ATMOSPHERIC MONITORS

INTRODUCTION

Atmospheric monitoring is necessary to mitigate a variety of incidents as well as manage the working environment of fire department personnel. A hazardous environment may be primary hazard or reason that 911 was called, or it may be secondary to another event such as a fire, mechanical failure, illness, or hazardous material release. Some hazardous environments are identifiable to responders in the form of a visible cloud, a distinct smell, or by triggering consumer alarm devices (CO alarms). However, it is insufficient to rely upon human senses alone to identify, monitor, or mitigate hazardous atmospheres. Human sensitivity can be inconsistent, can become dulled, or can provide insufficient advance warning of a dangerous condition. Likewise, personnel should be cautious not to rely solely upon the atmospheric monitoring equipment for decision-making. Appropriate response to atmospheric incidents requires gathering all available clues from all available sources to formulate accurate situational awareness.

Atmospheric monitoring equipment provides consistent, verifiable, and reliable means of early warning and detection of hazardous environments. These devices not only identify the presence of harmful gases, but also provide a resource to measure (e.g., as a percentage or in parts per million) various gas or particle concentrations in ambient air. Atmospheric monitoring equipment that is standard to an engine company also provides an audible and visual warning when potentially harmful atmospheres are encountered or atmospheres are approaching harmful levels.

HOW ATMOSPHERIC DEVICES WORK

Monitors (or meters) are designed to provide a responder with early warning and detection of potential atmospheric dangers. Depending upon the gases being monitored, they may display concentrations as parts per million (ppm) or percentages of ambient air.

It is important to note that no single monitoring device is capable of measuring or warning about every gas or particle a responder may encounter. The monitoring equipment carried on Engine Companies is designed to monitor the most common situations encountered, but specialized monitoring equipment may be required for some incidents. Personnel must be capable of interpreting various meter readings, as well as understanding why and how a given device responds in a given atmosphere. Without this knowledge, responders may walk into toxic or oxygen deficient atmospheres without warnings. Personnel should review manufacturer’s reference materials for the monitoring equipment available on their apparatus.

Each sensor housed within a given atmospheric monitoring device is calibrated to alarm at a specific point or concentration. Monitors may contain a single sensor or multiple sensors to address multiple gases. Each sensor activates an alarm when detecting specific gases or toxins for which they are calibrated. When using a multi-gas monitor the user needs to read the screen to identify which sensor, or sensors, is alarming. The most common multi-gas monitors are configured for confined space entry and include sensors for combustible gas (LEL), oxygen, hydrogen sulfide (swamp gas), and carbon monoxide. The fire service has traditionally adopted these monitors as they address a broad spectrum of the most common emergency incidents.

Combustible Gas Sensors(CGI) measure the amount of flammable vapor in ambient air. Most meters are set up to measure flammable vapor concentrations as a percentage of LEL (0%-100%). LEL refers to the lowest concentration of a flammable gas, when mixed with ambient air, forms an ignitable mixture. Most commonly the monitor alarms when the concentration reaches 10% of the Lower Explosive Limit (LEL) of the gas being measured, thus permitting personnel to evacuate the space prior to a flammable mixture developing. The monitor will often display the percentage of LEL until 100% of LEL is reached and then it displays a specific visual warning that LEL has been reached. A monitoring device that is displaying 100% LEL is located within a flammable atmosphere that is imminently dangerous to the user!!

Oxygen Sensors measure the amount of oxygen present in ambient air. Normal atmospheric oxygen levels are approximately 20.9%. Humans are extremely sensitive to oxygen deficiency; therefore the alarm sounds when oxygen levels fall below 19.5%. An oxygen deficient atmosphere may occur due to poor ventilation or when oxygen is replaced in the air by another gas. A low oxygen alarm in an otherwise ventilated space is reason to suspect a high concentration of some other potentially hazardous gas; even if none of the other sensors are alarming.

Likewise, abnormally high levels of oxygen can create other hazards and the monitor will sound when levels reach 23.5% or greater. Oxygen enriched air poses the potential for rapid or explosive fire spread. In some cases, oxygen enrichment can cause ordinarily inert materials to become unstable or explosive.

In addition to supporting life, oxygen needs to be present for accurate “LEL” sensor function. In general, LEL sensors require a minimum of 10% oxygen to be reliable without the use of some type of dilution appliance.

Toxic Sensors used by fire service monitoring equipment are most commonly seeking Carbon Monoxide (CO) or Hydrogen Sulfide (H_2S). The unit of measurement utilized by toxic sensors is parts per million (ppm). CO is a by-product of the combustion process and is usually associated with malfunctioning fossil-fuel burning furnaces or appliances. Carbon monoxide is by far one of the most common toxic gases encountered by the fire service and the source of many incident responses. The prevalence of consumer CO alarms (initiating both legitimate and false alarms), energy efficient buildings that allow gases to accumulate, and the lack of maintenance or misuse of common gas-fueled appliances all contribute to the frequency of carbon monoxide incidents. Barbecue grills, generators, backup power systems, forklifts, and any small equipment that uses an internal combustion engine can be the source of carbon monoxide. CO can also be present in hazardous levels during fire attack and overhaul operations.

Hydrogen sulfide is much less common to encounter than carbon monoxide. H_2S is a product of decaying organic materials. It is most often found in manholes, sewers, or other confined spaces. It is accompanied by a distinct “rotten egg” odor, however humans are rapidly de-sensitized to the odor and it is not a reliable indicator of the level of danger. H2S can be hazardous to humans at very low levels, therefore the sensor will sound an alarm at 10ppm.

The alarm levels for each sensor are generally set based upon acceptable occupational exposure levels established by the Occupational Safety and Health Administration or NIOSH.

INTERPRETING METERS

Monitoring devices may display atmospheric conditions being measured or they may only offer an alarm when hazardous levels are detected while not telling the user the conditions being detected.

All of the meters in use on Engine Companies are direct-reading meters, which means they are providing nearly immediate results to the user for evaluation of the atmosphere. Meters that are not direct-read only collect samples of the atmosphere that are then interpreted in a laboratory, hence they are called “air sampling” devices.

Personnel need to be familiar with the sensors installed in the monitoring devices available to them. Devices that have multiple sensors most often display each sensor simultaneously on a digital screen. Personnel need to know which number corresponds to which sensor. Most combustible gas (LEL) and oxygen sensors display concentration values in terms of percentages. Toxic sensors display concentrations in ppm.

It is imperative that users of any atmospheric monitoring device familiarize themselves with the individual capabilities of each device in their workplace. Instruction manuals are the best source for acquiring this information.

Personnel must recognize the limitations of the meters. Every sensor is calibrated to a specific chemical or gas. If a meter detects the specific gas, it will show a “direct” reading for that gas. Specific to the combustible gas sensor, it may be calibrated to methane or pentane. Since the sensitivity of combustible gas sensors varies with exposure to different types of atmospheres, any attempt to measure the concentration of gases other than that used during calibration will result in a reading that is likely greater or less than the actual concentration. In practical terms, the LEL may not be exactly accurate if measuring propane versus natural gas. Equipment manufacturers provide correction factors or relative response curves specific to the gas or vapor measured to obtain more accurate results.

HOW SENSORS WORK

In practice, sensors operate on a simple process. Essentially, air passes over a sensor(s) either passively or when pumped mechanically into the meter. The sensor absorbs the sample, converts it to an electrical signal, and transmits a reading to the display screen. In some instances, the electrical signal activates an alarm.

Combustible Gas Indicators (CGI) utilize a system of Catalytic Beads connected by a balanced resistor which measures the electrical resistance between the "Sensing Bead" (actually burns the flammable gas) and the "Reference Bead" (stays at a neutral temperature). This electrical resistance between the tow beads is converted into an electrical signal sent to the display screen to be read as a percentage of the "LEL". Even though there is actual burning going on inside the sensor, a Flame Arrestor is employed to make the meter intrinsically safe.

CGI sensors are also susceptible to being "Poisoned" or "Inhibited". Poisons are substances that will adhere to the Catalytic Bead and cause permanent damage to a portion and/or the entire Sensing Bead. A sensor that has been exposed to a poison becomes desensitized and cannot recover. Such poisons include TRV Silicone, Armor-All, and Tetraethyl Lead (found as a gasoline additive). Inhibitors are also substances that adhere to the Catalytic Bead and decrease the "life of a sensor. These substances include Sulfur Compounds, and Halogenated Compounds. Calibration is the only way to identify if there has been any loss of sensitivity to that sensor or if the sensor needs to be replaced.

Toxic and Oxygen sensors utilize an Electrochemical Sensor which consists of two electrodes (the Working electrode and the Counter electrode) suspended in a liquid electrolyte. When the toxic gas or oxygen reaches the Working Electrode, an electrochemical reaction occurs. The electrical resistance between the Working Electrode and the Counter Electrode is measured and converted into an electrical signal that is sent to the display screen as a parts per million (ppm) or percentage (%)reading depending on what you are measuring.

While fire service meters are reasonably rugged, any sensor is susceptible to damage from adverse conditions. Humidity, extreme high or low temperatures and corrosive atmospheres can have an adverse effect on a sensor. These effects can be seen by a "stray" in a sensor's reading. The numbers displayed may fluctuate abnormally. Often, "zeroing" the meter in a clean atmosphere will correct this condition. If the problem persists, have the meter calibrated.

There are chemicals that may have a "cross-sensitivity" with a specific sensor. You may see a reading on the display screen that is not the gas the sensor normally looks for. An example of this is Hydrogen. Hydrogen is a byproduct of a charging battery. As the battery charges, Hydrogen gas is produced and off-gased. If entering an area with a meter containing a CO sensor, the CO sensor will react to the Hydrogen present in the room. It will appear that you have a reading for CO, but you may actually be detecting the cross-sensitivity to Hydrogen. Along with Hydrogen, the CO sensor will also show a cross-sensitivity to any chemical in the "ENE" family such as Acetylene and Ethylene. This does not mean that the CO sensor can be used as a substitute metering device for these materials, but it may explain why you see a CO reading when CO is not present. This illustrates why it is important to evaluate all clues presented and not blindly rely upon the monitoring device.

ACCEPTABLE RANGES

The Occupational Health and Safety Administration and the National Institute for Occupational Safety and Health have established acceptable occupational exposure limits for numerous chemicals. These levels are designed to ensure safe operating environments for affected employees during short and long-term exposures. Since fire/rescue personnel are often faced with incidents requiring interior operations or confined spaces, it is important to consider all environmental and physical characteristics of an incident. Serious consideration must be granted to the existence of, or potential for, leaks (gas or liquid) within, or outside, the confines of a given structure. Recognize that the layout, air currents, physical characteristics of a given space or incident area, and the properties of the chemicals involved all impact the concentrations of exposures. Hazard levels may vary from floor to floor or even room to room.

When working in the presence of combustible gases, one must consider the following operating guidelines:

- Atmosphere less than 10% of the LEL – continue work with caution;
- Atmosphere is 10% - 25% of the LEL – meter alarms will be sounding, continue work with extreme caution and levels must be visually monitored; and
- Atmosphere is greater than 25% of the LEL – withdraw immediately!

When working in the presence of potentially hazardous oxygen-rich or oxygen-deficient atmospheres, one must consider the following operating guidelines:

- Oxygen is between 19.5 and 23.5% - normal range;
- Oxygen is below 19.5% - oxygen-deficient atmosphere, SCBA required, combustible gas values may be inaccurate;
- Oxygen is greater than 23.5% - oxygen-enriched atmosphere – expect unpredictable or extreme fire or explosive behavior from ordinary materials, withdraw until levels can be reduced

FRC Policy 25-08 addresses carbon monoxide emergencies. When working in the presence of Carbon Monoxide (CO), one must consider the following:

- Carbon monoxide is greater than 35 ppm – utilize SCBA;
- Carbon monoxide is IDLH at 1,200ppm
- The LEL for carbon monoxide is 125,000 ppm – most monitoring equipment does not read this high

When working in the presence of Hydrogen Sulfide (H_2S), one must consider the following:

- Hydrogen Sulfide is greater than 5 ppm – utilize SCBA;
- Hydrogen Sulfide is IDLH at 100ppm

Percentage to parts per million (ppm): 1% = 10,000 ppm

CALIBRATION, ZEROING and BUMP TESTING

Calibrating a metering device ensures it will respond accurately and appropriately in a given atmosphere for which it is designed to operate. Calibration is accomplished by exposing the sensor(s) to a known concentration of gas and adjusting their response. Many modern meters are capable of self-calibration without much intervention by a technician. Since improper calibration techniques may lead to equipment failure, only trained personnel should perform this function. Furthermore, trained personnel should follow all manufacturer guidelines and recommendations. Calibration is often conducted on a monthly basis, however manufacturer recommendations vary.

Bump Testing is a field operation that should be done to all meters at the beginning of every shift or prior to placing any air monitoring meter into service. A bump test is a functionality test to ensure that all sensors in the meter are working. This is done by exposing all the sensors to the gases that they are designed to meter. The meter should react to all of the gases and reach alarm levels during a bump test. Modern meters will use the bump test to automatically detect if more extensive calibration or sensor replacement is needed.

Zeroing a meter ensures that all sensors are aligned to normal atmospheric measurement parameters. Most multi-gas meters display a menu-driven guide on their displays explaining the process to the user. Zeroing is also part of the startup process for most meters. Zeroing must always be performed in a "clean" air environment – not in a potentially contaminated area such as next to the tailpipe of the apparatus. When investigating an inside gas leak or carbon monoxide incident, always zero the meter outdoors to avoid inadvertently normalizing the meter to a bad atmosphere. Prior to entering the atmosphere being monitored, the meter should display:

- Combustible Gas = 0% LEL
- Oxygen = 20.9% to 21.0%
- Toxic Gas = 0 ppm

CARE AND MAINTENANCE

Without a doubt, the most important factors impacting the readiness and serviceability of any piece of machinery is proper maintenance and upkeep. As such, always follow manufacturer guidelines regarding the use and care of their products. Battery life is dependent on regular charging and maintenance. Meters stored in chargers on fire/rescuer apparatus may require the availability of trickle chargers and shore lines. Battery packs may be removable or may last for years without operator intervention. Some meters possess a low battery alarm.

Meter sensors require the same, if not more thorough, care and maintenance as batteries. In general, meters are delicate instruments and are highly susceptible to damage. Sensors are usually replaceable, however require a qualified technician to perform the work. Various chemicals may damage sensors or exposure to extremely high concentrations of gases can permanently saturate the sensor. In some instances, a damaged or defective meter may produce unreliable readings or lose its sensitivity. Sensors also have a specific shelf life. Outdated sensors will tend to drift during use, offering its user wide variances in actual measurements. Monitoring equipment that is suspected of malfunctioning needs to be submitted for repair.

PRACTICAL USE

Most atmospheric incidents will present the responder with various clues as to the potential hazards posed. Some clues will be obvious, such as occupancy types, tank or container shapes, placarding, and color markings. Other clues are subtle and require the responder to maintain vigilance to identify them. Not all incidents involving hazardous atmospheres will be immediately recognizable.

Just like any other equipment, meters are only useful if they are functioning properly and used by trained personnel. It is a good practice to have redundancy in monitoring, so the operation of two meters in the atmosphere can give more confidence in the readings. When readings differ significantly between two meters exposed to the same atmosphere additional monitoring and other investigative methods may be required.

In general, incidents where monitoring equipment is used should apply the following:

1. Turn on the meter in a clean atmosphere and allow it to cycle through its warm-up and zeroing functions. Pay attention to the screen as the startup proceeds to identify any odd messages or unusual service indicators by the meter.
2. Allow the readings on the meter to stabilize while in the clean atmosphere.
3. While holding the meter in a manner that does not block the air intake, proceed to the perceived start of the questionable atmosphere. Most of the time this means the exterior door to the structure. When encountering a closed door, check the areas around the door frame in preparation for opening the door. In a multi-unit dwelling or office building, checking around the door frames in the public hallway can help narrow down the source of the hazard reasonably quickly.
4. Pause and allow the meter to read the atmosphere. Each instrument has a lag time between exposure to the atmosphere and providing a reading or alarm. Be sure to identify these specifications for the meter you are using. Normally 15 to 30 seconds will cover all types of sensors.
5. As conditions allow, proceed into the scene and continue to pause occasionally to let the meter work. Do not forget to check various levels and rooms as the physical properties of the gases within the ambient air may cause them to accumulate in different locations within a space. For example, natural gas is lighter than air and tends to rise whereas propane is heavier than air and will sink into lower areas. A common mistake for unfamiliar personnel is to move too quickly through an

atmosphere with the meter. By the time the meter sounds an alarm or gives a reading the user has already moved into a different region of the atmosphere.

If the meter alarms, note what is alarming and the concentration. Is the alarm necessitating a rapid evacuation or is it a cautionary sign? Use the readings to begin to identify the perimeter of the hazardous area so the scope of the incident can be identified. Note where concentrations are heaviest so that the source of the hazardous gas may be identified as well. This also aids with planning for evacuations or additional entry precautions.

Unless there is an immediate need to intervene to prevent death or injury, avoid prematurely ventilating enclosed spaces and artificially reducing the atmospheric contaminants. Approach the use of the meters much like the administration of a drug to a patient. Evaluate prior to the intervention, perform the intervention, then evaluate again to identify the effect of the intervention. In this case, do nothing to introduce fresh air into the atmosphere until readings are taken.

As a matter of practice, ensure all sensor readings are considered and evaluated. If, for example, the oxygen sensor is reading low oxygen levels, it is obvious an atmospheric contaminant is displacing the “good” air. Also note any readings that do not seem to fit the situation or readings on multiple sensors at once.

If there is any doubt about the ability to properly monitor or control an atmosphere, consider a consultation with the on-duty Hazardous Materials Officer or summon the Hazardous Materials Team to the incident.

RADIATION MONITORS

Another type of atmospheric condition monitored by MCFRS Engine Companies is gamma radiation. Gamma radiation can come from many sources, including medical equipment, humans receiving radiation therapy, soil testing equipment, and terrorist devices. Gamma radiation occurs naturally and is present in normal levels of 5 to 25 μR/hr, therefore do not expect the monitor to read zero normally. Radiation monitors are programmed to alarm before radiation exposure reaches harmful levels. The radiation monitors are an early detection device only and not intended as diagnostic or investigative tools for an Engine Company. Any alarm condition on a radiation monitor should result in the crew leaving the area, isolating, and denying entry until the Hazardous Materials Team can evaluate further.