THE CHALLENGE OF CAPTURING SMALL PARTICLES DURING REMEDIATION PROJECTS

A March 2018 addendum to the white paper entitled:
The Importance of Dust Control during Construction and Remediation Projects[1]

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INTRODUCTION

In March of 2017, a white paper was released for the construction, cleaning, restoration, and remediation industries. That paper defined what dust is both historically and how it has changed since the dawn of the "chemical age." It also described current dust management strategies including: containment through the installation of isolation barriers, creation of negative pressure inside the work area, utilization of HEPA filtration, use of dust collection systems at the point of dust generation, detailed cleaning of surfaces, and methods for cleaning the air inside the work area.

The information was deemed useful enough that it was published in a modified format in the summer 2017 edition of the *Journal of Cleaning, Restoration, and Inspection*[3].

Figure 1: Image of the summer 2017 issue of the IICRC publication the *Journal of Cleaning, Restoration, And Inspection* showing that dust control was the primary/cover article for that edition.

The broad scope of the original white paper led to a wide variety of feedback. The substantive response, both direct and through a number of industry forums and social media platforms, confirmed the usefulness of the information for a number of different industry segments including construction and professional cleaning. Within that broad-based

response, it was clear that the potential impact of many of the concepts discussed in the white paper was greatest, by far, on the restoration and remediation industry.
Specifically, many of the comments involved the discussion of the common experience of mold or infection control contractors of "failing" different sorts of projects even when past performance and a post-work visual inspection indicated that the work area was "clean." The frequency of this phenomenon led to the supposition that residual contamination in the air was causing the problem directly if air samples were utilized or indirectly. This would contribute to the contamination of clean surfaces after the work activities were completed when surface samples determined the outcome.

The same thread of conversation also occurred in various training classes, industry association presentations, webinars, and seminars. For example, at the 2018 annual conference for the Indoor Air Quality Association (IAQA), one of the best attended technical sessions was entitled: *How Do Particles Get Removed to Get Cleaner Air?*

Two important sub points emerged as part of the response to the dust control white paper. A growing awareness of the ill health effects of small particles, regardless of their source or make up, is a clear driving factor in minimizing such contamination during working buildings. The other primary area of interest was the description of new technology that can be used to address the control of small airborne particles and some measure of the effectiveness of such products, equipment, and work practices. It was the interest in these two sub points that led to the development of this addendum.

SMALL AIRBORNE PARTICLES ARE DANGEROUS

The original white paper introduced the term "particulate matter"[4] since the Environmental Protection Agency (EPA) uses this term to distinguish materials that stay suspended in the air as compared to "coarse dust" which quickly precipitates out. Particulate matter (PM) can be further subdivided by size with PM 10 which describes particles smaller than 10 microns (µ) in diameter and PM 2.5 representing the smallest particles with a diameter of less than 2.5 µ.

Interestingly, the EPA utilizes a very broad, and somewhat unusual, definition of particles. In many of their explanatory documents, the Environmental Protection Agency describes particulate matter as “the term for a mixture of solid particles and liquid droplets found in the air[5].” The interesting part about this is, from a pure science standpoint, liquid droplets in the air are not classified as a "particle" but as a "vapor[6]." This inclusion of water droplets in the definition of particulate matter is likely prompted by the fact that as water vapor condenses into actual droplets, it requires a "condensation nuclei"[7] to form around. These
tiny particles not only pose a problem from the health perspective but can also have a negative impact on the restoration contractor in regards to their cleaning efforts.

The EPA makes it clear that small airborne particles, particularly in the PM 2.5 range, are a health hazard. One of their general public information pieces puts it quite bluntly[8]:

Exposure to such particles can affect both your lungs and your heart. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including:

- *premature death in people with heart or lung disease*
- *non-fatal heart attacks*
- *irregular heartbeat*
- *aggravated asthma*
- *decreased lung function*
- *increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing.*

Nor is the EPA alone in their assessment that small airborne particles are dangerous. The World Health Organization is as frank in their discussion of the issue[9]:

PM10 and PM2.5 include inhalable particles that are small enough to penetrate the thoracic region of the respiratory system. The health effects of inhalable PM are well documented. They are due to exposure over both the short term (hours, days) and long term (months, years) and include: respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions; mortality from cardiovascular and respiratory diseases and from lung cancer. … There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur.

Even innocuous small particles can cause health problems, but when the small particles are known hazards themselves, the importance of removing them from the air is magnified. Typical restoration activities liberate small particles from a variety of known contaminants including asbestos, lead, silica, mold, and microorganisms from water losses. Both the physical and legal threats to contractors who inadvertently disperse such contaminants are significant enough that control of such particles has led to the introduction of a variety of new methods and products for contractors to reduce these concerns.

WHY SMALL PARTICLES ARE A PROBLEM FOR REMEDIATION PROJECTS

There is no denying that technology has advanced rapidly over last 20 years, especially in the construction and restoration industries. New tools and techniques are entering the industry every day which claim to offer greater efficiency, but also tend to have their own drawbacks.

A very visual example of this change can easily be seen by looking at the evolution in the approach to removing gypsum board from a structure. Whether it is a section of the ceiling that has to be cut out because of water pooling on top from a pipe leak, a wall section that needs to come out because of mold contamination, or a hole that has to be cut to provide access to a mechanical component, the process requires that a number of cuts be made in the existing finish material. Just a few years ago the choice of tool and work procedure was pretty simple for such a project. The worker would either grab a razor knife or a drywall saw from the toolbox and start hacking away. In an effort to improve the efficiency of such work, contractors started using reciprocating saws to do the job -- the ever handy “sawz-all.” But the danger of a mistake with a reciprocating saw, cut water or electrical lines from blades angled in too deep, prompted the development of heavy-duty roto-zip tools for such tasks. Even this advancement was soon eclipsed by the introduction of oscillating cutting tools.

Each step of the way, the tool made it easier to complete the task. However, an unintended side effect was that the nature of dust created during the process changed dramatically. The razor knife or drywall saw produces a lot of chips and coarse dust during the cutting process. Progressively finer dust particles are created as you move from the reciprocating saw, to the roto-zip, to the oscillating cutting tool. Interestingly, the oscillating cutting tool operates at such high speed and produces such small particles that a significant percentage of the dust being created may not be visible.

Whether initially visible or not, dust in the air will be noticed in terms of fall-out on surfaces and its impact on health. The changes in cutting technology have spurred other changes as well. Dust barriers have migrated to isolation barriers. Negative pressure has been added to the mix to keep particles from migrating to non-work areas. HEPA-filtered vacuums and air scrubbing equipment have been added to eliminate the recirculation of dust once it has been directed to the capture device (negative air machine). Still, these efforts have not been completely successful.

UNDERSTANDING THE AIRBORNE DYNAMICS OF SMALL PARTICLES

For bigger particles, the shape and substance of the material can play a role in their dispersal through the air. Asbestos fibers, for example, tend to stay airborne much longer on average than coarse dust from lead containing paint. However, when the particles are smaller than sub-micron size, the weight and shape of the aerosolized material are not as great a factor in how the particles react in the air. Soot, bacteria, mold spore fragments, mycotoxins, allergens, gypsum dust, paint droplets, and an endless variety of other materials float in the air and do not necessarily precipitate out through the normal process of gravitational settling[10].

From a practical standpoint this means that the standard remediation techniques of waiting after the completion of the project before sampling, or even air scrubbing, may not be effective in addressing the concentration of small particles in the air. Numerous mold remediation contractors have learned this the hard way. Re-cleaning multiple times on some projects, have been ordered when surface samples are clean but samples in the breathing zone recover unacceptable levels of spores. In such instances, it is no surprise that the problem spores often fall into the category of "*Aspergillus/Penicillium* type" as these are some of the smallest and aerodynamically active type of fungus[11].

Even if the contractor has put up isolation barriers and is utilizing negative pressure to minimize escape of contaminants to the *outside* of the work zone, such safety measures may not be enough to ensure the removal of small particles from the air *within* the work zone. This difficulty in removing small particles from the air is a result of a combination of factors including:

- poor capture efficiency of negative air machines at even a few feet away from the intake
- a lack of air movement inside the work area leading to the creation of “dead spots”
- vertical stratification

ADDRESSING THE PROBLEMS RELATED TO REMOVING SMALL PARTICLES FROM THE AIR

Remediation contractors trying to control airborne contaminants of any size using a negative air machine in their work area are impacted by some of the basic laws of physics. One of the primary principles used in the ventilation design field is the concept of "capture velocity.” In essence, to reach capture velocity, enough air has to be moving at the right speed in order to get the aerosolized particulate matter to move to the intake of the negative air machine. But most remediation professionals do not understand that to capture suspended particulate matter, air volume requirements increase based on the square of the distance rather than in a one-for-one pattern[12]. Figure 2 provides both an illustration and a mathematical example in why the physics principle of capture velocity is important in everyday remediation situations. It shows the relationship between distance and air flow requirements necessary for capture velocity.

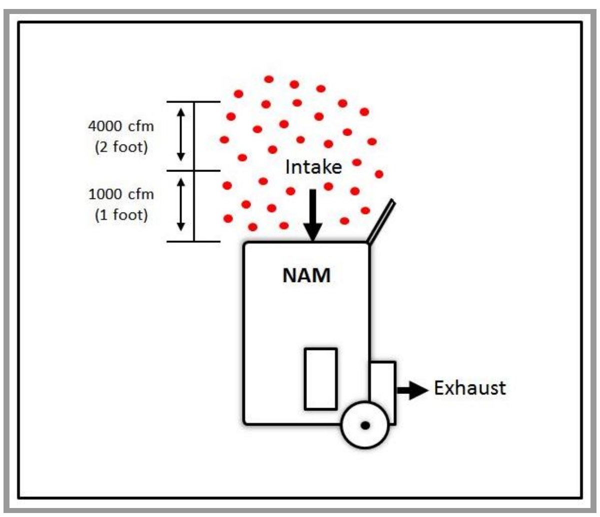


Figure 2: Illustration of the principle of capture velocity for particulate matter too small to be significantly influenced by gravity. As the particle distance from the intake of the negative air machine (NAM) doubles the air requirement quadruples. For example, if 1,000 cfm is needed to get a small particle into the filters from one foot away it will take 4,000 cfm from two feet away.

The physics make it clear that negative pressure alone is not enough to get most suspended particulate matter in the room to the face of the negative air machine where it can be trapped on the various filters. That is why remediation classes should also emphasize the importance of air flow to improve the conditions in the work area. It is not enough to have a room with tightly sealed isolation barriers and a negative air machine exhausting to the out-of-doors if there is little makeup air that is allowed in. Just as important, the makeup air has to be controlled and directed in a fashion that provides the most benefit to the project.

The most efficient contamination control occurs when a thoughtful setup of the work area intentionally produces an air flow that comes in from the decontamination chamber and runs past the areas where the most significant work will occur before migrating toward the intake of the negative air machine. In such cases, the airflow supplements the limitations of the capture velocity of the standard negative air machine by moving some of the particulates to the point where the capture velocity takes over. Figure 3 provides a visual representation of the process.

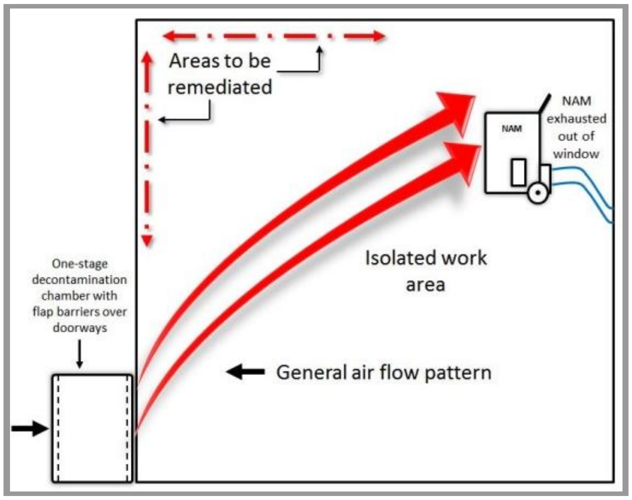


Figure 3: Standard set-up of engineering controls for a negative pressure enclosure to minimize migration of airborne contaminants. Both negative pressure and properly directed airflow are necessary to keep airborne contaminant levels low.

DEAD SPOTS CAN BE DEADLY TO THE SUCCESS OF THE REMEDIATION PROJECT

Given the limitations of the negative air machine to capture small particles from anything more than a foot or two from the intake, air movement is necessary to *push* the particulate matter toward the front of the NAM so that the suction close to the opening can take over and *pull* the small aerosols into the unit. This combination of a push/pull system being the most efficient for small particles is well known and utilized in industrial facilities for downdraft tables and surgical suites in medical facilities. Figure 4 illustrates the general mechanics of this push/pull approach; also known as laminar flow.

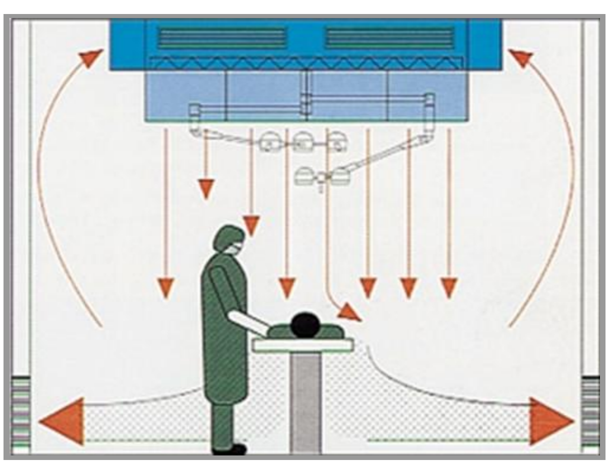


Figure 4: Diagram of a typical air flow system in an operating room. To make sure that microscopic contaminants such as bacteria and virus do not infect a patient, clean air is provided from the top and pushed down over the occupants. The majority of the air is then pulled back toward the floor level return air vents.

The difficulty with remediation projects as compared to industrial or medical situations is that the setup of a remediation work area is different every time. The variability in the setup makes it almost impossible to have a push/pull system for the air which evenly covers the entire space. As a result, there are many areas of the negative pressure enclosure that are not in the direct path of the airflow. These areas where there is little air movement are known as "dead spots." Even negative pressure enclosures with relatively simple configurations tend to have a number of dead spots as shown in figure 5. The effectiveness of the push part of the push/pull process for removing small particles is further compromised in real world scenarios by oddly shaped rooms, obstructions such as freestanding kitchen islands, and ceiling fans or light fixtures.

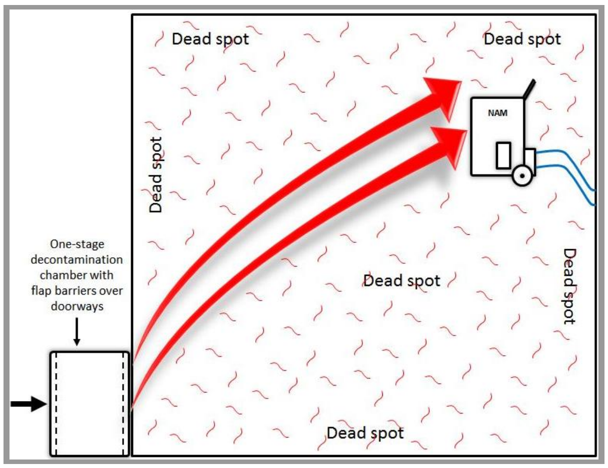


Figure 5: Typical 'dead spots' in a negative pressure enclosure. Even setting up the enclosure so that the air coming in from the decontamination chamber moves across the area where the most dust will be created leaves quite a few areas where air movement is negligible.

In an effort to eliminate dead spots, many remediation contractors have adopted a procedure where they adjust the setup of the engineering controls in the enclosed work area after the primary dust-producing activities (such as demolition and gross cleaning) are completed. At the point where the final cleaning activities are about to commence, some or all of the negative air machines are reconfigured so that the exhaust is no longer directed outside of the work area. Instead, air is brought into the intake, pulled through the two or three levels of filtration (including a HEPA filter), and exhausted back into the room. Figure 6 uses the same example layout of the work area as shown in figures 3 and 5 to illustrate the simple difference that changes the layout from a work area focused on the benefits of negative pressure compared to the advantages that may come from air scrubbing.

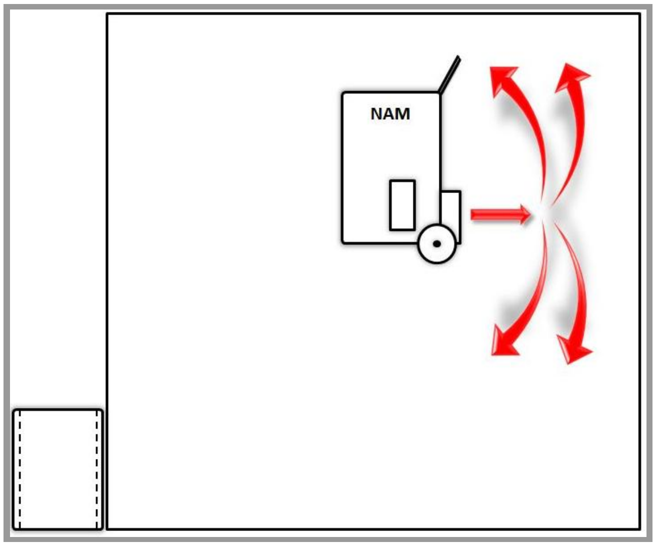


Figure 6: Air scrubbing can be accomplished inside a negative pressure enclosure by allowing the exhaust of the NAM to recirculate in the work area.

This process is known as "air scrubbing" because it significantly reduces the amount of makeup air brought into the work zone and allows more of the air to be recirculated through the filters of the NAM. It is important to note that no special, or different, equipment is necessary. Every HEPA-filtered negative air machine is also an air scrubber; the difference in terminology is based strictly on the setup of the machine, not the type or brand.

It is also critical to remember that adjusting the setup of the work area to move completely from negative pressure to air scrubbing may violate certain state regulations or put the contractor outside of the current industry standard of care for mold remediation. Many regulations, guidance documents, and individual project specifications require the use of negative pressure enclosures. The language of these documents typically indicates that the work area is to be kept under negative pressure until an inspection and/or sampling proves that the predetermined clearance criteria have been met. Therefore, it is standard practice to migrate some of the negative air machines from exhausting outside the work area to recirculating air inside as air scrubbing but at least leaving one machine in the negative pressure configuration. This combination approach maintains some level of negative pressure while adding the benefits of air scrubbing. It does, however, force the use of at least two machines, even on the smallest of projects.

Even employing the process of air scrubbing does not necessarily address all of the issues with dead spots. If the exhaust air is just allowed to escape from the negative air machine in an unrestricted fashion, it produces a column of air reminiscent of the exhaust from a jet engine. The air leaving the machine is focused in a single direction and moving at a high speed. This airstream will bounce around when it encounters an obstruction. There is no guarantee that the air patterns created will result in any less dead spots than were present when the work area was under negative pressure.

To improve the circulation of the air around the enclosure, a diffuser or "tail" can be added to the exhaust of the NAM. Figure 7 provides an example of how a diffuser can be quickly and inexpensively constructed using disposable plastic tubing. Such a diffuser is constructed by attaching one end of a long piece of tubing[13] to the exhaust port to the machine. The opposite end of the plastic is sealed by rolling and taping, stapling, or tying the tube in a knot. Once the NAM is turned on, it is easy to take a razor knife or other cutting tool and slice half-moon cuts into the tubing all along its length. This process allows the exhaust air to be diffused gently in a lot of different areas[14]. Pushing the air in so many different directions increases the likelihood that some of the small particles will become entrained in that airflow and move toward the negative air machine where they can be removed by the filtering process.

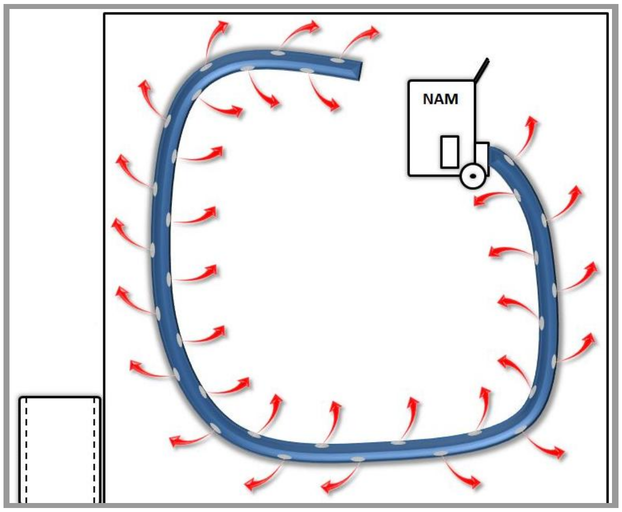


Figure 7: Improving air scrubbing by adding a diffuser tail to the NAM exhaust. Typically, disposable plastic tubing, often referred to as "lay flat", is attached to the exhaust of the NAM. Rather than letting all the air shoot down the hose and out the end, the plastic is sealed and a half moon shaped slices are put into the lay flat along its length.

REMEMBERING THAT THERE ARE THREE DIMENSIONS, NOT TWO

Understanding the limitations on small particle removal inherent due to physics of capture velocity and the development of dead spaces even when a push/pull airflow system is involved, indicates that air scrubbing should take care of the problem. The difficulty is we live in a three-dimensional world of length, width, and height rather than the two-dimensional diagrams utilized to explain critical concepts in figures 2-7. The height of the workspaces can lead to an additional challenge for small particle removal known as "vertical stratification."

Simply put, vertical stratification is a phenomenon where small particles in the remediation work space are cleansed from the lower section of the work area through a combination of airflow and capture velocity, but not from the upper portions of the enclosure. Sealing supply and return vents located in the upper parts of the room as part of the isolation of the space contributes to the problem; as does the fact that a majority of work in remediation projects is done from head height down to the floor.

One of the main reasons that this stratification occurs is that the smallest of the particulate matter is not impacted to a substantial degree by the forces of gravity. They are so small and aerodynamically active that the smallest particles that are prone to going deeper into the lungs if inhaled are not necessarily going to end up on the floor by gravitational settling. Even if they do happen to get close to a moving air stream, their lighter mass means they will not necessarily get swept into the air current and moved toward the intake of the negative air machine. The lower-level turbulence may actually result in the small particles "bouncing" away from the faster moving air. This principle is so well known that it is employed in sampling devices designed to capture only small particles, such as those that fit the PM10 definition for pollution monitoring[15]. Figure 8 illustrates the concept of the vertical stratification inside a typical negative pressure enclosure after the larger, heavier, particles have precipitated out.

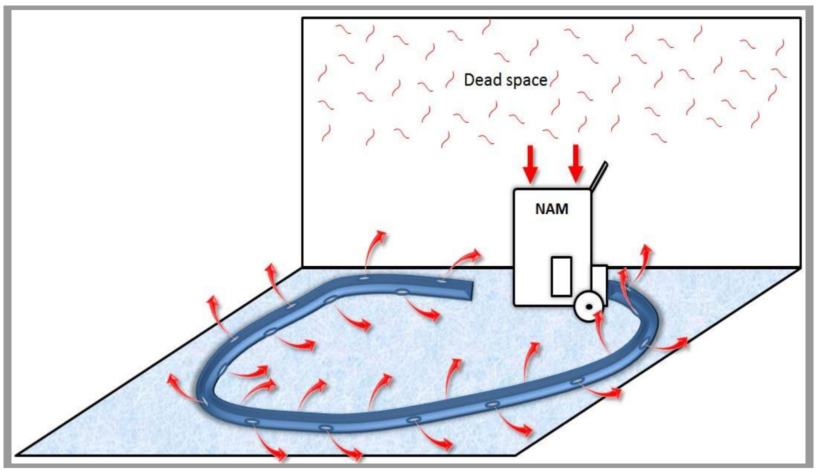


Figure 8: Vertical stratification of small particulate matter even with air scrubbing. Even if small particles that are floating above head height move toward the air stream in the lower part of the room they may not be dragged into the air flow but, instead, "bounce" back to the higher elevation.

UNDERSTANDING THE CHALLENGES OF SMALL PARTICLES IS NOT USEFUL UNLESS YOU CAN USE THE INFORMATION TO SOLVE THE PROBLEM

All the evidence makes it clear that small particles that get suspended in the air during remediation activities can be dangerous. To add to this bad news is the fact that airborne particulate matter can be difficult to remove, even with all of the equipment and techniques typically available to the restoration contractor. But, as the English philosopher and scientist Sir Francis Bacon said: "knowledge is power[16]." Understanding the intricacies of how small particles behave points us to a practical answer.

Ironically, the answer was discussed in great detail in the original white paper. Pages 7 through 9 of the document provide in-depth information relating to fogging. While this technique is relatively new for mold remediation and other restoration/infection control projects, it is a proven technique that has a long history of effective dust control in other industries.

When used in conjunction with negative pressure, air flow, and air scrubbing, fogging water with a mixture of surfactants can greatly enhance the removal of small particles from the air. While this certainly works on a theoretical basis (as the fogging solution turns the small suspended particles into condensation nuclei), it works on a practical basis as well.

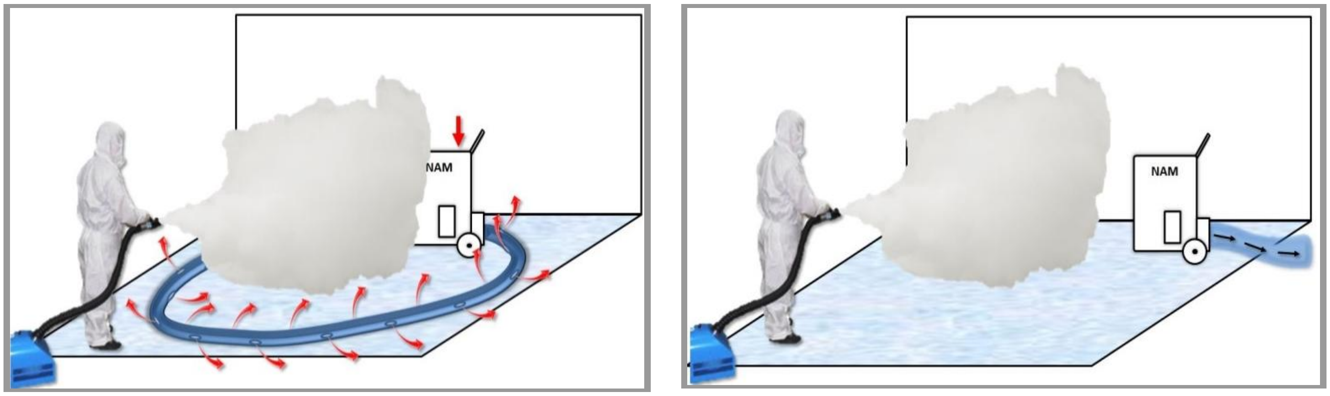
Restoration contractors that add the fogging step to their standard mold remediation process have found that it reduces the amount of time they have to spend on air scrubbing, improves the air quality inside the workspace, and virtually eliminates the aggravation of failing post remediation air samples after passing a visual inspection.

Contractors who have gained experience with fogging understand that it is the second to last step in the process and it should be completed using specific supplies, equipment, and work procedures. As noted in the white paper: "Ultralow volume foggers are fairly good at creating droplets in a relatively small size range, but sprayers or foggers that utilize tips that employ ionizing or ultrasonic technology can create droplets in a tighter size range which allows them to disperse farther into room air."

With equipment in hand, a good fogging agent should be employed. First and foremost, the product should be non-toxic. Because of the number of sensitized individuals that are occupants in buildings being remediated, many contractors are opting for solutions that do not have any fragrances and meet the qualifications as a low VOC product. Other factors restoration professionals consider before employing a fogging product for mold remediation or infection control projects (especially in medical facilities), is whether the fogging solution can contribute to the corrosion of electrical equipment or react with residue from antimicrobial chemicals used during the project. Although most people would not expect to find heavy metals as a component of fogging solutions, some manufacturers do add such hazardous ingredients. In addition to the health effects, the addition of heavy metals may make the fogging solution noticeably abrasive to smooth surfaces during the final cleaning of the settled residue.

Once the application equipment and fogging solution have been selected and prepared, the actual application has to be done intelligently for the project to have the best chance of success. As part of the restoration process, mold remediation contractors have learned that fogging can be used at multiple points, including demolition, to control the initial generation of airborne particulate matter. Nevertheless, as part of the final cleaning process fogging is best accomplished in conjunction with both negative pressure and air scrubbing. From case studies and multiple discussions of projects in training classes, using all of the proven techniques to capture small particles appears to have a synergistic effect on the outcome.

After the workspace has passed an aggressive visual inspection, only then can fogging be used as part of the final cleaning process. Having source material visible prior to the fogging means the air turbulence generated by the air scrubbing set up and pressure of the fogging application could actually increase the number of small particles suspended in the air. Once the area is visibly clean, fogging should proceed in a pattern that starts at the spot where makeup air enters the enclosure and works in a progressive pattern from side to side moving toward the negative air machine. As the fogging progresses from one side of the room to the other, a full vertical pattern of the fog solution also has to be generated. An analogy was offered by a contractor in Texas as a visual of herding cattle to a transport trailer from all parts of the stockyard for how the fogging should progress. Whatever visualization is used, the fogging process should end up near the intake of the negative air machine. Figures 9 and 10 illustrate the fogging process in connection with air scrubbing and negative air pressure for simplicity. However, the recommendation is that both negative pressure and air scrubbing should be utilized in conjunction with the fogging.



Figures 9 & 10: Air washing or fogging to improve removal of airborne particulate matter-
Fogging can be done with the NAM set up as an air scrubber or in the negative pressure configuration. In essence, fogging turns any small particulate matter left in the air into condensation nuclei. The added weight of the liquid droplet is what brings the small particles down to the surfaces of the room where they can be captured by a final HEPA vacuuming or wiping with a microfiber cloth.

SUMMARY

The original white paper opened the eyes of the restoration industry to some of the basic science related to dust in its health effects as well as general strategies for controlling airborne particulate matter. This recognition of some of the aspects of dust in the air led many professionals to realize that some of the dynamics of how small particles react in the air might explain the vexing problem of the occasional, seemingly random, failure of various remediation efforts.

This addendum was designed to address those concerns by offering more information regarding the potential health effects and risks posed by small particulate matter in the air. It also expands on the scientific underpinnings of how dust moves in the air with an emphasis on how those properties impact the contractor's ability to remove the aerosols. Specifically, an expansive discussion of the principles of capture velocity, dead spaces, and vertical stratification provides an understanding for what control techniques are most suited for in taking care of small particles as part of the remediation project.

In the end, science and practical experience come together to validate three main techniques for dealing with airborne contamination during remediation projects. This information confirms that the use of isolated negative pressure enclosures (which is an increasingly common part of the restoration industry), will continue to grow. It is also clear that specific techniques to improve the process of air scrubbing can be helpful. Nevertheless, the actual science makes it clear that the use of negative pressure enclosure and air scrubbing, without the use of a fogging process as part of the remediation, will lead to continued and almost unexplainable, project failures.

Detailed advice about the selection of equipment and supplies for fogging as part of the final cleaning process in the remediation project was presented. This included general considerations for the fogging agents so that the process becomes a net benefit rather than a problem because of unanticipated issues such as corrosion, adverse reactions of the occupants from residual VOCs or allergens, or unpleasant odors from added fragrances. This addendum also helps restoration professionals understand the actual mechanics of fogging as part of the cleaning process. Using the fogging material to both capture and "corral" microscopic contaminants is done through a logical pattern where the fogging begins at the point where the makeup air enters the negative pressure enclosure and finishes at the intake of the negative air machine.

Clearly, addressing the issue of small particle contamination during remediation efforts is a challenge. This addendum, in addition to the original white paper, provides the know-how for professionals in the remediation and cleaning industries to efficiently and effectively address airborne contamination from small particles. Together, the two documents validate the statement that "knowledge is power."

END NOTES

1. The initial report published in March of 2017 can be accessed by following this link to the Bad Axe website: https://badaxeproducts.com/pages/particulate-control-in-remediation
2. Financial support for the research and development of this paper was provided by Bad Axe Products.
3. The Journal article can be accessed at http://journal.iicrc.org/2017/IICRC_Sum17_V4I3/page_28.html
4. The Importance of Dust Control During Construction and Remediation Projects, page 1
5. United States Environmental Protection Agency website, Particulate Matter (PM) Pollution, Particulate Matter (PM) Basics, accessed 3/13/18.
6. For example, the Chemistry Dictionary defines a vapor as "A gas formed by boiling or evaporating a liquid."
7. Dictionary.com defines condensation nuclei as "any tiny suspended particles in the atmosphere, either liquid or solid, upon which condensation of water vapor begins."
8. United States Environmental Protection Agency website, Particulate Matter (PM) Pollution, Health and Environmental Effects of Particulate Matter (PM), Health Effects, accessed 3/13/18
9. WHO Regional Office For Europe; *Health Effects Of Particulate Matter Policy Implications For Countries In Eastern Europe, Caucasus And Central Asia*, page 6.

10. As noted in Chapter 20 of the manual *Subsurface Ventilation Engineering* by Malcolm J. McPherson entitled *The Aerodynamics, Sources, And Control Of Airborne Dust*: “The smallest particles act almost as a gas and react to molecular forces while the larger particles are influenced primarily by inertial and gravitational effects.”
11. See the medical study entitled *Aspergillus fumigatus—What Makes the Species a Ubiquitous Human Fungal Pathogen*? by KJ Kwon-Chung et al; especially the section titled *Aspergillus fumigatus Conidia Are Dispersed More Efficiently in the Air Than Those of Most Other Molds* where the authors state that *Aspergillus fumigatus*: “… are notorious for their high dispersibility. The slightest air current can cause conidia to disperse due to their remarkable hydrophobicity…”
12. The 2006 presentation entitled *Principles of Ventilation* offered by Patrick Breysse and Peter Lees of the Bloomberg School of Public Health at Johns Hopkins University provides a wealth of information related to dust control and capturing contaminants using ventilation equipment.
13. Many professionals consider 15 feet to be the minimum necessary to slow down the airflow and provide appropriate air mixing even for situations where a small negative air machine is involved.
14. A more extensive discussion of air scrubbing, along with a diagram and picture, can be found on page six of the white paper cited in note number 1.
15. A good laypersons explanation of this "bouncing" of smaller, lighter particles (along with informative illustrations) can be found in the article entitled *Measuring The Air Quality* which can be accessed at: http://vertlhorizon.com/measuring-the-air-quality/
16. Actually, the common quote attributed to Francis Bacon is a bit of the misquote as the English translation from his Latin statement of "ipsa scientia potestas est" from his 1597 paper entitled *Meditationes Sacrae* (Sacred Meditations) is “knowledge itself is power.”