CHAPTER 13

MONITORING STRATEGIES AND DEVICES

INTRODUCTION

Today, chemical surveillance of the workplace is standard practice, with specific requirements defined not only by regulatory authority (e.g., emergency response, laboratory standard, confined space entry, respiratory protection, hazard communication, chemical process safety) but also by corporate insurance carriers, corporate legal counsel, health and safety professional organizations, and employees themselves. Chemical surveillance is, in fact, as intrinsic to modern business practice as loss control, total quality management, and human resource development.

Given the broad legal, political, economic, and ethical ramifications of exposure to workplace chemicals, it is useful to distinguish between *chemical monitoring* and *chemical surveillance.*

Chemical monitoring connotes the technical and methodological aspects of any qualitative or quantitative analysis of process or fugitive chemicals. It may be undertaken for a variety of reasons, including not only the management of potential human exposure, but also to control production processes or the quality of intermediate and finished products. Chemical surveillance is a much broader, programmatic approach to the management of human exposure to chemicals. Surveillance includes monitoring, but also includes a variety of other efforts, such as the control of chemical inventories, waste minimization, chemical substitution, and process management.

In the United States, chemical monitoring for the purpose of managing human risk is historically linked to industrial compliance with chemical-specific health and safety standards (e.g., 29 CFR 1900 Subpart Z), with generic hazard and risk management regulations (e.g., laboratory standard, hazard communication), and, most recently, with standards established for hazardous waste sites (RCRA, CERCLA) and operations involving especially hazardous chemicals and chemical processing (e.g., SARA Title 3).

The rapid development of a wide range of workplace standards in the 1980s and 1990s coincided with two other significant developments: the explosive progress in materials sciences and electronic engineering (which provide the physical means for monitoring technology), and the growing recognition of the potential chemical risks associated with modern industry, including not only normal design and operational risks, but also those engendered by natural catastrophe, human error, and acts of terrorism.

All three factors (i.e., regulatory standards, monitoring technology, and catastrophic chemical release) continue to underscore the vital importance of monitoring capability in modern emergency planning and response—a capability which, while necessarily responsive to potential chemical risk, is not limited to chemical monitoring but includes a wide range of sensor systems necessary to achieve proactive and reactive response objectives.

CHEMICAL MONITORING TECHNOLOGIES

Common techniques for monitoring hazardous chemicals maybe conveniently divided into three basic types:

1. Ambient air monitoring: techniques that provide rapid on-site detection or measurement of chemicals that are present in the air as dusts, vapors, gases, or mists,
2. Ambient materials testing: techniques that typically require off-site laboratory analysis of samples, including solids (e.g., soil samples) and liquids (e.g., groundwater, hazardous waste mixtures), and
3. Personal monitoring: techniques that involve the detection or measurement of chemicals (a) within body tissues such as blood or urine, or (b) in the immediate vicinity of a worker equipped with a personal monitor to measure cumulative exposure over a specific period of time.

Ambient Air Monitoring Devices

By far the most commonly used chemical monitoring devices, ambient air monitoring devices provide a rapid, direct reading of chemical concentrations in air. However, there are usually significant limitations associated with any particular device, including:

- Most detect or measure only specific chemicals or chemical classes; none detect all possible chemicals

TABLE 13.1 Data and Information Typically Provided by Manufacturers of Colorimetric Devices Used for the Monitoring of Common Industrial Chemicals

Gas or Vapor To Be Monitored	Catalog Number	Range (ppm/hours)	Detection Limit (ppm; 8-hour)	Color Change	Storage Temp.	Shelf-Life (years)
Ammonia	3D	25 - 500 ppm	1.0	Purple to Yellow	Room Temp.	3
Carbon Dioxide	2D	0.2 - 8.0% hr.	0.015%	Blue to White	Room Temp.	2
Carbon Monoxide	1D	50 - 1000ppm	2.5	Yellow to Dark Brown	Room Temp.	2
Chlorine	8D	2 - 50 ppm	0.13	White to Yellow	Room Temp.	2
Formaldehyde	91 D	1 -20 ppm	0.06	Yellow to Red Brown	Refrigerate	1
Hydrogen Cyanide	12D	10 - 200 ppm	0.5	Orange to Red	Room Temp.	2
Hydrogen Sulfide	4D	10 - 200 ppm	0.25	White to Dark Brown	Room Temp.	3
Nitrogen Dioxide	9D	1 - 30 ppm	0.06	White to Yellow	Refrigerate	1
Sulfur Dioxide	5D	5 - 100 ppm	0.13	Green to Yellow	Room Temp.	2

- While the sensitivity of such devices is always subject to the development of new technology, they are generally incapable of detecting airborne concentrations of chemicals below 1 mg/m3
- Many can give false readings because, although designed to detect one particular substance, they are subject to interference (i.e., poisoned) by the presence of other chemicals

1. Colorimetric Indicator Tube

This relatively low-priced and easily used device consists of (a) a tubular glass ampoule containing an *indicator chemical* that reacts with a specific ambient contaminant of interest, and (b) a manual or motorized pump to draw a calibrated amount of ambient air through the ampoule. The reaction of the indicator chemical and the air contaminant changes the color of the indicator chemical. The linear length of the color change in the ampoule is proportional to the concentration of the air contaminant. Calculating the air concentration of the contaminant requires a simple mathematical operation involving the calibrated length of the color reaction in the ampoule and the volume of air pumped through the device. Depending upon the specific chemical being measured, the calculation may also require correction for barometric pressure. The measurement of certain air contaminants may also require the simultaneous use of a second ampoule, which is affixed to the indicator tube.

Manufacturers of colorimetric indicator tubes provide detailed information on the limits of each indicator tube that is specific to the ambient gas or vapor of interest (Table 13.1). In addition to such chemical-specific limitations, all colorimetric tubes share certain general limitations:

- While each indicator tube is specific to a particular ambient chemical, other ambient contaminants can interfere with the indicator chemical
- Most tubes can be affected by high humidity, thereby giving false readings
- Tubes available from different manufacturers may have different sensitivities, thereby providing different measurements of ambient concentrations
- Because of the variability of color perception among persons, different personnel may make different judgments as to the length of the color stain within the indicator ampoule.

Another common problem associated with colorimetric indicator devices is the problem of *false negatives.* If, after use, an ampoule shows no color reaction, the negative result may be due to (a) the concentration of the ambient contaminant being lower that the sensitivity of the tube, or (b) the indicator tube being defective. In such a case, the user is well advised to test the negative ampoule with a known high concentration of the contaminate vapor.

Finally, it must be stressed that the volume of air perfused through the indicator tube is typically very small and therefore represents a tiny portion of the ambient atmosphere. The location of the air intake to the detection device is therefore critical with regard to estimating air quality in the total volume of breathable air. It is, therefore, always advisable to conduct colorimetric monitoring within the immediate breathing space of personnel at risk.

High-flow personal samplers are increasingly available and should be considered as an important adjunct to any monitoring program. Single pumps are typically housed in a lightweight plastic case that clips to the user's belt. Multiple pumps are also available and can be used for simultaneous monitoring of atmospheric samples taken at different locations within the same general area. Battery packs for both single and multiple samplers allow continuous sampling over an 8- to 10 hour period.

2. Electronic Devices

A wide range of electronic devices are available for the detection of specific chemicals and broad categories of chemicals, and typically include such additional capabilities as data retrieval and storage, database searching, automatic calculations, and the formatting and printing (or modem transmission) of written reports and display graphics. Some, such as the combustible gas indicator, flame ionization detector, portable infrared spectrophotometer, and ultraviolet photoionization detector (Table 13.2), have broad application for compliance with numerous health and safety stan-

TABLE 13.2 Basic Types of Electronic Monitoring Devices (Adapted from NIOSH, USCG, and EPA, 1985: Occupational Safety and Health Guidance Manual for Hazardous Waste Activities)

Combustible Gas Indicator (CGI)

- Measures the concentration of a combustible gas or vapor
- A filament, usually made of platinum, is heated by burning the combustible gas or vapor; the increase in heat is measured
- Accuracy depends, in part, on the difference between the calibration and sampling temperatures
- Sensitivity is a function of the differences in the chemical and physical properties between the calibration gas and the gas being sampled
- The filament can be damaged by certain compounds, such as silicones, halides, tetraethyl lead and oxygen-enriched atmospheres

Flame Ionization Detector (FID) with Gas Chromatography Option

- In *survey mode*, detects the total concentrations of many organic gases and vapors; all organic compounds are ionized and detected at the same time
- In *GC mode*, identifies and measures specific compounds; volatile species are separated
- Gases and vapors are ionized in a flame; a current is produced in proportion to the number of carbon atoms present
- Does not detect inorganic gases and vapors, or some synthetics; sensitivity depends on the compound
- Should not be used at temperatures < 40 deg. F (4 deg. C)
- Difficult to identify compounds absolutely; specific identification requires calibration with the specific compound of interest
- High concentrations of contaminants or oxygen-deficient atmospheres require system modification
- In *survey mode*, readings can be only reported relative to the calibration standard used

Portable Infrared (IR) Spectrophotometer

- Measures concentration of many gases and vapors in air
- Passes different frequencies of IR through the sample; the frequencies absorbed are specific for each compound
- In the field, must make repeated passes to achieve reliable results
- Not approved for use in a potentially flammable or explosive atmosphere
- Water vapor and carbon dioxide interfere with detection
- Certain vapors and high moisture may attach to the instrument's optics, which must then be replaced

Ultraviolet (UV) Photoionization Detector (PID)

- Detects total concentrations of many organic and some inorganic gases and vapors; some identification of compounds is possible if more than one probe is used
- Ionizes molecules using UV radiation; produces a current that is proportional to the number of ions
- Does not detect a compound if the probe used has a lower energy level than the compound's ionization potential
- Response may change when gases are mixed
- Other voltage sources may interfere with measurements; response is affected by high humidity

dards. Others, such as an oxygen meter or sound meter, obviously have much more narrow application.

Increasingly available today are electronic instruments that combine monitoring capabilities for different chemicals. Examples of such combined capabilities include:

- A combustible gas meter that also measures oxygen, hydrogen sulfide, and carbon monoxide
- A toxic gas meter that can detect oxygen and combustible gases and which can also be equipped to monitor hydrogen cyanide, hydrogen chloride, nitrogen dioxide, nitrous oxide, and sulfur dioxide
- A hazardous gas detector that provides continuous measurements of many gases or vapors, including acetone, ammonia, arsine, benzene, carbon monoxide, ethylene oxide, and formaldehyde

Of critical importance in emergency response is the combustible gas indicator. As shown in Fig. 13.1, the combustion of a substance depends upon an adequate supply of both burnable fuel and oxygen. The relative amounts of oxygen and fuel that will support combustion are described in terms of both the lower explosive limit (LEL) and the upper explosive limit (UEL). Below the LEL, there is insufficient fuel to support combustion; above the UEL, there is insufficient oxygen.

The readout of the combustion meter is usually given in terms of percentage of LEL, with 100% indicating that the mixture of fuel and oxygen meets the minimal requirement for explosion. On such a scale, a reading of 10%, which is increasingly used to trigger the evacuation of an area, means that the concentration of flammable vapor is one-tenth of that required for a state of imminent explosion.

Portable detectors (Table 13.2) can, with proper calibration, detect hundreds of individual toxic vapors and gases. FID (flame ionization detector) and PID (photoionization detector) units can also be operated to measure total concentrations of ambient chemicals without regard to individual chemical species. This mode of operation (i.e., survey mode) is useful because its lack of chemical specificity provides an inherent safety factor.

For example, in the survey mode, a reading of, say, 250 ppm, which could represent a total concentration of potentially hundreds of organic compounds, could also be interpreted to represent the concentration of a particularly toxic compound of concern. Such a worst-case interpretation of the reading might or might not be realistic in a particular circumstance, but such an interpretation always has very real value as a criterion for further investigatory (if not corrective) action or even the initiation of area evacuation.

An oxygen meter (and, in some circumstances, a toxic gas and/or combustible gas meter), is a basic requirement in any situation in which

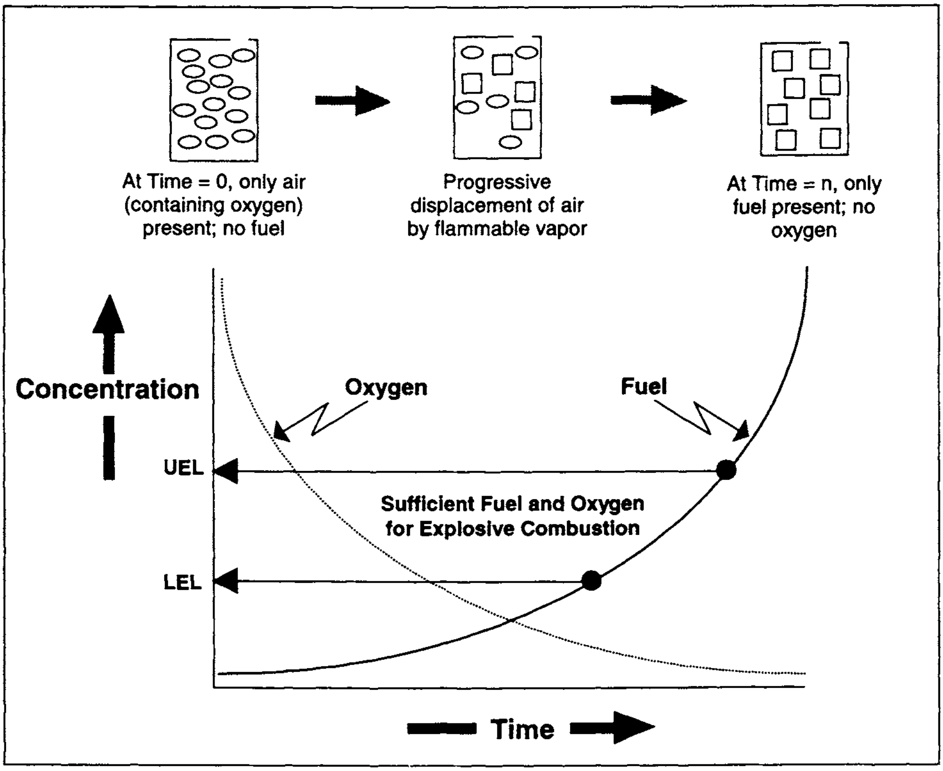

FIGURE 13.1 Lower and upper explosive limits. As the air in a container is progressively displaced by a flammable vapor (upper portion of figure), the concentration of oxygen in the container decreases while the concentration of potential fuel increases. At concentrations of fuel (expressed as percentage of atmosphere) below the LEL (lower explosive limit), there is too little fuel to support burning; at concentrations of fuel above the UEL (upper explosive limit), there is too little oxygen to support burning. Explosion may occur only when the relative concentrations of fuel and oxygen are at or between the LEL and UEL. On a scale where 100% represents the LEL, 10% is typically used as the trigger for implementing personnel evacuation.

confined space entry is required. While there are many different designs of oxygen meters, it is imperative that the meter be provided with a long probe that can be lowered or otherwise extended into a confined space without the operator becoming exposed to an atmosphere that is potentially oxygen deficient and/or toxic. It is also important that the operator understand that an oxygen meter is typically sensitive to a range of environmental factors, including barometric pressure and ambient concentrations of carbon dioxide and other oxidizing agents (e.g., ozone).

A wide variety of radiation survey meters are available for the detection of alpha, beta, and gamma radiation and X rays. It should be noted that, while alpha particles (energetic helium nuclei) are relatively large and slow-moving particles that are easily stopped by the outer layer of skin, they are also very hazardous if inhaled (e.g., via contaminated dust). Gamma and X rays (electromagnetic radiation) and beta particles (high-speed electrons) may have high penetration capabilities.

It must be stressed that, despite their apparent simplicity of design and operation, all electronic detectors are sophisticated instruments and require a precise understanding of their inherent limitations and requirements regarding calibration, care, and maintenance. Users are well advised to ensure that the manufacturer of any electronic detector provide proper instruction in all aspects of operation and maintenance, with particular emphasis given to the routine documentation of calibration, precision, and accuracy.

Ambient Materials Testing

In many situations a safety officer may require analyses of site materials and resources that cannot be performed on site, such as the analysis of:

- Potable water supplies, including wells, public water supply mains and lines, and other sources that might be contaminated with biological or chemical agents
- Surface or groundwater supplies that might become contaminated as a result of an incident and/or incident response activities
- On-site soils and dusts possibly contaminated with heavy metals and hazardous contaminants
- Structural and other on-site materials containing toxic substances (e.g., asbestos, pesticide residues, lead-based paint)

Such analyses typically require the use of specialized laboratories, including commercial water testing laboratories and materials testing laboratories. Where such professional analytical services are required, only those vendors who are certified by legal authority should be selected—and, more precisely, those who are specifically certified for the particular analysis to be performed.

For example, in the United States, a water testing laboratory may be certified through a state agency under the aegis of the U.S. Environmental Protection Agency; however, the certification is typically highly specific on the basis of the different types of analyses required by the Federal Safe Drinking Water Act, with certification for the analysis of heavy metals, for example, being separate and distinct from certification for the analysis of microorganisms.

Having procured the professional services of an appropriately certified laboratory, the safety officer must ensure that all samples are collected,

TABLE 13.3 Examples of Gases and Vapors That Can Be Monitored by Means of Open Diffusion Detector Tubes

Gas or Vapor	8 Hr. Measuring Range (ppm)
Acetic acid	1.25 - 25
Ammonia	2.5 - 187.5
Butadiene	1.25 - 37.5
Carbon dioxide	62.5 - 2500
Carbon monoxide	6.25 - 75
Ethanol	125 - 3000
Ethyl acetate	62.5 - 1250
Hydrochloric acid	1.25 - 25
Hydrocyanic acid	2.5 - 25
Hydrogen sulfide	1.25 - 37.5
Nitrogen dioxide	1.25 - 25
Olefin	12.5 - 250
Perchloroethylene	25 - 187.5
Sulfur dioxide	.63 - 18.8
Trichloroethylene	25 - 125

stored, and delivered in full compliance with relevant regulations. While it is usually desirable that the contracted certified laboratory itself collect and handle samples, this is typically impossible during an emergency. The site safety officer should therefore obtain written directions from the certified laboratory for the proper procedure for collecting, handling, packaging, preserving, transporting, and documenting samples.

Personal Monitoring

Personal monitoring devices include such devices as badges, monitors, dosimeters, and open diffusion detector tubes, all of which can easily be clipped or otherwise attached to personal clothing. Monitors may be dedicated to a particular chemical species (e.g., mercury vapor, trichlorethylene) or provide detection of a broad class of chemicals (e.g., organic vapors). In some designs, monitors that detect classes of chemicals may be processed to yield specific exposure data regarding a limited number of specific chemicals out of several dozen possibilities. Some devices give direct readouts of timed exposure (Table 13.3) or require simple comparison of color changes with standard color charts or data sheets; others require off-site laboratory processing, which introduces delays of several or more days in obtaining results.

Because of the necessary delays in obtaining data from badges that require off-site processing, it is imperative that such devices not be used in emergency response where exposure can exceed health or safety standards. The basic rule is that personal monitoring devices be used only after a comprehensive survey of an area has established, by means of ambient monitoring devices, potential worst-case exposures—and even then, only when there is assurance that worst-case exposures cannot exceed health and safety standards within the estimated time frame of on-site personnel work schedules.

OTHER MONITORING TECHNOLOGIES

In addition to the technologies discussed above, which are standard technologies employed by industrial hygienists, regulatory compliance officers, and hazardous waste emergency response personnel, other monitoring capabilities should be assessed for their relevance to the health and safety of response personnel.

Some of the more common monitoring devices that should be considered have long been used by industrial hygienists in the routine surveillance of workplace conditions and, depending upon incident site conditions, may be important tools for managing site-specific risks, including:

- Temperature and relative humidity monitors (especially important when incident conditions and operations enhance the risk of heat stress and dehydration; also available are heat stress monitoring systems that, while essentially hand-held units, can be connected to fixed or remote sensors)
- Sound meters (for continuous and intermittent noise that may not only result in significant damage to hearing, but also interfere with communication as well as concentration among site personnel)
- Particle analyzers (concentration and size distribution; an important adjunct to respirator use)
- Hand-held gas tracers and leak (gas and liquid) detectors (including colorimetric developers that can detect specific liquids, such as oil and chlorine)

Depending upon the nature of the incident and site operations, other more specialized but long developed technologies may be appropriate, such as:

- Vibration and dynamic strain sensor, as well as a variety of structural motion and/or level sensors (e.g., during technical rescue operations inside unstable structures)
- Piezoelectric films, cables, and other devices (which, by converting mechanical stress or strain into proportionate electrical energy, may also be adapted to monitor stability of on-site structural features)

- Personal alert safety system (PASS; to monitor motion of isolated personnel working under hazardous conditions and, as necessary, sound rescue alarm)
- Hand-held thermal sensor (to detect hot spots in overhaul and other response-related operations)
- Fixed and portable traffic monitors (which, in situations of public panic and/or in situations involving multiple incidents in dense population centers, can prove to be of inestimable value for achieving both strategic and tactical response objectives)
- Meteorological monitors (that can supplement regionally available data with site-specific details or, in case of communication failure and/or multiple incidents, provide basic data [e.g., wind speed and direction, barometric pressure] and forecast capability needed for operational management)

In addition to existing technologies, critical assessment of developing monitoring and alert technologies must be maintained as an on-going emergency management planning effort. This is especially important with regard to the monitoring of chemical and biological warfare agents that may be purposely used by terrorists or inadvertently released during a nonterrorist incident.

Both manual and electronic techniques are employed (and are under constant development) for detecting warfare agents, including:

- Detection paper, which is impregnated with dyes and pH indicators and yield characteristic colors when in contact with specific chemical warfare agents
- Detection tubes, which (as discussed above) involve chemically specific colorimetrically defined reactions between a known substrate and target agents
- Detection tickets, which consist of enzyme- and substrate-impregnated papers that mediate detectable reactions with various nerve gases
- Ion mobility spectroscopy (IMS) system, such as the Chemical Agent Monitor (CAM), which is currently in worldwide use for the detection of nerve gas, blister and choking agents
- Flame photometric detector (FPD), which can detect certain chemical warfare agents through the photometric analysis of air–hydrogen combustion residues
- Biosensors, which utilize enzymes and/or bioreceptors to detect chemical agents

DESIGN AND IMPLEMENTATION OF MONITORING PROGRAM

Different response services have different monitoring needs that may or may not overlap in the progress of a particular incident. The design and implementation of an effective monitoring program is therefore essentially a two-tiered effort: the first, focusing on specific in-service (or, in the case of the industry, in-plant) informational needs; the second, on mutual assistance among community services and support resources to provide a comprehensive monitoring capability.

In-Service Monitoring Capability

The design of an in-service monitoring capability should be viewed as basically an on-going process of matching operational decision-making needs with available technologies—and, of course, an assessment of potential applications within the constraints of costs and available personnel. Costs must include not only capital costs, but also direct and indirect costs associated with maintenance and replacement, quality control testing and calibration, and personnel training requirements. Basic steps in the design and assessment process should, at a minimum, include the following:

1. Conduct a Needs Analysis

This is a methodical examination of all decision-making needs during the conduct of response operations. Decision-making needs must be clearly and specifically defined with respect to (a) which monitoring data are actually used to choose from among which alternative courses of action, and (b) alternative sources and/or types of data and information that may serve the same decision-making objective. A proper needs analysis includes not only a detailed examination of the linkage of certain types of data to certain types of operational decisions, but also an evaluation of the relative importance or criticality of both the data and the decisions under emergency conditions.

For example, it may not at first appear to be necessary to use a field detector to monitor for toxic organic fumes if it is definitely known that toxic organic fumes are present and that search and rescue teams will wear SCBA—and, perhaps most importantly, that there are victims that must be recovered as quickly as possible. However, a properly conducted needs analysis will force additional considerations that can significantly increase the criticality rating of monitoring data—such as, in this example:

- If a SCBA system fails or there is a physical tearing or ripping in protective clothing, what is the health consequence to the wearer, and what is the time frame in which these consequences may become irreversible?
- Are the permeability ratings of fully functional protective clothing adequate under actual response conditions?

The answers to these questions depend, of course, on knowing just what the organic fume is, its concentration and physical and chemical properties, its combustion products, and other ambient conditions that affect its permeation into clothing (e.g., temperature).

2. Document Reliability of Monitoring Device or Procedure

Once it is demonstrated that specific monitoring data are necessary for operational decision-making, it is necessary to demonstrate the field reliability of the monitoring device or procedure selected to provide that data. This is best done by documenting its actual field use by other agencies and organizations, testing laboratories, and regulatory agencies, with particular attention given to observed failures and limitations. Design specifications should also be submitted to prospective vendors to ensure that devices and procedures can be successfully used under typical field conditions. Finally, actual field testing of the device or procedure should be conducted under simulated emergency conditions.

3. Develop Standard Operating Procedures

Once there is demonstrable assurance that the device or procedure meets practical decision-making needs under actual field conditions, comprehensive SOPs should be developed with regard to proper use, storage, maintenance, cleaning and decontamination, calibration, and any other protocol that may be necessary to ensure effective readiness and reliability.

SOPs should also give particular attention to *action levels*—i.e., specified monitoring data (e.g., concentration, % LEL, radiation level) that require the implementation of predetermined actions by specifically identified personnel. SOPs should also specify personnel training requirements, with appropriate attention given to ensuring the ready availability of properly trained personnel under likely field conditions.

Finally, it is vital that SOPs specify backup or *fail-safe* requirements for each device or procedure. For example, it may be deemed necessary to require the on-site availability of two or more fully functional devices so that the failure of any one device will not result in the loss of key monitoring capability. In some instances, it may be possible to provide manual monitoring capability (e.g., indicator tube technology) as a backup to an electronic monitoring device (e.g., photoionizing device).

Mutual Assistance Monitoring Programs

While there is much monitoring technology that is moderately priced, there is also much that is expensive not only in terms of capital costs, but also in servicing and maintenance costs. No response service is therefore likely to have the full primary and backup monitoring capability that may be called for in a particular incident. It is therefore necessary that careful attention be given to developing mutual assistance programs among both governmental and private sector organizations at local, regional, and even national levels. Just who should initiate this action and take responsibility for developing such programs is arguable. However, because any incident presents potential risks to the community as a whole, it is reasonable to suggest that municipal authority assume lead responsibility. In the United States, this approach is consistent with the establishment of local emergency response commissions (LERCs) under the U.S. Emergency Planning and Community Right-to-Know Act. However, more regionally or even nationally centralized authority is most appropriate to the political structures of many other countries.

Whatever its position in the sociopolitical hierarchy, the lead authority must ensure the on-site ready availability of an appropriate, fully functional monitoring capability that is likely to be composed of different resources supplied by a variety of response and support organizations.

In many instances, monitoring devices are only part of the total resources (which may include heavy equipment and/or transport vehicles as well as radiation meters available through a civil defense or state emergency response center) to be mobilized to meet incident response needs. However, there are also many circumstances in which vital monitoring equipment may be most readily available only through a particular source that has no other resource of potential response value (e.g., local pharmaceutical company, industrial chemical manufacturer, research and development facility).

The questions to be addressed by the lead organization for mutual assistance are essentially simple, including: Who has what device? Where is it ? How will it be delivered to where it is needed? Who takes responsibility for delivery? How long will it take to obtain it? Will it be functional when it arrives? Who knows how to use it? Obtaining clear, reliable answers, of course, is very difficult and requires significant, long-term commitment to preincident planning, coordination, and (especially) training.

PROACTIVE INDUSTRIAL MONITORING

Because the industrial facility must always be considered a potential source of risk to the surrounding community, in-plant monitoring of potentially hazardous substances, which is subject to extensive regulatory scrutiny in the United States, should be considered not simply a means of achieving regulatory compliance but also a key step in proactive emergency planning.

While monitoring technologies are equally available to community response services and industrial facilities, the industrial safety officer and incident safety officer have essentially different objectives, even if both must be primarily concerned with the health and safety of their respective personnel. In particular, the industrial safety officer must focus on the use of monitoring as a primary means of preventing or correcting a situation that can otherwise evolve into a full-blown emergency.

Identification of Monitor Parameters

The essential first step to implementing an effective in-plant monitoring program is to identify potential parameters to be monitored on the basis of (a) regulatory requirements (e.g., 29 CFR 1910 Subpart Z, hazard communication regulations, confined space regulations, OSHA laboratory standard, hazardous waste regulations, chemical process safety regulations), (b) requirements imposed by corporate insurance carriers, (c) state-of-the-art practices within the industry, (d) concerns of personnel, and (e) recommendations of a facility safety committee. This is typically accomplished by means of a comprehensive hazard assessment of the total facility, which usually (and preferably) includes a prioritization of hazards. The prioritization of hazards is important for two basic reasons:

1. prioritization facilitates the implementation of appropriate mitigation techniques, including administrative and engineering control measures and the required use of personal protective clothing and equipment
2. because even a moderate size manufacturing facility may have a chemical inventory of several thousand chemicals, prioritization of hazards requires not only an assessment of the degree of hazard but also detailed assessment of the technological feasibility of monitoring individual chemical species

In identifying potential chemical agents and available technologies for monitoring those agents, the safety officer must ensure that chemical by-products and processing intermediaries are considered along with feedstock product chemicals.

Finally, it must be noted that the availability of a monitoring technology does not necessarily imply the existence of a health or safety standard that can be used to interpret generated data. The safety officer must ensure that the final selection of parameters and monitoring technology is based on clear criteria for acting upon monitoring results.

Establishing Baseline Conditions

The concentration of ambient substances (e.g., chemical fumes, dusts) in the workplace typically varies greatly over the workday. Before any schedule of ambient monitoring or sampling is established, it is necessary to conduct a baseline study to identify the range of variation that may be correlated with routine workplace production schedules, seasonal patterns of temperature and humidity (which may directly influence in-plant ventilation), and plant production levels. A baseline study must also establish variations in ambient concentrations with regard to nonroutine situations, as in the case of power outages and staged shutdowns of ventilation for equipment repair or replacement.

The importance of establishing a comprehensive baseline cannot be overemphasized simply because it is the deviation of monitored concentrations away from baseline conditions that may indicate an impending or actual emergency situation. In some situations, deviations away from in-plant baselines may even indicate off-site emergencies that have resulted in atmospheric plumes which have subsequently become entrained in the make-up air of downwind facilities.

Action Levels

Some regulations (e.g., 29 CFR 1910 Subpart Z) specify actions to be taken if monitoring data regarding certain chemicals (e.g., formaldehyde) meet or exceed certain limits (i.e., action levels). While the number of chemicals having action levels defined by safety and health regulations is small, the key requirement for any monitoring program is that corporate action levels be clearly defined for all monitored parameters.

In the typical situation, routine monitoring data are collected, recorded, and, over some period of time involving days, weeks, and months, processed and eventually filed. Oftentimes, the employee who conducts the monitoring is not the employee responsible for reviewing the data. This situation is in direct opposition t the objective of using monitoring data to protect human health and safety. Persons who conduct the monitoring and have first access to the resultant data must be equipped with clear criteria for immediately initiating any protective or correction action. Data that meet or exceed established action levels are not to be used to call a meeting to discuss the ramifications of the data; they must trigger immediate response to protect personnel and the general public and to correct a hazardous situation—actions that have already been assessed, fully formulated, and coordinated with external authorities.

Carry-Home Contamination

Most often overlooked in corporate monitoring programs is the contamination that may be carried home or elsewhere from the workplace by hair, clothes, shoes, and other personal clothing. Even where the company attempts to control such carry-home contamination by the use of site-restricted shop uniforms and specially required workplace practices (e.g., workplace showers, hair nets), it is advisable to consider including personal clothing and other items in a comprehensive monitoring program. Even where the potential for such carry-home contamination is negligible, periodic monitoring data can provide documentation that might prove important in a legal proceeding involving any claim of corporate negligence. Such data are also important in setting contractual responsibilities with company out-service contractors, including corporate laundry services.

Quality Control

In addition to routinely scheduled monitoring activities, the safety officer is well advised to consider implementing unscheduled or even randomized monitoring efforts. Such unscheduled monitoring, whether conducted by in-plant personnel or external consultants, is a very useful means of ensuring the adequacy and quality of routine monitoring. Where external consultants are used, data sets generated by those consultants should be carefully compared to data sets generated internally. Consideration should also be given to using external consultants (including representatives of local response services) to conduct or to participate in a comprehensive annual review and assessment of the entire monitoring program.

ALARP Principle

While regulatory standards must always inform and guide any program of in-plant monitoring and surveillance, the objective of keeping workplace ambient concentrations of hazardous substances *as low as reasonably possible* (ALARP) is internationally recognized as a universally relevant objective. Elevated to a principle within a globally competitive business community, ALARP properly emphasizes that regulatory standards should be considered maximum allowable limits. However, within those regulatory limits, the company should endeavor to set action levels for monitored data that minimize all workplace and environmental exposure to hazardous substances within the constraints of available technology and economic reasonableness.

In formulating a program of workplace monitoring that is consistent with ALARP, companies are well advised to consider that, notwithstanding the necessity of employing legally enforceable health and safety standards, specific technological and economic criteria for setting action levels are also to be assessed in terms of the state-of-the-art—i.e., what the "best" companies actually do.

Because what happens in the workplace can so easily happen to the community which surrounds that workplace, it can be expected that state-of-the-art practice will increasingly become the measure of competent industrial planning and management rather than, as is too often now the case, economic practicality.