





# Analyzing the Incident: Detecting, Monitoring, and Sampling Hazardous Materials

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## Key Terms

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# Analyzing the Incident: Detecting, Monitoring, and Sampling Hazardous Materials

## JPRs Addressed In This Chapter

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7.2.1, 7.2.5

## Learning Objectives

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After reading this chapter, students will be able to:

1. Explain critical factors in preventing exposure to hazardous materials. [NFPA 1072, 7.2.1]
2. Explain methods for quantifying radiological and biological exposures. [NFPA 1072, 7.2.1, 7.2.5]
3. Describe types of sensor-based instruments and other devices used for detecting hazards. [NFPA 1072, 7.2.1]
4. Describe other detection devices that can be used for detecting hazards.
5. Skill Sheet 6-1: Demonstrate proper use of pH meters to identify hazards. [NFPA 1072, 7.2.1]
6. Skill Sheet 6-2: Demonstrate proper use of a multi-gas meter (carbon monoxide, oxygen, combustible gases, multi-gas, and others) to identify hazards. [NFPA 1072, 7.2.1]
7. Skill Sheet 6-3: Demonstrate proper use of colorimetric tubes to identify hazards. [NFPA 1072, 7.2.1]
8. Skill Sheet 6-4: Demonstrate proper use of pH paper to identify hazards. [NFPA 1072, 7.2.1]
9. Skill Sheet 6-5: Demonstrate proper use of reagent test paper to identify hazards. [NFPA 1072, 7.2.1]
10. Skill Sheet 6-6: Demonstrate proper use of radiation detection instruments to identify and monitor hazards. [NFPA 1072, 7.2.1]
11. Skill Sheet 6-7: Demonstrate proper use of dosimeters to identify personal dose received. [NFPA 1072, 7.2.1]
12. Skill Sheet 6-8: Demonstrate proper use of photoionization detectors to identify hazards. [NFPA 1072, 7.2.1]
13. Skill Sheet 6-9: Demonstrate the use of a noncontact thermal detection device to identify hazards. [NFPA 1072, 7.2.1]

## Chapter 6

# Analyzing the Incident: Detecting, Monitoring, and Sampling Hazardous Materials



This chapter will discuss several factors of a successful response operation including:

- Exposure
- Radiological and biological exposures
- Sensor-based instruments and other devices
- Other detection devices

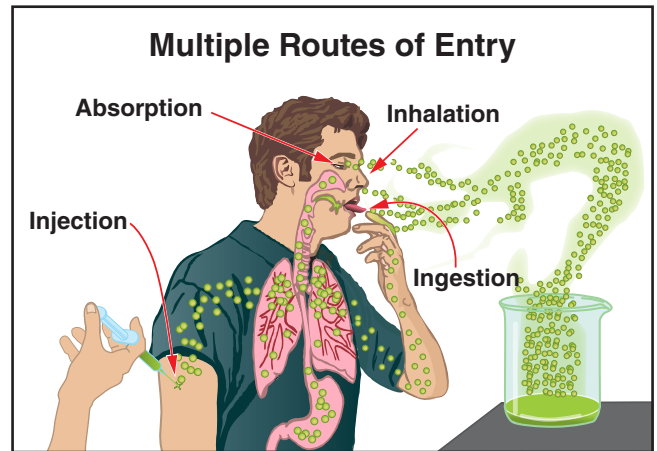
## Exposure

Even the most cautious emergency responder has the potential of being exposed to a chemical at the scene of an emergency. No defined order exists for detection and monitoring activities, nor for applying the findings/results to the next operational tactics. Technicians must maintain risk-based response to get a clear picture of the entire incident profile. Regardless of the hazards that are immediately apparent, responders should also evaluate other risks. The best way to protect against toxic chemicals is to prevent exposure to them. The following sections explain three critical factors in preventing exposure.

## Routes of Entry

Technicians should maintain the mindset of risk-based response when taking information presented by detection tools (including meters) into account. For example, always consider whether the PPE you are wearing will keep you safe against the types of risks that you are responding to, or that may be in the area. The following are the main **routes of entry** through which hazardous materials can enter the body and cause harm (**Figure 6.1**):

- **Inhalation** — Process of taking in materials by breathing through the nose or mouth. Hazardous vapors, smoke, gases, liquid aerosols, fumes, and suspended dusts may be inhaled into the body. When a hazardous material presents an inhalation threat, respiratory protection is required. Inhalation is the most common route of exposure for responders and civilians.
- **Ingestion** — Process of taking in materials through the mouth by means other than simple inhalation. Taking a pill is a simple example of how a chemical might be deliberately ingested. However, poor hygiene after handling a hazardous material can lead to accidental ingestion. Examples include:



**Figure 6.1** Hazardous chemicals can enter the body in four common ways.

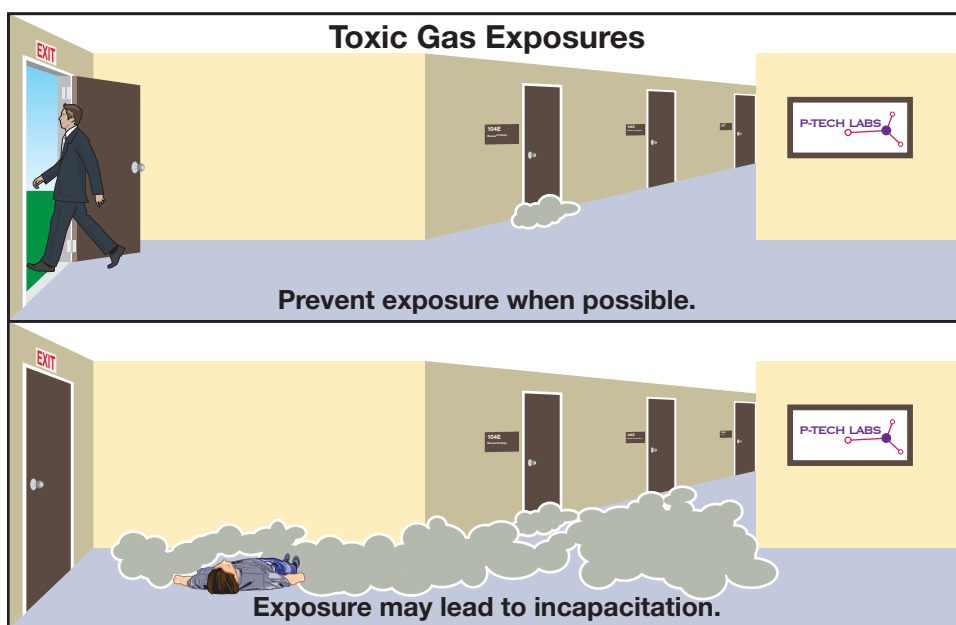
**Route of Entry** — Pathway via which hazardous materials get into (or affect) the human body.

- Chemical residue on the hands that can be transferred to food and then ingested while eating; hand washing is very important to prevent accidental ingestion of hazardous materials
- Particles of insoluble materials that can become trapped in the mucous membranes and ingested after being cleared from the respiratory tract
- **Absorption** — Process of taking in materials through the skin or eyes. Some materials pass easily through the mucous membranes or areas of the body where the skin is the thinnest, providing the least resistance to penetration. The eyes, nose, mouth, wrists, neck, ears, hands, groin, and underarms are areas of particular concern. Many poisons are easily absorbed into the body. Others can enter the body through the eye such as when a contaminated finger touches the eye.
- **Injection** — Process of taking in materials through a puncture of the skin. Protection from injection must be a consideration when dealing with any sort of contaminated (or potentially contaminated) objects easily capable of cutting or puncturing the skin. Such items include: broken glass, nails, sharp metal edges, and tools like utility knives.

## Contamination versus Exposure

Previous chapters introduced the concept that a chemical can react with air, water, light, and other chemicals. However, hazardous materials technicians need to understand what can happen when they come in contact with a chemical and what can happen when the chemical reacts with the emergency responder.

An individual can be exposed to a product in a number of settings without being aware of the exposure. For example, a building with a malfunctioning furnace can expose the occupants to the toxic properties of carbon monoxide. If individuals remain in the building over a period of time, they may start to feel the effects of this toxic chemical. By leaving the structure, they are no longer exposed to the hazard (**Figure 6.2**). Exposure is said to occur when a toxic or infectious substance directly contacts the human body or is introduced into the body.



**Figure 6.2** Exposure occurs when a toxic substance contacts or enters the body.

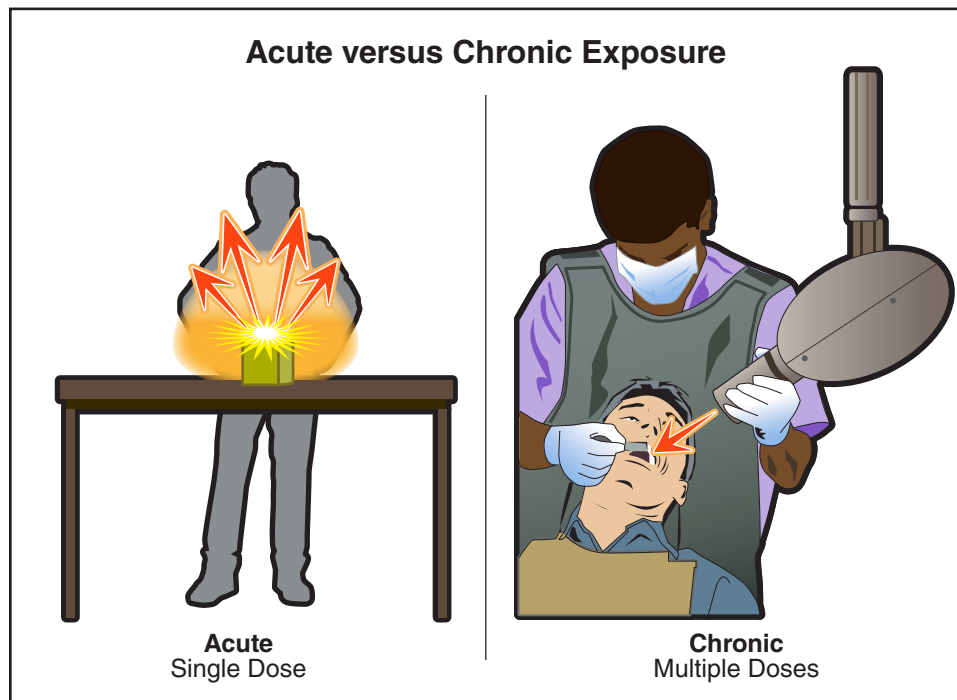
Contamination is the result of direct contact with a product, and it occurs when a product adheres to or wets any kind of exposure. A person is considered to be contaminated if in the course of working with a liquid chemical or a solid product, the product somehow spills and contacts clothing or skin.

Understanding the nuances of these terms and concepts is important in maintaining both a safe response and a safe work environment. For example, in an incident including only radioactive materials, a person in close proximity to a radioactive source can be exposed without being contaminated. Once the responder leaves the area, he or she is no longer exposed and has not been contaminated.

A responder working within a hot zone can also be contaminated without being exposed. This can occur if the responder is in approved and appropriate chemical protective clothing and the CPC is saturated with a chemical.

### Acute versus Chronic Exposure

If an individual comes in contact with a chemical, several variables may influence the effects of the exposure. For example, responders may not have to come into contact with a product; merely being in proximity to the product may have a detrimental effect. When the toxicity of a chemical is discussed in relation to its effects on the body, how long a person was exposed must be evaluated. An acute exposure may be a single exposure over a relatively short period of time to a high level of a dangerous product. A chronic exposure may be an exposure over a longer duration. To put this in perspective, if a person were exposed to a high level of a radioactive source for a period of two minutes, it could be considered an acute exposure. If a person worked in a radiology department of a hospital and had prolonged exposures to X-rays over the course of his or her career, this would be considered a chronic exposure (**Figure 6.3**).



**Figure 6.3** Acute and chronic doses are differentiated by the frequency of the incident.

## Radiological and Biological Exposures

There may be a possibility for exposure even if the emergency responder operates safely on the scene of a hazmat emergency. For example, firefighters understand that in an ordinary structure fire, there is still the potential for exposure to toxic products of combustion long after the fire has been extinguished. Hazmat responders must also understand that even though they have taken precautions, exposure may still be possible. Because of this fact, they must thoroughly understand toxicology and exposures.

The ability to research a toxic material and fully understand the information provided in the research data is one of the most helpful aspects of a safe response. Research will help the responder determine the toxic properties of the products involved.

### Exposure Limits

#### Exposure Limit —

Maximum length of time an individual can be exposed to an airborne substance before injury, illness, or death occurs.

**Exposure limits** are used to estimate potential harm and outcomes at hazardous materials incidents. The National Institute for Occupational Safety and Health (NIOSH) Pocket Guide and other resources provide exposure limits for many materials. The following sections will provide definitions to several of the terms used to express these limits.

#### Immediately Dangerous to Life and Health (IDLH)

— Description of any atmosphere that poses an immediate hazard to life or produces immediate irreversible, debilitating effects on health; represents concentrations above which respiratory protection should be required.

Expressed in parts per million (ppm) or milligrams per cubic meter (mg/m<sup>3</sup>); companion measurement to the permissible exposure limit (PEL).

#### *Immediately Dangerous to Life and Health (IDLH)*

The National Institute for Occupational Safety and Health (NIOSH) quotes the Occupational Safety and Health Administration (OSHA) standard number 29 CFR 1910.120 in one definition of an atmosphere considered to be **immediately dangerous to life and health (IDLH)**: “An atmospheric concentration of any toxic, corrosive, or asphyxiating substance that poses an immediate threat to life. It can cause irreversible or delayed adverse health effects and interfere with the individual’s ability to escape from a dangerous atmosphere.”

The Occupational Safety and Health Administration (OSHA) also further identifies an IDLH atmosphere in standard number 29 CFR 1910.134(b): “An atmosphere that poses an immediate threat to life, would cause irreversible adverse health effects, or would impair an individual’s ability to escape from a dangerous atmosphere.”

The exposure period is immediate. The NIOSH definition also states that the IDLH is the maximum concentration from which an unprotected person can expect to escape in a 30-minute period of time without suffering irreversible health effects.

#### *Other Exposure Limits*

Hazmat technicians commonly encounter other types of exposure limits when conducting research on hazardous materials. These limits typically come from industry, and responders must be familiar with the terminology (**Table 6.1**).

**NOTE:** For more information on exposure limits, refer to Chapter 7, Air Monitoring.

Standards development entities such as American Conference of Governmental Industrial Hygienists® (ACGIH) may provide some data. Exposure limits separate from IDLH include:



**Table 6.1  
Exposure Limits Terminology**

<b>Term</b>	<b>Definition</b>	<b>Exposure Period</b>	<b>Organization</b>
<b>IDLH</b> Immediately Dangerous to Life or Health	An atmospheric concentration of any toxic, corrosive, or asphyxiating substance that poses an immediate threat to life. It can cause irreversible or delayed adverse health effects and interfere with the individual's ability to escape from a dangerous atmosphere.*	Immediate (This limit represents the maximum concentration from which an unprotected person can expect to escape in a 30-minute period of time without suffering irreversible health effects.)	<b>NIOSH</b> National Institute for Occupational Safety and Health
<b>IDLH</b> Immediately Dangerous to Life or Health	An atmosphere that poses an immediate threat to life, would cause irreversible adverse health effects, or would impair an individual's ability to escape from a dangerous atmosphere.	Immediate	<b>OSHA</b> Occupational Safety and Health Administration
<b>LOC</b> Levels of Concern	10% of the IDLH		
<b>PEL</b> Permissible Exposure Limit**	A regulatory limit on the amount or concentration of a substance in the air. PELs may also contain a skin designation. The PEL is the maximum concentration to which the majority of healthy adults can be exposed over a 40-hour workweek without suffering adverse effects.	8-hours Time-Weighted Average (TWA)*** (unless otherwise noted)	<b>OSHA</b> Occupational Safety and Health Administration
<b>PEL (C)</b> PEL Ceiling Limit	The maximum concentration to which an employee may be exposed at any time, even instantaneously.	Instantaneous	<b>OSHA</b> Occupational Safety and Health Administration
<b>STEL</b> Short-Term Exposure Limit	The maximum concentration allowed for a 15-minute exposure period.	15 minutes (TWA)	<b>OSHA</b> Occupational Safety and Health Administration
<b>TLV®</b> Threshold Limit Value†	An occupational exposure value recommended by ACGIH® to which it is believed nearly all workers can be exposed day after day for a working lifetime without ill effect.	Lifetime	<b>ACGIH®</b> American Conference of Governmental Industrial Hygienists
<b>TLV®-TWA</b> Threshold Limit Value-Time-Weighted Average	The allowable time-weighted average concentration.	8-hour day or 40-hour work week (TWA)	<b>ACGIH®</b> American Conference of Governmental Industrial Hygienists
<b>TLV®-STEL</b> Threshold Limit Value-Short-Term Exposure Limit	The maximum concentration for a continuous 15-minute exposure period (maximum of four such periods per day, with at least 60 minutes between exposure periods, provided the daily TLV®-TWA is not exceeded).	15 minutes (TWA)	<b>ACGIH®</b> American Conference of Governmental Industrial Hygienists

*Continued*

**Table 6.1 (continued)**

<b>Term</b>	<b>Definition</b>	<b>Exposure Period</b>	<b>Organization</b>
<b>TLV®-C</b> Threshold Limit Value-Ceiling	The concentration that should not be exceeded even instantaneously.	Instantaneous	<b>ACGIH®</b> American Conference of Governmental Industrial Hygienists
<b>BEIs®</b> Biological Exposure Indices	A guidance value recommended for assessing biological monitoring results.		<b>ACGIH®</b> American Conference of Governmental Industrial Hygienists
<b>REL</b> Recommended Exposure Limit	A recommended exposure limit made by NIOSH.	10-hours (TWA) ††	<b>NIOSH</b> National Institute for Occupational Safety and Health
<b>AEGL-1</b> Acute Exposure Guideline Level-1	The airborne concentration of a substance at or above which it is predicted that the general population, including “susceptible” but excluding “hypersusceptible” individuals, could experience notable discomfort. †††	Multiple exposure periods: 10 minutes 30 minutes 1 hour 4 hours 8 hours	<b>EPA</b> Environmental Protection Agency
<b>AEGL-2</b> Acute Exposure Guideline Level-2	The airborne concentration of a substance at or above which it is predicted that the general population, including “susceptible” but excluding “hypersusceptible” individuals, could experience irreversible or other serious, long-lasting effects or impaired ability to escape. Airborne concentrations below AEGL-2 but at or above AEGL-1 represent exposure levels that may cause notable discomfort.	Multiple exposure periods: 10 minutes 30 minutes 1 hour 4 hours 8 hours	<b>EPA</b> Environmental Protection Agency
<b>AEGL-3</b> Acute Exposure Guideline Level-3	The airborne concentration of a substance at or above which it is predicted that the general population, including “susceptible” but excluding “hypersusceptible” individuals, could experience life-threatening effects or death. Airborne concentrations below AEGL-3 but at or above AEGL-2 represent exposure levels that may cause irreversible or other serious, long-lasting effects or impaired ability to escape.	Multiple exposure periods: 10 minutes 30 minutes 1 hour 4 hours 8 hours	<b>EPA</b> Environmental Protection Agency
<b>ERPG-1</b> Emergency Response Planning Guideline Level 1	The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.	Up to 1 hour	<b>AIHA</b> American Industrial Hygiene Association

*Continued*

**Table 6.1 (concluded)**

<b>Term</b>	<b>Definition</b>	<b>Exposure Period</b>	<b>Organization</b>
<b>ERPG-2</b> Emergency Response Planning Guideline Level 2	The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.	Up to 1 hour	<b>AIHA</b> American Industrial Hygiene Association
<b>ERPG-3</b> Emergency Response Planning Guideline Level 3	The maximum airborne concentration below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.	Up to 1 hour	<b>AIHA</b> American Industrial Hygiene Association
<b>TEEL-0</b> Temporary Emergency Exposure Limits Level 0	The threshold concentration below which most people will experience no appreciable risk of health effects.		<b>DOE</b> Department of Energy
<b>TEEL-1</b> Temporary Emergency Exposure Limits Level 1	The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.		<b>DOE</b> Department of Energy
<b>TEEL-2</b> Temporary Emergency Exposure Limits Level 2	The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.		<b>DOE</b> Department of Energy
<b>TEEL-3</b> Temporary Emergency Exposure Limits Level 3	The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.		<b>DOE</b> Department of Energy

\* The NIOSH definition only addresses airborne concentrations. It does not include direct contact with liquids or other materials.

\*\* PELs are issued in Title 29 *CFR* 1910.1000, particularly Tables Z-1, Z-2, and Z-3, and are enforceable as law.

\*\*\* Time-weighted average means that changing concentration levels can be averaged over a given period of time to reach an average level of exposure.

† TLVs® and BEIs® are guidelines for use by industrial hygienists in making decisions regarding safe levels of exposure. They are not considered to be consensus standards by the ACGIH®, and they do not carry the force of law unless they are officially adopted as such by a particular jurisdiction.

†† NIOSH may also list STELs (15-minute TWA) and ceiling limits.

††† Airborne concentrations below AEGL-1 represent exposure levels that could produce mild odor, taste, or other sensory irritation.

- **Permissible Exposure Limit (PEL)** — OSHA’s definition of a regulatory limit on the amount or concentration of a substance in the air. PELs may also contain a skin designation. The PEL is the maximum concentration to which the majority of healthy adults can be exposed over a 40-hour work week without suffering adverse effects. The PEL is reported as an 8-hour, time-weighted average (TWA) unless otherwise noted.
- **Permissible Exposure Limit - Ceiling (PEL-C)** — OSHA’s definition as the maximum concentration to which an employee may be exposed at any time.
- **Recommended Exposure Limits (REL)** — Recommendations provided by NIOSH and based on a 10-hour, time-weighted average.
- **Threshold Limit Value® (TLV)** — Value provided by the American Conference of Governmental Industrial Hygienists® (ACGIH). TLV® is an occupational exposure value to which it is believed nearly all workers can be exposed day after day for a working lifetime without any ill effects.
- **Threshold Limit Value® - Ceiling (TLV-C)** — The ACGIH® has defined as a concentration that should not be exceeded for any time period, even instantaneously.
- **Threshold Limit Value® - Short Term Exposure Limit (TLV-STEL)** — The ACGIH® has defined as the maximum concentration for a continuous 15-minute exposure period. The TLV®-STEL is calculated on a daily basis as four 15-minute continuous work periods with a minimum of a 60-minute period between each exposure provided the TWA is not exceeded.
- **Threshold Limit Value®-Time Weighted Average (TLV-TWA)** — The ACGIH® defines the TLV®-TWA as the allowable time-weighted average concentration when an employee is exposed for 8 hours per day, 40 hours per week.

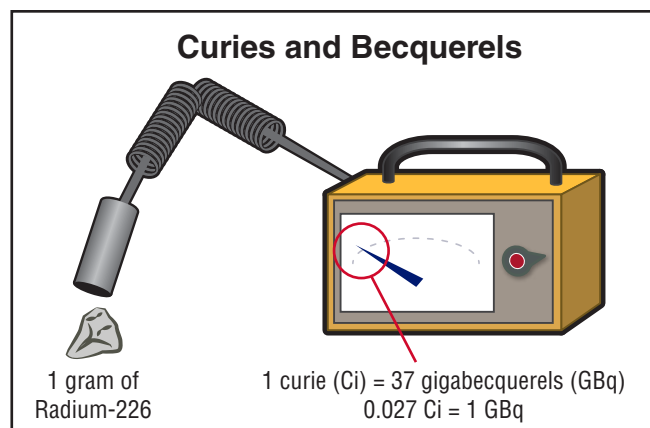
## Radiological Exposures

**Dosimeter** — Detection device used to measure an individual’s exposure to an environmental hazard such as radiation or sound.

Emergency responders should be familiar with the terms used to express radiation dose and exposure. These units may be used on radiation dose instruments, called **dosimeters** and *radiation survey meters* (Figure 6.4). As with curies and becquerels, two systems of units are used to measure and express radiation exposure and radiation dose (energy absorbed from the radiation) (Figure 6.5).



**Figure 6.4** Badge dosimeters typically display the absorbed radiation dose.



**Figure 6.5** Curies (Ci) are used to indicate large amounts of activity, and becquerels (Bq) are used to indicate small amounts of energy.

The U.S. still commonly uses the English System, and these units are as follows:

- **Roentgen (R)** — Used for measuring exposure and is applied only to gamma and X-ray radiation. This is the unit used on most U.S. dosimeters. Roentgen is expressed in R per hour (R/hr) and is used on radiation survey meters.
- **Radiation absorbed dose (rad)** — Used to measure the amount of radiation energy absorbed by a material. This unit applies to any material and all types of radiation, but does not take into account the potential effect that different types of radiation have on the human body. For example, 1 rad of alpha radiation is more damaging to the human body than 1 rad of gamma radiation.
- **Roentgen equivalent in man (rem)** — Used for the absorbed dose equivalence as pertaining to a human body and is applied to all types of radiation. This unit takes into account the energy absorbed (as measured in rad) and the biological effect on the body due to different types of radiation. Rem is used to set dose limits for emergency responders. For gamma and X-ray radiation, a common conversion between exposure, absorbed dose, and dose equivalent is as follows: 1 R = 1 rad = 1 rem.
- **Counts per minute (cpm)** is a measure of radioactivity and is the number of atoms in a quantity of radioactive material that is detected to have decayed in one minute. CPM is an aggregate measurement of radioactive decay at a certain point. When used with a **correction factor** and the type of material is known, it may be converted into Roentgen.
- **Sievert** is an International System of Units (SI) term used for a derived unit or dose of radiation. This modern unit of radiation dose incorporates quality factors for the biological effectiveness of the different types of ionizing radiation.

## Biological Exposures

Biological exposures can be very difficult to mitigate based on the fact that the emergency responder may not know they are present. Biological and chemical warfare agents affect humans in different ways. Effects of exposure to chemical agents are almost always immediate. However, effects of exposure to biological agents may not become apparent for several days and can affect wide geographical areas. The emergency responder must be familiar with the following concepts:

- **Incubation period** — Defined as the time from the exposure to a biological agent to the appearance of symptoms in an infected person. Also known as Latency. This is not a measurable time period for field or clinical applications.
- **Infectious dose (ID)** — Amount of pathogen (measured in number of microorganisms) required to cause an infection in the host. Identification can vary according to the pathogenic agent and the affected person's age and overall health. This is not a measurable factor for field or clinical applications.

**Roentgen (R)** — English System unit used to measure radiation exposure, applied only to gamma and X-ray radiation; the unit used on most U.S. dosimeters.

**Roentgen Equivalent in Man (rem)** — English System unit used to express the radiation absorbed dose (rad) equivalence as pertaining to a human body; used to set radiation dose limits for emergency responders. Applied to all types of radiation.

**Counts per Minute (CPM)** — Measure of ionizing radiation in which a detection device registers the rate of returns over time. Primarily used to detect particles, not rays.

**Correction Factor** — Manufacturer-provided number that can be used to convert a specific device's read-out to be applicable to another function. *Also known as Conversion Factor, Multiplier and Response Curve.*

**Sievert (Sv)** — SI unit of measurement for low levels of ionizing radiation and their health effect in humans.

## Sensor-Based Instruments and Other Devices

The following sections will detail some of the types of sensor-based instruments available to emergency responders. While this is not an all-inclusive list, it is a fair representation of common sensor-based instruments. The operation of each type of sensor will not be different between a standalone sensor versus a bundled detector, but other functionalities may be affected. For example, the sensor range may be significantly shorter in a bundled sensor device.

**NOTE:** Bundled detectors are included in more detail later in this chapter.



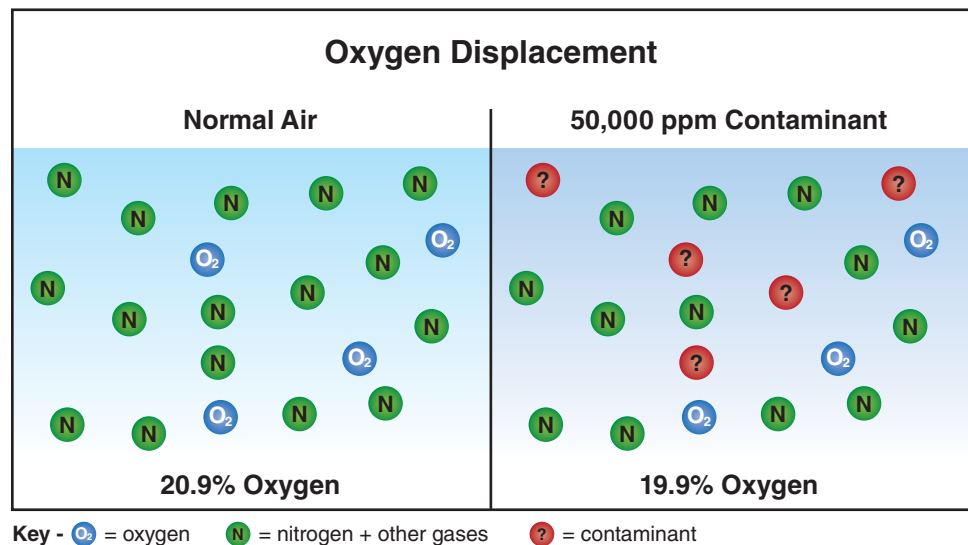
### Limitations of New Technology

Manufacturers of detection and monitoring equipment may be able to offer new options for response applications. Technicians must exercise caution when replacing or purchasing new equipment, because they must know the uses (readings, interpretations) and limitations (scope of use) of all equipment that they will rely on during a response. When researching new equipment, technicians should examine many sources of information to determine whether the equipment performs its intended task under the applicable conditions.

## Oxygen Indicators

OSHA defines action levels for specific oxygen concentrations. Risk-based response should focus on the specific incident and not limit evaluation to those numbers. Oxygen indicators are used to evaluate an atmosphere for the following:

- Oxygen concentration for respiratory purposes — Atmospheric oxygen levels should be monitored continuously during incidents. Any sustained change from normal or measured oxygen levels can represent a significant displacement of oxygen with some other product (**Figure 6.6**). Anyone without supplied air respirators/SCBA in a reduced oxygen environment may suffer harmful exposure to that environment and the hazardous chemicals within it.



**Figure 6.6** Any change in oxygen levels can indicate that a significant amount of another material is now in the atmosphere.

- Increased risk of flammability — High concentrations of oxygen, or any sustained elevations, increase the risk of material flammability.

Similar to an air freshener, O<sub>2</sub> sensors work continuously while activated. The sensor will last a shorter duration as more of it is used. To confirm the effectiveness of a detector, check it with a bump test. Then try calibrating. If neither test returns satisfactory results, replace the sensor. The owner's manual for the specific device should include guidance for frequency of bump testing and calibration.

**CAUTION**

A 1 percent drop in oxygen level indicates that 50,000 ppm of some other product has taken its place in the atmosphere.

**WARNING!**

Increases in the oxygen level may indicate that some type of reaction or displacement has taken place or is ongoing.

Oxygen sensors are often used in tandem with other sensors because instruments require sufficient oxygen for accurate results. Combustible gas indicators may not give reliable results if the oxygen concentration is below 10 percent (**Figure 6.7**).



**Figure 6.7** Combustible gas indicators may work reliably in oxygen-deficient atmospheres.

## CAUTION

Breathing into a sensor may provide erroneous readings because of the CO<sub>2</sub> levels in exhaled air.

Between freezing and boiling temperature ranges, most sensors should function accurately. At temperature ranges beyond those extremes, the sensor may be damaged or have slower response times. It is recommended that the instrument be calibrated at the temperature at which it will be utilized.

**NOTE:** Training on each type of sensor/detector/monitor should include reference to the effects of temperature and humidity on the specific device and its operation.

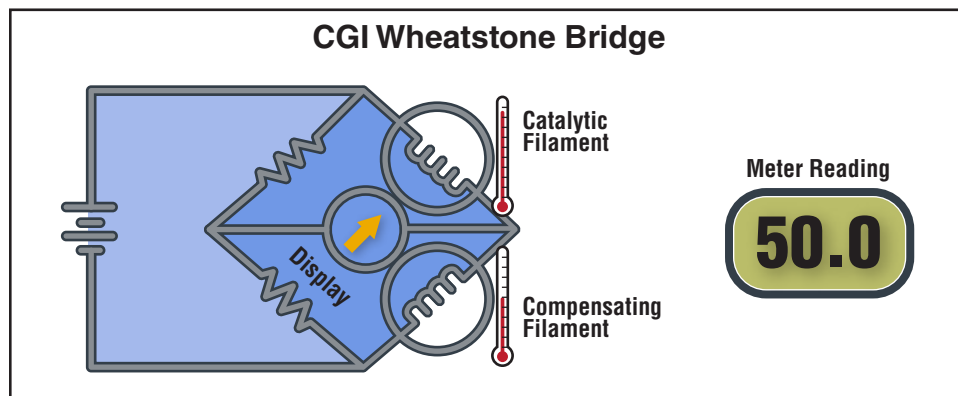
### Combustible Gas Indicators (CGIs)

**Combustible Gas Indicator (CGI)** — Electronic device that indicates the presence and explosive levels of combustible gases, as relayed from a combustible gas detector.

**Combustible gas indicators (CGIs)** are available in many styles and configurations. Some CGIs have a pump to draw the air sample into the detector, while other units use ambient air that diffuse over the sensor. Many units are combination meters that contain an oxygen sensor along with other gas or vapor detecting sensors.

Combustible gas indicators use a combustion chamber containing a filament that burns the flammable gas or an electronic sensor to measure the concentration of a flammable vapor or gas in air (**Figure 6.8**). The resulting reading is displayed via the CGI as a percentage of the lower explosive limit (%LEL) of the calibration gas. Utility companies sometimes use CGIs that measure the actual flammable range, not only a percentage of the LEL.

**Figure 6.8** One type of combustible gas indicator uses a hot filament coated with a catalyst to burn the flammable gas and then detect the results.



A concentration greater than the LEL and lower than the UEL indicates that the ambient atmosphere is readily combustible, and hazmat technicians must understand how their meter will react in this situation. They should operate equipment based on manufacturers' instructions and the AHJ's policies and procedures.

Similar to the oxygen sensor, the response of some flammable gas sensors is temperature dependent. If the temperature at which the instrument was calibrated differs from the temperature in the sample area, the accuracy of the reading is affected.



Hotter temperatures can provide a higher-than-actual reading and cooler temperatures can reduce the reading. It is best to zero (bump) the instrument in the temperature it will be used.

Flammable gas sensors are intended for use only in normal oxygen atmospheres. Oxygen-deficient atmospheres will affect readings, potentially to the point of invalidating the information.



The safeguards that prevent the combustion source from igniting a flammable atmosphere are not designed to operate in oxygen-enriched atmospheres. Organic lead vapors, sulfur compounds, and silicone compounds will also interfere with the operation of the filament. Acid gases may corrode the filament while silicone vapors even in small quantities may poison the sensor.

CGIs have specific calibration considerations. Common calibrant gases for CGIs include:

- Methane
- Pentane
- Propane
- Hexane

When responders use a CGI calibrated to one gas (such as methane) to measure other known flammable gases/vapors (such as propane), the actual LEL of the gas being measured may differ from the reading of the CGI. Examples of correction factors for various gases were included in Chapter 5 of this manual.

Responders using LEL meters must make allowances for these potential discrepancies in order to correctly interpret LEL readings. Manufacturers provide this additional data to work specifically with individual meters.

## Correction Factors

Combustible gas indicators (CGIs) and photoionization detectors (PIDs) are most useful when monitoring two categories of known gases:

- The calibrant gas
- Gases specified in the manufacturer's instructions

In some cases, the gas expected at an incident will be more hazardous than may be available in the area selected for calibration. In this case, a correction factor may be chosen to calibrate the meter to a "surrogate" gas. Correction factors are scaling factors that offer a correction to the readout of the gas to which the sensor was calibrated. They do not make the sensor specific to gas other than the calibration gas. A correction factor can be defined as a measure of the sensitivity of the PID sensor to a specific gas.

The PID can be calibrated to any gas, but the correction factors for all manufacturers refer to isobutylene (**Table 6.2**). The NIOSH Pocket Guide provides the ionization potential numbers for many materials.

**Table 6.2**  
**Sample PID Correction Factors\***

Compound Name	Correction Factor**		IP (eV)
	Lamp Strength 10.6	Lamp Strength 11.7	
Acetone	1.1	1.4	9.71
Ethyl Ether	1.1	1.7	9.51
Methyl Bromide	1.7	1.3	10.54
Nitrogen Dioxide	16	6	9.75
Phosgene	No Response	6.8	11.2
Toluene	.50	.51	8.82

\* For a RAE Systems, Inc. PID calibrated to isobutylene.

\*\* Technicians must understand how to use the correction factor based on the manufacturer's instructions, for example, multiplying the instrument's reading by the correction factor.

Manufacturers supply correction factors relevant to the readings of the detectors. Correction factors are intended to be a resource that a responder in the field can use to translate a reading into a potential other answer. Correction factors should be maintained so they are immediately accessible in the field during detection/monitoring operations. Monitors with a built-in electronic dictionary of these factors should be updated per the manufacturer's recommendations.

Correction factors are only useful if the technician knows the material that the monitor is sampling, and that material is included in the library. Correction factors are available for many gases, but not for all. For example, most monitors do not have a correction factor for gasoline. Some manufacturers offer a wider variety of conversion or correction factors than others. Ultimately, technicians must remember that any reading indicates a hazard. At most incidents, the AHJ will define a safe action level as 10 percent of the LEL.

## WARNING!

Any reading on a meter indicates the presence of a hazard.

## What This Means To You

### Limitations of Conversion/Correction Factors

Technicians should know how correction factors can be used to show hazards that their detectors may not specifically detect. Technicians can

use a chemical formula to predict whether the meter reading has included known risk factors. The use of correction factors may or may not be approved for technicians per their respective AHJ.

Reasons technicians may not choose to use conversion/correction factors include:

- Correction factors do not include a margin of error as a safety buffer, so the final range may not reflect safety considerations.
- The system of converting between actual readings and expected readings can be confusing.
- Technicians not familiar with the correction factors available in their meter may inadvertently choose the wrong one for the incident.
- Technicians may not have access (correction factor numbers may not be calculated) for the chemical they want to calculate.

## Electrochemical Cells

**Electrochemical cell sensors** are a type of fuel cell designed to produce a current that is precisely related to the amount of the target gas in the atmosphere. Measurement of the current gives a measure of the concentration of the target gas in the atmosphere. Essentially, the electrochemical cell consists of:

- Container
- Two electrodes
- Connection wires
- Electrolyte (typically sulfuric acid)

In the case of carbon monoxide (CO), the CO is oxidized at one electrode to carbon dioxide while oxygen is consumed at the other electrode. For CO detection, the electrochemical cell has advantages over other technologies. For example, CO detectors that use an electrochemical cell require a relatively small amount of power, operate at room temperature, and display CO readings as well as cross-sensitivities to some chemicals. The operational life spans of these sensors can vary based on:

- Manufacturer
- Frequency of use
- Concentrations of detected materials during use

### Electrochemical Gas

**Sensor** — Device used to measure the concentration of a target gas by oxidizing or reducing the target gas and then measuring the current.

## CAUTION

Be careful to choose a detector that can detect the target material.

## Metal Oxide Sensors

Metal oxide sensors are used to detect gases such as natural gas and hydrogen sulfide. Inside the sensor, gases interact with a thin film of metal oxide. Depending on their properties, the gases are either reduced or oxidized. This reduction or oxidation causes an increase or decrease in the conductivity of the metal oxide film. The degree of change in sensor resistance is translated into the concentration of the gas detected.



**Figure 6.9** pH meters must be calibrated for accuracy.

**pH Indicator** — Chemical detector for hydronium ions ( $\text{H}_3\text{O}^+$ ) or hydrogen ions ( $\text{H}^+$ ). Indicator equipment includes impregnated papers and meters.

**Multi-Use Detectors** — Device with several types of equipment in one handheld device. Used to detect specific types of materials in an atmosphere. *Also known as Multi-Gas Meter.*

**Nondispersive Infrared (NDIR) Sensor** — Simple spectroscope that can be used as a gas detector.

## pH Meters

Testing the acidity of liquids has been performed since the early 1900s. The use of pH paper is a common means of testing acidity and will be discussed later in this chapter (**Figure 6.9**). The basic principle of using **pH indicators** is to measure the concentration of hydrogen ions. Acids dissolve in water forming positively charged hydrogen ions. The greater this concentration of hydrogen ions, the stronger the acid. Similarly, alkalis or bases dissolve in water forming negatively charged hydrogen ions. The stronger the alkali or base in the solution, the higher the concentration of negatively charged hydrogen ions.

All pH meters must be calibrated. Technicians can achieve calibration by dipping the meter's probe into a buffer solution of a known pH and following the manufacturer's recommended steps for the specific pH meter in use.

Disadvantages of these meters include:

- They must be calibrated prior to each use.
- They are easily damaged.
- They require manual handling.

Because pH paper and strips are reliable, they are the primary means of determining pH levels in the field. Occasionally, pH meters are encountered and used in hazmat response. Steps for demonstrating proper use of pH meters to identify hazards are presented in **Skill Sheet 6-1**.

## Multi Sensor Instruments

Many sensor-based instruments are equipped to measure multiple specific gases, including oxygen. **Multi-use detectors** may include five or six different types of sensors. This setup may include a variety of configurations. When purchasing multi-sensor instruments, hazmat teams have the ability to specify the configuration of their sensors based upon their needs. For example, a **nondispersive infrared (NDIR) sensor** may be packaged onto other multi-use sensors to detect carbon dioxide. Steps for demonstrating proper use of a multi-gas meter (carbon monoxide, oxygen, combustible gases, multi-gas, and others) to identify hazards are presented in **Skill Sheet 6-2**.

Types of sensors that are commonly bundled include a PID plus four or five other sensors including an:

- Oxygen sensor
- LEL sensor
- CO sensor
- Hydrogen sulfide ( $\text{H}_2\text{S}$ ) sensor

Like other sensor-based instruments, these detection monitors are subject to interference from a variety of sources such as other gases, vapors, temperature, and barometric pressures. Sensors must be replaced periodically and calibrated with gas specific to the sensor.

## Colorimetric Methods

Colorimetric detection methods can help indicate and/or identify the presence of a chemical through a chemical reaction that results in the color change of the test medium. Technicians may view the color change visually or via more

sophisticated equipment. Hazmat response professionals use colorimetric methods widely. These methods have been found to be reliable, though some have a wide variance of accuracy called *standard deviation*. The following sections introduce the different colorimetric detection methods that are available to the emergency responder. Technicians can obtain more specific information on these methods directly from the manufacturer of these instruments. There may be multiple tubes with multiple ranges available for the same chemical.

Technicians would be wise to research the gaps that may exist between the detection capabilities of their equipment. For example, if a flame ionization detector (FID) is not available, a tube that can improve the detection range for a photoionization detector (PID) may be useful. It may be less expensive for a department to collect a set/box of tubes than a standalone instrument if the gap in detection devices is wide enough for chemicals that the technician frequently needs to detect.

### Colorimetric Tubes/Chips

**Colorimetric indicator tubes** consist of a glass tube impregnated with an indicating chemical. The tube is connected to a piston or bellows-type pump (**Figure 6.10**). The pump pulls a known volume of contaminated air at a predetermined rate through the tube. The contaminant reacts with the indicator chemical in the tube, producing a change in color where the length of the color change in the tube is proportional to the contaminant concentration. Steps for demonstrating proper use of colorimetric tubes to identify hazards are presented in **Skill Sheet 6-3**.

Detector tubes are normally chemical-specific. Some manufacturers do produce tubes for groups of gases, such as aromatic hydrocarbons or alcohols. Concentration ranges on the tubes may be in ranges defined by parts per million or a percent range. A preconditioning filter may precede the indicating chemical in order to:

- Remove contaminants (other than the one in question) that may interfere with the measurement
- Remove humidity
- React with a contaminant to change it into a compound that reacts with the indicating chemical

Colorimetric indicator tube kits are available from several different manufacturers. These kits identify or classify the contaminants as a member of a chemical group such as acid gas, halogenated hydrocarbon, and others. This identification is done by sampling with certain combinations of tubes at the same time using a special multiple tube holder or by using tubes in a specific sampling sequence. There are also screening kits designed specifically to detect weapons of mass destruction.

Due to gaps in technology, detector tubes are sometimes the only means of monitoring under some conditions. Detector tubes are not always as accurate or precise as other monitoring equipment, but they can be more accurate than LEL sensors.

**Colorimetric Indicator Tube** — Small tube filled with a chemical reagent that changes color in a predictable manner when a controlled volume of contaminated air is drawn through it. Also known as Detector Tube.



**Figure 6.10** Colorimetric tubes will show different colors based on the detection of specific chemicals. *Courtesy of MSA.*

The chemical reactions involved in the use of the tubes are affected by temperature. Cold temperatures slow the reactions and thus the response time. To reduce this problem, it is recommended that the tubes be kept warm (for example, inside a coat pocket) until used. Warm temperatures increase the reaction and can cause a problem by discoloring the indicator when a contaminant is not present. This discoloration can happen even in unopened tubes. Therefore, tubes should be stored at a moderate temperature.

Some tubes do not have a pre-filter to remove humidity and may be affected by high humidity. The manufacturer's instructions usually indicate whether humidity is a problem and list any correction factors to use if humidity affects the tube.

The chemicals used in the tubes deteriorate over time. For this reason, the tubes are assigned a shelf life. This varies from one to three years depending on the tube's manufacturer and chemistry. A tube is only certified to be accurate until the expiration date.

**NOTE:** Tubes that are out of date can be used for training exercises, but they may give false readings.



**Figure 6.11** The length of the stained section will indicate the concentration of the detected contaminant.

An advantage that detector tubes have over some other instruments is the possibility of selecting a tube specific to a chemical. However, some tubes will respond to interfering compounds. Fortunately, manufacturers provide information about interfering gases and vapors with the tubes.

Interpretation of results can be difficult. Because the tube's length of color change indicates the contaminant concentration, the user must be able to see the end of the stain (**Figure 6.11**). Color changes may not be precise or clear at times. Some stains are diffused and not clear-cut; others may have an uneven endpoint. The length of the stain may change over time and some tubes need longer reaction times before the color change is obvious. When in doubt, use the highest value that would be obtained from reading the different aspects of the tube.

The total volume to be drawn through the tube varies with the tube type and the manufacturer. The volume needed is given as the number of pump strokes required, i.e., the number of times the technician manipulates the piston or bellows. Also, the air does not instantaneously pass through the tube. It may take 1 to 2 minutes for each volume (stroke) to be completely drawn. Therefore, sampling times can vary from 1 to 100 minutes or

more per tube. This can make the use of detector tubes time-consuming. In addition, the responder must be stationary while conducting the test. Battery-operated pumps can make these tests easier to conduct.

Due to these many considerations, it is important to read the instructions provided with, and are specific to, a set of tubes (**Figure 6.12**). The information should include:

- The number of pump strokes needed
- Time for each pump stroke
- Interfering gases and vapors
- Effects of humidity and temperature
- Shelf life
- Proper color change
- Reusability of the tube

While there are many limitations and considerations for using detector tubes, they are versatile in being able to measure a wide range of chemicals with a single pump. Also, there are some chemicals for which detector tubes are the only direct-reading indicators.

Closely associated with colorimetric tubes technology are colorimetric chips. They may be referred to as a *chip measurement system (CMS)*. CMSs use chemical-specific measuring chips with an electronic analyzer. These chips have small tubes, sometimes referred to as capillaries, that are filled with a reagent system for the designated chemical.

Most CMSs are considered direct-reading instruments. These electronic analyzing instruments offer a highly reliable measurement for specific gases and vapors in a digital readout format. CMSs tend to offer a quick response, sometimes accurate to within 7 percent of measured values for some products. In addition to these features, CMSs are simple to use.

### **pH Paper/Strips**

pH is a logarithmic scale; the difference between each pH unit is a factor of 10-fold difference in concentration. For each whole pH value below 7, the representative material is 10 times more acidic than the next higher value. For example, a pH of 4 is 10 times more acidic than a pH of 5 and 100 times ( $10 \times 10$ ) more acidic than a pH of 6. The same holds true for pH values above 7, each of which is 10 times more alkaline than the value below it. Pure water is neutral, with a pH of 7.0 (**Figure 6.13**).



**Figure 6.12** Operating instructions may vary by manufacturer and device.

pH Concentration	
Concentration of Hydrogen Ions Compared to Distilled Water	pH
10,000,000	0
1,000,000	1
100,000	2
10,000	3
1,000	4
100	5
10	6
1	7
$1/10$	8
$1/100$	9
$1/1,000$	10
$1/10,000$	11
$1/100,000$	12
$1/1,000,000$	13
$1/10,000,000$	14

**Figure 6.13** The pH of water is 7.0, at the center of the scale.

pH paper is easy to use and interpret. It is used to visually determine whether a liquid or solution is acidic or basic. Acids turn it red, and bases turn it blue (Figure 6.14). pH paper can be used for both liquids and vapors. Steps for demonstrating proper use of pH paper to identify hazards are presented in Skill Sheet 6-4.

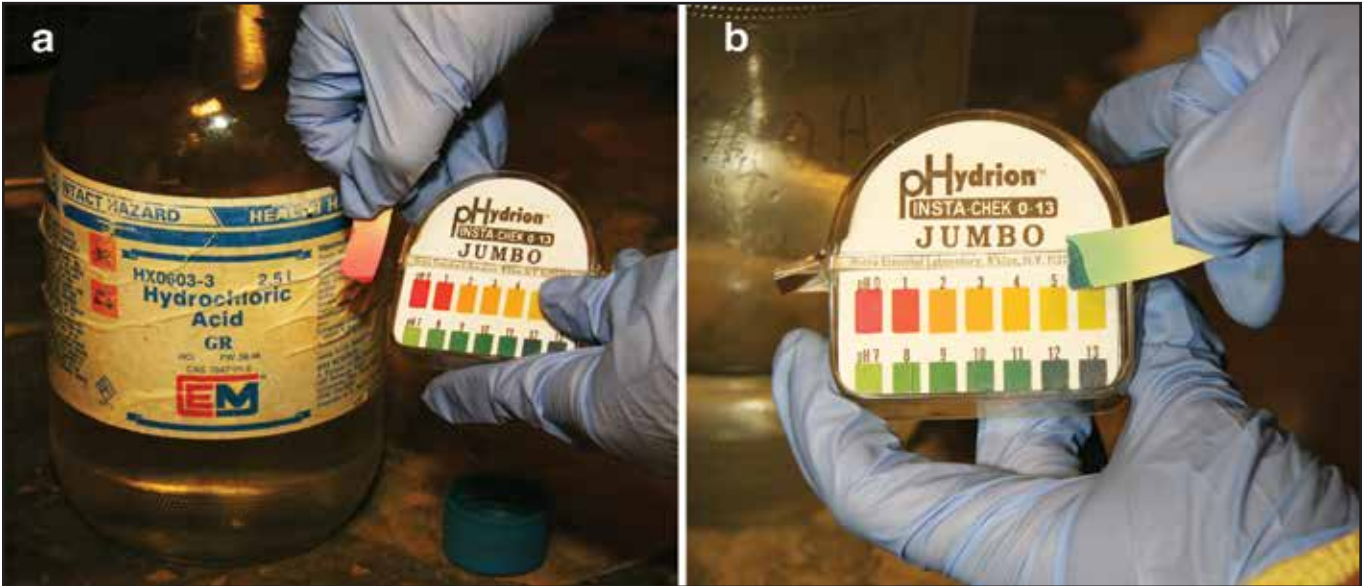
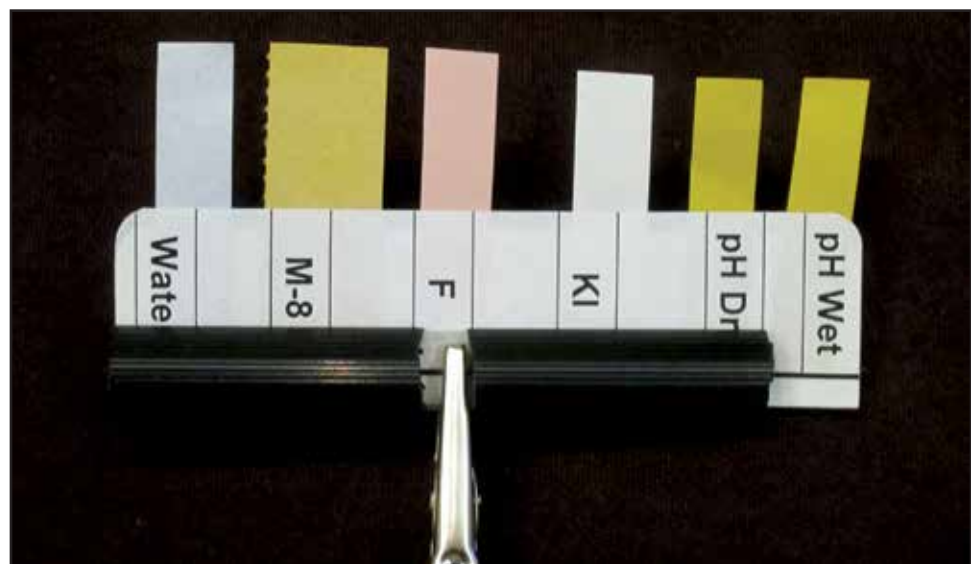


Figure 6.14 Acids turn pH paper red, and bases turn it blue.

There are several varieties of pH paper available with different pH ranges (Figure 6.15). pH paper is highly sensitive to differences in acid or base concentration. Since pH is a logarithmic scale, pH paper can be used to measure the acidity or alkalinity of liquid and solid samples by mixing the solid with water and measuring the pH of the resulting solution.

**NOTE:** The purity of the water, whether distilled water or tap water, may not make a significant difference for this application. Follow the AHJ's and manufacturers recommendations.

Figure 6.15 A “bear claw” can be constructed with some type of horizontal holder and a variety of detection papers.





When attempting to determine the corrosivity of an unknown atmosphere, the entry team may elect to tape a strip of pH paper to their outermost face shield. This will allow technicians to view the strip of pH paper while keeping their hands free for other tasks. Some manufacturers make pH paper with an adhesive backing to allow it to be taped to a suit to determine whether acids or bases are present in the air. Some vapors may not produce as quick of a color change when a preapplied adhesive is used. Attaching a strip with adhesive tape may be a better solution.

**NOTE:** In corrosive atmospheres, flammable gases may be released. In these instances, hazmat technicians can use pH paper in conjunction with other monitoring equipment to identify corrosive/flammable atmospheres.



### Reagent Papers

A variety of reagent and water finding papers are available for specific ions typically found in water. Chemical test strips are a type of **reagent** paper. Test strips used by technicians can include:

- pH
- Fluoride
- Chloride
- Nitrates
- Peroxides
- Oxidizers

These are colorimetric tests and are typically used for measuring water for these components at the low parts-per-million range. The presence of water is not necessarily a hazard in itself, but the ability to test for water is helpful during field screening at an unknown hazard response because it helps minimize errors in some types of equipment. Use of reagent papers coincides with pH paper and other risk-based response detection devices. These strips are used with pipettes to identify unknown liquids. Steps for demonstrating proper use of reagent test paper to identify hazards are presented in **Skill Sheet 6-5**.

Several types of multi-functional reagent papers are available. These typically will contain tests for pH, oxidizers, and others. These test strips must be

**Reagent** — Chemical that is known to react to another chemical or compound in a specific way, often used to detect or synthesize another chemical.



**Figure 6.16** This array of test strips includes a wastewater detector strip. *Courtesy of Scott Kerwood.*

stored in a climate-controlled environment to prevent deterioration and most have a limited shelf life. Types of Spilfyter® test strips include wastewater classifiers and chemical classifiers (**Figure 6.16**).

### **M8, M9, and M256 Chemical Agent Detection Papers**

M8 and M9 chemical agent detection papers change color in the presence of liquid nerve agents or blistering agents. M8 paper is dipped into the suspect liquid and the color change is compared to a color chart to identify specific chemical warfare agents. M9 detects nerve and blister agents as droplets in the air. Both types of paper are easy to use but will only show that there is a probable toxic agent (gas) present and will not display the level of material present. They are both extremely useful in

that they respond to a chemical warfare agent immediately. Both papers will also react to some industrial chemicals.

**NOTE:** M8 paper can also identify whether a liquid is organic or water. If the liquid is organic, the paper will absorb it. Water will bead on the paper.

The M256A1 Detector Kit is a handheld set of colorimetric tests that uses several different chemistries including immunoassay techniques (**Figure 6.17**). The M256A1 Detector Kit may indicate the presence of an agent when it is actually not present because of some types of interference.

This kit can detect the presence of airborne WMD agents including:

- **Nerve agents** – G and V series organophosphate agents
- **Blister agents** – Sulfur Mustard (H), Nitrogen Mustard (HN), Phosgene Oxime (CX), and Lewisite (L)
- **Blood agents** – Hydrogen Cyanide (AC) and Cyanogen Chloride (CK)



**Figure 6.17** The M256A1 Detector Kit can be used to detect airborne WMD agents.

The tests can take up to 30 minutes to perform and is effectively a two-person task since the testing requires specific steps be done at specific times. This is most frequently done by having one person read the instructions and monitor the time while a second person performs the test.

## Radiation Detection Instruments

Detection and measurement of radioactive contamination can help responders avoid hazardous exposure at the scene of a nuclear incident. Proper detection equipment is also needed to verify that victims are free from radiological contamination.

Monitoring instruments are used to detect the presence of radiation by collecting charged particles (ions). The radiation measured is usually expressed as exposure per unit time using various units of measure. These units include the curie (Ci), the becquerel (Bq), and counts per minute (CPM). A variety of instruments are available for detecting and measuring radiation.

Radiation detection and measurement instruments are used routinely to monitor personnel working around or with radiation sources. They are also used to check for any leakage of radiation from containers used to store or transport radioactive materials. Hazmat technicians should always utilize radiation detection equipment. Some types are small enough to clip onto an SCBA strap. Steps for demonstrating proper use of radiation detection instruments to identify and monitor hazards are presented in **Skill Sheet 6-6**.

### Geiger-Mueller

With a gas-filled detector, radiation ionizes the gas inside the detection chamber and the instrument's electronics measure the quantity of ions created. Ion chambers and **Geiger-Mueller (GM) detectors** are common examples of gas-filled detectors (**Figure 6.18**).



**Geiger-Mueller (GM) Detector** — Detection device that uses GM tubes to measure ionizing radiation. Also known as a Geiger Counter.

**Figure 6.18** Geiger counters are used to detect radiation.

An ion chamber is a simple type of gas-filled detector that often uses ambient air as the detection gas, which can cause the chamber to be affected by temperature and humidity. Ion chambers are often calibrated so that the response is directly related to the intensity of the radiation, making them reliable instruments when encountering radiations with varying energies.

#### **Geiger-Mueller (GM)**

**Tube** — Sensor tube used to detect ionizing radiation. This tube is one element of a Geiger-Mueller detector.

GM detectors are sealed from outside air and are not typically affected by temperature or humidity. **GM tubes** with a very thin window may be capable of detecting alpha, beta, and gamma radiation, making them useful for detecting radiological contamination. GM tubes that use a sealed metal body are better suited for measuring penetrating gamma radiation, a possible external exposure hazard. The metal case makes this type of probe less suitable for use in detecting radiological contamination.

### **Scintillation Detectors**

With scintillation detectors, radiation interacts with a crystal such as sodium iodide, cesium iodide, or zinc sulfide to produce a small flash of light. The electronics of the instrument amplify this light pulse thousands of times in order to produce a signal that can be processed. A device called a photomultiplier tube that is attached to the crystal provides the light amplification. Some scintillation detectors have a thin Mylar® covering over the crystal, making them useful for detecting radiological contamination. Generally speaking, scintillation detectors are most useful when detection of small amounts of radiation is required.

Scintillation crystals that are sealed in a metal body are better suited for measuring penetrating gamma radiation. Scintillation detector probes are usually larger than gas-filled detector probes because of the photomultiplier tube. They are also susceptible to breakage if not handled properly. Dropping the instrument can shatter the crystal, photomultiplier tube, or both.

### **Dosimeters and Badges**

Dosimetry devices are useful for keeping track of the wearer's total accumulated radiation dose. The dosimeter measures the total radiation dose an individual has received. Several different types of dosimeters are available. Dosimeters may be included as a feature in some commercial detectors. Steps for demonstrating proper use of dosimeters to identify personal dose received are presented in **Skill Sheet 6-7**.

#### **Self-Reading Dosimeter**

**(SRD)** — Detection device that displays the cumulative reading without requiring additional processing. *Also known as Direct-Reading Dosimeters (DRDs) and Pencil Dosimeters.*

**Self-reading dosimeters (SRDs)** are commonly used, partly because they do not require processing at a lab to retrieve dose information. Generally speaking, SRDs only measure gamma and X-ray radiation. An SRD measures the radiation dose in:

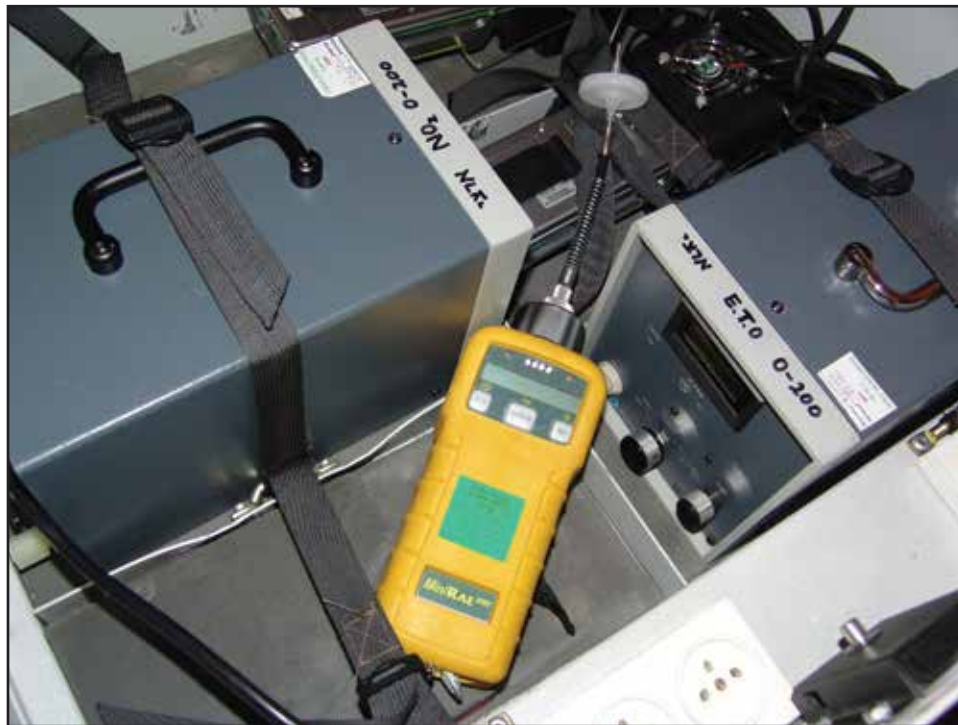
- Roentgens (R)
- Milliroentgens (mR)
- Microsieverts
- Milisieverts
- Gray (Gy)

Responders should record the SRD reading before entering a radiation field (hot zone). While working in the hot zone, responders should read the SRD at 15- to 30-minute intervals and again upon exit from the hot zone. If

a reading is higher than expected or if the SRD reading is off-scale, the AHJ should determine the appropriate action levels based on the hazards and the mission. As always, the IC, local SOPs, and the circumstances of the incident determine the appropriate response. Using the ALARA (As Low as Reasonably Achievable) principle, it should be possible to conduct many types of operations, including rescues, below the 5 rem (0.05 Sv) limit.

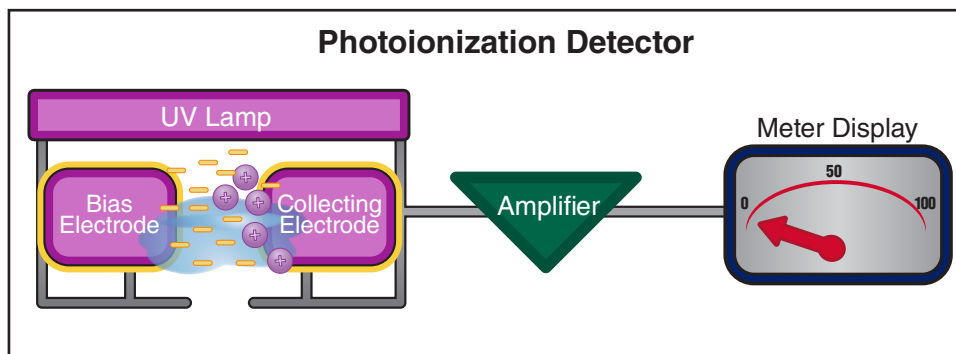
### Photoionization Detectors (PIDs)

A photoionization detector (PID) detects concentrations of flammable/combustible gases and vapors in air by using an ultraviolet light source to ionize the airborne contaminant (**Figure 6.19**). PIDs can detect levels as low as 0.1 part per million and in some instances even parts per billion. If a PID presents readings, a technician will know that some substance in the atmosphere will burn. Steps for demonstrating the proper use of photoionization detectors to identify hazards are presented in **Skill Sheet 6-8**.



**Figure 6.19** Photoionization detectors (PIDs) use a lamp to ionize contaminants.

PIDs use a fan or pump to draw air into the instrument's detector where the contaminants are exposed to UV light. The resulting charged particles (ions) are collected and measured (**Figure 6.20**). Once the gas or vapor is ionized in



**Figure 6.20** The components of a photoionization detector (PID) can be simplified as a lamp, electrodes, amplifier, and display. Other components can be added to increase the efficiency and range of the device.

**Ionization Potential (IP)**

— Energy required to free an electron from its atom or molecule.

the instrument, it can be detected and measured. Photoionization detectors are also used in gas chromatographs.

Since the ability to detect a chemical depends on the ability to ionize it, technicians must compare the **ionization potential (IP)** of a chemical to be detected to the energy generated by the UV lamp of the instrument (**Table 6.3**). There is a limit imposed by the components of air. That is to say, if the lamp is too energetic, oxygen and nitrogen will ionize and interfere with the readings for contaminants.

**Table 6.3**  
**Ionization Potential and Lamp Strength**

Chemical Name	Ionization Potential (IP)	Necessary Lamp Strength*
Isopropyl Ether	9.20 eV	9.5eV - 11.8eV
Methyl Ethyl Ketone	9.54 eV	10.0 eV - 11.8eV
Cyclohexane	9.88 eV	10.0 eV- 11.8eV
Ethyl Alcohol	10.47 eV	10.6 eV- 11.8eV
Acetylene	11.40 eV	11.7eV or 11.8eV
Hydrogen Cyanide	13.60 eV	Undetectable
Hydrogen Fluoride	15.98 eV	Undetectable

\*Typical Lamp Strengths: 9.5eV, 10.0 eV, 10.2 eV, 10.6 eV, 11.7eV, 11.8eV; lamp strength must be higher than IP for the material to be detected

**WARNING!**

Getting no response or no change on a meter does NOT mean that a hazard is not present.

Some limitations of photoionization detectors include:

- Dust may collect on the lamp and block the transmission of the UV light.
- Condensation may form on the lamp and reduce the available light.
- Moisture may reduce the ionization of the chemical and reduce the overall readings.
- As the lamp ages, output intensity will decrease.

**NOTE:** One way to field check the sensor is to cover or block the inlet with a gloved hand. If the sensor continues to show a reading, the bulb needs to be cleaned.

PIDs are calibrated to a single chemical. The instrument's response to chemicals other than the calibration gas/vapor can vary. In some cases, the instrument response can decrease at high concentrations.

Although PIDs are calibrated to a single chemical, it is still possible to gain an accurate reading of a target product even though the instrument was not calibrated to that specific product. The use of correction factors can help the responder determine that information based on the operator's manual.

Photoionization detectors, oxygen sensors, explosive detection meters, and chemical sensors can be grouped in different combinations in field instruments to measure air concentrations at a hazmat scene. These instruments are useful for continuous monitoring during operations or for perimeter monitoring to warn responders and the community of airborne contamination increases. Some units can be radio-linked to a central command post to provide real-time monitoring of conditions at multiple locations. An advantage of the PID is that it does not destroy the test sample and also allows for the sample to be retained for later analysis. A bigger advantage is that it reads materials that flame-burn (burn with a visible flame) at any detectable concentration.

## Biological Immunoassay Indicators

Biological **immunoassay (IA)** indicators (also known as assays) are identification systems that detect the effects of a biological agent by relying on the evidence of a reaction, in the form of **antibodies** (Figure 6.21). IAs can detect certain **antigens** (biological agents) by targeting proteins unique to that agent.

During risk-based response, biological assays can supplement other detection methods to help the hazmat technician provide the Incident Commander with information needed for critical decision-making. If malicious intent is suspected, technicians may use the IA (if available) to screen for the presence of a biological agent.

Technicians can also use **wet chemistry** in conjunction with IA indicators. If a material is a solid or a solid in a solution, and has a neutral pH value, the next step is to apply a protein test to the substance. Most materials will never create a positive protein test. If the protein test indicates a positive result, the application of an IA test would be appropriate. Wet chemistry is discussed in greater length later in this chapter.

Immunoassay methods are based on the response of specific antibodies to toxic materials. Living organisms, when exposed to toxic materials, will generate antibodies (proteins and enzymes) to respond to the attack as part of the organism's immune system. During subsequent exposures, these proteins and enzymes react to the presence of the toxic material rapidly and at low concentrations.

IA tests may offer quick results. One limitation of these tests is that they may indicate biological agents where none exist.

## Thermal Imagers

A **thermal imager (TI)**, also known as a thermal imaging camera (TIC), is a type of thermographic imaging device used widely by firefighters. By rendering

**Immunoassay (IA)** — Test to measure the concentration of an analyte (material of interest) within a solution.

**Antibody** — Specialized protein produced by a body's immune system when it detects antigens (harmful substances). Antibodies can only neutralize or remove the effects of their analogous antigens.

**Antigen** — Toxin or other foreign substance that triggers an immune response in a body.

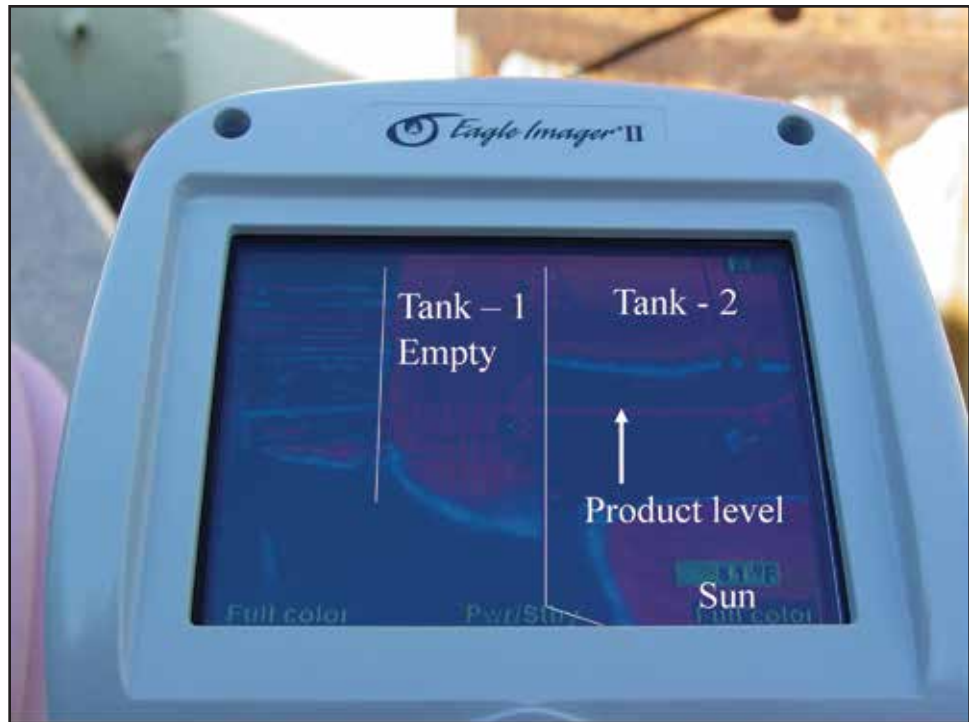


Figure 6.21 Immunoassay indicators are used to detect a reaction to a biological agent.

**Wet Chemistry** — Branch of analysis with a focus on chemicals in their liquid phase.

**Thermal Imager** — Electronic device that forms images using infrared radiation. Also known as Thermal Imaging Camera.

**Figure 6.22** In addition to helping firefighters find victims, thermal imagers can be used to detect hot spots and temperature differences in hazmat containers.



**Infrared** — Invisible electromagnetic radiant energy at a wavelength in the visible light spectrum greater than the red end but lower than microwaves.

**infrared** radiation as visible light, such imagers allow firefighters to see areas of heat through smoke, darkness, or heat-permeable barriers (**Figure 6.22**). TIs are typically handheld, but may be helmet-mounted. They are constructed using heat- and water-resistant housings, and are designed to withstand the hazards of fireground operations.

A TI consists of five components:

- Optic system
- Amplifier
- Display
- Detector
- Signal processing

These parts work together to render infrared radiation, such as that given off by warm objects or flames, into a visible light representation in real time. The imager display shows infrared output differentials, so two objects with the same temperature will appear to be the same “color.” Many thermal imagers use grayscale to represent normal temperature objects, but highlight dangerously hot surfaces in different colors.

Hazmat responders use TIs to look for hot spots or differences in temperature. Using a TI, the responder may identify a chemical reaction, such as a polymerization reaction, occurring in a container. They can also be used to determine the liquid level in uninsulated containers or flow in a transfer hose. Some TIs are sensitive enough to differentiate cold temperatures and are useful in identifying leaks involving products such as propane and ammonia. They also are useful for identifying differences in temperature between containers.

**Infrared Thermometer** — Noncontact measuring device that detects the infrared energy emitted by materials and converts the energy factor into a temperature reading. *Also known as Temperature Gun.*

## Infrared Thermometers

**Infrared thermometers** detect temperature using a portion of the thermal radiation (sometimes called blackbody radiation) emitted by the object of measurement (**Figure 6.23**). When IR thermometers are pointed at the object



to be measured, the device displays a temperature. By knowing the amount of infrared energy emitted by the object and its **emissivity**, technicians can often determine the object's temperature. Infrared thermometers are a subset of devices more precisely called *thermal radiation thermometers* or *radiation thermometers* for short. Infrared thermometers are typically very accurate. Steps for demonstrating the use of a noncontact thermal detection device to identify hazards are presented in **Skill Sheet 6-9**.

The most basic infrared thermometer design consists of a lens that focuses the infrared thermal radiation onto a detector. The detector converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This configuration facilitates temperature measurement from a distance without technicians having to come in contact with the target object. The infrared thermometer is useful for measuring temperature under circumstances where thermocouples or other probe type sensors cannot be used or do not produce accurate data.

Technicians can use infrared thermometers to serve a wide variety of temperature monitoring functions such as:

- Determining the surface temperature of a container
- Determining the temperature of a material
- Determining if a chemical reaction is taking place in and outside the container
- Monitoring materials in the process of a chemical reaction

## Other Detection Devices

To this point, this chapter has concentrated on the typical meters and instrumentation available to most hazardous materials technician teams. However, there are many nontraditional instruments that can be useful when attempting to mitigate a hazmat incident. The following sections address some instrumentation that technicians should consider when developing a cache of detection devices. Some of these devices may already be available to the emergency responder, while some may have to be researched and purchased. In any case, having the proper equipment available will not only assist in mitigation but also increase the safety of the response.

### Halogenated Hydrocarbon Meters

Halogenated hydrocarbons are **carcinogens** and can pose a serious health risk. Technicians can detect halogenated hydrocarbons by using colorimetric tubes and chips and other more advanced methods. Many "tic tracer" leak detectors are capable of monitoring for halogenated hydrocarbons. These portable devices are capable of detecting vapor concentrations of 25 parts per million by volume (ppmv) and indicating a concentration of 25 ppmv or greater. The devices do this by emitting an audible or visual signal that varies as the concentration changes. A disadvantage when compared to other detection devices is that these meters do not provide a numerical value. Another disadvantage is that they are not typically intrinsically safe.



**Figure 6.23** Infrared thermometers can sense temperature without contacting the material.

**Emissivity** — Measure of an object's ability to radiate thermal energy.

**Carcinogen** — Cancer-producing substance.

**Flame Ionization Detector (FID)** — Gas detector that oxidizes all oxidizable materials in a gas stream, and then measures the concentration of the ionized material.

Advantages of halogenated hydrocarbon meters include:

- Simple to use.
- Chemical family specific.
- Used to verify the readings from other detection devices.

## Flame Ionization Detectors

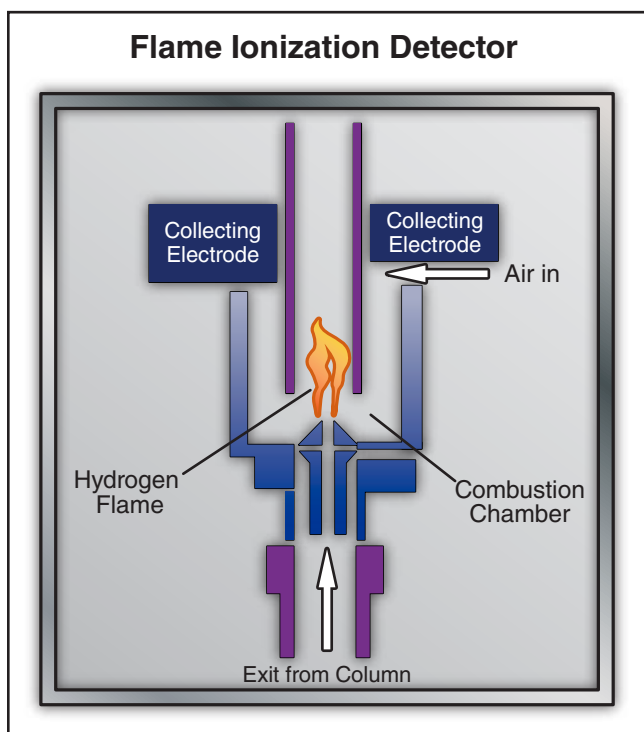


**Figure 6.24** Flame ionization detectors can return results on nearly all organic compounds.

**Flame ionization detectors (FIDs)** use a hydrogen flame (combustion) to ionize organic airborne contaminants in order to detect carbon-based flammable gas (**Figure 6.24**). Once they are ionized, many contaminants can be detected and measured. The FID responds to virtually all organic compounds.

### CAUTION

The recommended warm-up times are essential for proper functioning of a FID.



**Figure 6.25** Despite its use of a flame, an FID may be intrinsically safe.

FIDs primarily detect carbon (C) and hydrogen (H). This generalized sensitivity is due to the breaking of chemical bonds, which requires a set amount of energy and is a known reproducible event (**Figure 6.25**). FIDs are the most sensitive detector for saturated hydrocarbons, alkanes, and unsaturated hydrocarbon alkenes. Substances that contain substituted functional groups, such as hydroxide (OH) and chloride (Cl), tend to reduce the detector's sensitivity. Overall, however, the detectability remains sound.

FIDs respond only to organic compounds. Thus, they do not detect inorganic compounds like chlorine or ammonia. FIDs may detect some halogen compounds, but only if those compounds are present in large quantities.

FIDs are complementary for use with PIDs. Using these devices together is helpful because they expand the range of products that can be detected. Combination FID/PID meters are also commercially available. FIDs require some advanced knowledge for operation.

**Gas Chromatograph (GC)** — Apparatus used to detect and separate small quantities of volatile liquids or gases via instrument analysis. Also known as Gas-Liquid Partition Chromatography (GLPC).

## Gas Chromatography

A **gas chromatograph (GC)** is a tool used extensively to measure the presence and identity of chemicals in air, water, and soil. The role of GC is mainly to separate and measure the various components of the mixture of chemicals. This technique can be exceptionally sensitive and specific depending on the product to be measured.

GC is commonly used in many research and industrial labs. However, it does have some relevance in the hazmat response field. Technicians can analyze

a broad variety of samples as long as the compounds are sufficiently stable when exposed to high temperatures.

GC takes into account three different factors between the sample and a stationary phase:

- Affinity
- Volatility
- Molecular weight

During operation, a sample is injected into the column. An inert gas such as helium helps push the sample through. After the sample passes through the column, it reaches the detector, commonly a thermal conductivity detector, which will measure the thermal conductivity of the carrier gas. This will generate an electrical signal that transforms into a chromatogram.

Gas chromatography equipment requires additional training. Technicians should have an idea of what materials they expect to find, via use of a PID or FID, before using a **spectrometer**.

A significant issue with gas chromatographic data is the possible misidentification of the impurity peak due to interferences in the chromatogram. It is possible to report the presence and concentration of a product in air, water, or soil when the product may not be present or may be present at a much lower level. One of the most significant contributors of interference in a device's readings may be as simple as the software or hardware updates required to keep it current and functioning optimally.

## Mass Spectroscopy

**Mass spectrometers** are generally the most sensitive detectors for GC and may measure components in the low parts per million or even parts per billion ranges. Use of this technology can aid the responder in identification of unknown materials.

Mass spectrometers also have a two-fold advantage:

- Being able to break down individual compounds into fragments
- Comparing those fragments with the fragmentation pattern of a known sample of the component being measured for identification purposes

Mass spectrometers ionize samples in order to determine their composition. Like other **spectroscopy** devices, they compare test results to a library of known measurements in order to make a positive identification.

The operator of this technology must be a highly trained technician who can deliver viable samples to the equipment. New generations of GC/MSs are field portable, handheld, and easier to operate, but still require a high level of skill to interpret data (**Figure 6.26**). The GC/MS technology is best used to identify volatile and semi-volatile organic compounds including chemical warfare agents and toxic industrial chemicals.

**Spectrometer** — Apparatus used to measure the intensity of a given sample based on a predefined spectrum such as wavelength or mass.

**Mass Spectrometer** — Apparatus used to ionize a chemical and then measure the masses within the sample.

**Spectroscopy** — Study of the results when a material is dispersed into its component spectrum. *Also known as Spectrography.*



**Figure 6.26** GC/MS equipment has become more portable over time, but the results must still be analyzed and interpreted.



**Figure 6.27** Ion mobility spectrometry can help identify some materials that are difficult to detect via other methods.

**Ion Mobility Spectrometry (IMS)** — Technique used to separate and identify ionized molecules. The ionize molecules are impeded in travel via a buffer gas chosen for the type of detection intended. Larger ions are slowed more than smaller ions; this difference provides an indication of the ions' size and identity.

**Surface Acoustic Wave (SAW) Sensor** — Device that senses a physical phenomenon. Electrical signals are transduced to mechanical waves, and then back to electrical signals for analysis.

## Ion Mobility Spectrometry

**Ion mobility spectrometry (IMS)** is the basis of many chemical agent monitors used in emergency response (**Figure 6.27**). This technology is deployed in many airports and is used for detection and screening of explosives, chemical warfare agents, and illicit drugs. In an industrial setting, ion mobility is used to detect toxic or volatile chemicals that are otherwise difficult to detect based on their behaviors. A primary limitation of this technology is that analysis is dependent on vapor pressure, which may limit the detection of some explosives with low vapor pressure.

Chemical agent monitors (CAMs), improved chemical agent detectors (ICADs), automatic chemical agent detector alarms (ACADAs), and joint chemical agent detectors (JCADs) are gross-level detectors of nerve, blood, blister, and choking agents. They provide a visible and audible warning of agent doses, but only when the concentration is above the initial effects dose. These are handheld, battery-operated, post-attack devices for monitoring chemical agent contamination on personnel or equipment. Ion mobility detection may not yield accurate readings if certain organic solvents are present.

A Nickel-63 source ionizes gases from the sample which form a cluster of ions. A gate circuit opens and ions of a specific polarity enter a chamber called a drift tube or drift region. The clusters of ions are focused and accelerated by an electromagnetic field moving through the drift tube in approximately 10-20 milliseconds. The ions arrive at an electrode and produce an electrical current proportional to the relative number of ions present. The combination of the drift time and charge-current then causes an alarm to sound, indicating the presence of a nerve or blister agent.

Ion mobility tends to be fast and reliable instrumentation that has been tested under many circumstances and conditions. In most instances, the user can easily maintain this technology, which only requires periodic checks and yearly maintenance. Ion mobility will work efficiently for particulate analysis as well using wipe sampling technology. Ion mobility will attempt to offer a name for the detected material, as opposed to a library of potential options.

## Surface Acoustic Wave

**Surface acoustic wave (SAW) sensors** are based on technology that was developed in the early 20th century. SAW technology, used in meters such as MSA SAW MiniCAD®, may potentially be used in the detection of nerve and blister agents (**Figure 6.28**).

The MiniCAD® uses a pair of SAW microsensors that are extremely sensitive to small changes in the mass of the surface coatings that act as sponges for chemical warfare agents. A small pump collects the vapor samples, concentrates them, and passes them over the microsensors. An onboard microcomputer analyzes the responses to determine if a hazard exists. Analysis time is typically one minute.



**Figure 6.28** Surface acoustic wave sensors may be helpful in detecting nerve and blister agents.

### Gamma-Ray Spectrometer

— Apparatus used to measure the intensity of gamma radiation as compared to the energy of each photon.

## Gamma-Ray Spectrometer

A **gamma-ray spectrometer** determines the energies of the gamma-ray photons emitted by the source (**Figure 6.29**). Radioactive nuclei (radionuclides) commonly emit gamma rays corresponding to the typical energy levels in nuclei with reasonably long lifetimes. Such sources typically produce gamma-ray “line spectra” (i.e., many photons emitted at discrete energies).

Most radioactive sources produce gamma rays of various energies and intensities. When technicians collect and analyze these emissions with a gamma-ray spectroscopy system, the result can be a gamma-ray energy spectrum. A detailed analysis of this spectrum is typically used to determine the identity and quantity of gamma emitters present in the source. The gamma spectrum is characteristic of the gamma-emitting nuclides contained in the source. Just as in optical spectroscopy, the optical spectrum is characteristic of the atoms and molecules contained in the sample.

Gamma spectroscopy can serve a beneficial purpose in the hazmat response field if this technology is available to the responder. Gamma spectroscopy offers reliable quantitative results for gamma-emitting isotopes. It is also a fast, reliable, and sensitive means for the complete assessment of a gamma radiation field at a fixed location.

After using risk-based response to determine a name, gamma spectroscopy can differentiate between commercial/medical or illicit materials. Keep in mind that if the product is not in the purchased isotope library for the device, it will be unable to detect it.



**Figure 6.29** A gamma-ray spectrometer identifies the activity level of a source.

### Fourier Transform Infrared (FT-IR) Spectroscopy

— Device that uses a mathematical process to convert detection data onto the infrared spectrum.

### Spectrophotometer —

Apparatus used to measure the intensity of light as an aspect of its color.

## Fourier Transform IR

**Fourier Transform Infrared (FT-IR) spectroscopy** is similar to infrared spectroscopy and the principle of operation is also similar. The main difference is in the way the signal is received and processed. A simple optical device called an *interferometer* presents a unique type of signal which has all infrared frequencies encoded into it. The use of the interferometer allows for a quick response.

FT-IR spectroscopy was developed to overcome the limitations that may be found in dispersive instruments. In other IR technology, only one signal is received and processed to indicate the results. In FT-IR, many signals (potentially more than one thousand) are received and then averaged. This result offers much more sensitivity and accuracy.

Fourier Transform IR tends to be extremely accurate for specific materials that are included in the library. Types of materials that are detected reliably via FT-IR include:

- Solids, liquids, gels, and pastes
- Explosives
- Organic compounds
- Mineral acids
- Substances in aqueous solutions
- Crystalline semi-metals
- Fluorescent materials



**Figure 6.30** Fourier Transform Infrared (FT-IR) analysis requires controlled conditions for accurate results and interpretation.

FT-IR analysis should not take place in the field. This technology uses a limited number of moving parts, is internally calibrated, and must be returned to the factory for calibration (**Figure 6.30**). It may be necessary to consult the equipment's manufacturer in order to analyze the spectra. This approach, called "reach back" must be established via AHJ policies because it requires specialized interpretation of the equipment's readings. The product must be physically handled in order to obtain a sample. The presence of water may affect the results.

FT-IR technology cannot detect (see) through glass containers. The following chemicals or products can be difficult or near impossible to identify:

- Ionic substances
- Metals
- Elemental substances
- Complex mixtures
- Aqueous solutions
- Some strong acids

## Infrared Spectrophotometers

A **spectrophotometer** is a type of photometer that can measure intensity of a beam of light as a function of the light source wavelength (color). Techni-

cians cannot carry this equipment into the field for use. They may stage it in a mobile trailer unit, and a small number of features may be programmed after it is moved. Changes may easily unbalance its calibration. Other field-use instruments available can monitor and accurately identify thousands of compounds in their libraries.

The spectrophotometer operates by passing a beam of light through a given sample and measuring the strength of the light that reaches the detector. Organic compounds absorb infrared radiation at frequencies that are characteristic and different for various molecules, allowing for infrared analysis. Infrared absorbance patterns are distinct enough that a well-trained chemist can often interpret the patterns and identify the characteristics of the molecule, sometimes even identifying the specific molecule and identifying one isomer out of several possible structures. The amount of infrared energy that a sample absorbs can be related directly to the amount of a specific component in that sample.

Infrared instruments specifically designed to analyze samples in the field are available from a number of companies. A significant problem with the analysis of both liquid and solid samples is the impact of water contamination on the ability to obtain useable, interpretable spectra. Water has such a strong, intense infrared spectrum that a significant presence of water in the sample may obscure critical bands and make it impossible for the software to interpret the bands and make identification.

Some of these instruments allow a change in the compound being monitored, presuming that the compound is already in the instrument's database. In most cases, setting up the instrument to measure a compound that is not already in the database is difficult, if not impossible, in the field and will often require laboratory preparation of standard gas mixtures to allow the choice of monitoring frequencies and calibration factors.

Gas sampling is typically done by pumping ambient air through a transparent chamber between the infrared light source and a detector. An infrared scan is a plot of the amount of infrared radiation absorbed by the sample as a function of the wavelength of the IR radiation. The IR pattern is sometimes called a "fingerprint" because it is characteristic of a molecule. Similar molecules will display similar, but not identical, IR results.

## Raman Spectroscopy IR

In a **Raman spectrometer**, a sample is exposed to a high intensity light (**Figure 6.31**). The light reflected by, or scattered by, the sample is analyzed for absorbance characteristics of vibrational, rotational, stretching, or bending of the various bonds in the molecule. These energy characteristics are associated with the types of bonds and so they have the same values as the infrared absorbance. Raman spectroscopy is similar to infrared spectroscopy technology.

**Raman Spectrometer** — Apparatus used to observe the absorption, scattering, and shifts in light when sent through a material. The results are unique to the molecule.



**Figure 6.31** Raman spectroscopy uses a high intensity light, such as a laser, to identify materials.

In a Raman spectrometer, a high intensity light irradiates the sample (liquid or solid), and the light reflected or scattered by the sample is analyzed. Some of the energy from the light source is taken up by the sample and is “redistributed” between the various rotational, vibrational, stretching, and bending modes of the molecule. The net result is that the light reflected or scattered by the sample has “absorbance” bands characteristic of that specific molecule. Since these are the same energy absorbance as the infrared spectra, the interpretation of the Raman spectrum is quite similar to the IR. However, some of the vibrational, rotational, bending, and stretching frequencies present in the infrared spectrum will be missing in the Raman spectrum. The theoretical explanation as to why all of the same frequencies are not present in both infrared and Raman spectra is far beyond the level of this text. Raman spectra also tend to be “less intense” than the corresponding infrared spectra.

Raman spectroscopy has one significant advantage over infrared in that water does not have a Raman absorption spectrum. This is significantly different from infrared spectroscopy where water is a strong absorber — often absorbing so much of the infrared energy that no interpretable spectrum can be observed by infrared. Raman spectroscopy can often accurately analyze solid samples containing significant amounts of water and aqueous solutions. Using Raman technology in concert with FT-IR technology will aid the identification process.

**NOTE:** Field screening should detect water before a material is tested via Raman spectroscopy.

On the negative side, Raman spectroscopy is limited to the detection of visible quantities of liquids or solids. Depending on the model, most products using this technology will only detect substances in clear containers. Opaque containers such as brown bottles will not work. The use of a laser in this technology will also offer some limitations. The unshielded laser light may be an eye hazard and black or dark materials will not be able to be identified because they will absorb the laser light. Also, the laser may ignite flammables. Reducing the sample size and lowering the laser output and scan delay can help to reduce this risk.

**NOTE:** The Raman spectrometer will provide an estimated time to analyze the sample. The longer this sample estimate, the less potential for an accurate spectra.



### Hazards of Raman Spectroscopy

Explosive materials may ignite or explode when exposed to a laser. If the equipment allows, technicians should apply the lowest laser setting along with a scan delay. This procedure will increase the necessary number of scans to the process, but will protect the hazmat technician from delivering too much energy that could cause ignition or detonation.



## Mercury Detection

Mercury is a liquid metal that behaves like a solid in terms of vapor pressure. During risk-based response, technicians may detect mercury as a solid.

Mercury releases into the atmosphere primarily via burning fossil fuels. Once in the atmosphere, it is deposited on land and sea, where it eventually enters the food chain in fish or shellfish. Mercury is then transformed to methyl mercury and preconcentrated to potentially dangerous levels. Mercury can be found in industry and has a presence in laboratories. Mercury is used in thermometers and barometers, and in some floats and switches.



### Mercury Incident, Williamson County, Texas, December 2014

On the afternoon of December 15, a resident called the regional office of the Texas Commission on Environmental Quality. The resident had spilled mercury pellets in his garage a few months earlier, and wanted to be sure that his attempt at cleaning the spill was effective. The spilled amount was equivalent to 5-6 thermometers in volume, leftover from his father's gold mining operation.

He was asked to restrict access to the garage, and to expect an EPA team the next morning. On further interactions, the resident indicated that a few weeks after the spill, his three children had shown signs of fifth disease, a common and mild viral infection. One child had more persistent symptoms with no apparent cause, and at the beginning of the month, started having seizures. In the past few days, all three children were ultimately hospitalized with symptoms of chronic mercury poisoning, and responded well to treatment. On the day of the call, the children had been tested for mercury, with higher than normal results. Neither of the parents showed symptoms.

On December 16, the house was tested for mercury vapor, and readings were well above the allowable reading of one microgram per cubic meter ( $\mu\text{g}/\text{m}^3$ ) [1 ppb] on the Jerome 505 Mercury Analyzer. In one ice chest, the readings were over  $200 \mu\text{g}/\text{m}^3$  (20 ppb) and most of the house was over  $7 \mu\text{g}/\text{m}^3$  (.7 ppb). The Texas Commission on Environmental Quality (TCEQ) and Environmental Protection Agency (EPA) barred the family from the house while clean-up work was underway, and worked out a plan to conduct the work without billing the family. The rest of the day was spent removing items from the garage to see if the readings would come down.

On December 17, the EPA brought more sensitive equipment. The Mercury Vapor Analyzer (Lumex RA-915+) could not show readings higher than  $50 \mu\text{g}/\text{m}^3$  (5 ppb) but was able to help identify locations of the remaining mercury contamination. The first focus was the wall separating the garage and the house. With all items removed from the garage, the readings were still over  $50 \mu\text{g}/\text{m}^3$  (5 ppb).

On December 18, the base plate of the garage wall was identified as the place with the highest readings. A firefighter crew was called in to evaluate the structural stability of the wall. They braced the wall so the base plate could be removed. Under the baseplate, the clean-up crew found a silver dollar sized puddle of mercury. When it was removed, the readings were still over  $10 \mu\text{g}/\text{m}^3$ .

Over the 19th through 23rd, work continued with the garage warming to the temperatures that would be needed for a valid mercury reading: around

85° Fahrenheit (29 °C). Items were sorted for return to the family versus disposal based on their readings. During this process, a drain was identified as having the highest remaining readings: over 16 µg/m<sup>3</sup> (1.6 ppb) where the rest of the house was closer to 1.6 µg/m<sup>3</sup> (.16 ppb). A decontamination powder, HgX®, was left in the drains over the holiday break.

On December 27, the drain was treated again with HgX®, and this time the whole house tested under 1 µg/m<sup>3</sup> (.1 ppb) at temperatures between 80° and 90° Fahrenheit (27 and 32 °C). Results were finally good enough that the EPA was called to conduct their eight-hour test the next day. Results from that test were within acceptable parameters, and the house was returned to the residents on December 30.

**Lessons Learned:** Mercury is a highly potent toxin, and chronic exposure may not be immediately obvious. Mercury is also difficult and time-consuming to clean up, even with the correct materials and resources.

**Source:** Williamson County Hazardous Materials Response Team

An advantage to mercury detection is that it has a wide detection range. This technology is prone to few interferences. If technicians suspect the presence of mercury, field screening can be helpful. Two methods of field screening for mercury include the use of a silica optical cell, or a gold film detector.

Technicians can detect mercury concentration using an optical cell made of high purity fused silica. In this process, a sample is drawn continuously through the detector, and ultraviolet light is absorbed and measured. This so-called “cold vapor” measuring method is extremely sensitive for mercury determination and has been used successfully for many years. Sensitivity of cold vapor detections is about 0.1 µg/m<sup>3</sup> (0.01 ppb).

Another method of detecting mercury is by the use of gold film detectors. The gold film sensor is inherently stable and selective to mercury. When the sample cycle activates, the internal pump draws a precise volume of air over the sensor. Mercury in the sample **adsorbs** on the surface of the gold film, and the sensor registers it as proportional change in electrical resistance of the gold film. Sensitivity of the detector is about 0.003 mg/m<sup>3</sup> (3 µg/m<sup>3</sup> [.3 ppb]).

The gold film becomes saturated over time, and may be contaminated by touching surfaces. Gold film sensors may be cleaned (regenerated) by heating the mercury off of the sensor. This process is called regeneration. The process may be time-consuming, and it requires the use of AC power that may not be available at the emergency scene.

## Wet Chemistry

Wet chemistry encompasses many types of kits and strips, some of which have already been discussed in this chapter. Some wet chemistry kits contain portable chemistry sets designed to enable logical and progressive testing of a sample in order to identify a chemical or product.

Wet chemistry predates FT-IR and Raman spectroscopy in terms of resources available to field technicians. A number of field test kits are available, including test strips specific for different potential contaminants. Depending on the system being used, it may be possible to identify hazardous substances and common products. Responders must be aware that most tools and testing equipment may not readily identify unknown materials.

**Adsorb** — The collection of a liquid or gas on the surface of a solid in a thin layer.

The AHJ must determine, based on risk-based response, what functions of wet chemistry should be used within their system. Some kits require extensive training. Depending on the AHJ, wet chemistry approaches that may be used include:

- Reagent tests
- Chemical test strips
- pH paper
- Multifunctional test strips
- HAZCAT
- HEINZ 5 STEP™ Kit
- EPA Field Screening Kit

## DNA Fluoroscopy

DNA fluoroscopy devices are used in the detection of biological agents. They are designed to detect specific DNA sequences that are helpful in the detection of protein-based biological substances.

**Fluorimeters** can be used to determine whether a sample contains DNA and RNA because the pyrimidine and purine ring structures in these molecules are fluorescent.

A sample that contains baby powder (talc), corn starch, or other material that does not contain DNA will not fluoresce. A sample of biologically active material will contain DNA or RNA. This equipment is not portable in a conventional sense. It cannot be manually carried into the field.

**NOTE:** Biotoxins such as ricin or botulinus toxin will not contain DNA or RNA and will not show up in a fluorimeter analysis.

## Polymerase Chain Reaction Devices

Technicians can use a **polymerase chain reaction (PCR)** to quickly amplify or copy segments of DNA, as well as identify DNA. Devices using PCR can detect and identify biological agents and toxins.

PCR is an automated process that amplifies a segment of DNA. The sample segment is heated until it separates (denatures) into two pieces. This process results in a duplication of the original DNA sample with each of the samples containing a new and old strand of DNA. Each of these strands can be used to create new samples, and the process can go on exponentially. This automated process is relatively quick and is conducted by a machine called a thermocycler. The thermocycler is programmed to alter the temperature of the reaction every few minutes to allow the DNA denaturing and synthesis.

Polymerase chain reaction devices have evolved as a widely used methodology for biological investigation because they can detect and quantify trace samples of DNA. While accurate, its field use is limited. In addition, it takes an average of 30 minutes to process the test samples.

**Fluorimeter** — Device used to detect the fluorescence of a material, especially as pertains to the fluorescent qualities of DNA and RNA.

**Polymerase Chain Reaction (PCR)** — Technique in which DNA is copied to amplify a segment of DNA to diagnose and monitor a disease or to forensically identify an individual.

## Chapter Notes

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## Chapter Review

1. What is the difference between exposure and contamination?
2. What are exposure limits?
3. What two hazards are oxygen indicators designed to detect?
4. How does temperature affect the calibration of flammable gas sensors?
5. Correction factors for PIDs are useful only when what two variables are known?
6. Name four types of colorimetric detection methods and describe their basic functions.
7. Name three types of radiation detection instruments and describe their methods of detection.
8. What are some limitations of photoionization detectors?
9. What do biological assays test for?
10. What are four temperature monitoring functions that infrared thermometers can perform?
11. What are some other detection devices available and what hazards are they designed to detect?

**WARNING:** If this skill involves the use of actual hazardous material samples, hazardous materials can cause serious injury or fatality. Appropriate personal protective equipment (PPE) must be worn and safety precautions must be followed. The following skill sheet demonstrates general steps; specific hazmat incidents may differ in procedure. Always follow the AHJ's procedures for specific incidents.

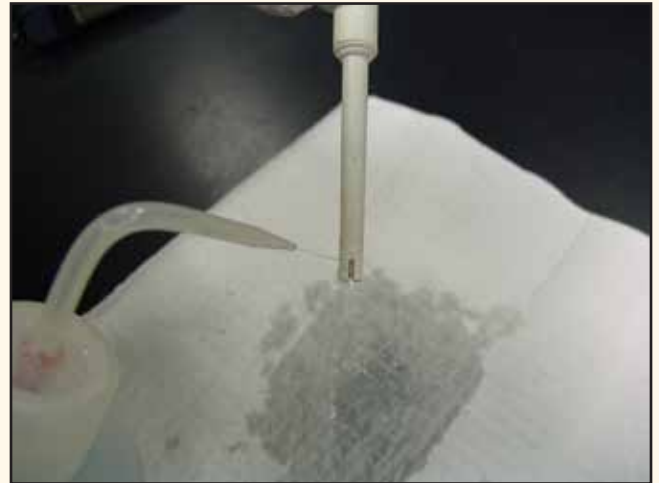
- Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.
- Step 2:** Ensure that all responders are wearing appropriate PPE.
- Step 3:** Perform initial inspection to ensure device is serviceable.
- Step 4:** Turn on the pH meter.
- Step 5:** Remove the protective cap from the electrode.



- Step 6:** Calibrate the pH meter in a test solution with a known pH per manufacturer's instructions.



- Step 7:** Once calibrated, rinse and return the electrode to its operational state per manufacturer's instructions.



- Step 8:** Place the electrode in the liquid to be tested and make note of the reading.



- Step 9:** Report readings according to AHJ's procedures.
- Step 10:** Remove electrode from the liquid, rinse, and return to operational state per manufacturer's instructions.
- Step 11:** Replace the protective cap on the electrode.
- Step 12:** Turn off the pH meter.
- Step 13:** Decontaminate equipment and return to operational state per manufacturer's instructions.
- Step 14:** Complete required reports and supporting documentation.

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**NOTE:** Specific procedures will vary depending on the equipment used. Refer to the manufacturer's instructions for complete directions.

- Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.
- Step 2:** Ensure that all responders are wearing appropriate PPE.
- Step 3:** Perform initial inspection to ensure device is serviceable.
- Step 4:** Select the monitor and identify the gases it will detect.



- Step 5:** Perform a bump test to ensure the meter is functioning properly.



- Step 6:** Perform a "fresh air" calibration of the monitor prior to entry.



**Step 7:** Properly monitor the area per AHJ's requirements.



**Step 8:** Report results according to AHJ's requirements.

**Step 9:** When monitoring is complete, turn off the instrument.

**Step 10:** Decontaminate equipment and return to operational state per manufacturer's instructions.

**Step 11:** Complete required reports and supporting documentation.

**WARNING:** If this skill involves the use of actual hazardous material samples, hazardous materials can cause serious injury or fatality. Appropriate personal protective equipment (PPE) must be worn and safety precautions must be followed. The following skill sheet demonstrates general steps; specific hazmat incidents may differ in procedure. Always follow the AHJ's procedures for specific incidents.

**NOTE:** Specific procedures will vary depending on the equipment used. Refer to the manufacturer's instructions for complete directions.

**Tube System**

**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.



**Step 2:** Ensure that all responders are wearing appropriate PPE.

**Step 3:** Use the manufacturer's instruction manual to select the proper colorimetric tube for sampling and check expiration dates for the tube.



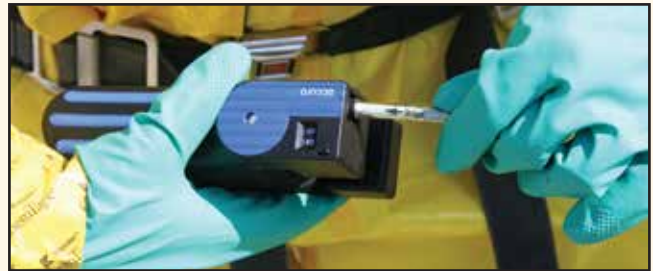
**Step 4:** Perform a functional test to check device per manufacturer's instructions to ensure correct operation.

**Step 5:** Reset the counter.

**Step 6:** Properly break both ends off of the tube(s) using the provided tube cutter.



**Step 7:** Insert the tube into the hand pump in the proper direction.



**Step 8:** Hold the tip of the tube an appropriate distance away from the product or container opening, taking care not to come into contact with any solid or liquid product.





**Step 9:** Sample the product based on manufacturer's instructions.

**Step 10:** Remove the tube from the pump and read, interpret, and record the results per manufacturer's instructions.



**Step 11:** Dispose of sampling tube in accordance with appropriate regulations.

**CAUTION:** Used tubes may be a hazardous waste and/or sharps hazard.

**Step 12:** Decontaminate equipment and return to operational state per manufacturer's instructions.

**Step 13:** Complete required reports and supporting documentation.

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**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.



- Step 2:** Ensure that all responders are wearing appropriate PPE.
- Step 3:** Inspect the paper to ensure it has not been exposed or expired.
- Step 4:** Remove a piece of appropriate size pH paper from the roll or remove strip from the container and secure the paper.



**Step 5:** Sample the product.

**NOTE:** If monitoring vapors or gases, pH paper should be wetted.



**Step 6:** Compare results to pH paper color scale to determine if the product is an acid, a base, or neutral. Record results.



**NOTE:** Confirmation of a corrosive atmosphere will eliminate the use of electronic meters for further testing.

- Step 7:** Report results according to AHJ's procedures.
- Step 8:** Dispose of pH papers in accordance with appropriate regulations.
- Step 9:** Decontaminate equipment and return to operational state per manufacturer's instructions.
- Step 10:** Complete required reports and supporting documentation.

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**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.



**Step 2:** Ensure that all responders are wearing appropriate PPE.

**Step 3:** Inspect the test paper to ensure it has not been exposed or expired.

**Step 4:** Remove a piece of appropriate size reagent test paper.



**Step 5:** Sample the product.

**NOTE:** Reagent test paper should be wetted per manufacturer's recommendations.



**Step 6:** Identify any color changes to the reagent test paper and compare them with the provided reference.



**Step 7:** Report results according to AHJ's procedures.

**Step 8:** Dispose of reagent test paper in accordance with appropriate regulations.

**Step 9:** Decontaminate equipment and return to operational status per manufacturer's instructions.

**Step 10:** Complete required reports and supporting documentation.

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**NOTE:** Specific procedures will vary depending on the equipment used. Refer to the manufacturer's instructions for complete directions.

**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.



**Step 2:** Ensure that all responders are wearing appropriate PPE.

**Step 3:** Select the appropriate monitor for the potential hazard(s).

**Step 4:** Perform initial inspection to ensure device is serviceable.

**Step 5:** Ensure that the monitor has been maintained and appropriately calibrated according to AHJ's SOPs and manufacturer's instructions.



**Step 6:** Turn on the meter and test detector against check source.

**Step 7:** Acquire background radiation levels.



**Step 8:** Properly monitor the area per AHJ's requirements.

**Step 9:** Determine the presence of ionizing radiation.



**Step 10:** Compare radiation values to AHJ's SOPs. Record results.

**Step 11:** Report results according to AHJ's requirements.

**Step 12:** When monitoring is complete, turn off the instrument.

**Step 13:** Decontaminate equipment and return to operational state per manufacturer's instructions.

**Step 14:** Complete required reports and supporting documentation.

**WARNING:** If this skill involves the use of actual hazardous material samples, hazardous materials can cause serious injury or fatality. Appropriate personal protective equipment (PPE) must be worn and safety precautions must be followed. The following skill sheet demonstrates general steps; specific hazmat incidents may differ in procedure. Always follow the AHJ's procedures for specific incidents.

**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.



**Step 2:** Ensure that all responders are wearing appropriate PPE.



**Step 3:** Perform initial inspection to ensure device is serviceable.

**Step 4:** Ensure the dosimeter is properly calibrated.

**NOTE:** The dosimeter should be logged to you.

**Step 5:** Ensure the dosimeter reads zero.

**Step 6:** Don the dosimeter per manufacturer's instructions.



**Step 7:** Perform mission activity.



**Step 8:** Doff the dosimeter.

**Step 9:** Follow manufacturer's instructions and AHJ's procedures regarding dosimeter analysis.

**Step 10:** Report results per AHJ's procedures.

**Step 11:** Decontaminate equipment and return to operational state per manufacturer's instructions.

**Step 12:** Complete required reports and supporting documentation.

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**NOTE:** Specific procedures will vary depending on the equipment used. Refer to the manufacturer's instructions for complete directions.

**Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.

**Step 2:** Ensure that all responders are wearing appropriate PPE.

**Step 3:** Perform initial inspection to ensure device is serviceable.



**Step 4:** Perform a "fresh air" calibration.



**Step 5:** Operate the device per manufacturer's instructions and AHJ's procedures.

**Step 6:** Properly monitor the area per AHJ's requirements.



**Step 7:** Identify correction factors and apply them as necessary.

**Step 8:** Report results per AHJ's requirements.



**Step 9:** When monitoring is complete, turn off the device.

**Step 10:** Decontaminate equipment and return to operational state per manufacturer's instructions.

**Step 11:** Complete required reports and supporting documentation.

**WARNING:** If this skill involves the use of actual hazardous material samples, hazardous materials can cause serious injury or fatality. Appropriate personal protective equipment (PPE) must be worn and safety precautions must be followed. The following skill sheet demonstrates general steps; specific hazmat incidents may differ in procedure. Always follow the AHJ's procedures for specific incidents.

- Step 1:** Ensure proper detection, monitoring, or sampling method and equipment is chosen.
- Step 2:** Ensure that all responders are wearing appropriate PPE.
- Step 3:** Perform initial inspection to ensure device is serviceable.



- Step 4:** Insert appropriate batteries and turn on the thermal detector. Select Celsius or Fahrenheit if applicable.
- Step 5:** Standing as close as safely possible, use the aiming laser to assess the target from the lowest point on the target and scan up slowly and methodically.



- Step 6:** Record results.
- Step 7:** When monitoring is complete, turn off the device.
- Step 8:** Decontaminate equipment and return to operational state per manufacturer's instructions.
- Step 9:** Return to proper storage per manufacturer's instructions.
- Step 10:** Complete required reports and supporting documentation.