoor and outdoor demolition sites. ICOHS 2018: 20th International Conference on Occupational Health and Safety, Miami, Florida, March, 2018.

5. Schwartz J, Durach M, Mitra A, Rashidi A, Sage G, Adhikari A. The effects of Stoke's drag, electrostatic force and charge on penetration of nanoparticles through N95 respirators. ICOHS 2018: 20th International Conference on Occupational Health and Safety, Miami, Florida, March, 2018.

<u>Journal publications</u>: We are expecting two journal publications from the findings of this project. The manuscripts are currently in preparation. We are planning to submit these manuscripts to *American Journal of Industrial Medicine* and *Annals of Work Exposures and Health*.

Dissemination plan

We have already disseminated project findings in some regional and national meetings/ conferences. For example, SETAC (Society of Environmental Toxicology and Chemistry)

Southeastern Region organized their 15th Annual Meeting in Brunswick, Georgia on September 28-30, 2017 and held a competition for student presentations. Ms. Imaobong Ekpo, a JPHCOPH Environmental Health MPH student and Mr. Jefferson Doehling, a Mechanical Engineering student from our research team received second place award for the poster presentation titled: Exposure to nanoparticles including submicron silica dust in a construction site during concrete blasting. Field data presented in this poster showed that workers were exposed to not only large particles but high levels of nanoparticles. The data showed that exposure to nanoparticles and submicron silica dust during construction activities like concrete blasting can be expected irrespective of proximity to the construction event.

Dr. Atin Adhikari attended COSHCON17 (National Conference on Worker Safety and Health 2017) on December 5-7 in Baltimore and presented a poster entitled, "A pilot study on nanoparticle levels and field evaluation of N95 respirator masks in construction sites". This conference arranged 45 interactive workshops on a wide range of topics including legal rights under OSHA, how to organize successful worker safety and health campaigns, strategies for policy advocacy, chemical hazards, and many other training topics for safety activists. Many construction workers participated in this conference and Dr. Adhikari disseminated the study findings with them and also explained why some respirator masks may not provide them adequate protection against nanoparticles in construction jobsites.

Drs. Mitra and Adhikari attended 20th International Conference on Occupational Health and Safety, Miami, Florida on March 12-14, 2018 and they have explored all dissemination pathways in the conference. The presentations were prepared in a reader-friendly manner and discussions were engaging for the conference participants.

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