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Short Communication

A Simple Proposition for Improving Industrial Hygiene Air Sampling Methods



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ABSTRACT

When conducting an exposure assessment, the primary goal of the industrial hygienist is to fully characterize the worker's exposure during a work shift to compare it with an occupational exposure limit. This applies regardless of the duration of the work activity as an activity that is relatively short in duration can still present exposure in excess of the occupational exposure limit even when normalized over an 8-hr shift. This goal, however, is often impeded by the specification of a minimum sample volume in the published sampling method, which may prevent the sample from being collected or submitted for analysis. Removing the specification of minimum sample volume (or adjusting it from a requirement to a recommendation), in contrast, allows for a broader assessment of jobs that consist of short-duration and high-exposure activities and also eliminates the unnecessary practice of running sampling pumps in clean air to collect a specified, minimum volume.

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The traditional industrial hygiene model was developed out of a need to characterize worker exposures for a given work shift where the worker would typically work with the same set of materials (e.g., mining, machining, smelting, welding, assembly line work, and so on) for the duration of the shift [1,2]. As such, worker exposure limits are typically expressed as 8-hr Time-weighted averages (TWAs) with the expectation that air sampling will also be performed for the full duration of (or as close to as possible) the 8-hr shift. For example, the United States (US) Occupational Safety and Health Administration (OSHA) Lead standard [3] states in Appendix B, Section II, that “sampling must be done to enable each employee's exposure level to be reasonably represented by at least one full shift (at least 7 hours) air sample.” However, with the transition from the industrial age to the current digital and information age, many of today's jobs have shifted from working with a defined set of materials for the duration of a full working shift to multiple tasks involving a variety of different materials (e.g., in a research and development environment) for short durations within a given shift. In either case, the primary goal of the industrial hygienist when conducting an exposure assessment is to fully characterize the worker's exposure, including when the work shift consists of short duration, but potentially high-exposure activities. This goal, however, is often impeded by the specification of a

minimum sample volume (MSV) in many published sampling methods, which can have several undesirable effects. To counteract these effects, an idea is proposed that can reduce already minimized occupational health and safety office budgets while significantly improving the practice of industrial hygiene. The idea is exceedingly simple and certainly familiar, yet not necessarily obvious. The proposal is as follows: *Remove the specification of “minimum sample volume” (or simply make it a recommendation) from industrial hygiene air sampling methods that measure mass concentration.*

The concept of MSV presents a plethora of issues. It is a red herring at best and detrimental to workers' health at worst. The concept has been embedded in methods in the US National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods [4] for as long as they have been in existence. It is presented in the form of “VOL-MIN.” OSHA sampling and analytical methods provide more flexibility by specifying a “recommended” air volume or air volume range, as opposed to minimum and maximum volumes, but for institutions that are required to sample in conformance with NIOSH methods, the VOL-MIN requirement must be met when conducting air sampling. While one may argue that professional judgment can be used to justify a divergence from this specification, the absence of qualifying

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language in most NIOSH methods regarding the use of the term “VOL-MIN” may make such justification difficult.

Most industrial hygienists in the current working environment have experienced something analogous to the following scenario. A worker is jackhammering concrete as part of a demolition job. The job only takes two hours to complete, which, in this example (for argument’s sake), is a typical and representative duration for this particular worker’s cohort, or a similar exposure group, during an 8-hr work shift. The industrial hygienist uses, for example, a Respirable Dust Aluminum Cyclone (SKC Inc., Eighty Four, PA, USA) attached to a personal sampling pump calibrated at 2.5 L/min (required for this sampler to collect the respirable fraction) and samples from the worker’s breathing zone for the entire duration of the two-hour demolition activity. The total volume of air collected is $2.5 \text{ L/min} \times 120 \text{ min} = 300 \text{ L}$. However, NIOSH Method 7500 [5] specifies 400 L as the MSV. Based on this specification, the industrial hygienist has three options: (1) Throw out the sample because the MSV required for the method was not collected; (2) Verify that the worker is not going to be exposed to silica (e.g., he or she works in a clean office or different work location) for the remainder of the shift, remove the cyclone and pump from the worker, and run the sampling pump in clean air for another 40 minutes to collect an additional 100 L of air; or (3) Leave the sampler on the worker and keep collecting air for another 40 minutes, even as the worker no longer performs work with potential exposure to silica.

Option 1 is the most problematic because by throwing out this sample, one cannot quantitatively assess this worker’s exposure. Without an exposure assessment, one would have to make a qualitative instead of quantitative decision on whether or not additional engineering or administrative controls would be required, whether or not the worker should be required to wear respiratory protection, and if so, what respirator the worker would need to wear. This may result in underprotecting or overprotecting the worker, either of which is less than ideal. Option 1 is also problematic because, in this example, one would potentially be out of compliance with the recently promulgated US OSHA Respirable Crystalline Silica rule [6] that requires the employer to assess the exposure of each employee who is or may reasonably be expected to be exposed to respirable crystalline silica at or more than the action level. For a job such as jackhammering concrete, even when performed for only two hours, one can reasonably be expected to be exposed to respirable crystalline silica at or more than the action level of 25 ug/m^3 , as an 8-hr TWA, particularly if performed indoors, on hardened concrete, or if the wet control method is inadequate.

Options 2 and 3 are also problematic, albeit to a lesser extent than Option 1. After confirming that the worker will not be exposed to silica for the remainder of the work shift, Option 2 would have the industrial hygienist remove the pump and cyclone from the worker and then run the pump in a clean environment for another 40 minutes. Similarly, Option 3 would have the industrial hygienist leave the pump and cyclone mounted on the worker and run the pump for another 40 minutes, even after the work activity has been completed. In either case, the additional sampling would be carried out for the sole purpose of meeting the MSV requirement specified by the method, but given that collecting air from a silica-free environment would not impact the mass of silica already collected or not collected on the filter, it would not add any value to the analysis and simply be a waste of time and resources. This begs the question of why a MSV is specified in the first place.

The concept of MSV arises from an attempt to describe a laboratory’s analytical reporting limit (also described as “limit of quantitation,” “limit of quantification,” “reliable quantitation limit,” or “quantitative limit of detection”) as a mass concentration instead of simply a mass. Appendix A of the Respirable Crystalline Silica

rule [6] reflects this approach by requiring employers to ensure that the laboratories they use to analyze silica “obtain a quantitative limit of detection that represents a value no higher than 25% of the permissible exposure limit (PEL) based on sample air volume.” Here, the quantitative limit of detection is expressed as a mass concentration for direct comparison to the PEL, which is also a mass concentration. However, there are several issues that arise from expressing the quantitative limit of detection as a mass concentration.

Allowing the quantitative limit of detection to be dependent on sample air volume and requiring that mass concentration to be no more than 25% of the PEL implies that one would want to directly compare the mass concentration from a shorter-than-full-shift sample with an 8-hr TWA PEL. The only practical scenario where one might do this for the purpose of determining compliance is when only a portion of the work activity can be sampled and the same exposure is assumed for the remainder of the shift. This would be similar to assessing the exposure during a shorter-than-full-shift activity against the PEL to confirm it is lower than the PEL, which would then ensure that the PEL would not be exceeded even when that same activity is performed any number of times within the same shift. However, this would typically not be done because it is always recommended to sample for the entire duration of the work activity within the shift and not just a portion of it. For the more common scenarios where work with a given hazard is performed for less than the duration of the shift and where there is no further exposure to the hazard for the remainder of the shift, the mass concentration determined from that sample would be normalized to an 8-hr TWA by assuming zero exposure for the remainder of the shift and then comparing this adjusted result directly with the 8-hr TWA PEL. For example, in accordance with NIOSH Method 7500, if an aluminum cyclone was used at 2.5 L/min for 2 hrs and 40 minutes to collect 400 L of sample air volume and silica content was not found more than the quantitative limit of detection of 0.02 mg, the result for the 400 L sample would be “< 0.05 mg/m³.” But if you calculate what the 8-hr TWA is for this sample, assuming zero exposure for the remainder of the shift, the result would be “< 0.017 mg/m³.” Because the 8-hr TWA PEL should be compared with the 8-hr TWA result, the “< 0.017 mg/m³” result and not the “< 0.05 mg/m³” result, should be compared with the PEL of 0.05 mg/m³. Based on this principle, collecting a sample air volume as low as 2.5 L (or even lower) for a task involving silica exposure, where silica content is not found more than the quantitative limit of detection of 0.02 mg, would give you a result of “< 8 mg/m³” for the 2.5 L sample; however, the 8-hr TWA based on zero exposure for the remainder of the shift would still be “< 0.017 mg/m³.” This illustrates how as long as sampling is conducted for the entire duration of the activity involving silica exposure, the normalized 8-hr TWA result for a shorter-than-full-shift sample depends on the mass of silica found (or not found) on the filter and the sampling flow rate (which determines the total volume of air that is or would be collected over an 8-hr shift) but is independent of the air volume collected over the duration of the task itself when it is shorter than eight hours.

This makes particular sense when one considers how samples are analyzed for determining mass concentration, whether it is through gravimetry, inductively coupled plasma atomic emission spectrometry [7], or any other analysis. In these analyses, the analytical reporting limit is determined by some multiple of the limit of detection, which is the minimum mass the instrument can detect. This typically corresponds to an instrument’s signal-to-noise ratio of 3:1. Therefore, the true quantitative limit of detection is defined in terms of mass and not mass concentration. Barring a media breakthrough scenario (which is why the specification of “VOL-MAX” is still important), the analytical instrument does not

care how much air is sampled; it only cares about the mass of analyte deposited on the filter or sampling medium.

Another problem with defining the quantitative limit of detection as a mass concentration and, as in the silica rule example, requiring laboratories to be able to achieve one that is no higher than 25% of the PEL based on the sample volume is that it forces the laboratory to make assumptions about the shortest activity one would ever need to assess. For example, if the laboratory determined that 80 minutes is the shortest activity it would want to assess for silica, its target for its quantitative limit of detection would be 0.0025 mg, assuming a Respirable Dust Aluminum Cyclone is used to sample the activity at 2.5 L/min, resulting in a sample volume of 200 L.

$$0.0025 \text{ mg} / 0.200 \text{ m}^3 = 0.0125 \text{ mg/m}^3 \quad (1)$$

This, of course, is assuming that one would even want to directly compare the mass concentration from a shorter-than-full-shift sample with an 8-hr TWA PEL, which one normally would not.

Yet another complication that the MSV presents is that in many NIOSH methods, VOL-MIN is specified not just as a volume but as a volume at a specified concentration, typically the occupational exposure limit (OEL). For example, NIOSH Method 7082 [8] specifies VOL-MIN as 200 L at 0.05 mg/m³, which is the PEL for lead. The intent behind specifying a minimum volume at the OEL is to inform the industrial hygienist of the MSV needed to collect mass at the quantitative limit of detection when the mass concentration of the air that is being sampled is at the OEL. While the intent is to help the industrial hygienist decide whether or not to sample a particular activity, given that it may be too short in duration to even assess against the OEL based on the quantitative limit of detection, the intent is based on the same misconception that was described earlier that one would even want to compare the result of a less-than-full-shift sample with an 8-hr TWA PEL. Another problem with specifying the MSV at a specified concentration is that it would not apply to scenarios where the actual concentration is greater than the specified concentration. For example, if the lead concentration in the sampled air was 0.10 mg/m³, the MSV needed to collect 10 ug of lead (the quantitative limit of detection) would be 100 L. While this volume is only half the minimum required when the lead concentration in the sampled air is assumed to be at the OEL, this sample would collect a sufficient mass to be analyzed for comparison against the OEL, either directly or normalized as an 8-hr TWA.

In a similar vein, NIOSH methods that specify VOL-MIN without specifying a corresponding concentration are intended to inform the industrial hygienist of the MSV needed to collect mass at the quantitative limit of detection (expressed as a mass quantity) when the mass concentration of the air that is being sampled is at some percentage of the OEL. This may be 10%, 25%, or some other fraction, depending on the method. This, too, runs into the same problems described in the preceding paragraph, with the outcome being that these methods are even more restrictive toward exposure scenarios that exceed the assumed low-level concentrations because an even greater volume (and therefore, a longer duration of activity) would be needed to meet these lower level target concentrations.

With all the problems the MSV presents, removing its concept when publishing sampling methods that measure mass concentration, or simply making it a recommendation, is a necessary change for the industrial hygiene profession. While this is admittedly a challenge to the current paradigm, the modern workplace is more dynamic than that in past years, with work locations and work-related professions moving away from production-line consistency of past days. With the acceptance of this proposal, the primary consideration when conducting personal air sampling,

then, would be that the entire duration of the activity is sampled, the activity and its duration are representative of the worker and/or similar exposure group that is being assessed, and the quantitative limit of detection of the sampling method is sufficiently low for a comparison between the result (typically the 8-hr TWA) and the OEL. These primary considerations would also apply when assessing exposures to acute hazards that have short-term exposure limits, except that the quantitative limit of detection would have to be sufficiently low for a comparison between the 15-minute TWA result and the short-term exposure limit. The industrial hygienist would be able to accurately assess exposure for every scenario of interest, including increasingly common work shifts that consist of high-exposure, short-duration tasks, and would no longer spend time needlessly running a sampling pump in clean air, whether mounted or not mounted on the worker, just to meet the method's MSV specification. Without a MSV requirement, the industrial hygienist would only be limited by the true analytical capability of the analytical instrument, expressed appropriately as a given mass per sample.

A corollary to this suggestion for improving industrial hygiene practice would be for analytical laboratories to establish their target quantitative limits of detection unequivocally on the basis of being able to measure 10% of the OEL as an 8-hr TWA and not as a task-based TWA. For example, if the OEL was 0.05 mg/m³ and the required sampling flow rate was 2.5 L/min, the method's target quantitative limit of detection, expressed as a mass, would be 0.006 mg.

$$8\text{-hr sample: } 0.006 \text{ mg}/1.2 \text{ m}^3 = 0.005 \text{ mg/m}^3 \quad (2)$$

2-hr sample, normalized as an 8-hr TWA, assuming zero exposure for the remainder of the shift:

$$0.006 \text{ mg}/0.3 \text{ m}^3 \times 120 \text{ min}/480 \text{ min} = 0.005 \text{ mg/m}^3 \quad (3)$$

If the laboratories were not able to achieve this target owing to analytical limitations, their goal would be to get as close to the target as possible while at least being able to measure 100% of the OEL as an 8-hr TWA. This would be clearer than what is currently described in the NIOSH "Guidelines for Air Sampling and Analytical Method Development and Evaluation" [9] publication, which specifies an evaluation range that "covers concentrations from 0.1 to 2.0 times the exposure limit" without explicitly stating that these concentrations should be based on 8-hr TWA concentrations. Moreover, the guideline states that "in cases where an atmosphere of an analyte was not generated, the evaluation range can be calculated as the range of concentrations that would be equivalent to the amounts of analyte fortified onto the samplers for the evaluation experiments, based on typical sampling times and rates." By allowing the range of concentrations to be based on "typical sampling times" as opposed to 8-hr TWA concentrations, the target quantitative limits of detection, expressed as masses, may differ from method to method for the same analyte based on the method developer's interpretation of what the typical sampling times are.

In conclusion, removal of the MSV specification in industrial hygiene air sampling methods (or making it a recommendation) would allow for a broader assessment of jobs that more accurately reflect the modern workplace by eliminating one of the common reasons cited for not air sampling or not submitting a sample, namely, the short duration of the work activity. It would also eliminate the needless practice of running sampling pumps in clean air to collect a specified, minimum volume, which have no bearing on the 8-hr TWA results of an exposure assessment.

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Conflicts of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.shaw.2019.07.001>.

References

- [1] Hamilton A. Exploring the dangerous trades, an autobiography of Alice Hamilton. M.D. Boston, MA: Little, Brown & Co; 1943.
- [2] Luxon SA. History of industrial hygiene. *Am Ind Hyg Assoc J* 1984;45(11):731–9.
- [3] Lead. Code of federal regulations title 29; 1978. Part 1910.1025; 1978.
- [4] The National Institute for Occupational Safety and Health. NIOSH manual of analytical methods (NMAM). 5th ed. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication; 2017. No. 94-113.
- [5] The National Institute for Occupational Safety and Health. NIOSH manual of analytical methods (NMAM). Method 7500, Issue 4. 4th ed. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication; 2003. No. 94-113.
- [6] Code of Federal Regulations Title 29, Part 1910.1053 Respirable crystalline silica; 2016.
- [7] Meyers RA. Inductively coupled plasma/optical emission Spectrometry. *Encyclopedia of analytical chemistry*. Chichester: John Wiley and Sons; 2000.
- [8] The National Institute for Occupational Safety and Health. NIOSH manual of analytical methods (NMAM). Method 7082, Issue 3. 5th ed. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication; 2017. No. 94-113.
- [9] The National Institute for Occupational Safety and Health. Guidelines for air sampling and analytical method development. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication; 1995. No. 95-117.