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U.S. Approach for Air Sampling of Workplace Contaminants: Current Basis and Future Options

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The evaluation and control of the workplace environment and worker exposures to air contaminants require an understanding of the levels of those air contaminants. In the past 20 years, the emphasis has been on monitoring specific chemical vapors and aerosols. The approach that has been taken, the reason for that approach, and the progress that has been made are the primary topics of this article. Another topic of this article concerns the future of workplace monitoring with regard to new instrumentation, instrument and computer networking, the growth of biotechnology, and concerns about indoor/office environments and the agriculture setting.
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Monitoring Strategies

There are two basic types of air sampling in the workplace: personal breathing zone and general air. Each sampling approach is used for unique purposes and they frequently give uncorrelated results. Special attention is placed on personal sampling for assessing worker exposure to air contaminants. Personal sampling means that a sampling device is worn by the worker and that the air is usually sampled near the face because inhalation is the primary route of entry for many contaminants.

The emphasis on personal sampling is based on the premise of the Occupational Safety and Health Act in which Congress expressed its intent ". . . to assure so far as possible every working man and woman in the nation safe and healthful working conditions. . . ."[1] This passage has been interpreted as addressing individual workers, not groups or aggregates; therefore, personal exposure monitoring is required to assess individual exposure. The Federal Mine Safety and Health Act is similar and states ". . . the first priority of concern . . . must be the health and safety of its most precious resource—the miner."[2] Both Acts declare the need to monitor or measure exposures so as to ensure the maximum possible protection when promulgating a health standard.

The need to conduct personal monitoring for determining worker exposure to air contaminants is further supported by the technical literature. Studies in the scientific literature frequently state that "environmental" air (general air) measurements do not correlate with personal exposure measurements. Personal exposure measurements are frequently several times higher than data collected from fixed point measuring instruments.[3–7] For a work force that moves through a heterogeneous and time-varying atmosphere of air contaminants, personal sampling is the only mechanism currently available to estimate exposure.

Various instruments are available to meet the need to determine worker exposure to air contaminants. The most common air sampling device for the industrial hygienist is the portable, battery-operated air pump attached to a filter to collect aerosol particles or a tube containing a sorbent to collect gases. Sometimes, the sorbent tube is placed between the filter and the pump, either to collect the vapor fraction of a volatile aerosol or to filter interfering substances. By placing specially designed preselectors before the air filter, particle size subfractions of the total dust that are known to cause adverse health effects can be determined, or complete particle size distributions can be estimated. Preselectors are available for many types of monitoring.[8,9]

There are many reasons for performing workplace monitoring other than the measurement of worker exposure. Some of these reasons are related to safety issues such as detection of explosive atmospheres, entry into confined spaces, or detection of hazardous gas concentrations that are immediately dangerous to life and health.[8,10] Also, monitoring of air concentrations is often necessary to determine the performance of control and process equipment to ascertain whether the equipment is operating properly. Each of these applications requires direct-reading instruments that permit immediate action, such as removal of workers from the area, use of personal protective equip-

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TABLE I. Measurement Performance Criteria*

Concentration	Accuracy (%)
Above the Permissible Exposure Level (PEL)	± 25
At or below the PEL and above the Action Level	± 35
At or below the Action Level	± 50

*The method of measurement shall have an accuracy, to a confidence level of 95% of not less than that presented.

ment, or repair of malfunctioning controls or process equipment. General air monitoring with direct-reading instrumentation can be used for many of the above-mentioned situations. Such instruments were used successfully in the plastics industry for monitoring vinyl chloride concentrations and locating the source of emissions. Once the vinyl chloride sources were identified, processes were modified. Also, the identification of vinyl chloride emission sources led to changes in production processes. Continuous monitors are now used to control for leaks and to keep worker exposure within permissible exposure limits.[11,12]

Performance Criteria

Estimates of worker exposure must be accurate and free of errors, if correct decisions are to be made regarding compliance with exposure limits or in health effect studies. While some sampling and analysis may appear costly, incorrect decisions made from poor data are even more costly, either in fines or human suffering.[13] For these reasons, performance criteria are required for collecting exposure data, the development and validation of sampling and analytical methods, and maintaining and reporting data. Performance criteria first began to appear in the gas detector tube certification program (which has since been discontinued) sponsored by the National Institute for Occupational Safety and Health (NIOSH),[14] followed by the Occupational Safety and Health Administration (OSHA) proposed regulations for butanone (Table I).[15]

NIOSH and OSHA committed themselves to developing performance criteria when they began the Standards Completion Program in the 1970s. Procedures were defined for determining noncompliance that set the stage for performance criteria for sampling and analytical methods.[16,17] In this context, an accuracy criterion was established as: "The goal is to assure that a single measurement by a method will come within ± 25% of the corresponding 'true' air concentration at least 95% of the time."[18] This, in turn, led to the development of protocols for evaluating sampling and analytical methods and for evaluating passive samplers.[18-23] As a minimum, it was decided that performance criteria require such information as the magnitude of the random error, the limit of detection (LOD), the limit of quantitation (LOQ), and an understanding of any biases. The evaluation protocols that were developed addressed these items, in addition to sample recovery, sample stability, and effects of humidity. NIOSH, the American Chemical Society, and others have been very active in developing definitions for commonly used terms such as LOD and LOQ.[24,25]

Even when an analytical method is thoroughly evaluated, the performance of the sampler is critical, especially for aerosols. Aerosol samplers inherently discriminate based on the aerodynamic properties of the aerosol. NIOSH, the American Conference of Governmental Industrial Hygienists, the International Standards Organization, and the European Community are developing definitions for particle subfractions and general performance standards for dust samplers.[26-28]

Performance criteria have not been developed for direct-reading instruments or continuous monitors. NIOSH has published several monitoring methods for instruments after they were evaluated using portions of the evaluation protocols that are used for sampling and analytical methods.[29,30] Also, over the years, NIOSH has evaluated several field portable instruments and published the results in technical reports.[31-37] These evaluations included portability, reliability, calibration, documentation, interferences, temperature and humidity effects, battery and sensor life, warm-up and response times, and other factors. Factors such as portability, reliability, and the ability to ship on common carriers influence whether an instrument will be taken into the field by an industrial hygienist. Ideally, an instrument should be easy to carry and expected to perform in the field as easily and reliably as a household appliance. Once on site, the instrument must be calibrated, and the quality of the user's manual and of the instrument/operator interface will affect how well that can be done. Self-calibration is a desirable feature and ideally, a skilled operator should not be required. The calibration must be stable under varying conditions of temperature, humidity, pressure, and electromagnetic interference. However, the calibration quickly becomes irrelevant if the selectivity of the instrument is insufficient to discriminate against common chemical interferences. Battery and sensor life are both economic and performance considerations; built-in tests indicating substandard performance are desirable. All these factors must be considered when an instrument is chosen for field work, with the realization that field measurement conditions are rarely the same from day to day, nor are they exactly the same as the conditions under which an instrument was evaluated. For that reason, instrument evaluations cannot be "pass/fail" tests but should be broad in scope and produce test results in sufficient detail to allow judgments to be made about each proposed application.

Other Types of Monitoring

Health complaints about indoor/office environments, the growth in biotechnology, and the recognition of health hazards in the agriculture setting have established the need to explore evaluation protocols for monitoring methods for biological aerosols. Methods are required for the study of

the reported health problems and any future exposure guidelines or regulations.

Emerging Monitoring Technologies

One of the more useful techniques for monitoring employs sensors that can continuously measure air contaminant concentrations or a property that can be related to the concentration. Having a time history of concentration permits detailed analysis that can be useful for designing controls. If the sensors are small, they can be worn by the worker and used for exposure analysis by combining exposure history with specific work regimes recorded by video cameras. In this way, process or work practices can be changed to bring exposures under control.[38,39]

Technology is progressing to the point that chemical concentration mapping will be useful for estimating worker exposure to air contaminants and controlling sources of emissions. This type of monitoring is in the research and development stages and has been demonstrated under limited applications. Chemical concentration mapping may be conducted in several ways. One way is to have a network of point sensors located throughout a plant environment. Another way is to use remote sensing devices, each of which can monitor the air contaminant of interest along a certain trajectory.[40,41]

Also, the use of miniature chemical sensors and modern electronics has expanded the capability for estimating worker exposures and controlling air contaminants. Radio transmitters, connected to sensors, can be assembled into a package small enough to be worn by a worker.[42] A receiver designed to receive signals from several sensors can now continuously monitor several air contaminants and resultant worker exposures. Such technology helps fulfill the recordkeeping requirements recommended by NIOSH and enforced by OSHA and the Mine Safety and Health Administration (MSHA).

Furthermore, data collected by one department within a facility may be of use to another department. For instance, the occupational safety and health management department might use data from the process control and facilities management departments to aid in controlling worker exposure to air contaminants. There is a trend toward having plantwide computer networks provide all the data communication needs of an industrial facility. The presence of networks offers an opportunity to access data that was not possible or very difficult when each department within a facility maintained its own database and could not conveniently share data. Occupational safety and health professionals should explore how these networks can provide useful data for limiting exposures to workers and manage the health of their work force.[43-45]

Summary

Accurate workplace exposure information is needed for compliance with exposure limits, recordkeeping requirements, health studies, and various safety issues. Several new developments will influence future options for worker exposure measurement and control. Most notable are international standards, the ability to exchange data, and improvements in science and technology.

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