Silicosis; An Invisible Enemy

By J Tyler Teague
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Know your enemy…

According to the American Lung Association, silicosis is "a lung disease caused by breathing in tiny bits of silica, a mineral that is part of sand, rock, and mineral ores such as quartz. It mostly affects workers exposed to silica dust in occupations such as mining, glass manufacturing, and foundry work. Over time, exposure to silica particles causes scarring in the lungs, which can harm your ability to breathe." It is the result of inhaling silica particles that are 10 microns or smaller and the resulting scarring that forms nodular lesions in the upper lobes of the lungs, rendering them unable to properly absorb the oxygen you breathe. Silica is a main ingredient in the investment used in jewelry casting operations, meaning that those workers involved in those processes are at risk for exposure to respirable silica. Silicosis is typically a slow progressive disease that you may not even know you have until the damage has become severe. And the damage can be caused from a single intense exposure. A type of pneumoconiosis, silicosis is very similar to the 'black lung disease' that coal miners are prone to and, like black lung, unfortunately, it has no cure. Furthermore, for smokers, the risk factor is 50–75 times greater than for a non-smoker with the same exposure. So, while we discuss how to engineer your work space to reduce the exposure to silica, keep that in mind if you are a smoker or have workers who smoke.

There are three types of silicosis: chronic, acute, and accelerated.

- *Chronic silicosis* usually occurs after 10 or more years of exposure to crystalline silica at relatively low concentrations;
- *Accelerated silicosis* results from exposure to high concentrations of crystalline silica and develops 5 to 10 years after the initial exposure; and
- *Acute silicosis* occurs where exposure concentrations are the highest and can cause symptoms to develop anytime from within a few weeks up to 4 or 5 years after the initial exposure.

Any of these may apply to a jewelry casting operation. While I did not set out to scare casters with the potential dangers of unchecked silica, in the course of writing, I changed my mind. This is scary stuff and I want you to be aware and to be scared enough to take the risk seriously and to do something about it. My own lungs are damaged from 39 years of silica exposure, a car wreck, and one very serious acute exposure to jewelry-related carbon dust, leaving me with about 60% of the lung capacity that would be normal for my age and general health according to my doctor. It's a good thing I have never smoked huh? So for me, it's personal. Be afraid, be very afraid…

Where Do We Stand?

No factory, shop, retail store owner or employee in their right mind would intentionally expose themselves or others to a dangerous situation or chemical. The companies that manufacture the investment powders have been warning their customers for years. Casters may be aware of the dangers of silica dust in the investment they use, but what about others in the shop? Even if we know it's a health hazard, we often don't think about it because 1) I'm busy, 2) it doesn't stink, 3) I don't taste it, 4) it doesn't make me high, and 5) what the heck, it takes a long time for it to have any noticeable effect—I'll worry about it later. The problem is that even “a long time” eventually comes and “later” may very well be too late. You may be lucky, but no one is immune. In 10, 20, or more years, it could be you wishing you had worried about it while you could still breathe.

From the first year of the Santa Fe Symposium, 1987, papers have been presented that report on the silica hazards in jewelry manufacturing. The Silica Project started by Paul Pryor and Dave Schneller clearly outlined potential hazards, methods of measurement, and some unexpected danger zones. In the papers presented at the Symposium, “respirable silica” was defined as particles measuring less than 10 microns in size; particles this small are practically invisible to the naked eye. The respirable silica now referred to on all OSHA materials does not seem to be defined as a micron size but using the term “fine fraction” instead. This lack of definition could create problems later on as companies do their best to comply with the new rule that went into effect as of June, 2016.

The rules that were in effect at the time of the 1988 and 1989 Santa Fe Symposia were quite confusing as OSHA and NIOSH had different standards. Prior to 2016, NIOSH had a permissible exposure limit (PEL) of 50 micrograms per cubic meter of air (µg/m^3), with exposure averaged over 8 hours, while OSHA had a limit of 100 µg/m^3, averaged over 8 hours. To make it even more confusing, the threshold limit value (TLV) of the Association Advancing Occupational and Environmental Health (ACGIH) was 10 million parts per cubic foot (mppcf) of granite dust (which, when chemically separated just for respirable silica, just about equaled the OSHA limit of 100 µg/m^3). Even standards that agreed were presented in drastically different ways.

The research done by Paul and Dave in the SFS 1988 and 1989 *Proceedings* books revealed that several of the casting processes measured in a very small and exceptionally clean jewelry casting operation showed respirable silica levels that exceeded OSHA permissible exposure limits—even when averaged—and it’s important to note that while the OSHA limit is averaged over 8 hours, the investing, casting and quenching operations occur in a much shorter time frame during the day, so the exposure may be far greater during those operations and by those operators than it would appear when averaged over 8 hours. For our industry, averaging is not a good measure. As a sufferer of silicosis, I feel the acute exposure limits should be measured for the time the worker is at maximum exposure while they are performing each work process. I think the OSHA and other rules were based on an assumption that a worker does the same job continuously for 8 hours, which is normally not the case in the jewelry industry. You can get way over the limit exposure—damage-causing exposure—for short periods during the day that, when averaged over a longer period (such as the artibrary 8 hours), appears to be within limits and might not raise concern.

Up until this year, 50 µg/m^3 averaged over 8 hours was a recommendation for the maximum permissible exposure limit (PEL); now, it’s the law—and probably as a result of the SFS Silica Project. The law is already in effect as of June, 2016, but implementation is being given some ramp-up time. The deadline for compliance for the jewelry industry is June 23, 2018.

OSHA, The Final Rules (implementation beginning June, 2016**:**
Key Provisions (these are not well-written and can be confusing)

1) Reduces the permissible exposure limit (PEL) for respirable crystalline silica to 50 micrograms per cubic meter of air (µg/m3), averaged over an 8-hour shift.

2) Requires employers to:
   a) use engineering controls (such as water or ventilation) to limit worker exposure within the PEL.
   b) provide respirators when engineering controls cannot adequately limit exposure.
   c) limit worker access to high exposure areas.
   d) develop a written exposure control plan.
   e) offer medical examinations to highly exposed workers.
   f) train workers on silica risks and how to limit exposure.

3) Requires employers to provide medical examinations to monitor highly exposed workers and give them information about their lung health via medical reports issuing from those examinations.

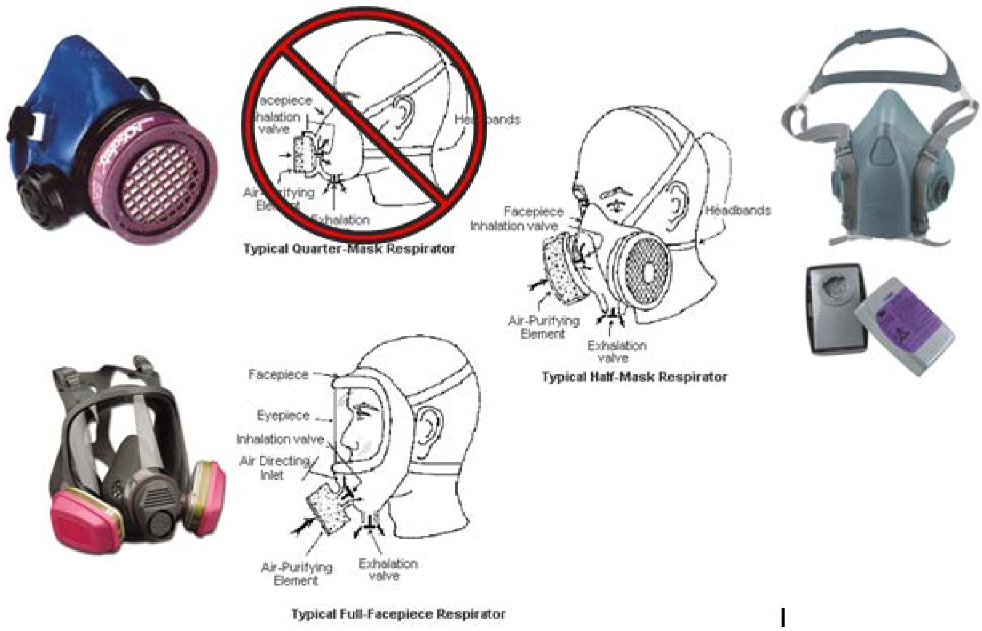
4) Provides flexibility (via a stepped compliance schedule) to help employers—especially small businesses—protect workers from silica exposure.

Compliance Schedule
Both standards contained in the final rule took effect on June 23, 2016, after which date industries have one to five years to comply with new requirements based on the following schedule:

1. Construction – June 23, 2017, one year after the effective date.
2. General Industry (includes the jewelry industry) and Maritime – June 23, 2018, two years after the effective date. (Jewelry mfg.)
3. Hydraulic Fracturing – June 23, 2018, two years after the effective date for all provisions except engineering controls (see 2a. above), which have a compliance date of June 23, 2021.

So, with the background information established, let's take a closer look at the sources of silica and then at solutions you can put into operation to minimize or eliminate exposure to these sources.

Respirators



Images from the Department of Labor illustrating respirator definitions

If you work in an environment that has a PEL greater than 50 µg/m3 but less than 500 µg/m^3, NIOSH standards *require* that you engineer your work space to eliminate the dust issue or that you provide and use a particulate respirator equipped with an N95, R95, or P95 filter (including N95, R95, and P95 filtering face pieces) **except quarter-mask respirators**. The N99, R99, P99, N100, R100 and P100 filters may also be used.

If the measured average in your work space exceeds 500 µg/m^3, then you are required to provide and use full face respirators or better. The caveat to this rule is that, if the operators have facial hair, they might as well not be wearing a mask at all. The reason for this would show up in the fit test for the respirator: facial hair prevents an acceptable seal between the mask and the skin. And, even after a successful fit test, it just takes a few days without shaving to render that fitting pointless. Paul Pryor and Dave Schneller did make this point back in 1988, but neither OSHA nor NIOSH specify this in their rules. When it comes to protecting your lungs, it's usually not what you know that kills you, it's what you don't know that does.

You will notice that the pictures of approved masks shown above do not include any paper masks. The most common "dust masks" I see in factories are cheap paper masks that simply don't work. Paper masks sold by most supply companies are not suitable to filter the respirable silica particles in our investing, quenching, and devesting processes. The respirable silica particles either pass right through them or around the sides. These paper masks are mainly surgical masks designed for aerosol "particulate" protection. They are designed to protect others from what is coming out of your nose and mouth, not so much to protect you from what is going into yours.

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Even if you have the correct respirator gear, most folks don't wear them consistently. What I hear from workers when the boss isn't around is, "it's too hot to wear," "the mask stinks," "it's hard to breathe through this thing," "nobody can hear what I'm saying with the mask on," but the most outrageous one was "it messes up my hair." The bottom line is that humans are not going to do something uncomfortable if they don't perceive that doing so solves an immediate threat. The best plan is to engineer your work areas in such a way that respirators are not needed.

1. Cristobalite and Quartz Silica:

As most of us know, the powders that we use for investment casting of precious metals are made up of combinations of cristobalite and quartz silica along with some kind of binder. In the case of typical gold and silver gypsum-bonded investment, 35% is gypsum (calcium sulfate), and the rest is a combination of cristobalite and quartz silica. Platinum and palladium casting investment is nearly all quartz silica. According to a paper called "Crystalline Silica: Variability in Fibrogenic Potency" by M. Meldrum* and Peter Howden, the experimental evidence indicates that the toxicity of crystalline silica varies according to polymorphic form: "cristobalite and quartz appear more reactive and more cytotoxic" than other forms.

Illustration 1A

All casters have seen the cloud of powdery dust that arises when you dump investment powder into the mixing container with the liquid (1A). That is one location for controlling the dust. In this picture there is no hood at all so any silica particles are free to move about the factory on the air currents. The fact is that it's not the powder you can *see* that gets you; as stated earlier, respirable silica is in the sub 10-micron range and is invisible to the human eye, so it is what you are *not seeing* that hurts you. A more surprising danger zone discovered during the Silica Project was the exposure to respirable silica at quenching. According to their information, *more respirable silica is released into the breathing zone of the operator during quenching of a hot flask than in all other operations involving investment.*

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Illustration 1B : Bucket Quenching

Quenching hot flasks in a bucket of water doesn’t seem so dangerous because you put the flask under water and you see steam, not powder. You would think that the powder is trapped by the water. The investment material at the point of contact with the water is basically exploding, boiling, and the microscopic bits of investment (smaller than 10 microns) don’t really attach to water molecules but are ejected out inside the bubbles along with the water vapor, the “steam,” rising up into the breathing zone and into the lungs of the operator. This is where the particles stick, collect and, over time, cause the scar tissue that collects into nodules and becomes what is known as silicosis.

Any time there is movement of investment powder in your shop, there is some risk of exposure. At every opportunity, we need to manage, exhaust, or eliminate free silica in the work space. A lot of free silica can be remedied with good housekeeping that includes a mop, a wash rag, and a bucket of water. A well-maintained HEPA vacuum cleaner is good to have around. The minimum HEPA category requires the filter to capture 99.97% of particles 0.3 micron or larger from the air passing through the filter. Another good idea is to hook up a hose with a vacuum end to an exhaust port that blows the silica particles outside. Regular shop vacuums that exhaust into the room may not be adequate for particles smaller than 10 microns unless they have the correct—and regularly changed—HEPA filters. If not maintained well, these filters will have just the opposite effect by launching respirable particles into the work space.

2. Effective Dust Collection, Containment and Disposal

Proper design of exhaust hoods must effectively control atmospheric contamination at its source with minimum air flow and power consumption. The more energy in the silica liberation, the higher the exhaust air flow velocity needs to be. The good news is that even the most energetic liberation, respirable silica particles lose that motion very quickly because they are so light; however, the bad news is that they can hang suspended for hours if not days. We must capture the respirable silica and get it outside where it will be diluted so much that it is no longer a threat.

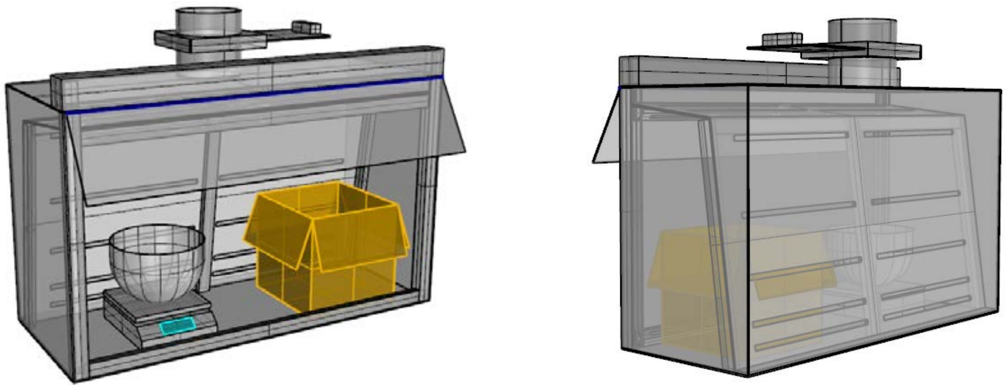

Illustration 2A; Dust Containment Work Station

When you are handling investment powder, you also need a dust control system that pulls the dust back and away from the operator's breathing zone and not up through it. Consider the operator's posture when working with any potentially hazardous material. You can change the work station to modify the worker's posture and direct the exhaust air flow to keep the dust out of the breathing zone of that operator. An enclosure should limit the air intake to only the front of the enclosure toward the back of the enclosure as shown in the illustration above (2A). You can also see that the back wall of this enclosure is slanted and the slots are spaced to create a similar velocity in the back of the enclosure from top to bottom. If you want to further enhance this design, you can add directed makeup air at the bottom and top of the front opening to help direct any errant dust toward the vacuum slots in the back. The intake on the top of this enclosure would be about 8" or more in diameter, and the blower fan would need to be rated in the neighborhood of 1000cfm or more in an enclosure this large.

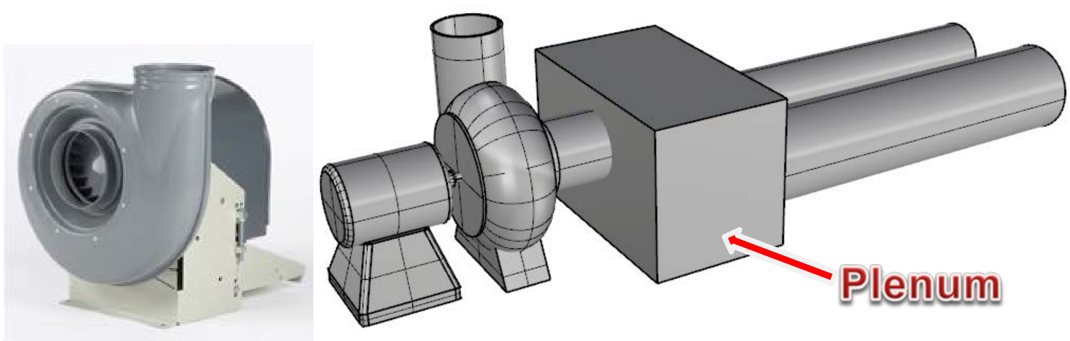

Illustration 2B: Blower and Plenum

An industrial blower of this size can cost $1500 or more but it's an inexpensive investment by comparison to your long-term health. One thing you can do to reduce costs for your shop is to use a single blower that draws through a single plenum for all your dust-generating locations, as illustrated above (2B). A plenum is basically a box where several different pipes can connect to the single source of vacuum. The blower is attached to the plenum and directs everything that comes into it to the outside of the building. You can use different pipe diameters based on the velocity needs at each of the various work stations or locations. As long as you use blast gate valves on each pipe, you can turn them off and on as needed for each location. Most factories are not running all the operations simultaneously. Depending on the material you use to make this plenum, and the way you attach the exhaust blower, you could use it for dust, fumes, smoke, and maybe even heat. If you were using a single exhaust that included lots of heat or possibly acid fumes, then that requires a great deal of consideration and a completely different blower configuration that uses a Bernoulli-type effect to draw rather than having the fumes or heat go through the blower itself.

Illustration 2C

Illustration 2D

The point of these dust extraction hoods is to draw the dust back and away from the operator at the closest possible point where dust is being generated. In illustration (2C), you see that the hood is over the top of the chamber so the worker's face would be about level with the top of that bowl when they are pouring the powder into the bowl. Even if the hood could draw that powder up well enough, it is drawing it right up through the operator's face. In illustration (2D), the exhaust hood will be right at the lip of the chamber when it is in position to pour in the powder. Because the exhaust is properly shaped and right at the point of the dust ejection, a much lower powered exhaust will create much higher air velocity that will remove the respirable silica. You can also see in this same illustration that these workers double-down on safety; not only do they have a good exhaust, they are also using good respirators.

Hoods for Investing Work Stations

If you go online and search "dust hood," 90% of what you will find is the opposite of what you want. Most of these hoods will have the hose connecting the vacuum blower at the small end in the back and the dust collecting opening is larger as it goes towards the source of the dust, much like our polishing hoods in the jewelry business. That is not what you want for investing operations.

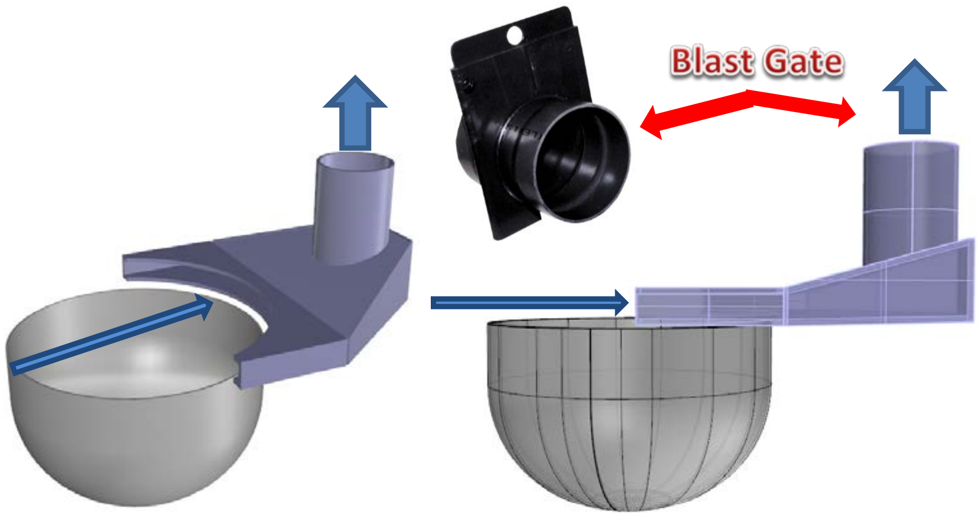

Illustration 2E

Illustration 2E, above, shows a smaller version of the same type that might be used on a large Vac-U-Vest™ mixer or even a smaller version on a Hobart mixer bowl. Again, the exhaust hood is right at the lip of the mixing bowl. You can use a blast gate (damper) to control the flow of air so that you are just drawing off the errant dust and not sucking your investment out of the bowl. I have used short, wide arrows in illustration 2E to indicate lower velocity but high volume air movement. The longer, slender arrows represent a similar volume of air that, because of the narrow opening, is moving much faster; that is how you create increased velocity in the movement of air. The inlet is necked down to a one-inch slot compared to the back of the exhaust hood where a four-inch or larger hose or tube is connected.

3. Creating Your Own System

You could build this exhaust hood yourself using flat PVC sheet that is available from many hardware stores or online. All the plans of the CAD illustrated hoods are available free through Rio Grande in Rhino format.

It's basically just flat sheet glued together with PVC glue and one piece of round PVC pipe. Add a cage blower that exhausts to the outside via a PVC pipe, and you're golden. A blower that is specifically designated for this location would only need to be between 200cfm and 300cfm if it were fairly nearby and you necked the opening down from a four-inch intake to a one-inch slot as described. Using hard PVC pipe is better than wire-reinforced flexible hose because the inside is smooth and does not create the turbulence of the uneven flex hose. If your choice is flex hose or nothing, definitely go with flex hose.

Illustration 3A

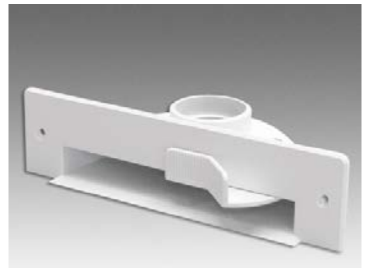

Illustration 3B

Illustration 3C

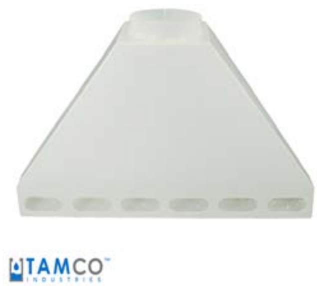

Illustration 3D

If you don’t have time to build a good exhaust, you can find some good options in many locations. Illustration 3A is a lower exhaust hood that is available from Grainger. Illustration 3C is also from Grainger. U.S. Plastics carries much the same thing (3D) at a lower price.

Illustration 3E

U.S. Plastics carries nearly everything you would need to build a proper dust collection and exhaust system for any size operation, but nearly every town has a local Grainger or Lowe's location. Many usable types of vents are available in home improvement super-stores such as Lowe's stores but you have to know where to look. Many times these special things are only available online. For example, the hood pictured in 3B is a floor sweep vent for a whole-house vacuum system. With a little ingenuity, you could easily use this to exhaust your investment mixer. Illustration 3E is a mobile exhaust system from U.S. Plastics; it could be fixed in one position in your shop and double as an exhaust for investing and quenching if you use the right shaped hood in those locations. Your exhaust fans will all need duct work to exhaust the dust outside. Once outside, it becomes so diluted that it's no more dangerous than going to the beach.

4. Quenching and Devesting

Illustration 4A: Quenching and Devesting: What not to do

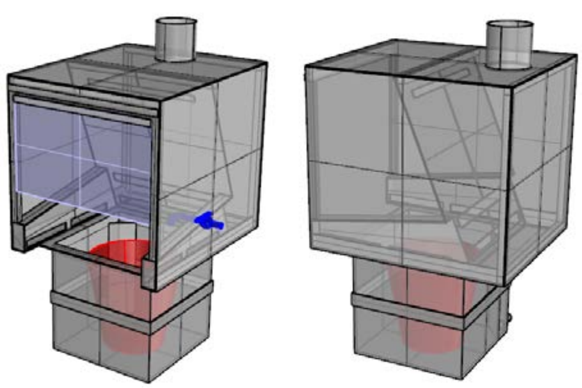

Illustration 4B

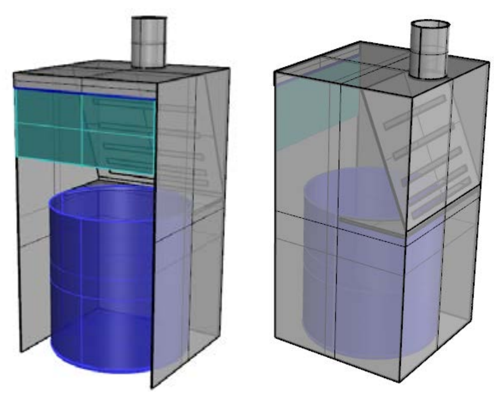

Illustration 4C

According to the results gleaned from the research done in 1987 and 1988 (and since that time as well) the respirable silica released by the quenching operation presents the highest concentration and risk for exposure. Illustration 4A is a great example of what *not* to do, and I can assure you that such set-ups are rare to non-existent anymore. The quenching and devesting operations are where you need to combine both the high-velocity back-draw and the containment-type systems. These operations also require the highest velocity of air. Like I said before, that does not mean high cfm ratings; velocity means the *speed* of the air traveling from one point to another not the *volume* of air that is moving. The cfm rating is important to creating velocity when combined with the hose connection to the hood as it relates to the shape of the exhaust opening. In the two illustrations above (4B and 4C), you can see by looking at this ghosted view that the draw is not only back and out of the operator's breathing zone, the direction of pull is limited by the structure of the hood just as shown in illustration 2A, the dust containment work station. On both of these units, there is a hinged door (that I usually make out of a sheet of stainless steel) hanging down in front that further limits where the air can come from. The weight of the steel keeps it from moving with the exhaust but gets out of the way when the operator is putting a flask into the quench tank. I normally quench into a separate bucket that is inside the quench tank so that if a part comes loose from the tree it's easier to find. This also makes daily cleanup a bit easier. I do the same thing in the larger barrel (illustration 4B) for large-scale casting operations, but it is not shown in the illustration. (In both cases, there are also spillways for the water and settling tanks to keep the investment out of the sewer system that are also not pictured here.)

Making the vacuum chamber wider where the pipe comes into the exhaust hood and tapering it down toward the bottom is intended to maintain the velocity of the air flow in all slots coming through the face plate. On the smaller unit, I even put tapered vacuum chambers to pull to the side as well as to the back. That is an ideal design and one that I am working on for larger facilities now. Please note that the distance between slots is greater toward the larger part of the chamber. I really want to get rid of the dust as soon as it comes off the top of the water. The higher slots and the front door are to limit the movement and capture any particles that may have been missed by the slots at the quench tank edge.

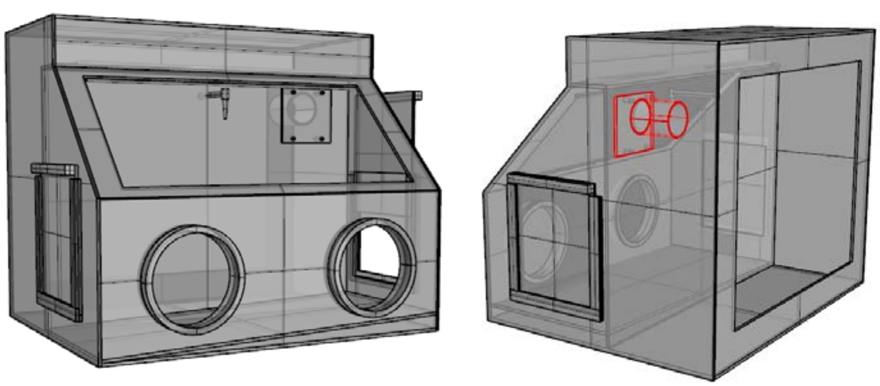

Illustration 4D

Devesting operations are not usually considered as a source of respirable silica because devesting is a wet operation. Anybody who has done a lot of this knows that there is steam and mist coming out of these cabinets and, while I have not measured this for respirable silica, it's so easy to modify one of these cabinets and hook it into one of the exhaust lines that why would I not do it? You only need to cut a hole for a minimal two- or three-inch pipe, glue or weld it in place, and make an offset cover to keep water from spraying into the hose. This will create negative pressure in the cabinet when the doors are closed so when you open them to take out your castings, any and all vapor and whatever might be with it, exits the box through the vacuum and not through the door. In taking this extra step, you certainly demonstrate that you are looking out for the well-being of yourself and your workers.

General Guidelines:
Operations that need general back draw containment - 1000 cfm+
Illustration (2A)

- Opening the container of investment
- Scooping the investment powder onto a scale for weighing

Operations that need directed high velocity dust control at the point of operation – 200cfm to 300 cfm of high velocity directed vacuum.

- Dumping the powder into the mixer (illustrations 1A, 2D, 2E
- Turning on the mixer with powder in the bowl and the time before it mixes with water enough to prevent powder dispersal
- Pressure or vacuum release after metal injection (maybe???)
- High speed centrifugal fanning of investment during centrifugal casting
    - Need an enclosed casting Shield (with lid)
    - Need exhaust with makeup air source before opening lid
    - Need serious velocity across if open torch casting or just use a respirator
- **<u>Steam being ejected during the quench operation</u>** (illustration 1B)

Housekeeping Issues (require HEPA vacuum, mop, rag, water)

- Loose powder on work surfaces, floor, in the oven, etc.…

Hood Design:
If you are designing or redesigning your facility from scratch, here are some things you will want to consider for design elements in a casting shop:

1. Investing Room design (Everything needs to be able to get wet and clean)
    a. Do investing and devesting in the same room to collateral silica exposure.
        i. Do not do jobs <u>not related</u> to investing or devesting in that room.
        ii. Have a small pass through window between casting and devesting for flask movement.
    b. Use water and mold-resistant sheet rock for construction.
    c. Cover the walls with cheap, slick, plastic bathroom paneling, it is best for hosing down the room for major cleanups.
    d. Simple concrete floors with good quality, smooth, hard, epoxy coatings are ideal for cleanup. Do not use coatings that include plastic chips!
        i. Perforated rubber mats are great to prevent slipping on these hard epoxy-coated concrete floors.
    e. Have a central floor drain in your investment area it's a plus for cleanup.
    f. If possible, use restaurant-grade, open front, wire shelf, stainless counters and islands in the investing area.

        i. Cheap pressboard cabinets and countertops cannot stand up to the needed cleaning.
    g. Air returns in investment rooms that are part of a shared HVAC system should be oversized and well filtered to prevent spreading silica to other areas.
    h. Use sliding doors (pocket or hanging barn door style), instead of swinging doors to reduce air turbulence in the room.
    i. Eliminate all room fans in the investing area. A good investing area should be comfortable and climate controlled anyway.
    j. Balance the HVAC system to have a negative pressure in the investing room.

2. Controlling the direction of the air movement with exhaust design
    a. I suggest using a dual speed exhaust fan for the investing and devesting locations.
        i. High speed when work is being done at that location
        ii. Low speed to reduce conditioned air loss during other normal operation hours and off when nobody is home.
    b. Exhaust systems require the pipe to be stepped down based on station cfm requirements and distance from the exhaust fan. (velocity loss from air to pipe friction)
        i. Just calculating the cross section of the pipes is a good start when comparing them for cfm changes (pi*[pipe ID radius]^2).
    c. Always create a back draw of air, never up through the breathing zone.
    d. Control the direction of the air movement by blocking 4 or 5 sides of an exhaust enclosure.
    e. The shape of the actual hood should maximize the velocity at the closest point of fume removal with the least power consumption and hardware costs.

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