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Current Best Practices for Handling Inorganic Nanoparticles Waste in a Laboratory Setting

Tracy M. Mattox*, Carleton Falzone, and Jeffrey J. Urban*

Molecular Foundry, Lawrence Berkeley National Laboratory, USA

***Corresponding authors**

Tracy M. Mattox, Molecular Foundry, Lawrence Berkeley National Laboratory, One Cyclotron Rd, Berkeley, CA, 94720, USA, Tel: 510-495-2649; Fax: 510-486-6166; Email: tmmattox@lbl.gov

Jeffrey J. Urban, Molecular Foundry, Lawrence Berkeley National Laboratory, One Cyclotron Rd, Berkeley, CA, 94720, USA, Tel: 510-486-4526; Fax: 510-486-6166; Email: jjurban@lbl.gov

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Abstract

Nanoparticles-based products are becoming very popular for consumers, however, consumer adoption has outpaced a full understanding of the potentially new safety concerns that these materials can present. As particle size is decreased, irrespective of any chemical changes, the particles themselves can become easier to liberate into the ambient atmosphere and therefore carry an enhanced inhalation concern. Although a thorough understanding of the hazards associated with nanoparticles is nuanced and will take decades of devoted research to achieve, it is most prudent to protect researchers from unstudied hazards by developing custom engineering controls and safe waste handling practices. This work goes beyond common personal protective equipment to describe how researchers can set-up fume hoods and glove boxes to help mitigate the unknown dangers associated with nanoparticles. We treat all engineered nanoparticles as if they are hazardous in every research lab, and explain current best practices and our institutional norms for handling nanoparticle waste in a way that minimizes potential exposure and keeps laboratory air pristine.

ABBREVIATIONS

NP: Nanoparticles; NPW: Nanoparticles Waste; SAA: Satellite Accumulation Area

INTRODUCTION

Nanoparticles (NPs) are particles that are 1-100nm in size in two or more dimensions. Over the past decade, they have become ubiquitous in commercial applications as varied as sunscreens, makeup, window coatings, solar panels, and cookware. The nanoscale dimensions of NPs can drastically change a material's physical properties compared to the same material in bulk sizes, making them intriguing in many respects. Unfortunately, researchers are just starting to understand the environmental and health impacts of using these tiny particles. For example, silver NPs are thought to support the immune system with their antimicrobial properties [1] and are sold in health food stores simply as "colloidal silver," but ingestion of silver is known to cause argyria [2]. Silver NPs can also be detrimental to human health [3] and interfere with nitrification in water systems [4]. Carbon nanotubes are popular because of their unusually high thermal conductivity, and as electronic devices become increasingly small nanotubes offer a solution to prevent damage to devices from overheating [5]. However, carbon nanotubes have also been shown to exhibit asbestos-like pathogenicity [6]. Quantum dots are another example of useful NPs and are semiconductors with interesting electronic and optical properties. Lead sulfide in particular is of interest for photoelectrochemical devices [7], yet it is extremely toxic and can be absorbed by the bone and kidneys [8]. The list of intriguing applications for NPs goes on, and unfortunately so do studies on their health hazards. However, more research is needed to establish whether it is the nanoscale dimensions themselves, the surface chemistry, aspect ratios, or other factors that are responsible for these potentially deleterious health effects. NP science has grown exponentially in recent years and new properties are being explored at a staggering rate, but studies on health and environmental impacts lag behind.

Common research practices like injection molding [9] and sonication [10] easily aerosolize NPs and increase researcher exposure to potentially harmful materials. Fortunately, this topic is gaining momentum and new assessments on workplace NP exposure continue to emerge [11]. This further highlights the importance of working to reduce the release of NPs into the breathing environment in research laboratories, where the very nature of the work puts researchers at higher risk of exposure than the general public.

Regardless of the NP-based products already on the market, how do researchers protect themselves from their newly developed NPs when they have no clue about the associated hazards? NPs have to be synthesized before they can be tested for toxicity after all. The goal of this perspective is not to focus on studies of potential health problems, but to present our thoughts on safe practices for handling nanoparticle-waste (NPW) in a research laboratory environment. This article highlights steps we have taken at the Molecular Foundry, a User Facility at Lawrence Berkeley National Laboratory that specializes in the science and discovery of nanoscale materials, to mitigate potentially unhealthy exposure to Inorganic NPW when the hazards are unknown. We detail and explain fume hood flow rate optimization, best practices for organizing work space and glove box setup to safely manage the handling of NPW.

DISCUSSION

Regardless of the hazards of the reactants in chemical reactions, it is extremely important for researchers to know that the hazards of the NPs they are making are not fully understood. As such, it's important to treat new NPs as hazardous materials and to design methods and best practices to ensure that NPW is carefully handled in a way that minimizes potential exposure.

As a User Facility, we work with researchers from a wide range of scientific and safety backgrounds, so have found it necessary to develop and implement safe practices for the handling of NPW. We have strict guidance that all Inorganic NPs must be synthesized within a fume hood or glove box to help ensure that the lab's breathing space remains clean and free of engineered NPs, and all NPW is properly enclosed prior to collection by the on-site hazardous waste group. This paper outlines measures that can be taken when developing a lab space to help minimize exposure to NPW beyond standard personal protective equipment[12], focusing on keeping NPs out of the lab's breathing environment by properly outfitting and monitoring constant velocity fume hoods and inert atmosphere glove boxes. Our hope that these methods and thoughts on lab set-up will help researchers develop better or improve upon existing NPW-handling practices to keep their lab air NP-free.

FUME HOOD SET-UP

When handling NPs and NPW in a fume hood the air flow is crucial. Fume hoods can leak when the hood's face velocity is too low, but maintaining a velocity of 80–120 ft/min prevents leakage of NPs into the breathing zone (Figure 1) [13]. Traditional constant-flow fume hoods can release a significant amount of airborne NPs into the breathing zone of workers, especially when the hood sash is fully open or when there is a lot of air movement in the lab environment, because the rate of the air flow velocity is not maintained when the sash is moved [14]. As a result, there is typically one safe position (typically mid-height or lower, Figure 1) in which the fume hood is at optimum flow and is safest to use. Constant-velocity fume hoods, by contrast, automatically adjust to maintain the same airflow regardless of the sash height, [15] though a fully open hood sash is not ideal as it requires a lot of energy to maintain the velocity, straining building ventilation systems. Given the wide background of researchers in a User Facility, all of our fume hoods are of the constant-velocity style, which don't require constant attention to airflow when Users are adjusting the sash height (Figure 1).

It is commonly recommended that fume hoods operate at a velocity between 80-120 ft/min, and it has been shown that when handling NPs a constant velocity of 100 ft/min is enough to prevent NPs from leaking into the breathing zone [13]. At this velocity there is also little impact when arms enter into the fume hood work space [15]. As a result, all fume hoods in the Molecular Foundry are maintained above 100 ft/min.

Even at ideal velocity it's possible for NPs to enter into the breathing zone if researchers don't take care with handling. Figure 2A illustrates how NPs and NPW move in a fume hood. When a container holding dry NPW is at the front of the hood (closest to the researcher), NPs can enter the breathing zone because the air flow pattern changes. This is why we have a strict policy that researchers should not clutter their work space or block the threshold (space below the sash). NPW should ideally be placed toward the back of the fume hood, but with airflow patterns the middle is also safe. Colloidal Inorganic synthesis usually requires the use of a Schlenk line and hot plate/stirrer, which take up hood space and moves NPW and the reaction itself toward the front of the hood. This was taken into account in our facility so the fume hoods were designed to be six inches deeper than is standard. As a result, a Schlenk line can be mounted on a rack in the back of the hood while leaving room for chemistry and NPW to reside in the middle of the hood. There is easily enough space for NPW containers (for solids, solvents, and sharps) to sit directly next to or next to and behind any ongoing chemical procedures (Figure 2).

GLOVE BOX DESIGN

When a fume hood is not practical for the relevant chemical procedure, NPs may alternatively be synthesized in an inert atmosphere glove box. Though the use of a fully contained glove box as a safety measure may seem obvious when dealing with NPW, it's important to highlight that they are not foolproof, and active measures must be taken to help maintain a safe breathing environment in the lab space. Figure 3 is an illustration of the glove box setup that we use for NP syntheses, highlighting extra measures taken to minimize potential NP exposure. Glove boxes

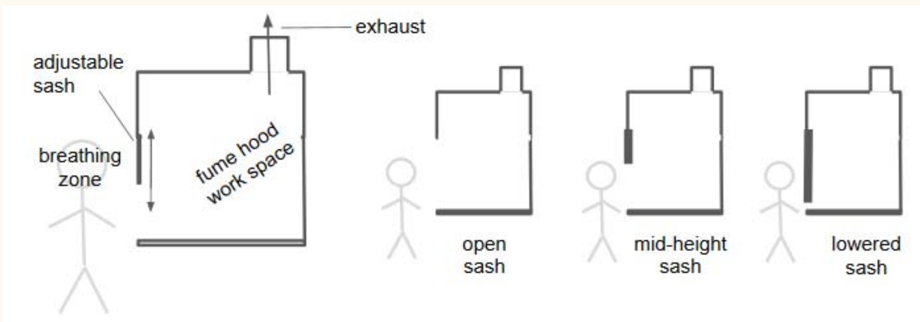

Figure 1 Cartoon depicting a chemical fume hood showing breathing zone, sash heights, and work area.

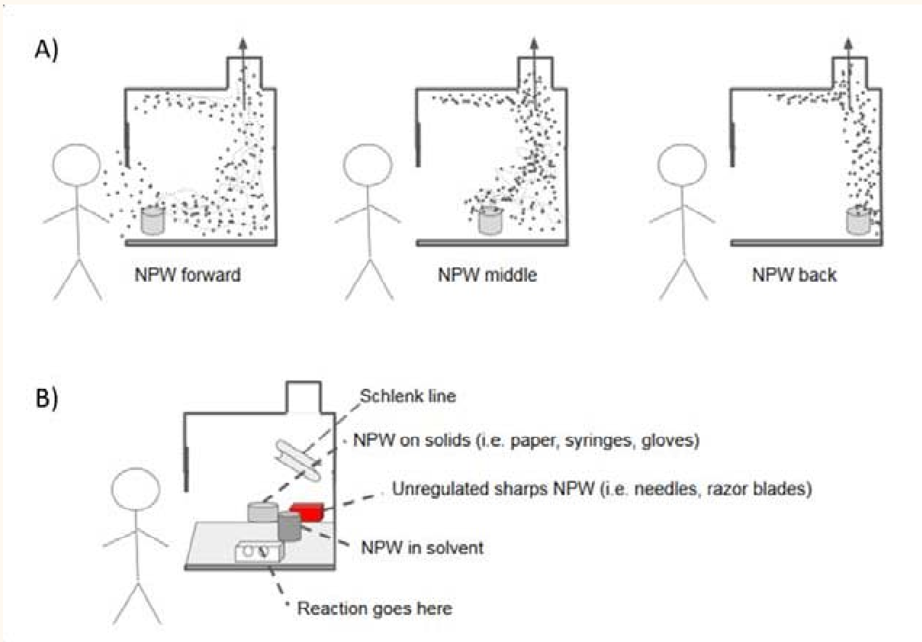

Figure 2 A) Movement of NPs from NPW in fume hood dependent upon location of container (forward, middle, or back) and B) typical set-up of a fume hood for Inorganic NP synthesis including Schlenk line, reaction set-up, and NPW containers.

should be equipped with a filtration method to prevent NPs where possible from traveling beyond the glove box. We rely on HEPA filters on the exit points of every box to accomplish this, as this filter type has proven effective down to sub-10nm particle sizes [16]. As an extra precaution the vacuum pump and purge valve outlets connect directly to the house exhaust system, which has been shown to be effective in removing NPs from the air [17-19], so there is no exposure to the lab space. Though sometimes overlooked, the regeneration of the catalyst also has the potential to release NPW into the lab air, so the output from every regeneration is collected in a closed jar that is also plumbed directly to the building exhaust system. The last potential point to mention is that the antechamber door, which is the only access point to move samples in and out of the box, by necessity, opens into the lab space and has the potential to release NPW into the lab air. To prevent NPs from moving into the lab air, every antechamber has a snorkel installed directly above the antechamber door that maintains the same >100 ft/min velocity as the fume hoods. The snorkels are connected directly to the building exhaust system and prevent NPs floating freely in the glove box from entering the breathing space of the lab when opening an antechamber door. Cartoon is drawn from the perspective of looking directly at the face of the glovebox. Star designates connections made directly to the building exhaust system (Figure 3) [20].

NPW COLLECTION

When working with NPs either in a fume hood or glove box, it is important to minimize the potential of the NPW generated from getting into the breathable airspace of the lab. To help ensure safe work practices, we teach common best practices to all Users working within the lab. Surfaces with nanoparticles present are wiped with a wet towel (dryer NPs are easier to aerosolize) and the cleaning towel as well as any solids with the potential of containing residual NPs (e.g. gloves, kimwipes, used plastic syringe plungers, etc.) are collected in a small sealable bag. NP-contaminated sharps are placed in unregulated sharps boxes with sealable lids. At the end of the day or completion of the NP reaction, the containers are sealed in the fume hood or glove box, properly labeled, and placed in a satellite accumulation area (SAA) to await waste pick up. Any NP-containing solvents are collected in a bottle next to the synthesis being performed and once the reaction has been completed the NP-containing solvents are transferred in the hood or glove box into an acceptable waste container, then properly labeled and placed in a SAA to await picked up by the waste group. Sealing NPW containers and pouring NP-containing solvents into waste containers only within a glove box or fume hood ensures that safety measures designed for these work spaces are utilized and there is little chance of NPW entering the breathing space of the lab (21-23).

There are many more operations with the potential to release NPs into the research lab air, such as sample transfer between work spaces, stirring speeds, and the quantity of NPs being handled. Though we focus here solely on safe practices for NP handling in glove boxes and fume hoods, maintaining a safe breathing environment within a research lab remains a very complex issue.

CONCLUSION

This paper describes NPW-handling methods to keep NPs, with their unexplored hazards, out of lab air. Constant velocity fume hoods operating > 100 ft/min are ideal for keeping NPs out of the breathing zone, and designing reaction set-ups to keep reactions as well as NPW away from the fume hood threshold help ensure a safe lab environment. Furthermore, taking care to minimize potential access points where glove boxes can transfer

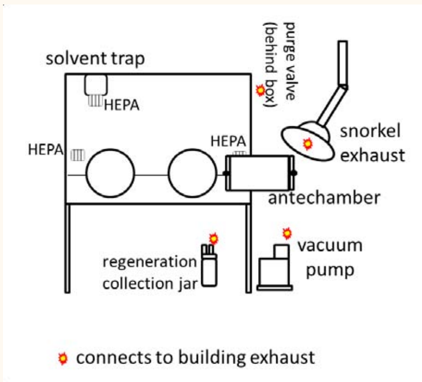

Figure 3 Diagram showing recommended glove box set-up to minimize NP exposure at the Molecular Foundry.

NPs into the air as well as ensuring NPW is completely sealed prior to disposal help keep even inexperienced researchers safe in a NP research environment. Instilling good habits and developing engineering controls will help keep researchers healthy and able to find the next amazing innovations in nanoscience.

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