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Analytical Performance Issues

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Analytical Performance Issues
Integrating Direct-Reading Exposure Assessment Methods into Industrial Hygiene Practice

INTRODUCTION

Real-time and near real-time methods for assessing workplace exposures are becoming increasingly available. While many conventional exposure assessment methods require collecting the agent of interest on some type of sampling media and subsequently sending it to a commercial laboratory for analysis, some workplace hazards are already routinely monitored in real time. Noise is the primary example of a workplace hazard that is monitored by direct-reading instruments, with the regulation governing the allowable exposure also specifying the operating characteristics for the monitors

Advancements in the technology for monitoring the range of workplace hazards have led to increased usage of real-time monitoring either as a supplement to or a replacement for conventional workplace sampling. Direct-reading methods are also being used in innovative ways, such as for identifying workplace factors that influence exposure (determinants of exposure). Such characterization is possible because these methods have unique capabilities for measuring peak concentrations and for differentiating exposures across different work tasks or manufacturing processes; such determinations are not usually possible with conventional time-weighted average (TWA) exposure assessment methods.

Direct-reading exposure assessment methods may be either real-time (instantaneous readings) or near real-time (field-based analysis providing shorter turnaround times between sample collection and result determination than is typical with laboratory analysis). Methods considered real-time generally rely on field-portable instruments that give instantaneous measurements, often as a visual display on the body of the instrument.

In addition to monitors for noise and radiation, real-time monitors are widely available for gas and vapor or aerosol measurements, and new technologies are emerging for other workplace hazards, such as force strength monitors for ergonomic assessments. In the case of near real-time monitoring, advances in developing field portable versions of what were previously laboratory methods have expanded capabilities for short turnaround times between sample collection and analysis. Examples include field portable gas chromatographs for volatile and semivolatile compounds; X-ray fluorescence detectors for metals determinations; and immunochemical assay kits for methamphetamines, microorganisms, and other kinds of immunologically active contaminants.

Rapid response times and immediate or near-immediate results provided by direct-reading methods have great potential for workplace interventions by identifying hazardous conditions or exposures prior to adverse effects on workers. The level of

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performance required from these methods will be in direct proportion to the accuracy and precision requirements for determining the hazard.

Other important considerations will be the sensitivity or specificity of the method for the agent of interest and whether any potential bias may exist across the range of exposures encountered in the workplace. The allowable tolerances across the measured parameters must be decided prior to designing the exposure assessment strategy. Once those parameters are decided, then understanding the capabilities of a given method for meeting that level of performance will be important for ensuring the quality of the exposure assessment.

This column will provide different examples of the ways in which direct-reading methods or instruments have been used in industrial hygiene and will discuss some of the aspects of utilizing the output from these methods for making decisions about worker exposure.

Direct-Reading Exposure Assessment Approaches

Hazard Screening

Assessing some exposures may require only a qualitative approach to identifying whether an agent is present in the workplace, with the exposures characterized as presence/absence or above/below a certain level. Emergency responders often encounter situations where determining the presence or absence of a suspect agent is key for defining the appropriate response. While a wide array of direct-reading methods and instruments are utilized by emergency responders, immunochemical and biosensor technologies are emerging as important for detecting occupational and environmental agents. The anthrax attacks in 2001 increased the interest in real-time detection of biological warfare agents, with immunoassay methods being increasingly utilized for that purpose.[1]

Another approach may utilize direct-reading instruments to identify areas of concern within a facility to optimize a future sampling strategy requiring more sophisticated methods or instruments. One example was work conducted by Methner and Bowman,[2] who used a structured walk-through survey format to evaluate ambient magnetic fields in 62 industrial facilities to identify those with the highest readings for later, more extensive evaluation. Those authors concluded that such a procedure allowed for identifying workplaces with the highest exposure potential in ways that could not be determined by other factors, such as industry classification code or electrical power usage.

Direct-reading instruments have been put to use for screening potential hazards to workers in the emerging field of nanotechnology. The lack of occupational exposure limits for nano-engineered materials has led to a generalized industry approach that controls exposures as much as possible. The National Institute for Occupational Safety and Health (NIOSH) has published its screening approach known as the Nanoparticle Emission Assessment Technique (NEAT).[3] NEAT utilizes real-time monitors in conjunction with air sampling onto filters for evaluating potential emissions from nanomaterial production processes.

When considering the essential performance characteristics of methods used for hazard screening, requirements for accuracy and precision are not as stringent as long as the method can discern the presence of the agent of interest at levels that are protective. Knowing whether there is potential for interference from other agents or a tendency for bias with environmental conditions can be important for interpreting results under field conditions. If multiple units or tests of the same type are conducted, understanding the level of agreement between the individual units or between replicate tests will also be important when making determinations across time or location.

Task- or Process-Based Analysis

Confined space entry is a workplace task routinely monitored using direct-reading methods, often hand-held or person-wearable instruments. The Occupational Safety and Health Administration (OSHA) requires that methods for monitoring confined spaces, at a minimum, be able to determine oxygen deficiency and the presence of combustible gases.[4] The potential that other hazardous contaminants may be present in confined spaces means that commercially available instruments often are capable of monitoring other parameters. Birch et al.[5] recently reviewed the capabilities of current commercially available confined space instruments.

Direct-reading aerosol monitors have been used in the automotive industry for mapping concentrations of metalworking fluid mist[6] and size-fractionated particles.[7,8] Those authors found that both process and nonprocess sources of particles were present in the facilities. They concluded that the presence of nonprocess particles could potentially compromise particle attribution, since particle monitors cannot differentiate the types of particles being measured. More recently, one of those researchers augmented real-time aerosol instrument evaluations of nanoparticle exposure with conventional filter-based sampling to discern whether elevated concentrations, as indicated by the instruments for certain tasks, were indeed due to the nanoparticles that the workers were handling.[9]

Real-time and near real-time instruments and methods are increasingly used for routine monitoring of workers, as they provide great insight for elucidating exposure profiles over a specific time course, such as a workday. The ability to characterize the contributions of certain tasks or processes, often called determinants of exposure,[10] has long been an essential element of industrial hygiene. Such determinations require not only measuring exposures but also utilizing professional judgment to identify other factors that are thought to play a role in exposure. Where possible, those other factors are measured; when not possible, some other type of assignment is made to link the factor with worker exposure. Direct-reading methods lend themselves to the determinants of exposure approach. A study evaluating the determinants of noise exposure in four lumber mills utilized personal dosimeter results and found that although hearing protection compliance was high, hearing protectors alone were not sufficient for conserving worker hearing at the observed exposure levels.[11]

Using a direct-reading method for task- or process-based analysis often means that the user will have a greater need for understanding its performance limits. Instruments optimized for monitoring a continuous atmosphere may not be as capable of responding if contaminant concentrations change rapidly or exceed the capacity of the detector. Other factors such as ambient temperature and humidity can also influence instrument performance, meaning that hot or cold work environments may not be as amenable to evaluation.[12] For example, changes in atmospheric pressure were found to create signal spikes for oxygen sensors in confined space monitors, which thereby increased the likelihood of false alarms.[13]

Many commercially available monitors are capable of measuring multiple types of gases; however, they are not specific to the particular gas of interest and are consequently prone to interference when other gases are present. This phenomenon is of particular concern for emergency responders, who may not know the identity of compounds they will encounter in a particular event.

However, few studies have investigated the effect of interferents on performance. In a relevant study, Longworth et al.[14] tested three units of a particular analyzer to characterize the chemical warfare agent vapor detection capability of that instrument. These authors concluded that (1) the analyzer did not provide sufficient warning to ensure the safety of first responders when exposed to chemical warfare agents, (2) interferent vapors affected the detection performance, and (3) high humidity decreased the instrument response. Another study evaluated a combination photoionization detector (PID) and flame ionization detector (FID) for measuring warfare agents.[15] Those authors found that the PID detectors were impractical for the field, as they were easily contaminated and needed frequent cleaning. They also found the FID to be strongly affected by interferents. Longworth and colleagues concluded that neither the PID nor FID detectors could be relied on for detecting chemical warfare agents, particularly since other contaminants adversely affect their performance.

No studies were found that evaluated the influence of interferents on measurement of other chemical types. Nonspecific monitors may provide incorrect or misleading measurements in the presence of similar contaminants, so using them may require confirmatory methods for contaminant identification. Song et al.[16] have developed a structured approach for defining performance when screening tests are to be used in the field.

Compliance with Regulatory Limits

The most stringent requirements for a direct-reading method or instrument occur when the method is used for determining compliance with regulatory limits. The most developed example would be noise exposure monitoring devices that, according to the OSHA regulations, must provide performance that conforms to the applicable American National Standard Institute (ANSI) specifications.[17] Specific criteria for other direct-reading methods are not as developed for other workplace hazards as the criteria for noise, although OSHA has established equivalency criteria that allow for the use of alternative monitoring methods. The equivalency criteria require the user to demonstrate that the alternative method provides results comparable to the method specified by the regulation for the agent of interest.[18] The criteria generally require that the accuracy and precision of the replacement method be within 25% of the standard. Similar criteria for determining the accuracy, precision, and bias of gas monitors were applied by Shulman and Smith[19] to data from a carbon monoxide monitor.

The response of monitors capable of measuring multiple types of gases has been of particular interest; their performance has been compared with concentration results obtained from conventional methods, i.e., charcoal tubes. In one study, Drummond[20] placed a standard charcoal tube on the outlet of a PID equipped with a positive displacement sampling pump, and tested this system in both the laboratory and in the field. The author found that a consistent response factor could be determined by taking the time-weighted average (TWA) concentration from the charcoal tube and dividing it by the TWA concentration of the PID. For a truck driver loading gasoline, the benzene response factor was 0.20.

In another investigation, Poirot et al.[21] compared the response of a PID with charcoal tubes sampling known chemicals in the laboratory and unknowns at two different workplaces (during house painting and industrial site reclamation). In all cases, good correlation (i.e., r^2 close to 1) was found between the PID responses and the charcoal tube concentrations, leading the authors to conclude that the PID is an excellent means to show possible changes in a worker's exposure.

Elsewhere, Coy et al.[22] compared 26 side-by-side TWA personal breathing samples on construction painters using standard charcoal tubes analyzed by gas chromatography and a PID. Those authors concluded that the PID response was representative of the TWA total hydrocarbon exposure based on the high correlation ($r^2 = 0.95$) but found that it underestimated exposures in comparison with the charcoal tubes.

More recently, Coffey et al.[12] conducted a laboratory comparison of multiple units of five types of organic vapor monitors measuring hexane vapor at two concentrations to results from charcoal tubes sampling in parallel. It was found that none of the monitors was able to provide comparable results at an agreement criterion of 25%. Those authors identified some elements of the instrument operation that might have influenced their comparability and concluded that until those issues were resolved, the instruments tested were not adequate replacements for the conventional method, i.e., charcoal tubes.

Using direct-reading methods in this last context, that is, as replacements for defined methods used to determine compliance with a specified exposure limit, will require that the accuracy, precision, and bias of the replacement method be demonstrated in a manner that will allow it to be legally defensible. In addition to the OSHA equivalency criteria, NIOSH has criteria for evaluating sampling and analytical methods.[23]

However, any such determination is dependent on choosing an appropriate reference method. Choosing a reference method is not a simple task, as any such "gold standard" will also

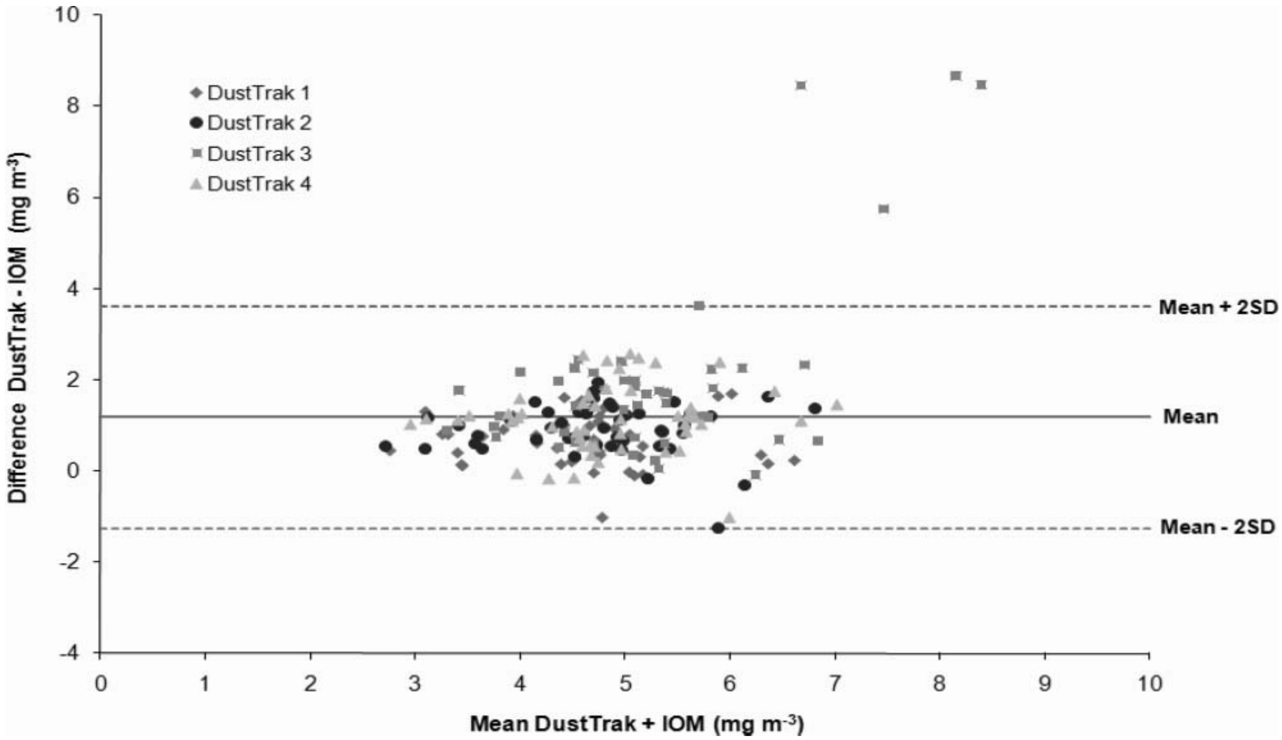

FIGURE 1. Tukey mean-difference plot of results from four individual DustTraks sampling a test dust vs. the result from an IOM sampler in the center of the dust chamber. Mean difference between the DustTraks as a group and the IOM was 1.18 mg m^{-3}.

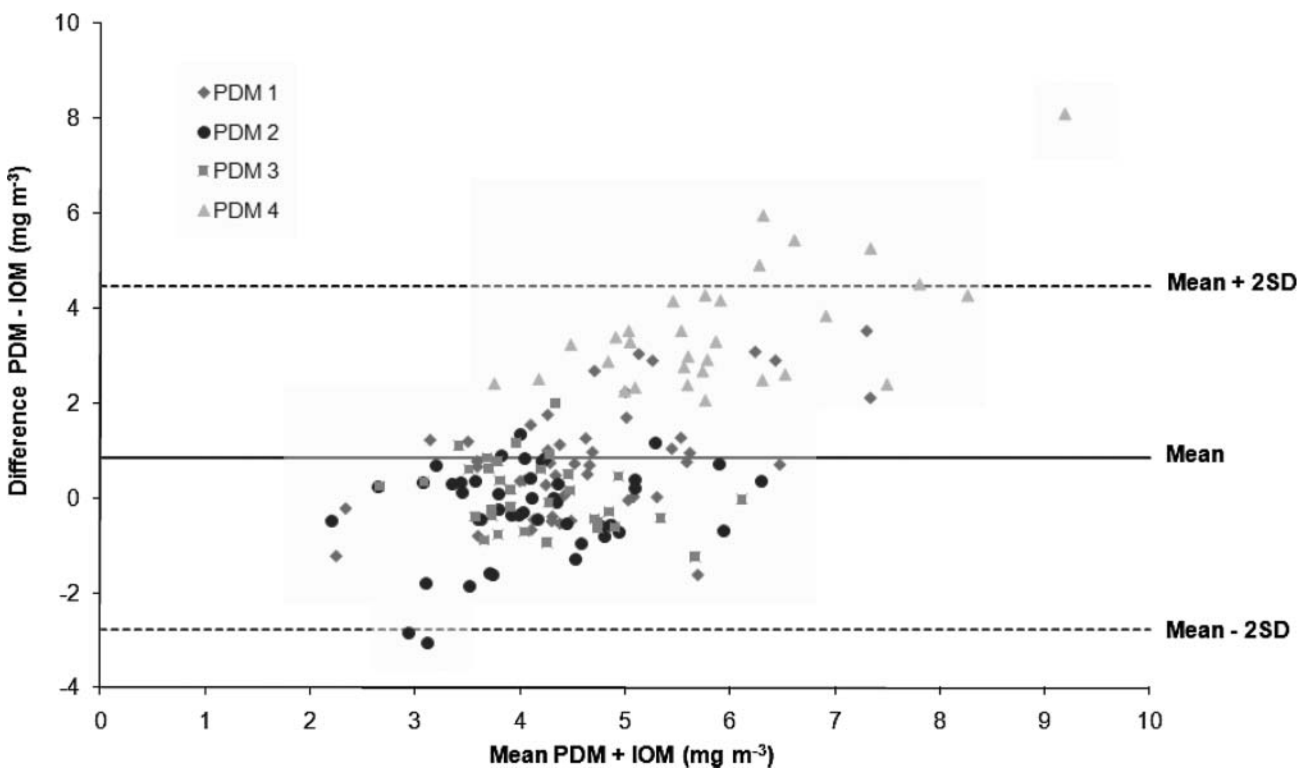

FIGURE 2. Tukey mean-difference plot of results from four individual PDMs sampling a test dust vs. the result from an IOM sampler in the center of the dust chamber. Mean difference between the PDMs as a group and the IOM was 0.85 mg m^{-3}.

possess limits for its accuracy and precision. Designing the comparison must take this variability into consideration when analyzing the data from the replacement vs. the standard. Bland and Altman[24] have proposed the use of Tukey mean-difference plots for analyzing the agreement between two different assays known to each possess inherent measurement error.

Figures 1 and 2 provide Tukey mean-difference plots from an ongoing study in the authors' laboratory, comparing results from commercially available dust monitors with results obtained with personal filter samplers when measuring a test dust in a dust exposure chamber. Figure 1 provides results from four individual units of the DustTrak Aerosol Monitor (Model 8520; TSI, Inc., Shoreview, Minn.) to concentration results from an Institute of Medicine sampler (IOM; SKC Inc., Eighty Four, Pa.). Figure 2 provides similar data from four Grimm Personal Dust Monitors (PDM, Model 1.108; GRIMM Technologies, Douglassville, Ga.) operated in the dust chamber at the same time as the DustTraks. In general, the results from all of the monitors were within two standard deviations of the mean of the IOM-measured concentrations but exhibited a tendency to overestimate the exposure, as demonstrated by a mean difference greater than zero. The plots indicate that individual monitors of a given type could have more measurement bias and therefore a greater influence on the overall comparability for that group.

Emerging Trends

Improvements in microelectronics and sensor technologies will likely mean that direct-reading exposure assessment methods will become increasingly available for assessing most types of workplace hazards, with better accuracy and with more sensitivity and specificity. A recent example is provided by a person-wearable monitor for real-time detection of personal exposure to hydrocarbons and acids.[25] The authors report that the unit communicates wirelessly with a cell phone and is inexpensive, yet provides powerful chemical sensing capabilities.

The field of biosensing and bioelectronics is expected to yield increasingly effective detection technologies based on immunochemical and other biological processes. A recent overview by Biagini et al.[26,27] elucidated the science behind immunoassay technologies and their great potential for specificity to particular agents that may not be possible with other technologies.

Finally, developments in nanotechnology have given rise to many new types of sensor technologies. A recent review[28] elucidated the potential for chemical sensing using metal oxide nanowires. Boron-doped silicon nanowires were found to be useful for detecting both biological and chemical species.[29] Nanosensors based on detecting optical or magnetic properties of materials are also being developed with the potential applications for many of these devices still largely unexplored.

Integrating direct-reading methods into exposure assessment strategies allows for previously unavailable opportunities to intervene early in the process of negative impacts on worker health and productivity. Improvements in the technologies will require the industrial hygiene community to adapt to the changes and incorporate them into the world of workplace exposure assessment. Utilizing these technologies will require some innovative approaches to ensure smooth transitions between data obtained with conventional methods and those obtained with their replacements. Industrial hygienists possess the unique set of skills and abilities necessary for utilizing these technologies to their utmost potential for protecting worker health. However, diligent care must be taken to ensure that data quality is adequate for the task at hand.

REFERENCES

1. **Fischer, N.O., T.M. Tarasow, and J.B.-H. Tok:** Heightened sense for sensing: Recent advances in pathogen immunoassay sensing platforms. *Analyst 132*:187–191 (2007).
2. **Methner, M.M., and J.D. Bowman:** Hazard surveillance for industrial magnetic fields: I. Walkthrough survey of ambient fields and sources. *Ann. Occup. Hyg. 44*:603–614 (2000).
3. **National Institute for Occupational Safety and Health (NIOSH)**: *Approaches to Safe Nanotechnology* (Pub. no. 2009–125). Cincinnati, Ohio: NIOSH, 2009.
4. "Permit Required Confined Spaces." *Code of Federal Regulations Title 29*, 1910.146. 1998.
5. **Birch, M.E., T.A. Pearce, and C.C. Coffey:** *Direct-Reading Instruments for Gas and Vapor Detection (Pub. no. ASI18).* Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists (ACGIH), 2009.
6. **O'Brien, D.M.:** Aerosol mapping of a facility with multiple cases of hypersensitivity pneumonitis: Demonstration of mist reduction and a possible dose/response relationship. *Appl. Occup. Environ. Hyg. 18*:947–952 (2003).
7. **Peters, T.M., W.A. Heitbrink, D.E. Evans, et al.:** The mapping of fine and ultrafine particle concentrations in an engine machining and assembly facility. *Ann. Occup. Hyg. 50*(*3*):249–257 (2006).
8. **Evans, D.E., W.A. Heitbrink, T.J. Slavin, et al.:** Ultrafine and respirable particles in an automotive grey iron foundry. *Ann. Occup. Hyg. 52*(*1*):9–21 (2008).
9. **Peters, T.M., S. Elzeyc, R. Johnson, et al.:** Airborne monitoring to distinguish engineered nanomaterials from incidental particles for environmental health and safety. *J. Occup. Environ. Hyg. 6*:73–81 (2009).
10. **Burstyn, I., and K. Teschke:** Studying the determinants of exposure: A review of methods. *Am. Ind. Hyg. Assoc. J. 60*:57–72 (1999)
11. **Davies, H.W., K. Teschke, S.M. Kennedy, et al.:** Occupational noise exposure and hearing protector use in Canadian lumber mills. *J. Occup. Environ. Hyg. 6*:32–41 (2009).
12. **Coffey, C.C., T.A. Pearce, R.B. Lawrence, et al.:** Measurement capability of field portable organic vapor monitoring instruments under different experimental conditions. *J. Occup. Environ. Hyg. 6*:1–8 (2009).
13. **Dabill, D.W., J.A. Groves, and D.R. Lamont:** The effect of pressure on portable gas monitoring equipment during compressed air tunneling. *Ann. Occup. Hyg. 40*(*1*):11–28 (1996).
14. **Research and Technology Directorate, Soldier and Biological Chemical Command, AMSSB-RRT:** *Domestic Preparedness Program—Testing of MIRAN SapphIRe Portable Ambient Air Analyzers against Chemical Warfare Agents Summary Report* by T.L. Longworth, J.I. Barnhouse, and K.Y. Ong. Aberdeen Proving Ground, Md., 2000.
15. **Research and Technology Directorate, Soldier and Biological Chemical Command, AMSSB-RRT:** *Testing of Commercially Available Detectors Against Chemical Warfare Agents Summary Report* by T.L. Longworth, J.C. Cajigas, J.L. Barnhouse, K.Y. Ong, and S.A. Procell. Aberdeen Proving Ground, Md., 1999.

16. **Song, R.**, **P.C. Schlecht**, and **K. Ashley:** Field screening test methods: Performance criteria and performance characteristics. *J. Hazard. Mater*. *83*:29–39 (2001).
17. "Occupational Noise Exposure," *Code of Federal Regulations Title 29*, Part 1910.95. 2008.
18. "Cotton Dust," *Code of Federal Regulations Title 29*, Part 1910.1043. 1978.
19. **Shulman, S.A, and J.P. Smith:** A method for estimation of bias and variability of continuous gas monitor data: Application to carbon monoxide monitor accuracy. *Am. Ind. Hyg. Assoc. J*. *63*(*5*):559–566 (2002).
20. **Drummond, I.:** On-the-fly calibration of direct reading photoionization detectors. *Am. Ind. Hyg. Assoc. J*. *58*:820–822 (1997).
21. **Poirot, P.**, **I. Subra**, **F. Gerardin**, **V. Baudin**, **S. Grossman, and M. Hery:** Determination of short-term exposure with a direct reading photoionization detector. *Ann. Occup. Hyg*. *48*(*1*):75–84 (2004).
22. **Coy, J.D.**, **P.L. Bigelow**, **R.M. Buchan**, **et al.:** Field evaluation of a portable photoionization detector for assessing exposure to solvent mixtures. *Am. Ind. Hyg. Assoc. J*. *61*(*2*):268–274 (2000).
23. **National Institute for Occupational Safety and Health (NIOSH):** *Guidelines for Air Sampling and Analytical Method Development and Evaluation (Pub. no. 1995–117)*. Cincinnati, Ohio: NIOSH, 1995.
24. **Altman, D.G., and J.M. Bland:** Measurement in medicine: The analysis of method comparison studies. *Statistician 32*:307–317 (1983).
25. **Negi, I.**, **F. Tsow**, **K. Tanwar**, **et al.:** Novel monitor paradigm for real-time exposure assessment. *J. Expo. Sci. Environ. Epidemiol*. Jun 16, 2010; [Epub ahead of print].
26. **Biagini, R.E.**, **J.P. Smith**, **D.L. Sammons**, **et al.:** The use of immunochemical and biosensor methods for occupational and environmental monitoring. Part I: Introduction to immunoassays. *J. Occup. Environ. Hyg*. *5*:D25–D32 (2008).
27. **Biagini, R.E.**, **J.P. Smith**, **D.L. Sammons**, **et al.:** The use of immunochemical and biosensor methods for occupational and environmental monitoring. Part II: Immunoassay data analysis and immunobiosensors. *J. Occup. Environ. Hyg*. *5*:D37–D42 (2008).
28. **Shen, G.**, **P.-C. Chen**, **K. Ryu**, **et al.:** Devices and chemical sensing applications of metal oxide nanowires. *J. Mater. Chem*. *19*:828–839 (2009).
29. **Cui, Y.**, **Q. Wei**, **H. Park**, **et al.:** Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species. *Science 293*:1289–1292 (2001).