University of Wyoming | Extension

Category 909

Soil and Non-soil Fumigation for Commercial Applicators

Adapted from Pesticide Educational Resource Collaborative (PERC), September 2021
by Jeff Edwards, University of Wyoming Extension, March 2024

PERC
Pesticide Educational Resources Collaborative

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Contributors

Pesticide Educational Resources Collaborative (PERC) Director, Suzanne Forsyth, University of California Davis Extension Deputy Director, Kaci Buhl, Oregon State University
Project Officers, Matt Lloyd & Stephanie Burkhardt, U.S. EPA, Office of Pesticide Programs
PERC Primary Authors
Project Lead, Sandra McDonald, Mountain West Pesticide Education & Safety Training Lead Writer, Steve Tomasko, University of Wisconsin-Madison

Adapted and reviewed by Jeff Edwards, UW Extension.

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Dan Wixted, Cornell University
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Derrick Lastinger, Georgia Department of Agriculture
Dale Dubberly, Ensystex
Ed Crow, Pennsylvania State University
Erin Smilanich, State of Minnesota Department of Agriculture Garnet Cooke, State of Oregon–Oregon OSHA
Jeremy Jackson, UPL
Jim Fredricks, National Pest Management Association
Leslie Talpasanu, California Department of Pesticide Regulation Linda Johns, University of Minnesota
Michael Murray, Wisconsin Department of Agriculture, Trade and Consumer Protection Mickey Taylor, The University of Georgia
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Introduction

Purpose of This Manual

The purpose of this training manual is to provide study material for people interested in becoming a certified pesticide applicator in Category 909 Soil and Non-soil Fumigation for Commercial Applicators, specifically for the use of fumigants to control prairie dogs and stored grain pests. It covers the basic knowledge and skills required to apply non-soil fumigants safely, effectively, and correctly. The EPA has defined these uses as non-soil fumigation (NSF). Even though rodent burrows are in the soil, the term "soil fumigation" is reserved for broad applications to agricultural fields.

Information in this manual is supplemental to the basic pesticide law and safety information provided in the Wyoming Core Manual. The aim of both core and specific use manuals are to help people learn to handle pesticides correctly so they protect themselves, coworkers, the public, and the environment from adverse effects of pesticides. This manual is a study guide to prepare you for the closed book exam so that you can purchase and apply fumigant products. Always read and follow the pesticide product label, which is a legally binding document. This manual focuses on the safe and proper use of pesticides by people who have determined that fumigants are the necessary control tactic.

This manual does not:

- Contain product-specific directions for use.
- Advocate pesticide use over other means of pest management.

Preparation for Your Exam

If you are preparing to take the Wyoming Commercial Pesticide Applicator Exam for category 909, review this manual several times. Please read and study to the learning objectives in each section.

Exam questions are derived from the text of this manual and may come from any section, including the glossary.

Note:

- Exams are proctored by the Wyoming Department of Agriculture and local county UW Extension office personnel. You must call and make an appointment to take the exam(s).
- It is recommended you bring a basic hand-held calculator and a pencil.
- Cell phones and other communication devices are prohibited—you will be failed if you use your cell phone during the exam.
- Exams are closed book. You will not be allowed to refer to any notes, manuals, or other unauthorized training materials during the exam.
- You must pass with a 70% or better to be issued a license.
- Words in italics are defined in the text and glossary and may be included on the exam.

CHAPTER 1

Fumigant Basics

LEARNING OBJECTIVES

- ☑ **Explain what a fumigant is and what makes fumigants different from other pesticides.**
- ☑ **Explain how fumigants change from a liquid or a solid into a gas.**
- ☑ **Outline the chemical characteristics of fumigants.**
- ☑ **Describe and explain the factors that affect movement of fumigants through an application site.**
- ☑ **List the common fumigants used for non-soil fumigation.**
- ☑ **Describe characteristics of those common fumigants.**
- ☑ **Discuss the importance of proper pest identification.**
- ☑ **Explain which pest factors determine if the target pest can be controlled with fumigation.**
- ☑ **Explain the importance of choosing the proper application rate and timing of application.**

Fumigants Are Gases

Fumigants, by their chemical nature, are *volatile*, meaning they readily turn into a *gas*. Gas is also called vapor. It is this characteristic that makes fumigants so useful in certain situations. Fumigants in gas/vapor form are *toxic* when *absorbed* or inhaled.

Aerosols are often referred to as smoke, fog, or mist, but they are not gases or vapor. Aerosols are particulate suspensions in air. It is important to make this distinction because it emphasizes one of the most distinctive properties of fumigants—as a gas, fumigants spread out through the space they are applied as separate *molecules*.

Even though a very fine particulate mist droplet or smoke particle seems quite small, they are still massively larger than the individual gas molecules of a fumigant (Figure 1).

Volatile and Related Words

Volatile: A substance that readily changes from a liquid, or a solid, into the gas phase.

Volatility: A measure of how easily a substance turns into a gas.

Volatilization: The process or act of changing from a liquid or solid to a gas.

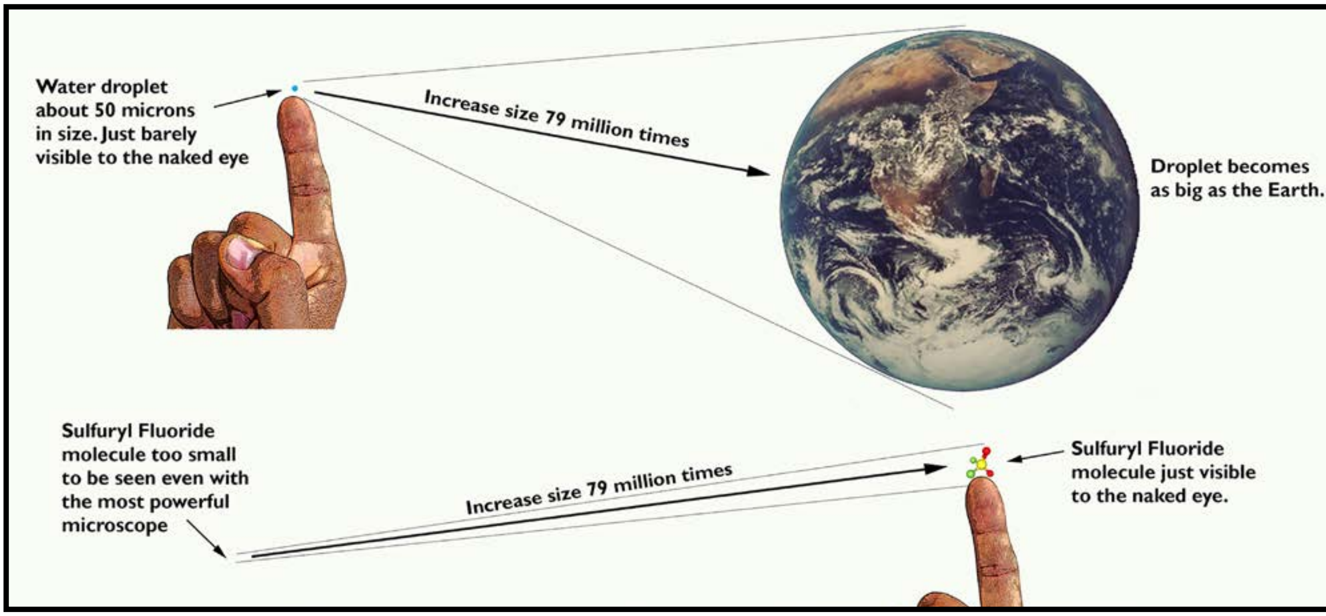


Figure 1: The graphic above attempts to illustrate how small individual molecules can be (in this case, of the fumigant sulfuryl fluoride). If we take a very small spray droplet of 50 microns in size (actually smaller than a period at the end of this sentence), and enlarged it 79 million times, it would be about the size of the earth. If we did the same with a molecule of sulfuryl fluoride, it would be barely visible to the naked eye. This shows how small fumigant molecules can be, even when compared to a water droplet we would consider to be a "mist." (Illustration © UW-Madison Pesticide Applicator Training Program).(Illustration © UW-Madison Pesticide Applicator Training Program).

Although fumigants are gases when in use, they may be packaged in another form. Fumigants can be purchased in the following forms.

- **Gases:** Carbon dioxide (CO2) kept under pressure as a gas in cylinders is used to treat commodities in storage and containment structures and for outdoor burrowing pest control.

- **Liquefied gases:** These are kept under pressure in cylinders as a liquid. They change from a liquid to a gas when released. Methyl bromide and sulfuryl fluoride are typically packaged this way. Some phosphine, and mixtures of phosphine and carbon dioxide (CO2), also come in pressurized cylinders.

- **Volatile liquids:** Some fumigants, such as chloropicrin, are liquid at normal temperatures but they volatilize (turn into gas) when exposed to air. You cannot use chloropicrin as a stand-alone fumigant for non-soil fumigations. Because of its strong odor, it is sometimes used with other fumigants as a *warning agent*.

- **Solids:** Some fumigants, such as aluminum or magnesium phosphide, are packaged as solid pellets or tablets and volatilize when exposed to moisture in the air.

How Fumigants Kill

Fumigants are non-selective pesticides and kill a wide variety of organisms, including insects, fungi, nematodes, and rodents. They also can kill non-target organisms, including people. Some fumigants kill by interfering with an organism's respiration. Other fumigants enter tissues and disrupt the metabolism or other essential processes of animal or plant cells.

The killing action of a fumigant is influenced by its *concentration* in the atmosphere, the length of time it stays in the air, the temperature and humidity, and other factors at the time of fumigation. Because they are active as a gas, fumigants have dissipated soon after fumigation process is complete. Therefore, unlike some other types of pesticides, **there is no residual** and they **do not** provide any post-application protection from pests.

Advantages and Disadvantages of Fumigants

Fumigation is a highly technical operation that requires equipment, techniques, and skills not generally used for applying other types of pesticides.

Advantages of using fumigants over other pesticides include:

- fumigants are highly toxic to almost all pests (Viruses an exception?)
- Fumigants will usually reach pests where you cannot apply sprays, powders, or dusts.
- Some fumigants can be used to kill pests in or near food, leaving no harmful residues while other fumigants and pesticides can contaminate food.
- For certain commodities, fumigation is the only practical way to control pests.

Disadvantages of fumigants:

- Fumigants are highly toxic to people.
- Fumigants have no residual pest control action. Once the application site is cleared of fumigant, control ceases.
- Applicators need special (and often expensive) protective equipment, such as self-contained breathing apparatus (SCBA), gas leak detectors, and more.
- Applicators of fumigants require more technical skill.
- Fumigants must be retained in the gas form for the proper length of time to be effective, often requiring extra supervision.

Physical and Chemical Characteristics of Fumigants

To understand how fumigants work, you need to understand certain physical and chemical characteristics of fumigant molecules. These characteristics determine how quickly a gas will spread to fill a space, how the gas might damage certain objects in the fumigation space, and more. Some of these attributes include:

- *Molecular weight* and *specific gravity*,
- *Volatility* and *vapor pressure*,
- *Boiling point*,
- *Solubility*,
- *Flammability*, and
- *Chemical reactivity.*

These characteristics are different for each fumigant. Understanding how these factors affect application can help you select the best product for a particular job and, just as importantly, help you make a safe application.

Molecular Weight and Specific Gravity

Molecular weight is a measure of the weight of the atoms that form all substances. For example, table salt has a molecular weight of about 58 and table sugar has a molecular weight of about 342. More complex molecules have greater molecular weight because they have more atoms.

> **Molecular Weight Units**
>
> The units for molecular weight are given in grams per mole, abbreviated as g/mol. In the text, we simply give molecular weights as a plain number.

Specific Gravity

Specific gravity is the ratio of the density of a substance to the density of some other substance used as standard. For gases such as fumigants, we use air as the standard, giving it a specific gravity of 1. Fumigants with a specific gravity greater than 1 are heavier than air and can sink. Fumigants with a specific gravity less than 1 are lighter than air and can rise.

The molecular weight and specific gravity of a fumigant indicate how well it will distribute in a fumigation site. Most fumigants are heavier than air. For example, the specific gravity of phosphine is 1.17, which means it is 0.17 times heavier than air. When fumigants are heavier or lighter than air, the label will tell you if you need to use fans and/or other methods to evenly distribute the active ingredient during fumigation.

Volatility and Vapor Pressure

The terms "volatility" and "vapor pressure" are often used interchangeably. Although they are related, there is a subtle, but important, difference between the two. Volatility describes how easily a substance will turn into a gas or vaporize. The vapor pressure is an actual measurement of a physical property—how strongly a substance pushes against the atmosphere. If you place a chemical in a closed container, some of it will vaporize. The pressure in the space above the liquid increases from zero and eventually stabilizes at a constant value, which is its vapor pressure (Figure 2). Since vapor pressure determines the concentration that can be maintained during fumigation, materials of high vapor pressure will be more concentrated and therefore have better fumigant qualities.

Volatility and Temperature

Volatility increases as the temperature rises. Some fumigants, such as sulfuryl fluoride, exist as a gas at room temperature. Other fumigants are liquids or solids at room temperature (e.g., paradichlorobenzene and naphthalene, which are active ingredients used in moth balls and crystals). Some of the "solid" fumigants, such as aluminum and magnesium phosphide, are not fumigants themselves but react with moisture to form a fumigant gas (e.g., phosphine or hydrogen phosphide).

Pluses and Minuses of Fumigant Volatilization

The fact that fumigants move as individual molecules has both positive and negative consequences. On the plus side, fumigants can easily penetrate tiny spaces, diffusing into concrete, brick, and wood, or between the spaces of grains in a grain bin. This extends their reach into areas where pests might otherwise escape contact with non-fumigant pesticides. The particles that make up aerosols are much larger and are unable to penetrate even a short distance into materials.

On the negative side, the gaseous nature of fumigants can more easily cause harm beyond the treatment site. This is why it is so important to seal off treatment areas, monitor concentrations outside the area, post warning signs, and follow other safety precautions per the product label.

Boiling Point

The boiling point of a chemical is the temperature at which it becomes a gas. In general, the higher the boiling point, the lower the vapor pressure, and the slower a fumigant will change to a gas.

Some fumigants, such as methyl bromide, have low boiling points so they are gases at normal temperatures. These fumigants are usually stored as liquids under high pressure. Other fumigants have a high boiling point and are described as liquid or solid type fumigants depending on the way they are shipped and handled.

The boiling point of a fumigant can determine the type of application equipment you use. For example, to use fumigants with high boiling points you might need to wait for a warm day or increase the temperature with heaters within the treatment area (this will be noted on the label).

Solubility

Solubility is a measure of how readily a fumigant gas dissolves in certain materials such as water, oil, or other liquids. Highly soluble fumigants can dissolve in commodities that have high moisture or oil contents.

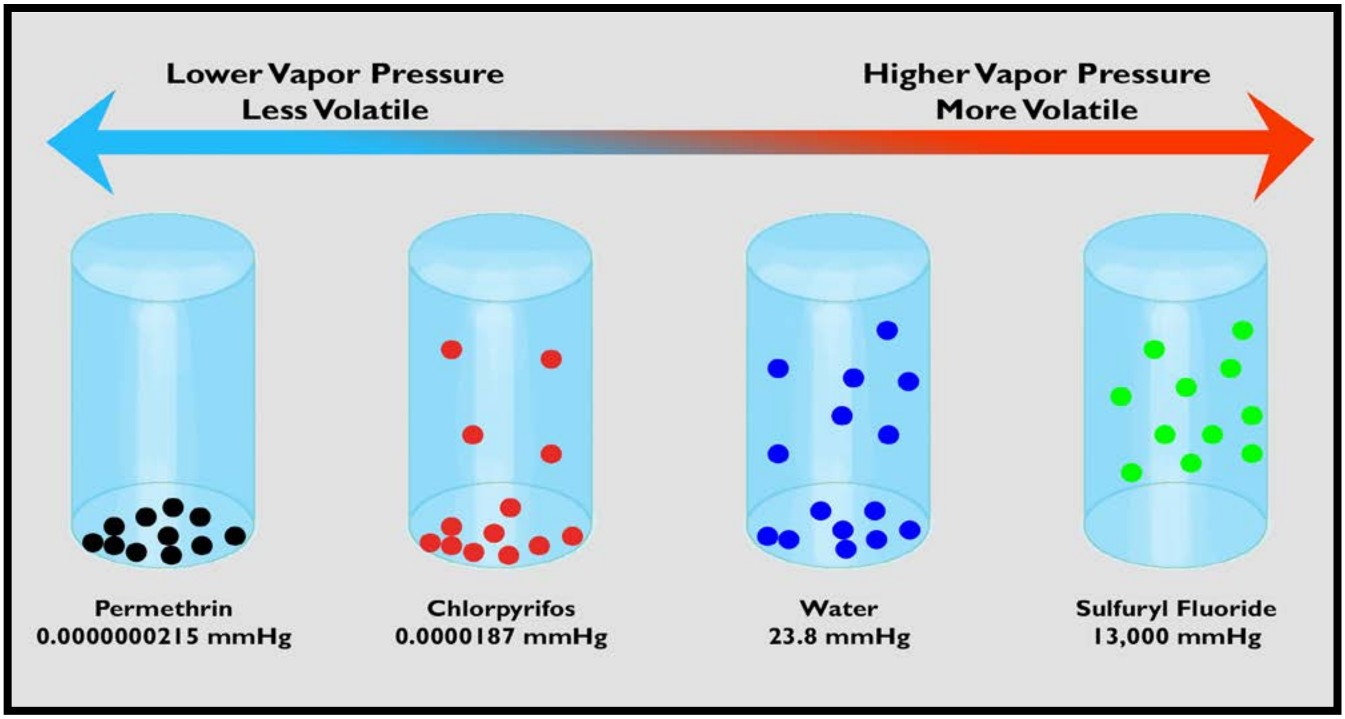


Figure 2: Vapor pressure can be measured in different units; in this case, they are given in millimeters of mercury (mmHg). The larger the number, the greater the pressure and the greater the tendency of the compound to turn into a vapor. The insecticide permethrin has low vapor pressure and barely volatilizes. However, the fumigant sulfuryl fluoride has a high vapor pressure and easily turns into a vapor. Vapor pressure is dependent on temperature. Generally, the higher the temperature, the greater the vapor pressure. (Illustration © UW-Madison Pesticide Applicator Training Program based on an illustration from the National Pesticide Information Center. npic.orst.edu). (Illustration © UW-Madison Pesticide Applicator Training Program based on an illustration from the National Pesticide Information Center. npic.orst.edu).

Some Chemical Characteristics of Commonly Used Non-soil Fumigants

Fumigant	Molecular Weight	Boiling Point (°F)	Specific Gravity	Flammability (in air)
Carbon Dioxide	44.01	-109.3	1.52	Nonflammable
Chloropicrin	164.29	233.6	5.67	Nonflammable
Metam Sodium	129.18	230.0	1.16	Flammable (as MITC)
Methyl Bromide	94.95	38.4	3.28	Nonflammable
Phosphine	34.00	-125.9	1.17	Flammable
Sulfuryl Fluoride	102.07	-68.0	3.52	Nonflammable

Flammability

Some fumigants, such as phosphine, are extremely flammable. When using highly flammable fumigants you need to carefully follow procedures designed to eliminate the probability of fires (this will be noted on the label).

Chemical Reactivity

Some fumigants react with other chemicals where they are released. For example, methyl bromide combines with sulfur-containing compounds (such as rubber, leather, and other animal products) and gives off a strong, foul odor that is hard to eliminate. **Phosphine gas reacts with copper (in electrical wiring, motors, and plumbing) to cause serious corrosion.** High temperatures around an open flame can cause some fumigants to form corrosive acids. Certain fumigants might make photographic film and paper unusable because of chemical reaction. The label will advise you of these potential reactivities.

Movement of Fumigant Through the Application Site

The movement of fumigant molecules released at the application site is determined by the chemical properties above and by *sorption*, discussed below. Once released,

Figure 3: Diffuse (verb): to cause a gas or liquid to spread through or into a surrounding substance by mixing with it. **Diffusion** (noun): a process by which there is a net flow of matter from a region of high concentration to a region of low concentration resulting from random motion of molecules. The pictures above demonstrate diffusion using food coloring and water. The same principle applies to a how a fumigant diffuses in air. (Illustration © UW-Madison Pesticide Applicator Training Program). (Illustration © UW-Madison Pesticide Applicator Training Program).

fumigant molecules spread in the space they are contained in (e.g., building, burrow, fumigation chamber, or tarped site) by natural *diffusion* through the air until they are evenly distributed (Figure 3). The speed that they move through air is directly related to their molecular weight. Heavier gases *diffuse* more slowly, and it may be important to help move these gases with fans or blowers. The rate that fumigants diffuse is also influenced by temperature: the warmer the temperature, the faster the diffusion.

Sorption

When a fumigant gas contacts materials, gas molecules undergo the process of *sorption*. There are two types of sorption: ***adsorption*** and ***absorption*** (Figure 4).

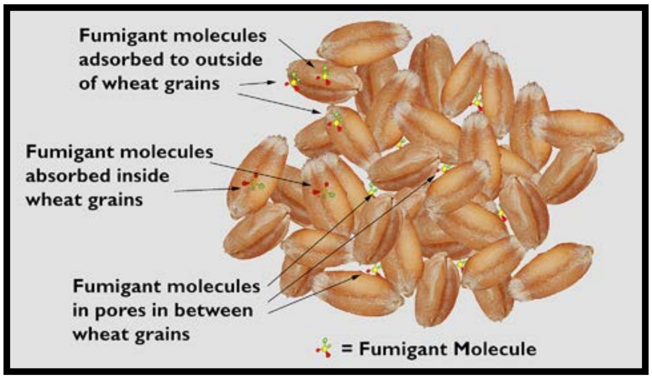


Figure 4: Both adsorption and absorption reduce the effectiveness of fumigants. These bits of fumigant are no longer able to move freely and kill the target pest(s). Sorption also slows aeration, which is the process of releasing the fumigant after treatment. (Illustration © UW-Madison Pesticide Applicator Training Program).

Adsorption occurs when fumigant molecules stick to the surface of something. That could be a treated material, such as grain, or the structure being fumigated.

Absorption occurs when the molecules penetrate some material (such as the treated product or the structure).

Desorption is the opposite process: It is the release of gas molecules from a material or surface to which the gas has attached itself.

Sorption Effects on Fumigation

Some fumigants are more subject to sorption than others. Commodities and the structures that house them also vary in their sorptive capacity. For example, loads of grain with many small pieces have a lot of surface area and are more sorptive. Inert surfaces such as metal are less sorptive (but porous concrete may be more so).

It is critical to know how sorptive certain surfaces and commodities are. When treatment is complete, *aeration* periods must be long enough to allow the fumigant to desorb from the commodity. If aeration is too short, traces of fumigant could remain on the product. This can cause toxic residues, off flavors, or odors in the treated material. As a rule, sorption is greater at cold temperatures.

Pest Factors That Influence Fumigation

Pest Identification

Proper pest identification is key to deciding which control method(s) to address a problem. Different pests respond to control methods in different ways and knowing your target can make the difference between good pest control and no control.

Pests Not Controlled with Fumigation

Fumigants tend to affect all forms of life. Almost any pest in an enclosed area can be killed if exposed to the right concentration of a fumigants. Fumigants might not be the best choice for every situation.

A fumigation will only kill the pests inside the treated area. If there is a pest problem outside the treated area, this pest population can quickly reinfest the treated area. To avoid this issue, make sure all available entry points are properly sealed so the pests cannot enter or re-enter.

Different life stages of the pest might also respond differently to fumigation. For example, many insects are relatively non-susceptible to fumigants or other insecticides during their egg and pupal stages. In periods of dormancy, insects are also less susceptible because their respiration is very slow, and they will not take in much fumigant.

Pest Density

High pest densities and/or targeting multiple pest species may require using higher fumigant application rates (although you should never apply higher than label rates).

Application Rate and Timing

The pest's biology can influence the effectiveness and timing of a fumigant application. Some biological factors include the:

- **Stage of growth:** Adult and immature insects are generally the easiest to kill. The eggs and pupae, depending upon the fumigant, are the most difficult life stages to kill.
- **Activity level:** Active immature and adult insects are easier to kill because they respire more, which means they take in more fumigant. Their higher metabolism also means they process the fumigant faster.
- **Size of the infestation:** Smaller infestations are easier to control. Large masses of pests may generate dust, damaged grain, webbing, and cast skins that interfere with fumigant penetration.

Pesticide Resistance

As with other pesticides, pests can develop resistance to fumigants. Once a population becomes resistant to normal rates of fumigants, they become hard or impossible to control with that fumigant. **In the U. S., phosphine resistance has been reported for red and confused flour beetles, the lesser grain borer, almond moth, cigarette beetle, Indian meal moth, rusty grain beetle, and, most recently, the sawtoothed grain beetle.**

The following practices can help reduce pesticide resistance.

- Use Integrated Pest Management. Combine all available control measures into a practical pest management program.
- Use fumigants only when necessary. If you use a fumigant when you don't need to, you may unnecessarily increase the proportion of individuals resistant to that fumigant.
- Rotate chemistry whenever possible.
- Make sure to use the proper dosage rate and exposure time as the label directs. Ineffective fumigations applied at very low concentrations can contribute to the development of resistance.

Fumigant Resistance Issues

Due to the following issues, fumigant resistance can be especially problematic.

- There are a limited number of fumigants to use for non-soil fumigations. This means that rotating chemistries for pest control is often not an option.
- Quarantine protocols might force the issue of using fumigants over other strategies.
- Even low numbers of pests can have major consequences when transported from one part of the world to another, making total eradication of pests in transit a high priority. In other areas of pesticide use, smaller populations of pests can be tolerated, which leads to less resistance because susceptible populations are left intact.
- In a grain bin, on a cargo ship, or any other place where a resident population of insects is treated repeatedly with the same fumigant, resistance might develop.

When a Fumigation Goes Wrong

Real-world Examples

What Happened

An unlicensed seed warehouse applicator placed Fumitoxin (aluminum phosphide) pellets inside cloth sacks to fumigate seed. Afterward, the applicator put the sacks, with partially spent pellets, into the garbage. After the garbage was picked up, the garbage truck driver discovered his load was on fire, so he returned to the yard and dumped the load on the cement and contacted the fire department. The fire department arrived, and applied water, which made things worse. They discovered the source of the reactivity: the cloth sacks that popped and smoked when water hit them. Squatting alongside the sacks, without wearing SCBAs, they pondered what might be inside. It wasn't until a sheriff's deputy retraced the route of the driver that the material was determined to be Fumitoxin.

What Should Have Happened

The seed company should have created a fumigation management plan and had a licensed applicator make the application; when the fumigation was complete, the partially spent product should have been properly deactivated as per directions in the applicator's manual. The seed company should also have notified the local fire department.

How It Could Have Been Avoided

Following the label and applicator's manual and having a trained and certified applicator.

The Consequences

Eleven individuals sought medical treatment. The seed company and the applicator were cited by the Washington State Department of Agriculture.

CHAPTER 2

Fumigant Labels and Fumigant Handling

LEARNING OBJECTIVES

- ☑ **Describe the main purpose of a pesticide label and its legal implications for an applicator.**
- ☑ **Define the terms "label" and "labeling."**
- ☑ **Describe fumigant-specific information found on the label.**
- ☑ **Outline the procedures for transporting fumigants.**
- ☑ **Outline the characteristics of proper fumigant storage. Describe how to respond to fumigant spills, leaks, exposure, or accidents.**
- ☑ **Explain how to safely dispose of leftover fumigant and fumigant containers.**

Labeling and Labels

The pesticide label is the main method of communication between pesticide manufacturers and pesticide users. Manufacturers are required by law to put certain information on the label. To use the product safely and effectively, you must read, understand, and follow all the information on the label.

The label is the law. The label (and any supplemental labeling referred to on the label) is a legally binding document. That means that you must follow label directions explicitly.

Labeling

Labeling might include information that accompanies the product in the form of a comprehensive applicator manual, brochures, leaflets, and more. Fumigants almost always have separate, comprehensive *applicator manuals* that you must follow to use the product safely and legally (Figure 1). **ALL information, whether on the label attached to the product or that the label refers you to, is legally binding.** In this manual, when we refer to "the label," we mean any information on the attached label or any other information (i.e., applicator's manual) the label refers to.

RESTRICTED USE PESTICIDE
DUE TO HIGH ACUTE INHALATION TOXICITY OF PHOSPHINE GAS
For retail sale to Dealers and Certified Applicators only.
For use by Certified Applicators or persons under their direct supervision, and only for those uses covered by the Certified Applicator's certification. Refer to the directions in the application manual for requirements of the physical presence of a Certified Applicator.

THE COMPLETE LABEL FOR THIS PRODUCT CONSISTS OF THE CONTAINER LABEL AND APPLICATOR'S MANUAL WHICH MUST ACCOMPANY THE PRODUCT. READ AND UNDERSTAND THE ENTIRE CONTAINER LABEL AND APPLICATOR'S MANUAL. REFER TO THE APPLICATION MANUAL FOR DIRECTIONS FOR USE, PRECAUTIONS AND RESTRICTIONS.

A FUMIGANT MANAGEMENT PLAN MUST BE WRITTEN FOR ALL FUMIGATIONS PRIOR TO ACTUAL TREATMENT.

CONSULT WITH YOUR STATE LEAD REGULATORY AGENCY TO DETERMINE REGULATORY STATUS, REQUIREMENTS, AND RESTRICTIONS FOR FUMIGATION USE IN THAT STATE.

VAPORPH$_3$OS® Phosphine Fumigant

Pure phosphine gas for on-site blending with registered or food grade carbon dioxide or forced air to produce a non-flammable fumigant gas for use in controlling pests in enclosed empty spaces and enclosed space (including temperature-controlled spaces such as cold storage chambers, transport containers and other suitable fumigation spaces) containing listed raw agricultural commodities, processed foods, stored tobacco, animal feeds, and nonfood products. Not for use on barges. Not for burrow treatment. For details refer to the VAPORPH$_3$OS® Phosphine Fumigant Application Manual.

Figure 1: Above is an example of a fumigant label referring users to the product's applicator manual. This is a separate document the user must read before using the product. Both the label and applicator manual are legally binding documents. **NOTE:** References to, or images from, specific products in this manual are used **ONLY** for explanatory purposes and are not an endorsement of any product over another.

Information on Labels

Fumigant labels contain the usual identification, safety, and other information you need to use the product correctly and safely.

Fumigant Label Information

- **Restricted Use Information:** Most fumigants are classified as *restricted-use pesticides* (RUPs). The restricted-use statement will always be found at the top of the first page of the label. **Only certified applicators may purchase and apply RUPs.**
- **Site information:** Make sure the site you wish to fumigate is listed on the product label. For example, some products may only be used in non-residential structures so you could not use those fumigants in an apartment building.
- **First Aid:** All pesticides have first-aid information on their labels, and you should always familiarize yourself with that information before using the product. Fumigants, by their nature, often have very specific first aid information.
- **Personal Protective Equipment (PPE):** Many fumigants have very specific PPE requirements, especially when it comes to respirator use. Some of the respirator requirements will depend upon what action you are performing, such as releasing the gas or checking air concentrations. Other PPE directions are also product specific.
- **Physical and Chemical Hazards:** Many fumigants have specific temperature requirements for storage and/or use. Some can react with certain materials and damage them. Others are highly flammable, and all sources of flame or sparks (e.g., pilot lights, heating elements) must be turned off before fumigation.
- **Environmental Hazards:** Some fumigant labels might state that the product is toxic to wildlife and that non- target organisms exposed to it will be killed.
- **Container Handling:** Fumigants come in many different containers and have different temperature requirements for storage. Be extremely cautious when transporting and opening pressurized containers. Labels also specify how to dispose of containers. Some can be returned to the dealer for refilling, while others are non-returnable and need to be rinsed and/or punctured before disposal in a sanitary landfill.
- **Monitoring:** Depending on the fumigant, you might have to monitor the air concentrations for the chemical during the application. You also might need to monitor outside the application area to check for leaks. The label will specify specific monitoring equipment to use (Figure 2).
- **Aeration:** Aeration procedures, implemented when the fumigation is complete, vary depending upon the type of fumigant and site of application. The label will specify proper aeration protocols.
- **Pest Factors:** Labels specify dosages and exposure times needed for different pest species of pests and life stages. Be sure to check if there are any minimum temperatures or exposure times associated with a particular life stage.
- **Number of Applicators:** Many labels will specify that more than one trained and certified applicator must be present during certain stages of the application. Some labels require that anyone working with the product must be certified in non-soil fumigation.

Transporting Fumigants

All fumigants are classified as hazardous materials by the U.S. Department of Transportation (DOT) and are subject to extensive transport regulations. When transporting such materials you may need to:

- Receive hazardous material training;
- Carry emergency response information in your vehicle;
- Carry shipping papers in your vehicle;
- Placard your vehicle;
- Or have a Commercial Driver's License (CDL).

You also should have vehicle safety kits and inspection and maintenance logs. Refer to both federal and state DOT

Only a detection device of sufficient sensitivity (LOD ≤1 ppm), such as the INTERSCAN gas analyzer [Model GF 1900] or MIRAN vapor analyzer [SapphIRe], can be used to confirm a concentration of ProFume of 1 ppm or less. The Interscan gas analyzer GF 1900 must be calibrated within one month prior to use as a detection device. All other approved detection devices must be calibrated according to manufacturer recommendations. The concentration of ProFume must be monitored throughout the structure in the breathing zone. The structure or enclosure must remain posted for fumigation until cleared for reentry.

Figure 2: Above is an example of a fumigant label specifying what monitoring equipment to use. It is extremely important to use the correct equipment since precise measuring is essential for both effective treatment and the health and safety of applicators and the public.

Figure 3: An example of possible placards that may need to go on the outside of your vehicle when transporting certain pesticides.

Figure 4: (Left) It is extremely important to secure fumigants so they will not move or get damaged during transport. Note that these cylinders are held fast with multiple ratchet straps. (Center) Always make sure the safety bonnets are screwed on over the valves except when in use. Fumigant cylinders may also come with covers over the outlet valves that also need to be in place until use. A valve cover is shown on the right. Photo and illustration credits: (left) © Garo Goodrow, Penn State; (center) diagram of cylinder based on © photos from Garo Goodrow, Penn State; (right) © Dale Dubberly.

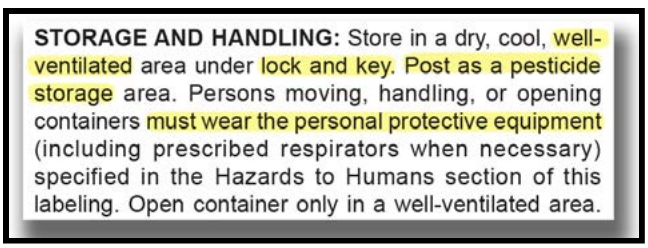

STORAGE AND HANDLING: Store in a dry, cool, well-ventilated area under lock and key. Post as a pesticide storage area. Persons moving, handling, or opening containers must wear the personal protective equipment (including prescribed respirators when necessary) specified in the Hazards to Humans section of this labeling. Open container only in a well-ventilated area.

Figure 5: Above is a snippet from a methyl bromide product label showing some of the specific storage requirements for that product.

regulations to determine the placarding requirements for transporting each fumigant. Contact the fumigant manufacturer or distributor for more information on placarding for transportation (Figure 3).

Always refer to the transportation instructions on the label.

Other Precautions

When transporting fumigants, take the following precautions:

- Always transport fumigants in a separate air space from vehicle occupants.
- Secure fumigant gas cylinders or other containers so they do not move during transport (Figure 4).
- Be sure you have the required driver's license with any appropriate endorsements for the specific fumigant you plan to transport.
- Transport pressurized cylinders with the valve cover and safety bonnet attached.
- Do not remove protective valve covers until just before use.
- Always follow federal and state DOT regulations when transporting fumigants and/or their containers.

Storage of Fumigants

Many businesses store pesticides in existing buildings that have other uses. However, a separate building that is well-ventilated and/or has a mechanical exhaust system is best, especially for fumigants. Make sure you can properly heat and cool the storage facility to ensure the temperature requirements listed on the labels are met. Also, check the label to make sure there are no potential problems storing fumigants where pilot lights or other heating elements are present.

You must protect and secure (i.e., lock) the storage area to keep out unauthorized people (especially children) and animals. Some labels might require fumigants to be locked away when not in use. In addition to any label requirements, be sure to check with appropriate officials to ensure you are meeting any state, county, or local requirements for fumigant storage.

Placards and Warning Signs

Make sure you properly placard all fumigant storage areas. The label and/or Safety Data Sheets (SDS) will specify what must be on the placards. National Fire Protection Association (NFPA) placards act as an immediate warning system for emergency service personnel, helping them identify the kinds of material present and the dangers they pose (Figures 5 and 6).

Benefits of Proper Storage

Storing pesticides poses hazards because many pesticide concentrates are kept together in a small area. A well-designed pesticide storage area

- Limits access;
- Allows for better inventory control;
- Protects people from exposure;
- Reduces the chance of environmental contamination;
- Prevents damage to pesticides from temperature extremes and excess moisture;
- Safeguards pesticides from theft, vandalism, and unauthorized use;
- And allows fire departments to easily identify products.

Inspect Valves and Containers

Fumigants can escape their containers through faulty, damaged, or corroded valves or containers. Leaks can cause dangerous fumigant concentrations to build up in closed areas. You should routinely check valves and containers for leaks using gas detection equipment. Before entering any storage area, run an exhaust fan to remove vapors that may have built up inside.

Other Storage Precautions

- Store cylinders secured in place (to prevent from falling over) with safety caps and protective bonnets securely in place.
- Wear any label-required eye protection when handling pressurized equipment.
- Always store fumigants (and other pesticides) in areas separate from food and feed.
- Never put fumigants in other containers.
- Keep metal fumigant containers off the ground to reduce moisture exposure, which can lead to rusting and leakage.
- Keep an updated and accurate inventory of all fumigants in storage.

Spills and Leaks

Fumigant labeling and SDS's will provide you with instructions on how to respond to pesticide spills, leaks, and fires. For example, the label will tell you:

- When you need to wear a respirator,
- Whether the material can be salvaged, and
- What actions to take to minimize the risks to others.

If a leak occurs, evacuate the immediate area. **Always** put on appropriate PPE before attempting to move the leaking or damaged container outdoors or to an isolated area. Be familiar with and follow label instructions for handling leaks.

Emergency Response Plans

Fumigant labels, often under the Fumigant Management Plan (FMP) section, **will direct you to prepare a written Emergency Response Plan**. This plan usually contains explicit instructions for dealing with a spill or other emergency. It also lists contact information for people and local authorities who must be notified if fumigant levels reach concentrations that could be dangerous to bystanders and/or domestic animals. FMPs are covered in more detail in Chapter 4, "Fumigant Safety."

Safe Disposal of Leftover Fumigant

All labels state that "Improper disposal of excess pesticide is a violation of Federal Law." You can contact your state pesticide or environmental control agency or hazardous waste specialist at the nearest EPA Regional Office for guidance on proper disposal.

The process for disposing of leftover fumigant is specific to the fumigant and the type of packaging it came in.

Solid Phosphide Products

Leftover phosphide products call for different handling procedures than completely spent residue. When properly exposed, the dust remaining after fumigation using aluminum or magnesium phosphides is a grayish-white powder. This residue is non-hazardous waste. However, residual dust from incompletely exposed products (green dust) must be deactivated before disposal. Deactivation

Figure 6: The photos above show the outside and inside of a fumigant storage locker located next to grain silos where they will be used. You must secure pesticides storage areas for any pesticide, but it's especially important for fumigants because of their high toxicity. Proper warning signs and placards are important and often prescribed by the label **and** sometimes by state regulations. Make sure you are following all guide- lines. Photo credits: © J. Ples Spradley, pesticidepics.org at Virginia Tech.

procedures may vary depending on the product formulation (e.g., pellets, tablets, or gas bags). Be certain to read the label on how to deactivate products.

Never store spent residual phosphide dust in a confined space or closed container. Confining, collecting, or storing large quantities of dust may result in a fire hazard.

Management of Empty Containers

Aluminum Flasks

In general, aluminum flasks that contained phosphides are nonrefillable containers; however, make sure to follow all label instructions. **Do not** reuse or refill aluminum flasks for any purpose.

Some labels will direct you to triple rinse empty flasks and stoppers with water. Afterward, they may then be recycled or reconditioned or punctured and disposed of in a sanitary landfill.

Some labels may instruct you to remove lids and expose empty flasks to atmospheric conditions until residue in the flasks is reacted. In this case, puncture and dispose of in a sanitary landfill or other approved site, or by other procedures approved by state and local authorities.

You **cannot** recycle pesticide containers of any material (aluminum, paper, or plastic) with household recycling, even if they are triple rinsed.

When a Fumigation Goes Wrong

Real-world Examples

What Happened

A farmer found an old box of phosphine canisters in a storage room in his barn. He moved them outside, along with other things he was discarding. He planned to load his truck and take it to the dump later in the week, but it rained before he was able to do so. It turned out the phosphine canisters were not well sealed (probably due to age), and the rain activated the tablets. He had beehives nearby and all of the bees died. Luckily no livestock or people were in or near the barn.

What Should Have Happened

The farmer should have read the labels or called the manufacturer to find out about proper disposal of the phosphine canisters.

How It Could Have Been Avoided

Reading the pesticide label to get information on proper disposal along with awareness of the fact that fumigants cannot be disposed of like other trash.

What Was the Consequence

Bees in the farmer's beehives died. The consequences could have been worse if people and/or livestock were also impacted.

Planning for a Fumigation

LEARNING OBJECTIVES

- ☑ **Describe factors to consider when selecting an application method to use for a particular site.**
- ☑ **Explain the importance and outline the process of inspecting the application site prior to fumigation.**
- ☑ **List and explain how certain site characteristics and environmental factors can impact a fumigation.**
- ☑ **Explain why label statements may limit applications when conditions are unfavorable.**
- ☑ **Outline how to calculate the amount of product required for a treatment area.**
- ☑ **Describe how to determine area and volume of a structure to be fumigated.**
- ☑ **Explain the importance of sealing a fumigation site.**
- ☑ **List the methods used to seal an area for fumigation.**
- ☑ **List the two main reasons for air monitoring of fumigant levels.**
- ☑ **Explain when, where, and how to take air samples.**
- ☑ **Discuss why proper calibration of your monitoring equipment is important.**
- ☑ **Compare and contrast equipment you might use to monitor site fumigant levels.**
- ☑ **Explain when and how to notify authorities about a fumigation.**

All methods of non-soil fumigation have one factor in common—the need to contain an adequate concentration of fumigant for the time necessary to kill pests.

Premise Inspection

A pre-fumigation inspection is an important step in the fumigation process and is usually required by the Fumigation Management Plan (see Chapter 4, "Fumigation Safety"). A site inspection can help determine which chemical you will use and how you will use it, as well as assess and plan for safety concerns.

Site Characteristics and Environmental Condition Effects on Fumigation

To ensure that fumigation is both safe and effective, make sure to consider the following factors.

Type of Structure

Pay attention to the type of structure, what it's made of, and how airtight it is (or how airtight it can be made). Wooden structures, even when tightly constructed and well sealed, do not retain fumigant as readily as steel, masonry, or concrete structures. In general, concrete usually retains fumigant better than other types of structures, and round steel bins retain fumigant better than flat grain storages.

Temperature

Temperature at the treatment site affects both the fumigant itself and the target pest.

- **Temperature Effects on Fumigation:** Higher temperatures affect the release rate of the fumigant and speed of penetration. As temperature increases, the volatility of the fumigant increases so that it is released more rapidly and disperses and penetrates more quickly than at lower temperatures. Also, both the *dosage* and exposure time vary with temperature differences. Temperature differences can cause a fumigant to stratify. *Stratification* occurs when the air and fumigant form layers and do not mix. In general, if the temperature of a fumigant is significantly lower than air, stratification becomes more severe.

- **Temperature Effects on Target Insects:** In general, insects are more difficult to control at lower temperatures. At temperatures below 50°F, many stored commodity insects exhibit little or no activity—they are essentially dormant. Because insects breathe at a very minimal rate in these conditions, they may not take in enough fumigant to kill them—or would require an exposure time longer than that allowed by the label. In general, insect activity (respiration, feeding, and growth) is more rapid as the temperature increases (up to a certain point, which varies by species). Preferred fumigation temperatures usually range between 50°F and 95°F. Although many label requirements state a minimum of 40°F to fumigate, fumigating at temperatures of 60°F or higher is generally more effective. Increasing the temperature increases the *metabolism* of all insect life stages, causing them to take in more fumigant, and requiring less fumigant (or less time) to provide effective control. Consult the fumigant label for its optimum temperature and acceptable temperature range.

Note that there are usually no low temperature restrictions for rodents, since they are warm blooded and their respiration does not change with temperature.

Humidity

Adequate moisture is required for the generation of some fumigants, including phosphine. If the air is too dry or the moisture content of the commodity is too low, these fumigants will stay in solid form.

On the other hand, as the moisture content of a commodity increases, it becomes more difficult for a fumigant to penetrate. This makes fumigants less effective on insects and can increase the potential for residues that exceed legal tolerances.

Sorption

The sorptive quality (either adsorption or absorption) of the treated commodity and/or the structure can affect how long it takes a fumigant to reach the desired concentration for effective pest control. Sorption also affects how long the aeration process takes.

Air Movement

Do not fumigate on a windy day. Winds can result in considerable loss of fumigant even in a well-sealed structure. For example, winds around a grain storage structure create pressure gradients across the grain surface, which can cause rapid loss of fumigant.

Some air movement is essential for effective fumigation. The gas must spread evenly and quickly throughout the commodity or space being treated. It must enter small crevices, cracks, or spaces so that a lethal concentration contacts every pest. Fumigants spread faster when their initial concentration is high, and the penetration distance is short. Fans are useful and may be necessary to uniformly distribute fumigant so that it reaches all target pests or to ensure penetration into bulk commodities.

Note that the product label and applicator's manual may prohibit use of the fumigant when some of the factors discussed are unfavorable. Unfavorable conditions could cause failure of the fumigation to control the pest, and/or cause exposure of non-target animals, people, or the environment to the fumigant.

As always, follow label directions.

Calculating Fumigant Dosage

Phosphine differs from most fumigation models because the relationship of dosage and toxicity to insects is not linear. Phosphine is most effective over longer exposure times of 1 day or longer. In general, longer exposures to phosphine, even at low concentrations, result in better efficacy than shorter exposures at higher concentrations.

Some manufacturers supply special calculators or computer-based programs to determine dosage. **Never exceed the highest dosage on the label.**

Calculating Area and Volume

Note that the following abbreviations are used in the this section.

ft = feet	ft^2 = square feet	ft^3 = cubic feet
l = length	w = width	h = height
r = radius	r^2 = radius squared (or r × r)	

The recommended rates, or *doses*, listed on fumigant labels are based on the volume of the structure to be fumigated. Make sure that you accurately determine a structure's volume before you begin a fumigation. If you use too little fumigant for a given volume, you may not achieve the desired level of pest control. Too much fumigant is wasteful, can damage the treated commodity, and is illegal if above the label rate.

Determining Volume

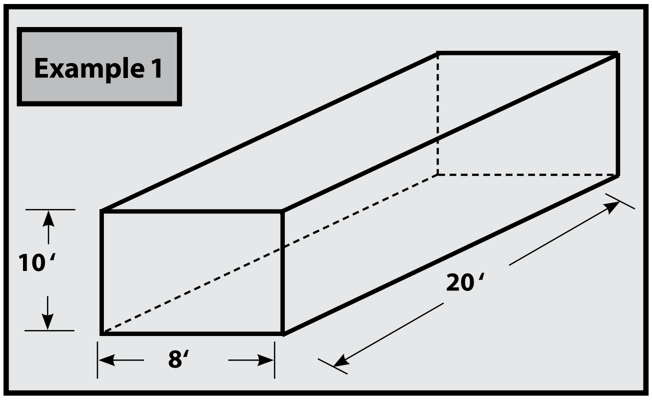
In simple terms, the volume (or cubic content) of a structure is equal to the structure's area times its height. The area is determined by multiplying the length by the width.

- Area = length × width
- Volume = length × width × height

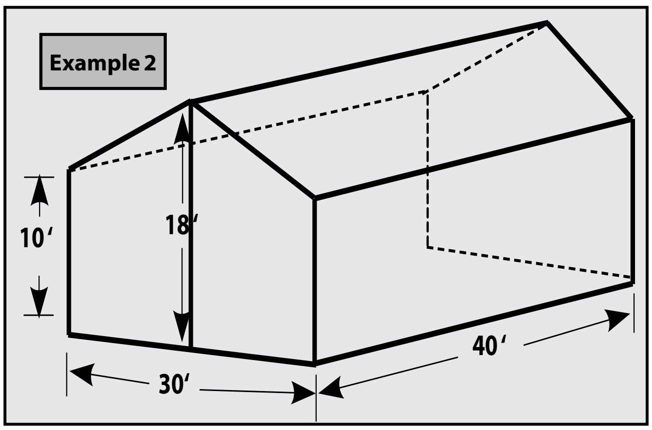
Length, width, and height are typically measured in feet, area in square feet (ft^2), and volume in cubic feet (ft^3).

The structure in **Example 1** is 20 feet long, 8 feet wide, and 10 feet high. What is its volume?

Volume = length × width × height
= 20 ft × 8 ft × 10 ft
= 1,600 ft^3



In practice, calculating volume is usually more involved because most structures are not simple squares or rectangles; instead, they are irregular in shape and might have peaked or gable roofs.



The structure in **Example 2** is 40 feet long and 30 feet wide. Notice that the height is different at different points along the roof. In order to calculate the volume of this structure, you must first determine the average height. The easiest way to do this is to take the average of the wall height and the height at the peak. The average height and volume can be calculated as follows.

$$\text{Average height} = \frac{\text{Wall height + peak height}}{2}$$

$$= \frac{10\text{ ft} + 18\text{ ft}}{2}$$

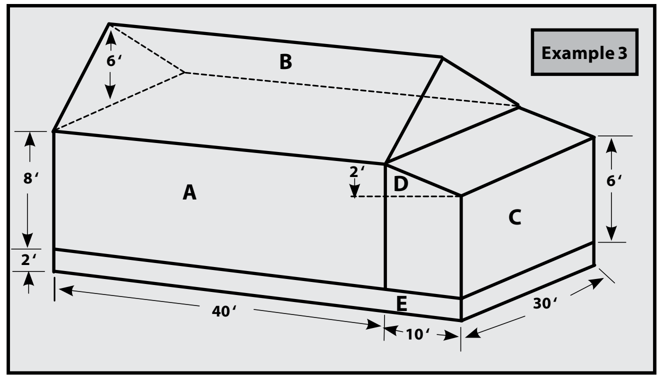
$$= 14\text{ ft}$$

$$\text{Volume} = \text{length} \times \text{width} \times \text{average height}$$

$$= 40\text{ ft} \times 30\text{ ft} \times 14\text{ ft}$$

$$= 16{,}800\text{ ft}^3$$

Let's now look at a more complicated structure, shown in Example 3.



There are two ways to compute the volume of the structure in **Example 3**. The first is to "divide" the structure into three main parts: the main room with its attic (A + B), the lean-to with its attic (C + D), and the crawl space (E). Use the procedure in Example 2 to first determine the average height of the main room with its attic.

Then, use this height to determine the volume. Likewise, use Example 2 to calculate the volume of the lean-to with its attic. You can calculate the volume of the crawl space as we did with the structure in Example 1. The total volume of the structure is the sum of the volumes of the three components.

Volume of main room:

Average height of **A + B** = $\frac{8\text{ ft} + 14\text{ ft}}{2} = 11$ feet

Volume of **A + B** = 40 ft × 30 ft × 11 ft = 13,200 ft^3

Volume of lean-to:

Average height of **C + D** = $\frac{6\text{ ft} + 8\text{ ft}}{2} = 7$ feet

Volume of **C + D** = 30 ft × 10 ft × 7 ft = 2,100 ft^3

Volume of crawl space:

Volume of **E** = 50 ft × 30 ft × 2 ft = 3,000 ft^3

Total volume of structure:
Total volume = (13,200 + 2,100 + 3,000) = 18,300 ft^3

Another way to calculate the volume of the structure in **Example 3** is to calculate the volumes of all five parts separately, and then add them to get the total volume.

This approach takes a little bit longer but yields the same total volume.

Volume of **A**: 40 ft × 30 ft × 8 ft = 9,600 ft³

To calculate the volume of **B**, we need to determine the average height. In this case, there is no "wall," so the wall height = 0.

$$\text{Average height of } \mathbf{B} = \frac{0 \text{ ft} + 6 \text{ ft}}{2} = 3 \text{ ft}$$

Volume of **B**: 40 ft × 30 ft × 3 ft = 3,600 ft³

Volume of **C**: 30 feet × 10 feet × 6 feet = 1,800 ft³

Volume of **D** is calculated the same way as that of B:

$$\text{Average height of } \mathbf{D} = \frac{0 \text{ ft} + 2 \text{ ft}}{2} = 1 \text{ ft}$$

Volume of **D**: 30 ft × 10 ft × 1 ft = 300 ft³

The volume of **E** (calculated the same way as before) = 3,000 ft³

Total volume = (9,600 + 3,600 + 1,800 + 300 + 3,000) cubic feet = 18,300 ft³

Note that the sum of the volumes of **A** and **B** (9,600 ft³ + 3,600 ft³ = 13,200 ft³) is the same as the volume we calculated for the main room in the first approach. The same is true for **C** and **D**.

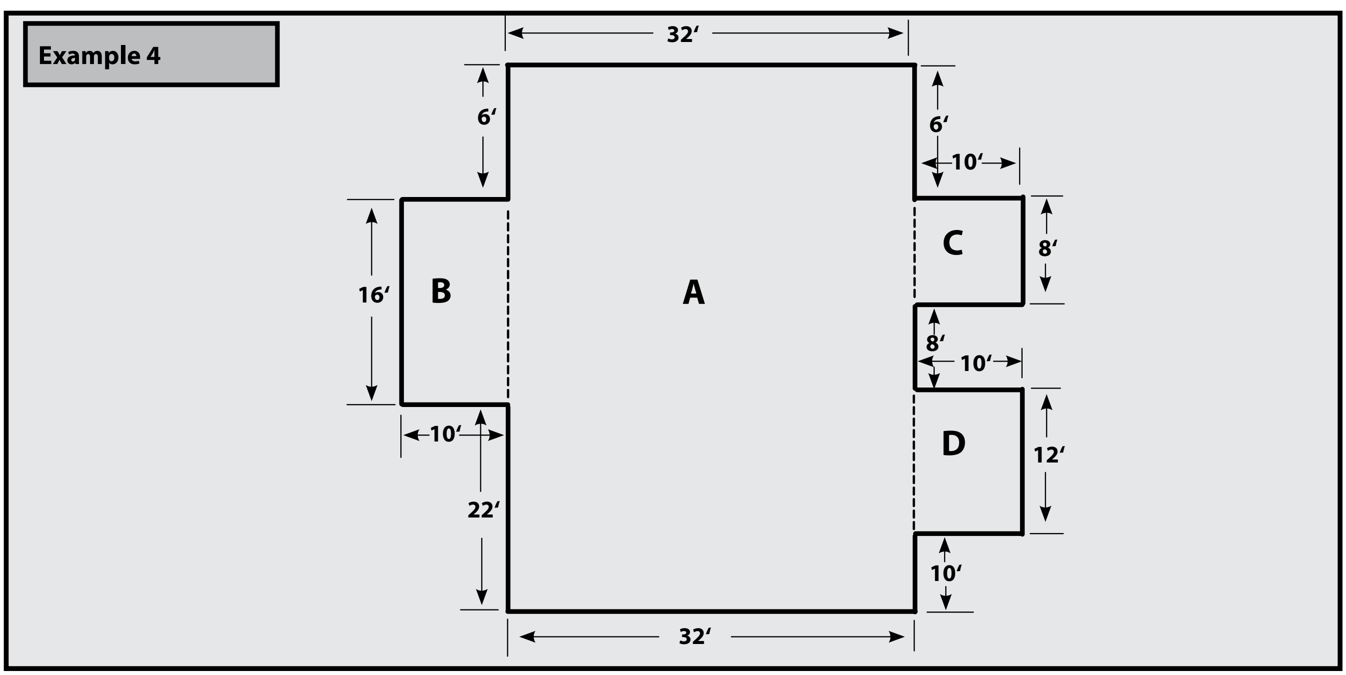
Example 4 shows a structure with an irregular floor plan. The first step in determining the total volume of the structure is to calculate the area and volume of each room (**A**, **B**, **C**, and **D**). The total volume of the structure is the sum of the volumes of the four rooms:
Total Volume = Volume **A** + Volume **B** + Volume **C** + Volume **D**
= (Area **A** × Height **A**) + (Area **B** × Height **B**) + (Area **C** × Height **C**) + (Area **D** × Height **D**)

You can use the equation above whether the heights of the rooms are different or not, though the calculation is a bit simpler if all rooms are the same height. For example, if a single flat roof covers all four rooms, the height is the same for each room. So, the total volume of the structure can be calculated by multiplying the height by the sum of the areas of the four rooms as follows:
Total Volume = Height × (Area **A** + Area **B** + Area **C** + Area **D**)

Let's try it with numbers. Assume that the structure in **Example 4** is covered with a flat roof and the height of each room is 10 feet. Calculate the total volume by adding the volumes of the four rooms.
Volume **A** = 44 ft × 32 ft × 10 ft = 14,080 ft³
Volume **B** = 16 ft × 10 ft × 10 ft = 1,600 ft³
Volume **C** = 8 ft × 10 ft × 10 ft = 800 ft³
Volume **D** = 12 ft × 10 ft × 10 ft = 1,200 ft³
Total Volume = 17,680 ft³

Because the height of the structure is the same for each room, the volume can also be calculated by multiplying the height by the sum of the areas of the four rooms.

Total Area = Area **A** + Area **B** + Area **C** + Area **D**
= (44 ft × 32 ft) + (16 ft × 10 ft) + (8 ft × 10 ft) + (12 ft × 10 ft)



$= 1{,}408\ ft^2 + 160\ ft^2 + 80\ ft^2 + 120\ ft^2$
$= 1{,}768\ ft^2$
Total Volume = Total Area × Height = $1{,}768\ ft^2 \times 10\ ft$
$= 17{,}680\ ft^3$

Note: Use this equation (Total Volume = Height × Total Area) only when the height is the same for all the rooms. If the height differs, use the first method (Total Volume = Sum of Individual Volumes).

The examples we've looked at so far are simple structures. Many buildings have overhanging eaves, chimneys, and dormers that add to the overall volume. If a building is covered by a tarp during a fumigation, be certain to account for the space between the tarp and the structure (e.g., when the tarp envelops a porch) when calculating the total volume to be fumigated. While the calculations may take longer in such cases, the basic methods of calculation are the same.

Round or Cylindrical Structures

Now let's look at a structure that is not rectangular. For example, how do you determine the volume of a grain bin?

The grain bin in **Example 5** can be represented by a cylinder with a conical (funnel-shaped) cap. The volumes of a cylinder and cone are calculated as follows, where r=the radius. The radius is most easily measured at the base of the cylinder and is equal to the distance from the center of the base to the edge. The number 3.14 (pi) is a constant.

$$\text{Volume of Cylinder} = 3.14 \times r^2 \times h$$

$$\text{Volume of Cone} = \frac{3.14 \times r^2 \times h}{3}$$

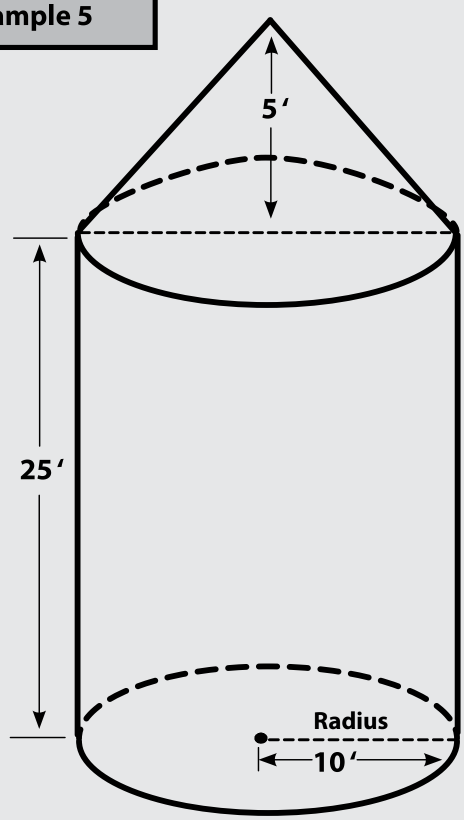
The total volume of the grain bin in Example 5 is calculated as follows:

$$\text{Volume of Cylinder} = 3.14 \times (10\ ft)^2 \times 25\ ft = 7{,}854\ ft^3$$

$$\text{Volume of Cone} = \frac{3.14 \times r^2 \times h}{3} = 523.6\ ft^3$$

$$\text{Total Volume} = 7{,}854\ ft^3 + 523.6\ ft^3 = 8{,}377.6\ ft^3$$

Example 5



Sealing Fumigation Sites

Almost all fumigation failures are due to inadequate sealing. When not properly sealed, the gas concentrations needed to control the pest cannot be maintained. Improper sealing means fumigant leaves the treated site, which can lead to health issues for people or animals and environmental harm.

Improper sealing results in lower fumigant concentrations, which increases the amount of time required to kill the pests and can contribute to fumigant resistance. When the site is not properly sealed, it is also a waste of product and money since any fumigant leaving the site is not controlling the pests.

Sealing Techniques

You can seal a structure or commodity in one of two ways:

1. Place a gas-tight tarp over the item or structure.
2. *Tape and seal* all potential openings within a structure with plastic and tape.

Finding Holes and Leaks

One method of finding holes or leaks in a grain bin is to use smoke. Prior to filling the bin, release a smoke canister in the bin. You can mark points where smoke escapes with paint or other marking substances and later seal with a caulking compound or sealant.

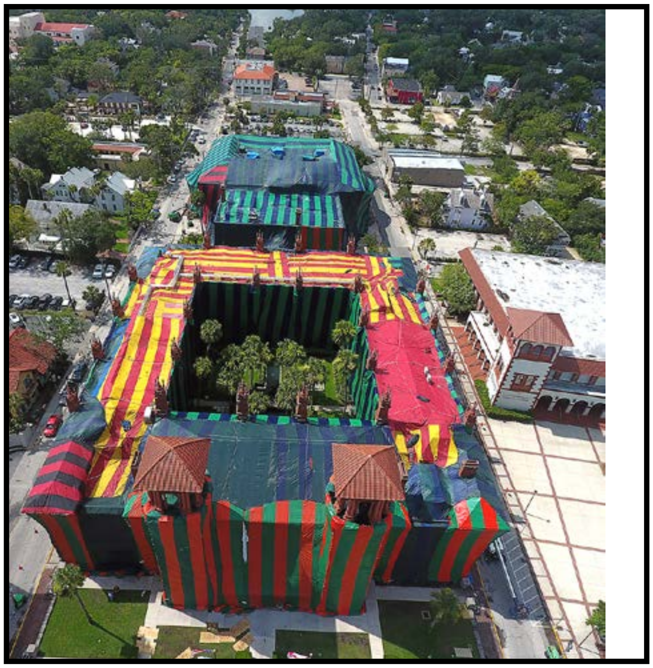
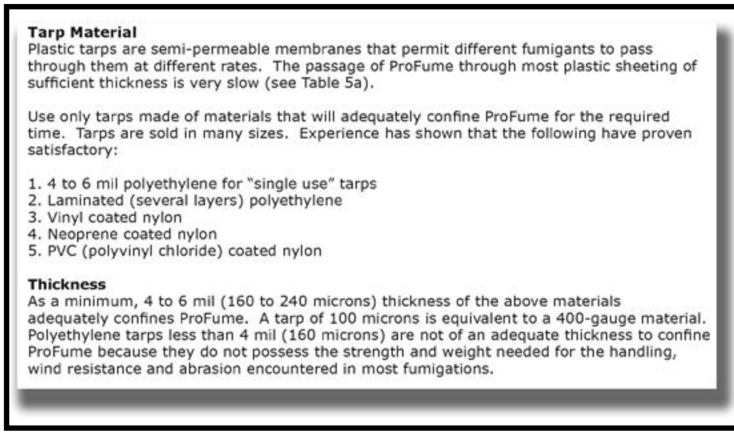


Figure 1: Even very large structures can be tarped and fumigated. (Photo © Roger Mensing).



Tarp Material
Plastic tarps are semi-permeable membranes that permit different fumigants to pass through them at different rates. The passage of ProFume through most plastic sheeting of sufficient thickness is very slow (see Table 5a).

Use only tarps made of materials that will adequately confine ProFume for the required time. Tarps are sold in many sizes. Experience has shown that the following have proven satisfactory:

1. 4 to 6 mil polyethylene for "single use" tarps
2. Laminated (several layers) polyethylene
3. Vinyl coated nylon
4. Neoprene coated nylon
5. PVC (polyvinyl chloride) coated nylon

Thickness
As a minimum, 4 to 6 mil (160 to 240 microns) thickness of the above materials adequately confines ProFume. A tarp of 100 microns is equivalent to a 400-gauge material. Polyethylene tarps less than 4 mil (160 microns) are not of an adequate thickness to confine ProFume because they do not possess the strength and weight needed for the handling, wind resistance and abrasion encountered in most fumigations.

Figure 2: Above are directions concerning tarp materials taken from the ProFume Applicator's Manual. This is shown as an example of what you may find for guidance on tarp and sealing issues.

Tarpaulin Sealing

You can use a tarp to seal a small item or an entire structure (Figure 1). Tarps need to be made of gas-proof material and must be thick enough that they do not puncture easily. The fumigant label and/or applicator's manual may require specific material and thicknesses (Figure 2).

Although fumigants can penetrate plastic, penetration is slow. Use gas-impervious tape to seal all seams where tarp or plastic join. Good sealing is more important than the thickness of the tarp or tape.

The tarp must be sealed to the ground with loose, wet sand; snakes (flexible tubes filled with water or sand); adhesives; or a combination of these materials. If using snakes, use 2 rows of snakes along the sides and 3 rows on the corners. Overlap the snakes by about 1 foot. You can use loose, wet sand where items used in the fumigation extend under the tarpaulin (e.g., fumigant introduction line, electrical cords, gas sampling tubes).

Taping and Sealing

Well-built structures (those with impermeable exteriors such as concrete or steel) are most suitable for tape-and-seal fumigation. For tape-and-seal fumigation, use spray adhesive and tape to affix plastic sheeting to windows, doorways, vents, and other openings (Figure 3). In grain bins, you should also seal unloading augers, roof exhaust vents, and eave gaps (openings where the roof meets the sidewalls).

Follow these guidelines when sealing.

- Make sure you have a clean, firm, and dry surface to seal to.
- For grain bins, seal outside whenever possible to minimize the need to enter the confined space containing grain.
- If you anticipate windy conditions, additional sealing may be necessary.

Permanent Sealing

For any fumigation site, especially one that will likely be treated more than once, it is best to permanently seal cracks and unused openings. You can use sealants to cover cracks and unused openings around windows, doors, and equipment, or electrical conduits through walls, ceilings, or junctions that penetrate walls to the outside or to non-fumigated areas.

In bins, you can permanently seal:

- Exterior under-roof vents;
- Roof deck-to-wall gaps;
- Clearance openings around centrifugal direct drive motor shafts;
- Bolt holes with missing bolts;
- Gaps between flanges on aeration fans connected to transition ducts;
- Aeration duct entrance through the bin wall or concrete foundation at the base.

Note: Before implementing permanent sealing measures, make sure to get approval from owners or managers.

Figure 3: Part of a large sealed fumigation job is shown above on the left. Note all the roof vents are heavily sealed. While necessary in cases where enclosing the whole building under a tarp is not practical, sealing can be labor intensive. Make sure to seal all places where fumigant gas could escape. Use gas-impervious tape, and in the case of entryways, such as that on the right, placard and secure the door from entry.(Photos © Douglas Products).

Fumigant Monitoring

Air monitoring of fumigant concentrations is the use of sensitive gas-monitoring devices to accurately gauge the dosage of the fumigant and/or to detect leaks from the application site.

There are two main reasons you need to perform air monitoring during a fumigation:

1. For efficacy of the fumigation, and
2. Safety (of applicators, other personnel, and bystanders). On labels, this aspect of monitoring is often referred to as "industrial hygiene monitoring."

Fumigant labels may require the use of sensitive gas-monitoring devices during the application and before warning placards can be removed after the end of the application (Figure 4). Monitor gas concentration during fumigation to ensure an adequate concentration is maintained long enough to be effective.

C. MONITORING

1. Safety
   a. Monitoring of phosphine conditions must be conducted in areas to prevent excessive exposure and to determine where exposure may occur. Document where monitoring will occur.
   b. Keep a log or manual of monitoring records for each fumigation site. This log must at a minimum contain the timing, number of readings taken and level of concentrations found in each location.
   c. When monitoring, document even if there is no phosphine present above the safe levels. In such cases, subsequent monitoring is not routinely required. However spot checks must be made occasionally, especially if conditions significantly change.
2. Efficacy
   a. For stationary structures, phosphine readings MUST be taken from within the fumigated structure to insure proper gas concentrations. If the phosphine levels have fallen below the targeted level, the fumigators, following proper entry procedures may reenter the structure and add additional product.
   b. All phosphine readings must be documented.

Figure 4: The example above is taken from a phosphine fumigant product applicator's manual. It shows that monitoring is required for both safety and efficacy and that applicators must keep a log of all measurements.

For safety reasons, it is essential to be able to immediately determine fumigant concentrations. Some fumigants have no detectable odor, and even fumigants with strong odors may not be detected by a worker with a poor sense of smell. Monitoring gas concentrations helps ensure that workers can take proper precautions, such as using respiratory equipment.

You may need to monitor both inside and outside the structure being fumigated during and after the fumigation. Make sure to take readings from several locations because fumigants may become trapped in local pockets. Also, different materials and commodities desorb at different rates, a process called "off gassing," which can allow toxic levels of the fumigant to appear in scattered locations.

Monitoring for Efficacy

If the fumigant concentration does not reach the desired level because of a leak or insufficient toxic rates, you can expect ineffective pest control and potentially a costly secondary application or continued pest damage. To avoid these issues, use high-concentration monitoring devices to check the efficacy of the fumigation. Collect air samples through lines that typically consist of ¼-inch tubing placed at critical spots inside the fumigated enclosure prior to introducing the gas. The lines are extended to a spot outside the enclosure to a detector

Figure 5: Monitoring for efficacy of fumigation is important to make sure the process is successful. Pictured above is one type of monitoring device, a fumiscope, which is generally used to measure methyl bromide or sulfuryl fluoride. (Photo © Carl Schnabel).

and readings are taken periodically (Figure 5).

Measuring fumigant concentrations inside structures, chambers, or tarped products allows you to:

- Check that the correct quantity of gas has been introduced into the site.
- Determine when the gas inside the site is evenly distributed and when to start timing the exposure period.
- Make dosage corrections if needed.
- Determine if and when the target endpoint (accumulated dosage of gas concentration × time) has been reached.

Monitoring for Safety

Monitoring is essential to identify leaks that could harm unprotected people. Prior to re-entry, perform air monitoring in workers' breathing zones and within the structure. Generally, low-concentration detectors are used for safety monitoring (also referred to as industrial hygiene monitoring).

After the gas has been introduced to a structure, use a low-concentration gas detector to check for fumigant leaks around the exterior perimeter of the site. Check seals with the detector to ensure gas is not leaking. You must repair leaks to minimize loss of fumigant and reduce risk of exposure to bystanders and/or occupants of nearby buildings (see Table 1).

After fumigation is complete and the structure has been aerated, monitoring must be used to ensure safe

Figure 6: Regardless of requirements, it is good fumigation practice, and protection from liability, to keep records showing that all such thresholds have been met. (Photo © Ed Crow, Penn State).

re-entry. Some pesticide labels require applicators to keep a log showing that gas concentrations are below threshold levels for any vulnerable sites identified in the site assessment (Figure 6).

Gas Detection Devices

A wide variety of gas-detecting equipment can be used to sample air for fumigant, though different equipment is used depending on the need for low- or high-concentration monitoring. All detection devices must be used and maintained according to the manufacturer's instructions and recommendations. Many types of detection devices require periodic calibration to ensure an accurate measurement. Before purchasing any equipment, read the pesticide labels of all products you will use to determine what monitoring equipment you need and if there is a specific sensitivity required. The label and/or applicator's manual often prescribes specific detection equipment (Figure 7).

The following are some of the more commonly used gas detection devices in fumigation.

Ambient Air Analyzers

Some *ambient air analyzers* (also called "infrared detection systems" or "IR devices") use infrared light to detect and measure gas concentrations (Figure 8). When infrared radiation strikes a gas, certain wavelengths of the radiation are absorbed. The device then measures this absorption and determines the gas concentration. Most ambient air analyzers can be calibrated at the factory to detect a single gas. Others are equipped with a fixed infrared filter.

Halide Leak Detectors

Halide leak detectors are useful for indicating the presence and approximate concentration of methyl bromide and sulfuryl fluoride. While these detectors are used to detect leaks and determine if the fumigant is present in a work area, the safe exposure limit for people is below the to unacceptable levels of ProFume. Use only a detection device of sufficient sensitivity such as the INTERSCAN gas analyzer [Model GF 1900] or MIRAN vapor analyzer [SapphIRe] to confirm a concentration of ProFume $\leq$1 ppm. If ProFume concentrations exceed 1 ppm then the sealing of the isolated space from the fumigated area is probably not working and the immediate space must be evacuated unless the ProFume concentration is continuously monitored to prevent exposure >1 ppm. SCBA must be worn by the applicator if the concentration exceeds 1 ppm. **Note:** All connected/adjoining areas must be vacated if required by state or local laws or regulations.

Figure 7: This example is taken from a sulfuryl fluoride applicator's manual prescribing a specific type of detector to use for monitoring.

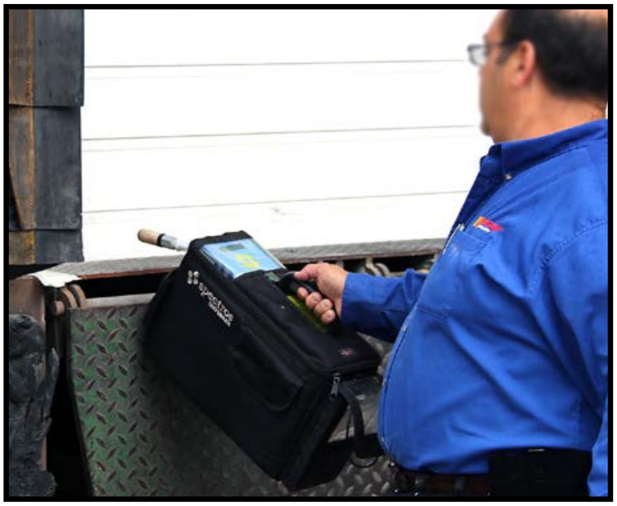


Figure 8: A worker takes a reading outside a warehouse door for sulfuryl fluoride using an infrared gas monitor. (Photo © Garo Goodrow, Penn State).

detection limit of these devices. Because halide detectors do not accurately determine exact concentrations of gas, make sure to use appropriate gas detector tubes to measure low concentrations of fumigants to ensure worker safety.

Also note that halide detectors have an open flame. Even when the detector is not in operation, do not store it in a frequently inhabited room. The fuel is a flammable gas under pressure and may explode. Do not use halide detectors in the presence of flammable or explosive gases such as gasoline vapors. Do not use halide detectors in mills, grain elevators, or other enclosures where there is a possibility of a dust explosion.

Thermal Conductivity Analyzers

Thermal conductivity analyzers (TCAs) measure the concentration of fumigant gases within a chamber or other enclosure during fumigation. Several types of TCAs are available. The Fumiscope®, which can be used to measure methyl bromide and sufuryl fluoride

Figure 9: (Top) A worker checks for leaks of phosphine gas from a grain bin using a detector tube. (Bottom) Glass detector tubes are "fumigant specific," meaning you need specific tubes to measure each type of fumigant you use. (Photo credits: (top) © Betsy Danielson, Iowa State University Extension and Outreach; (bottom) © Garo Goodrow, Penn State).

concentrations, is one of the most common TCAs.

Like the halide detector, TCAs should NOT be used to determine whether fumigant levels are safe for re-entry because they cannot measure gas concentrations below 5 ppm.

Detector Tubes

Detector tubes (also called colorimetric tubes) are sealed glass tubes filled with an indicator chemical that reacts with the fumigant to produce a color change (Figure 9). A measured amount of air is drawn through the tube by a pump; the resulting color change indicates the gas concentration in the sampled atmosphere. These detectors are easy to use and reasonably accurate when used according to directions. They measure very low concentrations and are used to detect leaks and to determine whether or not a fumigated space is safe to enter without respiratory protection. Extension tubes are available for sampling hard-to-reach areas.

In addition to tubes that provide immediate readings, long-duration tubes are available. These devices use a lightweight pump to continuously draw a measured volume of air through the tube. They can be carried on your clothing and are used for monitoring gases throughout the normal workday. At the end of a shift, you can check the tube for a time-weighted average of exposure. If the exposure level is above threshold limits, you must take corrective action to prevent future occurrences.

Be aware of the following precautions when using gas detector tubes.

- Tubes deteriorate with age. Some tubes have a shelf life of two years when stored at room temperature. Deterioration is more rapid above 86°F.
- Direct sunlight can affect the properties of the tubes.
- At low temperatures—around freezing or below—tubes may not give reliable readings. They should be warmed to room temperature for best performance.
- Tubes may have cross-sensitivity to gases other than those for which they are designed. You should obtain this information from the manufacturer.

Note that detector tubes are not as common as they once were.

Summary

- Always follow label / applicator's manual directions for types of detectors to use.
- Make sure you are using the appropriate detector (low- or high-concentration detector) for the task.
- Follow the device manufacturer's instructions for proper use and calibration.
- Make sure the detection device is calibrated and working properly.
- When using a detector to monitor for leaks outside the enclosed structure, make sure you are wearing appropriate PPE (i.e., respirator) or have it nearby if needed. If you do not know the concentration in an area, you must wear PPE.
- The same precaution applies when monitoring to see if the fumigant has been properly and completely aerated from inside the enclosed structure.

SECTION 14

NOTIFICATION REQUIREMENTS

14.1 AUTHORITIES AND ON-SITE WORKERS

As required by local regulations, notify the appropriate local officials (fire department, police department, etc.) of the impending fumigation. Provide the officials an MSDS and complete label for the product and any other technical information deemed useful. Offer to review this information with the local official(s).

14.2 INCIDENTS INVOLVING THESE PRODUCTS

Registrants must be informed of any incident involving the use of this product. Please call 1-800-438-6071 so United Phosphorus, Inc. can report the incident to Federal and State Authorities.

14.3 THEFT OF PRODUCTS

Immediately report to the local police department thefts of metal phosphide fumigants.

Figure 10: The example above is taken from a phosphine fumigant product applicator's manual. It shows that notification of local authorities may be required, especially in the case of accidents or theft of product. Note that the text refers to an "MSDS," which is now known as SDS.

Notify Authorities

Before performing a fumigation, check if there are local and/or state notification requirements. Notifying authorities may also be required by the product label (Figure 10). If required, notify appropriate agencies such as the fire department, local health agency, and the police department prior to the fumigation. Required information may include the following:

- The names and telephone numbers of all appropriate personnel in charge.
- The location, date, and time of application.
- The product and chemical name for the fumigant(s) used.
- The SDS and a copy of the label.
- The type of PPE and other safety equipment required.
- The fire hazard rating.
- Your fumigation management plan (FMP).

Even if not required by state or local laws, such notification is a "best management" practice and will help deal with any accidents or issues resulting from the fumigation.

When a Fumigation Goes Wrong

Real-world Examples

What Happened

A grain elevator/COOP that sold a variety of pesticides caught fire and was destroyed. To salvage some of the company's stock, the hazardous waste consultant was advised to keep 37 flasks of Phostoxin. The hazardous waste consultant placed the flasks in a 55-gallon unlabeled drum and sealed it.

The following year, the employee in charge of fumigation and the applicator were told to evaluate the contents of the unlabeled drum for potential use. Together they approached the drum, and the fumigator opened the lid a few inches, observed collapsing flasks and a silver fog, and shut the lid. As he attempted to tighten the bung nut with a regular (not non-sparking) wrench, a spark was generated, and an explosion occurred. The drum lid hit the applicator on the head, knocking him unconscious with a severe head laceration. The other employee thought he was dead. The fumigator sustained a skull fracture, eye damage, and 300 stitches to close the laceration.

What Should Have Happened

The hazardous waste consultant should have contacted the manufacturer for guidance on proper deactivation. The applicator's manual advises against confining aluminum phosphide because that can create an explosive atmosphere.

How It Could Have Been Avoided

Reading the applicator's manual, which is a continuation of the label, and also contacting the manufacturer.

What Was the Consequence

The company was cited by Oregon OSHA for a $20,000 willful violation for improper storage and $5,000 by the U.S. EPA for not following the applicator's manual.

Fumigation Safety

LEARNING OBJECTIVES

- ☑ Explain how applicators and others (handlers, bystanders) can become exposed to fumigants.
- ☑ Describe some common mistakes that lead to direct exposure to fumigants.
- ☑ Describe the signs and symptoms of human exposure to fumigants.
- ☑ Describe the human exposure concerns that are specific to non-soil fumigants.
- ☑ List measures you can take to minimize potential health effects from fumigants.
- ☑ Outline first-aid measures to take if someone is exposed to a fumigant.
- ☑ Describe when and where to take samples for monitoring.
- ☑ Explain what levels of fumigant air concentrations require handlers and applicators to wear respirators.
- ☑ Describe actions to take when an applicator experiences sensory irritation from a fumigant.
- ☑ Specify when handlers and workers must leave the work area entirely.
- ☑ Specify who can and cannot be in areas being fumigated or during aeration of a site.
- ☑ Specify who is permitted to be in a buffer zone.
- ☑ Define the types of buffer zones and how to determine their size.
- ☑ Explain what you can find on the product label regarding posting warning signs.
- ☑ Explain why posting of treated sites is required, who must comply with posting, and who is responsible for posting.
- ☑ Specify where warning signs must be placed.
- ☑ Explain what a Fumigation Management Plan (FMP) is and why it is important.
- ☑ Specify when an FMP is required.
- ☑ Explain how long you must keep an FMP on file, where to keep the plan, and who must have access to it.
- ☑ Specify who is responsible for verifying that the FMP is accurate.
- ☑ List resources that help you prepare an FMP.
- ☑ List and describe the elements of an FMP.
- ☑ Describe the purpose of a Post-Application Summary (PAS) and describe its elements.
- ☑ Specify who must prepare the PAS and when it must be completed.

Fumigation Safety

Fumigants are some of the most toxic pesticides we use. Treat fumigants with respect to protect yourself, your coworkers, and the public from accidental exposure. As an applicator you learn and are trained in how to do this, but keep in mind that the public is not. In nearly all cases, fumigants control pests on items or in areas where people and animals have direct contact. The sites you treat (grain bins, etc.) are often located near livestock and other animals. It is your responsibility to protect the public and the environment from exposure. To protect others from fumigant exposure, make sure to:

- Read and follow the label directions.
- Plan thoroughly before application.
- Seal and secure the fumigation site.
- Post *warning signs.*
- Monitor the fumigant.
- Safely transport, store, and dispose of fumigants and their containers.
- Properly aerate the treatment area.

Toxicity, Risk, and Exposure

Some pesticides are highly *toxic* to people—a few drops in your mouth or on your skin can cause extremely harmful, or even lethal, effects. Other pesticides are less toxic, but exposure to them may also harm you. Keep in mind that all pesticides have some level of toxicity, and there is always potential for risk.

- *Toxicity* is a measure of the capacity of a pesticide to cause injury. That injury can occur soon after the exposure (acute) or long afterward (chronic). Toxicity is a characteristic of the chemical itself— some chemicals are very toxic while others are less toxic.
- *Exposure* occurs when you come in direct contact with a pesticide, whether through your skin or eye, by ingesting it, or by breathing it in. Unlike toxicity, exposure is something you have control over.
- *Risk* is a measure of the likelihood that a person will be harmed by the pesticide and its particular use. It is a product of both the pesticide's toxicity and the amount of exposure.

Risk = toxicity x exposure

How People Are Exposed to Fumigants

While many pesticides can damage the skin and eyes, the most harmful toxic effects usually occur when pesticides get inside your body. There are four main routes that pesticides can enter your body:

- Dermal exposure (when you get a pesticide on your skin),
- Oral exposure (when you swallow a pesticide),
- Ocular exposure (in your eyes), and
- Inhalation or respiratory exposure (when you breathe in pesticide vapors or dusts).

Risk to Workers

Respiratory exposure is the most common and hazardous type of fumigant exposure. The risk to the applicator and other workers of inhaling pesticides is greatest:

- When opening and releasing the fumigant,
- During application,
- During aeration of fumigation enclosure, and
- When disposing of spent solid fumigants (e.g., phosphine).

Physical Condition and Fumigation

Before actively taking part in a fumigation procedure, make sure that you are in good physical condition. You do not want to make the use of fumigants dangerous to yourself or to the public.

- Have a physical examination at least once a year or more often if health conditions require them.
- Do NOT participate in a fumigation if suffering from colds or other respiratory problems that make breathing difficult.
- Do NOT participate in a fumigation while undergoing continuing medical treatments unless authorized to do so by medical personnel.

Always Work in Pairs

One of the most important things applicators can do to protect themselves from fumigant exposure is to always work with another person. One person can assist the other if one becomes injured or exposed to fumigant vapors. Some fumigant labels require two people trained in fumigant use to be present when there is the greatest potential for worker exposure—during fumigant introduction, reentry into the fumigated structure before aeration, initiation of aeration, and during re-entry when testing for clearance.

Risks to Workers and Bystanders

Exposure risks can involve bystanders as well as fumigant workers and applicators. Many of these situations arise from either not reading the label or not following its safety directions and precautions. Common mistakes include:

- Neglecting to post fumigant warning signs at the treatment and/or buffer areas so that people are not aware of the dangers.
- Failing to monitor fumigant levels or not using the proper detectors.
- Failing to monitor (or not using the proper detectors) during aeration.
- Not using the appropriate PPE.
- Not maintaining PPE and/or changing respirator cartridges when required.
- Using poorly fitted respirators.
- Failing to properly seal the fumigation site.
- Neglecting to seal off connected rooms or structures that should not be fumigated.

Signs and Symptoms of Fumigant Exposure in People

As with any pesticide exposure, fumigants can cause both acute and chronic effects.

General Symptoms

Mild to severe fumigant inhalation symptoms can present as follows:

- Mild inhalation exposure can cause a feeling of sickness, ringing in the ears, fatigue, nausea, and tightness in the chest. Exposure to fresh air usually relieves these symptoms.
- Moderate inhalation exposure can cause weakness, vomiting, chest pain, diarrhea, difficulty breathing, and pain just above the stomach.
- Symptoms of severe inhalation exposure can occur within a few hours to several days after exposure. Severe poisoning may result in fluid buildup in the lungs. This can lead to dizziness, blue or purple skin color, unconsciousness, and even death.

Symptoms of Phosphine Poisoning

Acute and Chronic Poisoning Terminology

Poisoning is poisoning, right? Not necessarily.

- Acute toxicity is a measure of the capacity of a pesticide to cause injury as a result of a single one-time exposure.
- Acute exposure is exposure to a single one-time dose of a pesticide.
- Acute effects are symptoms that usually occur within minutes or hours after exposure to a toxic substance. These effects can be dermal, oral, or respiratory.
- Chronic toxicity is a measure of the capacity of a pesticide to cause injury as a result of small, repeated exposures over a long period of time.
- Chronic exposure is repeated exposure to a pesticide over a long time (usually years).
- Chronic effects are those that appear a long time after exposure (months to decades). They are often caused by repeated low exposures that do not immediately cause acute effects.

Symptoms of phosphine exposure can be severe, but they are clearly recognizable and may be reversible if exposure is ended as soon as symptoms begin to appear. The route of potential exposure is primarily respiratory because phosphine is not absorbed through the skin.

Slight or mild poisoning symptoms of hydrogen phosphide gas (phosphine) include fatigue, buzzing in the ears, nausea, pressure in the chest, and uneasiness.

Medium to heavy poisoning symptoms include general fatigue, nausea, stomach-intestine symptoms with vomiting, stomachache, diarrhea, disturbance of equilibrium, strong pains in the chest, back pains, a feeling of coldness, and dyspnea (difficult or labored breathing). Note that phosphine does not build up in body tissues. Any phosphine entering the body will be eliminated within 48 hours.

Severe poisoning rapidly results in strong dyspnea, cyanosis (blue or purple skin color), agitation, unconsciousness, and death. Death may be immediate, or it can follow several days of chemical pneumonia, paralysis of the central respiratory system, and/or edema (fluid buildup) of the brain. A victim's breath and vomit will have a garlic-like odor.

First Aid for Fumigant Poisoning

While first-aid procedures are vital in helping a victim, they are not a substitute for professional medical help. Be able to recognize when someone needs medical attention and be prepared to get it. Seek medical attention whenever someone:

- Exhibits any illness while, or soon after, working with pesticides or in a treated area,
- Has swallowed a pesticide,
- Has gotten a pesticide in their eyes, or
- Exhibits symptoms of poisoning or injury following dermal or inhalation exposure to a pesticide.

When providing first aid, be sure to protect yourself (e.g., wear required PPE) before trying to help someone else, especially if you need to remove them from an area under active fumigation or aeration. Get yourself or the other person to fresh air as soon as possible. The first-aid section of the pesticide label will give you specific details for the fumigant you are working with.

There are situations where you should seek medical attention for yourself and others even if you do not exhibit any symptoms. For example, a person who has been overexposed to a fumigant (e.g., entered a fumigated space without respiratory protection) should be taken to a medical facility immediately for evaluation, even if they do not show symptoms of poisoning. The onset of poisoning symptoms can be delayed (e.g., acute symptoms for sulfuryl fluoride are delayed up to 24 hours and methyl bromide up to 48 hours).

It is the employer's responsibility to transport individuals to a medical facility. Never go alone or send someone else alone to get medical treatment. When transporting a victim of fumigant inhalation, drive with the windows open to prevent the driver from being overcome by fumes. Note that medical personnel need to know the EPA Registration number, full trade name, and active ingredient of the fumigant used, even if the product label is too contaminated to deliver to medical personnel.

Where to Get Help

As part of your fumigation management plan, you should have contact information for local medical facilities. Also, the first-aid section of the pesticide label includes numbers for the manufacturer and Poison Control. Anyone can call a Poison Control Center at any time for information regarding proper treatment of pesticide poisoning. If you call 1-800-222-1222, from anywhere in the U.S., your call will be automatically directed to a Poison Control Center in your area. While other hospitals and medical facilities may have some information, Poison Control Centers have the most complete and current files, and their personnel are specifically trained to deal with poison cases.

Air Monitoring

Chapter 3, "Planning for a Fumigation," discussed the use of air monitoring equipment. In this section, greater detail is provided on when air monitoring is required, where and when to take samples, when you might need to wear a respirator, and how to protect applicators, other workers, and bystanders.

When to Monitor

The *certified applicator-in-charge* must start an air monitoring program any time the label requires it. This varies by product and fumigation type. Read the label and applicator's manual for specifics. The following are some examples of times monitoring is required.

For phosphides, monitoring must be conducted when applicators are releasing pellets into the treatment area to determine their exposure.

Phosphine applicators need to monitor airborne phosphine concentrations in all indoor areas where fumigators and other workers have access during fumigation and aeration. Spot checks must be made, especially if conditions change significantly, an unexpected garlic odor is detected, or a change in phosphine level is suspected.

Where to Monitor

The label also dictates where you need to sample the air. Many labels note that samples need to be taken "in the breathing zone" of applicators or handlers. While some labels do not define the term, the following label definition provides a good rule of thumb: Breathing zones are areas where individuals typically stand, sit, or lie down while performing work functions.

In addition to breathing zones, labels may also require monitoring in other areas, including the following.

- Around the perimeter of the fumigation area (especially downwind) during release of sulfuryl fluoride.
- Around the grain bin to confirm any leakage is not above allowable limits in an area that would affect nearby workers or bystanders.
- All indoor areas where fumigators and other workers have access during fumigation and aeration.

When Respirators Are Required

Fumigant labels will provide direction for respirator use. They also list the maximum fumigant concentrations (or exposure limits) in which you can work without respiratory protection. See Table 1 in Chapter 5 ("Personal Protective Equipment") for fumigant levels that require wearing a respirator (as of September 2020).

Sensory Irritation

Sensory irritation may occur when people are exposed to fumigant vapors. Sensory irritation is a physical reaction to a certain fumigant air concentration. It can include burning, or irritation of the eyes, nose, or mucous

> **Note**
>
> **At the time of this writing, non-soil fumigant labels did not have information or requirements regarding the following sections: "Sensory Irritation" through the end of the "When Workers Must Leave an Area," although soil fumigant labels do. The EPA may call for similar requirements for non-soil fumigants. We present information below that presently applies to soil fumigations.**
>
> **As always, read the label to determine exactly what requirements pertain to you.**

membranes. If at any time a fumigant handler (or other worker) experiences sensory irritation, they must do one of the following, depending upon label instructions:

- Use an Air-Purifying Respirator (APR) to complete the task (if not already wearing one),
- Change to a full-face APR if experiencing sensory irritation while using a half-face APR, or
- Stop work and leave the application area.

Trigger Levels

Sometimes required actions for workers are based on *trigger levels*. A trigger level is a specific air concentration of fumigant that prompts or "triggers" a required action (Figure 1). Fumigant labels may specify trigger levels that require applicators to either use a respirator or leave the work area.

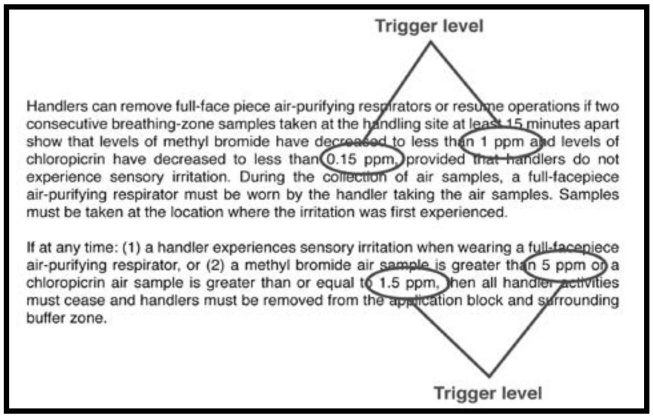


Figure 1: An example of trigger levels you might find on a fumigant label in the "Respiratory Protection and Stop Work Triggers" section.

When Workers Must Leave the Application Area

All applicators and workers must stop work and leave the application area under any of the following conditions:

- The certified applicator-in-charge makes the decision to not have handlers wear an APR after experiencing sensory irritation, or
- A fumigant handler experiences sensory irritation while wearing a respirator, or
- An air-monitoring sample shows fumigant concentrations above the Maximum-Use Concentration (MUC) for the respirators being worn.

Determination of Trigger Levels

Trigger levels are based on EPA exposure data and are used to prevent fumigant handlers from being exposed to the Maximum-Use Concentration (MUC). The MUC is the greatest air concentration of a hazardous substance (such as a fumigant) from which a person can expect to be protected while wearing a respirator.

The MUC is determined by the assigned protection factor of the respirator or class of respirators and the exposure limit of the hazardous substance.

The term "trigger levels" is found on some fumigant labels. The term "MUC" is not.

Secure the Fumigation Site

Only trained and authorized pesticide handlers wearing the appropriate PPE are allowed into the site or near the site during the application and when aerating. To ensure unprotected people are not allowed in or near the fumigation site, you must secure the site. You should lock all entrances to structures during fumigation. Some fumigant labels require you to use secondary locks to further guard against unauthorized entry (Figure 2). Use of a security guard may be prudent under extremely sensitive conditions, such as fumigating a building in the middle of a town. Always make sure to inform other people who regularly use the building about the fumigation.

Buffer Zones

Some fumigant labels require you to set up *buffer zones* to increase protection for anyone not protected by appropriate PPE (e.g., unprotected workers and bystanders). There are both **treatment** buffer zones and **aeration** buffer zones. For either zone, the certified applicator (and authorized fumigation handlers under the applicator's direct supervision) must prohibit entry by any other person.

The treatment buffer zone extends from the perimeter of the treatment area to a specified distance. The treatment buffer zone prohibits entry from when the fumigant is

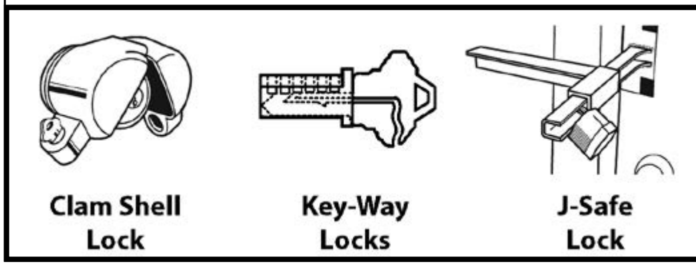


Figure 2: You might need to use different kinds of locks to prevent entry to the fumigation site. Three examples of locks you can use include clam shell, key-way, and J-safe locks. Clam shell locks are designed to prevent use of the door or occupants' keys to unlock entrance doors.

Key-way locks are designed to prevent use of the occupant's keys to unlock entrance doors. These function by inserting a two-part locking key into the door keyhole and removing only half of the key. The other half of the locking key remaining in the door prevents insertion of the occupant's key. J-SAFE lock or chains can also be used on certain structures. (Top photo © Bonnie Rabe).

introduced into the fumigation enclosure and ends when aeration begins.

The aeration buffer zone extends from where the fumigant is released in the treatment area (e.g., exhaust stack or building edge) to a specified distance. The aeration buffer zone begins when aeration begins and ends when the air concentration of the fumigant in the area is less than a label-specified concentration.

Determining Buffer Zone Size

Both the treatment and aeration buffer zones are specific to each fumigation. The buffer zone size depends on the application rate, method of aeration, air-exchange rate, and other factors. If products require a buffer zone, refer to the label for instructions on how to determine the size of buffer zones for each fumigation.

A Note on Buffer Zones

At time of this writing, the only non-soil fumigants that are required to have buffer zones are methyl bromide products. Most soil fumigants are already required to have buffer zones.

However, regulations do change, so make sure you know whether you need to determine and monitor buffer zones for the product you are using. The label will tell you.

Posting Warning Signs

Before fumigating, you are required to clearly mark the site to discourage entry. *Warning signs* (also called *warning placards*) inform the public during fumigation and aeration that the site is being treated. Placards must be placed on exterior sides of the treatment area and at all entrances (Figure 3).

Fumigant labels have specific requirements for wording and tell you what the warning signs should look like, what wording they need, when and where they should be placed, under what conditions they can be removed, and other information (Figure 4). Follow these instructions explicitly.

The certified applicator-in-charge is responsible for making sure areas have warning placards.

Re-entry and Removal of Warning Signs

People without appropriate PPE can only enter a fumigated site after a certified applicator has properly aerated or ventilated the area and has determined that the concentration of fumigant is at or below a safe level indicated on the label. Only a certified applicator (or certified applicator-in-charge, depending upon the label) may remove or direct another worker to remove posted warning signs.

Fumigation Management Plans

Most fumigant products require you to develop a *Fumigation Management Plan* (FMP). The FMP is an organized, written description of the required steps involved to help ensure a safe, legal, and effective fumigation. An FMP helps applicators organize their thoughts and materials in advance, comply with product label requirements, identify risks and hazards before

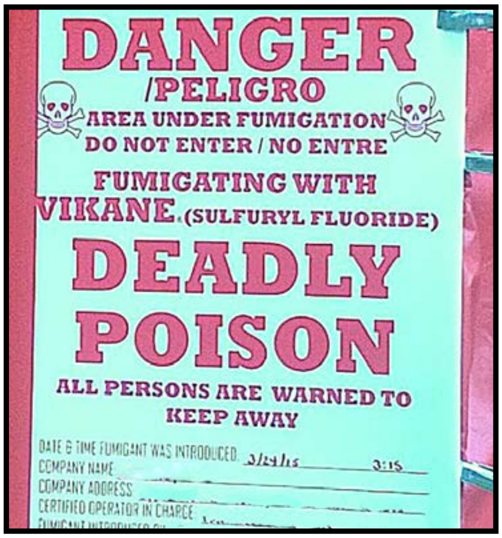
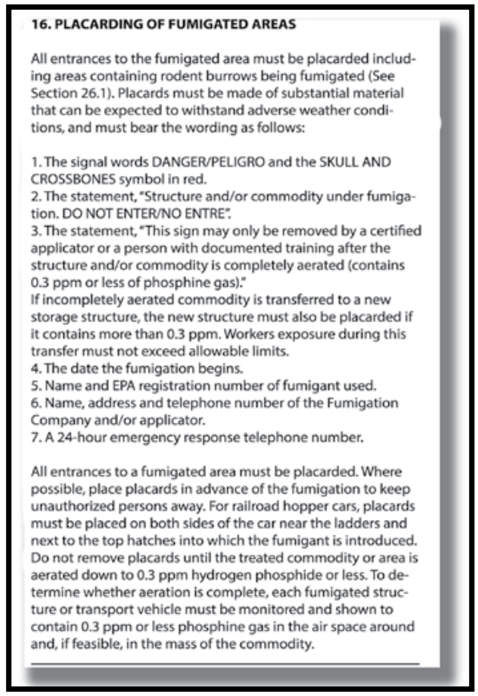


Figure 3: The image above is an example of one posted sign for a specific fumigation. Although posting requirements listed on different labels may be similar, there can be different requirements for wording and fumigant concentration levels at which signs may be removed. Follow the label directions for the product you are using. (Photo © Bonnie Rabe).



16. PLACARDING OF FUMIGATED AREAS

All entrances to the fumigated area must be placarded including areas containing rodent burrows being fumigated (See Section 26.1). Placards must be made of substantial material that can be expected to withstand adverse weather conditions, and must bear the wording as follows:

1. The signal words DANGER/PELIGRO and the SKULL AND CROSSBONES symbol in red.
2. The statement, "Structure and/or commodity under fumigation. DO NOT ENTER/NO ENTRE".
3. The statement, "This sign may only be removed by a certified applicator or a person with documented training after the structure and/or commodity is completely aerated (contains 0.3 ppm or less of phosphine gas)."
If incompletely aerated commodity is transferred to a new storage structure, the new structure must also be placarded if it contains more than 0.3 ppm. Workers exposure during this transfer must not exceed allowable limits.
4. The date the fumigation begins.
5. Name and EPA registration number of fumigant used.
6. Name, address and telephone number of the Fumigation Company and/or applicator.
7. A 24-hour emergency response telephone number.

All entrances to a fumigated area must be placarded. Where possible, place placards in advance of the fumigation to keep unauthorized persons away. For railroad hopper cars, placards must be placed on both sides of the car near the ladders and next to the top hatches into which the fumigant is introduced. Do not remove placards until the treated commodity or area is aerated down to 0.3 ppm hydrogen phosphide or less. To determine whether aeration is complete, each fumigated structure or transport vehicle must be monitored and shown to contain 0.3 ppm or less phosphine gas in the air space around and, if feasible, in the mass of the commodity.

Figure 4: Above is an example from a phosphine fumigation product label, which tells you what a placard should say, what it should look like, where to post it, and more.

Warning Sign or Placard?

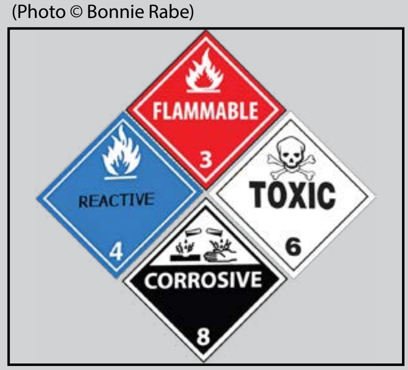
If a fumigant label tells you to post a warning sign or a placard, are these different things?

Some people would say a "placard" is a sign with a diamond symbol(s) to warn of flammability, toxicity, or other dangerous conditions. They may be correct in some circumstances. When transporting dangerous chemicals, vehicles do have to carry placards like those shown below on the right. However, when it comes to fumigant labels, both "placard" and "warning signs" seem to be used interchangeably—sometimes even in the same sentence as this example from a phosphine label shows:

"Placard all entrances to the treated spaces with fumigation warning signs."

So, what's an applicator to do? As always, follow the directions on the label. Even if it's using both the terms warning sign and/or placard, the label will direct you to use specific language. If the label requires posting entrances to the treated site with information as in the sign above, that is what you will need to do, even if it calls this a "placard."

(Photo © Bonnie Rabe)



beginning the treatment, and provide emergency protocols. Specific details of what needs to be included in an FMP varies from one product, and especially one type of fumigant, to another. When developing an FMP, refer to the applicator's manual for specific requirements.

- Like all label instructions, if an FMP is called for on the fumigant's label, it is a legal requirement. When required to draw up an FMP, you must develop it **before** you perform an application.

The certified applicator-in-charge is responsible for working with the owners and/or responsible employees of the site to be fumigated to develop an FMP and ensure that the FMP is accurate, completed, kept current, available for review, and followed.

An FMP requires that you:

- Keep the FMP and related documentation (i.e., monitoring records) on file for a minimum of 2 years.
- Keep the plan on the application site during all fumigation activities.
- Make the plan available to emergency responders and to local, state, and federal enforcement personnel.

Elements of an FMP

An FMP is often organized using descriptive subheadings. The applicator's manual for each product provides a detailed list of tasks to consider in each heading, typically in a section called "Required Written Fumigation Management Plan" or something similar. The FMP must address characterization of the site and include appropriate monitoring and notification requirements. If the same area is being fumigated a second time, you will need to update and modify the FMP for the new application.

Some of the general sections and steps of an FMP are listed in brief below. As always, follow the label for specific instructions.

Planning and Preparation: Read the entire pesticide label, applicator's manual, and Safety Data Sheet; make sure to keep a printed copy of all these documents on site. Inspect the structure and/or area to determine its suitability for fumigation and ensure the type of site is listed on the label. In the FMP, describe the purpose of the fumigation.

Common Headings Found in Fumigant Management Plans

- Planning and Preparation
- Personnel
- Monitoring
- Notification
- Site Prep and Sealing
- Application and Period of Fumigation
- Post-Application Operations

Personnel: Confirm in writing that all personnel in and around the fumigation site have been notified prior to application. Make sure all fumigation personnel have read the applicator's manual and are aware of potential hazards and emergency planning.

Monitoring: Prepare the proper monitoring equipment. Many labels may require you to keep logs of all monitoring activities and outcomes.

Notification: Confirm that appropriate local authorities (i.e., fire, police departments) have been notified prior to the release of fumigant. Prepare a written emergency response plan that contains instructions and the names and telephone numbers of authorities and other people to contact, if needed.

Sealing Procedures: Make sure to use proper sealing techniques for the site and ensure that the material will remain intact for the fumigation period. If the site was fumigated previously, review the previous FMP(s) to make sure that construction or remodeling has not changed since the last fumigation. You must place warning placards at all entrances and sides of the fumigation site.

Application Procedures and Fumigation Period: Make sure you have the number of trained and certified applicators on site required by the product label (often at least two). Provide sentries when entry into the fumigation site by unauthorized persons cannot otherwise be ensured (e.g., by secondary locks or barricades). When entering structures, always follow OSHA rules for confined spaces. If fumigating in-transit vehicles or containers, document that the receiver has been notified of the fumigation. Depending on the product, make sure to turn off sources of electricity, sparks, or flame as dictated by the label.

Post-Application Operations: Make sure unauthorized people cannot get near the site during aeration. Determine gas concentration in the fumigated environment from outside if possible. Use the proper gas detector to determine fumigant concentration before re-entry into a fumigated structure. Turn on ventilating or aerating fans where appropriate and make sure to minimize bystander exposure. Remove warning placards when aeration is complete and the fumigated space has been cleared for re-entry using a detection device of sufficient sensitivity. Keep records of gas concentration monitoring inside (efficacy readings) and outside (safety readings) the fumigation environment to document completion of aeration.

Help with FMPs

Visit https://bit.ly/wda-fmp-template for an online fillable FMP template created by the Wyoming Department of Agriculture.

Visit Bulletins Live! Two at https://bit.ly/epa-endangered-species-bulletins to access EPA bulletins detailing use restrictions related to endangered species.

Post-Application Summary

While the FMP describes the plan for conducting the fumigation, the *Post-Application Summary* (PAS) serves a different purpose. The PAS describes and includes the following elements.

- Application and application block details.
- Fumigant-treated area and buffer zone posting and removal dates.
- Weather conditions.
- The National Weather Service forecast during application and 48 hours following application.
- Information on complaints, incidents, equipment failure, or other emergencies, and emergency procedures followed.
- Air monitoring results.
- Deviations from the FMP.
- Any actions that occurred during the application that were different from the FMP.
- Measurements taken to comply with Good Agricultural Practices (GAPs), if not recorded in the FMP.

The certified applicator-in-charge must complete the PAS within 30 days following the application. As with the FMP, the certified applicator and the owner must keep a copy of the PAS for 2 years.

Note

At the time of this writing, non-soil fumigant labels did not have information or requirements regarding the previous section ("Post-Applicator Summary") although soil fumigant labels do. The EPA may call for similar requirements for non-soil fumigants. As always, read the label to determine exactly what requirements pertain to you.

When a Fumigation Goes Wrong

Real-world Examples

What Happened

A seed facility with bagged breeder seed had a mouse problem. Under a consultant's license, a fieldman employed by the company drove to Portland, Oregon, and returned with a cylinder of Chloropicrin gas. He stated he was amused by the way people got out of his way due to the poison gas placards on his truck. A warehouse worker helped him place the cylinder in the middle of the warehouse floor that Friday evening. When he turned the cylinder on and exited the building, he wore a filtering facepiece respirator as he'd seen others do before. Once outside, he took a sharpie marker and made signs on cardboard for the doors: "Poison Gas do not Pass." He returned on Sunday to ventilate the area and brought a friend to call 911 in case he didn't come out. This time he used a rag to cover his nose and mouth. He successfully emerged from the building and waited with his friend while the building aerated. After a few hours he shut the doors and windows and left.

The manager arrived on Monday and opened the office, which adjoined the warehouse, and was "almost knocked down" from the odor. Despite opening windows and doors and using of fans, employees remained symptomatic. In September, the Oregon Dept. of Agriculture and Oregon OSHA became involved. The seed was embargoed, and air sampling showed high levels of chloropicrin. Not until the bagged seed was re-bagged did air concentrations drop.

What Should Have Happened

- The label and applicator's manual should have been read and followed.
- Air sampling should have been performed prior to entry.
- Applicators should have been trained on appropriate personal protective equipment.

How It Could Have Been Avoided

- Use the correct product.
- Follow the label.
- Attempt to eliminate the problem by other means.

What Was the Consequence

- The seed was embargoed.
- The seed was breeder seed and chloropicrin can affect germination.
- Oregon OSHA cited multiple violations. The company did not appeal the citation.

Personal Protective Equipment

LEARNING OBJECTIVES

- ☑ **Explain why it is important to follow label directions for PPE.**
- ☑ **List what PPE you need for fumigation.**
- ☑ **Compare and contrast PPE for different kinds of fumigants.**
- ☑ **Explain how to properly use PPE.**
- ☑ **Describe and compare the different types of respirators to use (and not to use) for fumigation.**
- ☑ **Explain when you are required to replace respirator cartridges or canisters.**
- ☑ **Explain the importance of a medical evaluation before using respirators.**
- ☑ **Explain when you are required to use a self-contained breathing apparatus and how to use it.**

Personal Protective Equipment

Clothing and devices (such as respirators) that protect you from contact with pesticides are called personal protective equipment. In this chapter, we will discuss some of the special concerns regarding the use of fumigants and personal protective equipment (PPE).

The label for each product lists the minimum PPE required for using that fumigant. PPE requirements vary with the fumigant and with the task you are performing. You are legally required to follow all PPE instructions and to wear at least the minimum PPE listed on the label.

Note that fumigants are distinct from other pesticides in that they are toxic as gases. Because of this, the PPE required when handling fumigants is often quite different from that required when handling other types of pesticides.

Basic PPE for fumigant applications

General Precautions

Take the following precautions whenever you handle fumigants:

- PPE is effective only if it fits correctly and is used properly. Directions for keeping it clean and maintaining it properly are on the fumigant label and in the manufacturer use instructions.
- Do not wear jewelry, watches, or other items that may trap fumigant gas against your skin.
- As discussed in Chapter 3, "Planning for a Fumigation," you must have a proper detector to determine fumigant concentration and select the proper PPE (or no PPE, if the space has been adequately aerated as determined by label instructions).

Protective Clothing

Some fumigants packaged in cylinders require you to wear long-sleeved shirts and pants during fumigant introduction. Others direct you to wear loosely woven work clothes and even short sleeves when handling fumigants. Tightly woven and tightly fitted clothes can trap fumigants next to your skin, which can lead to severe burns. Do not assume that you should wear a chemical-resistant apron or spray suit—some labels specifically tell you not to wear such items.

Eye Protection

Fumigant labels may be very specific about the type of eye protection to wear when a full-face respirator is not required. Labels for products contained in pressurized cylinders often require eye protection, such as goggles or full-face shield, during fumigant introduction to protect your eyes if the introduction hose bursts or disconnects from the cylinder.

Gloves and Footwear

It is not always recommended that you wear chemical-resistant gloves or boots when handling fumigants. Some fumigant labels may tell you to wear cotton gloves (which are normally prohibited for non-fumigant pesticides), while others require chemical-resistant gloves and footwear.

The need for gloves varies with the product. For example, some fumigants require you to wear gloves because of possible skin irritation. Other fumigants, particularly liquid products, do not require gloves; some may even prohibit you from wearing gloves. This is because some fumigants, such as methyl bromide, can cause serious injury if clothing or jewelry holds the gas tight against the skin.

Specific Tasks

PPE requirements for fumigants often vary not only by the product, but by the task as well. Labels may have one set of PPE requirements for fumigant handlers when performing tasks that will not expose them to contact with liquid fumigant and a separate set of requirements for handlers who are more likely to contact liquid fumigant.

PPE for Phosphine

Solid phosphine formulations react with moisture to release phosphine gas. Wear only lightweight cotton gloves and loose-fitting clothing while fumigating with or handling solid phosphine formulations so residues will not be trapped against the skin or exposed to perspiration. The gloves need to remain dry during pellet or tablet application. Gloves and clothing worn during fumigation should be aerated in a well-ventilated area prior to laundering.

Leather work gloves or leather-faced cotton gloves are recommended for handling phosphine formulations in cylinders.

Respiratory protection is required when phosphine levels are 0.3 ppm or higher. From 0.3 to 15 ppm, you need to use a full-face gas mask with a phosphine-specific filter cartridge or a supplied-air respirator. At levels above 15 ppm, or when levels are unknown, a supplied-air respirator is required. Note: There is no antidote for phosphine and even exposure to small amounts of phosphine can cause headache, dizziness, nausea, vomiting, diarrhea, drowsiness, cough, and even death.

Respirators

The most important PPE for fumigators is the respirator. A respirator is a safety device that covers at least a person's mouth and nose and protects the wearer from breathing in hazardous substances. Respiratory protection is required when concentration levels of fumigants are unknown or above specified levels.

Employer Responsibilities for Respirators

Training is crucial for the safe and effective use of respirators. If respirators are required by the product's label, employers must develop a formal respiratory protection program. This program must meet all of the requirements outlined in the Occupational Safety and Health Administration (OSHA) Respiratory Protection Standard (29 CFR 1910.134). These requirements include:

- Guidelines for fit-testing and educating respirator users.
- Medical evaluations before fit testing.
- Written operating procedures and scheduled maintenance, cleaning, and storage of respiratory equipment.

Respirator Use

OSHA Respiratory Protection Standard

For more information on OSHA's Respiratory Protection Standard and developing a respirator protection program, see OSHA's website at osha.gov/SLTC/respiratory protection/standards.html

Carefully review the respirator requirements on the label to determine:

- Whether you need respiratory protection,
- The correct type of respirator for that fumigant, and
- Situations when respiratory protection is needed.

All respirators used by fumigant applicators must be approved by the National Institute of Safety and Health (NIOSH). The specific type of respirator required may vary depending on the health of the applicator, the type of fumigant used, and the conditions of its use. Never substitute another type of respirator that is not consistent with what the label requires.

Types of Respirators

There are two basic types of respirators: air-purifying respirators and atmosphere- supplying respirators.

Air-Purifying Respirators

As the name suggests, air-purifying respirators clean the air around the user and filter out some contaminants. Depending on the type of air-purifying device, they provide varying levels of protection.

Particulate respirators are the simplest, least expensive, and least protective type of respirator available (Figure 2). These respirators only filter out particles. They do not protect against chemicals, gases, or vapors, and so cannot protect you from fumigants.

Chemical cartridge/gas mask respirators include a facepiece or mask and a piece that filters out specific gases (either a cartridge or a canister). Straps secure the facepiece to your head. The headpiece can be a half-face, which only covers your mouth and nose, or a full-face, which covers your eyes as well (Figure 3).

Figure 1: There are respirators on the market that are not NIOSH-approved, such as nuisance dust masks and some surgical masks. For more information and to make sure your respirator is NIOSH-approved, go to the NIOSH Trusted- Source website

Figure 2: Never use dust/mist respirators, also sometimes called dust masks or "N 95s," for any fumigant work. (Photo © UW-Madison Pesticide Applicator Training Program).

Powered air-purifying respirators (PAPR) uses a fan to draw air through the filter to the user. Compared to other respirators, PAPRs are easier to breathe through; however, they need a fully charged battery to work properly. PAPRs use the same type of filters/cartridges as other air-purifying respirators. They may be attached to a full-face headpiece or a loose-fitting hood that fits completely over the user's head (Figure 3).

How Air-Purifying Respirators Work

Purifying elements in air-purifying respirators have cartridges that remove specific contaminants from the air passing through them (Figure 4).

There are many different types of cartridges; each type is color coded with stripes indicating limitations and approved uses. The pesticide label specifies which specific cartridge to use based on the anticipated hazard and vapor present in your breathing zone.

The effective life of an individual cartridge varies according to the fumigant concentration, humidity, respiratory rate of the applicator, exposure time, and type of fumigant. Each cartridge, or the instructional material it came with, will state its maximum limits. Cartridges also list an expiration date. Never use a cartridge past its expiration date, regardless of whether it was ever unsealed. Make sure to crush expired canisters before discarding so they cannot be reused.

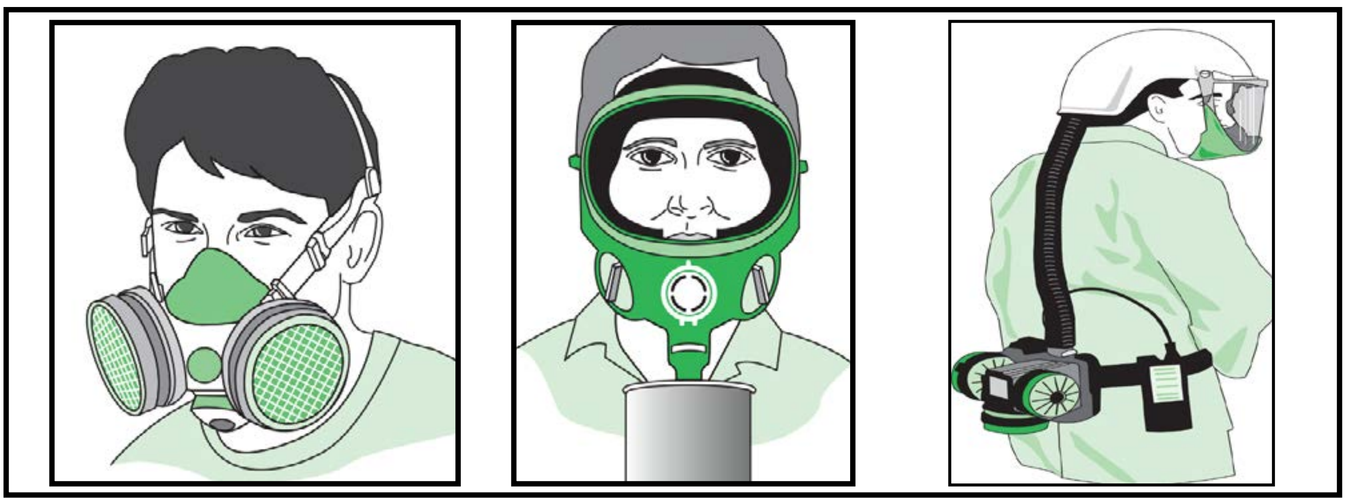


Figure 3: Half-face (left) and full-face masks (middle) use cartridges and/or metal canisters that contain material to filter air the user is breathing. Although the mask on the right shows a single canister, full facepieces also come with dual cartridges like the piece on the left. Anything that interferes with the respirator seal is not permitted when using a tight-fitting headpiece. This could include facial hair, earrings, scars, or facial piercings. A PAPR (right) is useful for people who may have problems breathing on their own through a regular air-purifying respirator. A full hood also helps people who cannot get a good seal on their face with tight-fitting headpieces. (Illustration © National Pesticide Applicator Certification Core Manual, NASDA).

Figure 4: A typical cartridge respirator has removable cartridges that filter out specific gases. They need to be replaced periodically. Some may also have a prefilter to trap particulates. (Photo © UW-Madison Pesticide Applicator Training Program).

To properly use a cartridge respirator, follow the practices below.

- Monitor the concentration of fumigant in the air you will enter to be sure the level does not exceed the level the canister is designed to purify.
- Make sure the cartridge brand matches the model and manufacturer of the facepiece. Cartridges and facepieces are not interchangeable among manufacturers. Also, match the cartridge to the fumigant.
- Remove the cartridge seals only when attaching them to the respirator. Be sure to remove both the top and bottom seal.
- Log the date and time when you removed the seals. This begins the life of the cartridge. Always dispose of any canister that has been unsealed for eight hours or more.
- Canisters and cartridges should be replaced whenever they are damaged, soiled, or cause noticeably increased breathing resistance. Do not rely on odor or taste.

Cartridge Replacement

Cartridges need to be replaced periodically to keep you protected. Most manufacturers provide information on their website to help in determining the appropriate change-out schedule for their product.

The specific fumigant, its concentration in the air while you are using the mask, and your length of exposure are the most important factors affecting how long a cartridge will last. Replace them under the following circumstances:

- At the first indication of fumigant odor, taste, or irritation
- According to the pesticide label or manufacturer instructions (whichever one is more frequent)
- When the end of service life indicator (ESLI) shows a color change indicating the unit has expired
- In the absence of any of the above instructions or indications, at the end of each day's work period.

Atmosphere-Supplying Respirators

Instead of purifying the surrounding air like cartridge respirators, atmosphere-supplying respirators provide clean air from an independent source. There are two types of atmosphere-supplying respirators: a self-contained breathing apparatus (SCBA) and a supplied-air respirator (SAR). Both have a full-face mask (or hood) that delivers air to the fumigator from a compressed air tank or from an ambient air pump. The main difference between the two is that with a SCBA, you carry the air with you in a tank on your back while with a SAR, the air tank or pump is located outside the fumigation area.

SCBA: Because you carry your air, you do not need to be connected to a stationary source of air, which gives you the mobility of a canister mask and does not restrict movement (Figure 5). However, the weight and bulk of a SCBA often makes work strenuous and difficult. Do not confuse SCBA with SCUBA (self-contained underwater breathing apparatus). These systems are not interchangeable.

Examples of Label Respiratory Requirements

A fumigant label specifies which type of respirator and cartridge to use for specific tasks. For example, a label may require:

- National Institute of Occupational Safety and Health (NIOSH) certified full facepiece air-purifying respirator equipped with an organic vapor (OV, NIOSH approval prefix TC-23C) cartridge and a particulate pre-filter (Type N, R, P, NIOSH approval number prefix TC-84A).
- Gas mask with a canister approved for organic vapor (NIOSH approval number prefix TC-14G).

Figure 5: SCBAs supply clean air from a tank you carry. They have an alarm to warn you when the air supply is low. (Illustration © National Pesticide Applicator Certification Core Manual, NASDA).

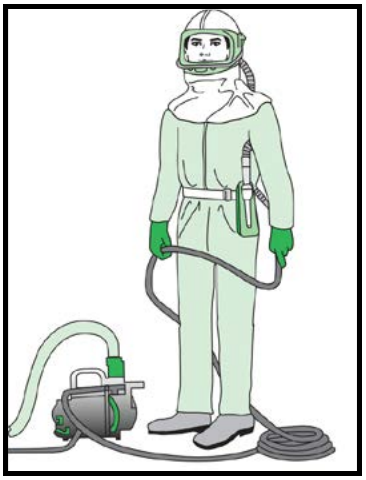


Figure 6: SARs provide longer use than SCBAs and are more lightweight. (Illustration © National Pesticide Applicator Certification Core Manual, NASDA).

SAR: SARs supply compressed air from a stationary source through a long hose (Figure 6). The air is supplied to a facepiece, helmet, hood, or a complete suit depending on the level of protection needed. However, there are drawbacks to SARs as well. The long hose can get kinks or be cut or damaged in some way that cuts off your air supply. The 200-foot maximum hose length also limits how far and in what direction you can move.

- Training is critical for the use of any SCBA or SAR. Before using one, you need to be thoroughly trained in how to store, inspect, maintain, and fit test the device. Before using the device, make sure that it is in good working order, has an adequate air supply for the job at hand, and provides an adequate seal around your face. You should also participate in periodic training exercises.

Respirator Medical Evaluation

Any fumigant handler who needs to wear a respirator is required by the label to be medically evaluated to ensure that their health and lung capacity are suitable for this task. Because of certain health conditions, some people do not medically qualify to wear respirators.

After a preliminary screening, a medical practitioner may determine that a physical exam is required. For example, if the fumigant handler has a heart condition, a medical evaluation is necessary before respirator fit testing.

Fumigant handlers must be reexamined by a healthcare professional if their health status, respirator style, or use conditions change.

Respirator Fit Test

After being cleared by a qualified medical practitioner to wear a respirator, you must be fit tested with the specific respirator you will use (Figure 7). A fit test verifies that a respirator is comfortable and correctly fits and protects the user. Fit test methods are classified as either "qualitative" or "quantitative." A qualitative fit test relies on the user's sensory detection of a test agent, such as a smell or involuntary cough (a reaction to irritant smoke). A quantitative fit test uses an instrument to physically measure the effectiveness of the respirator. You must be fit tested before you use your respirator for the first time and be re-tested every 12 months. Follow-up fit testing is also required under the following circumstances:

- The style of the facepiece has changed,
- The respirator size, model, or brand has changed,
- There is a physical change in the person's face (e.g., weight change or dental work) that would affect fit,
- Fit is unacceptable,
- At request of the user, or
- Employer policy.

Fit (or Seal) Check

Conduct a fit check (also called a seal check) before each use (Figure 8). This test helps you make sure your respirator forms a complete seal around your face. Be sure to clean your respirator according to manufacturer instructions after each use, inspect it regularly, and store it properly.

Figure 7: During a fit test, a user might be challenged with an irritating smoke or smell, such as a banana odor. If they can smell it, their respirator does not fit correctly. (Photo © Pacific Northwest Agricultural Safety and Health Center).

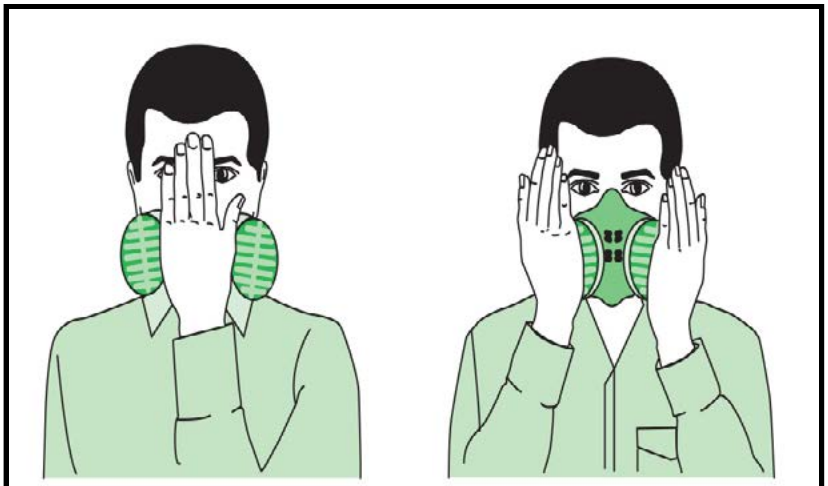


Figure 8: For a positive seal check, cover the exhalation valve on the front of the respirator and gently exhale. If you do not feel a rush of air around the faceplate, the seal is good. If you do feel air leaking under the facepiece, re-position and repeat the check until the seal is effective.

For a negative seal check, cover the inlet opening of each cartridge with your hands and inhale gently so the facepiece collapses. Hold your breath for about 10 seconds; if the facepiece stays collapsed, the seal is effective. If the facepiece expands or air leaks under the facepiece, re-position and repeat the check until the seal is effective. (Illustration © National Pesticide Applicator Certification Core Manual, NASDA).

When to Wear a Respirator and Which Type to Wear

Look to the label for guidance, when to wear and which type of respirator depend on what fumigant you are using and what exposure limits are listed on the label and the SDS. Exposure limits are the maximum fumigant concentrations applicators can be exposed to without using respiratory protection. Workers must wear respiratory protection when fumigant concentrations are greater than those limits, known as Permissible Exposure Limits (PELs), Threshold Limit Values (TLVs), or time-weighted average (TWA). These numbers represent the maximum concentration of a chemical considered safe for most people when exposed 8 hours a day, 40 hours a week. The goal is to keep exposure below these limits to protect yourself from adverse health effects (see Table 2).

More Information on Respirator Fit Tests

There are several sources to go to for more fit test information. To view OSHA's fit test rule: Appendix A to §1910.134—Fit Testing Procedures, visit https://bit.ly/osha-fit-test.

Table 1. Respirator Types and Characteristics

Respirator by Air Source	Respirator Type	Other Names Used	Coverage	Type of Protection
Air-Purifying	Particulate	N-95, dust mask, dust/mist respirator	Typically mouth and nose.	Particulates only. Cannot use for fumigants.
	Half-mask	Gas mask	Mouth and nose.	Protection by filtration: Can protect from particles and vapors/gases depending on the type of cartridge/canister.
	Full-face	Gas mask	Mouth, nose, and eyes.	Protection by filtration: Can protect from particles and vapors/gases depending on the type of cartridge/canister.
	Powered air-purifying respirators (PAPRs)		Can have a tight fitting* half- or full-face mask, or a loose-fitting* hood that goes over the whole head.	Protection by filtration: Can protect from particles and vapors/gases depending on the type of cartridge/canister.
Air-Supplying	Self-Contained Breathing Apparatus	SCBA (not to be confused with SCUBA, which **cannot** be used for fumigation)	Can have a tight fitting* half- or full-face mask, or a loose-fitting* hood that goes over the whole head.	Protection by a supply of clean air carried in a tank by the wearer.
	Supplied-air respirator	Airline respirator	Can have a tight fitting* half- or full-face mask, or a loose-fitting* hood that goes over the whole head.	Protection by a supply of clean air supplied to the wearer through hoses from a compressed air tank or from an outside ambient air pump.

* NOTE: Any "tight-fitting" headpiece needs to be fit-tested. Loose-fitting pieces do not need fit-testing.

Table 2. Fumigant concentration requiring respiratory protection:

Fumigant	Gas Concentration (PEL)	Respiratory equipment required
Phosphine	Less than 0.3 ppm	None required
	0.3 - 15 ppm	NIOSH approved full face canister respirator – hydrogen phosphide canister combination
	Greater than 15 ppm or when concentration is not known	NIOSH approved self-contained breathing apparatus (SCBA)

When a Fumigation Goes Wrong

Real-world Examples

What Happened

An irrigation district applicator was treating ditches with Acrolein. A neighbor wanted to enter their property and a hose was damaged in the process, spraying the applicator. The applicator took the label and SDS to the hospital with him. The SDS states that exposed individuals should be monitored for pulmonary edema. The emergency room doctor did not consult either the label or the SDS and sent the applicator home after an examination. The applicator's wife got him situated on the couch and went back to town to get his medications. When she returned, he had passed away where she had left him from pulmonary edema.

What Should Have Happened

The applicator should have remained hospitalized and monitored for pulmonary edema.

How It Could Have Been Avoided

Due to the limited awareness physicians have regarding pesticide poisoning, it is critical to self-advocate. If someone is incapacitated and can't do so, then someone working with that individual should speak up. If the physician is not receptive, one could contact the Poison Control Center to intercede on their behalf.

Also, the applicator should have had the neighbor wait until all the equipment was safely moved.

What Was the Consequence

Death of the applicator.

Fumigation Methods and Application Equipment

LEARNING OBJECTIVES

- ☑ **Describe the application methods and equipment commonly used for non-soil fumigation.**
- ☑ **Discuss the possible compatibility concerns for fumigants and application equipment, including tanks, hoses, and tubing.**
- ☑ **Describe how rate of air exchange, temperature, and sorption/desorption affect aeration time.**
- ☑ **Define half-loss time and load factor.**
- ☑ **Describe the basic procedures and precautions for aerating a fumigation chamber, sealed building, or the subject of a tarpaulin fumigation.**
- ☑ **Discuss what to do when there is an equipment failure.**

Steps to Fumigation

The objective of all non-soil fumigation methods is to introduce a lethal concentration of gas into all parts of the treatment site (e.g., rodent burrow or grain bin) and maintain that concentration long enough to kill all stages of pests present. The site and/or items that need to be treated usually dictate the best fumigation method. The following basic steps are part of all (or nearly all) fumigations:

- Secure the fumigation site,
- Seal the site,
- Release the fumigant,
- Monitor the fumigant,
- Determine exposure period,
- Aerate the site, and
- Clear the site.

Fumigation Methods

Non-soil fumigations can be categorized as *structural* or *burrow.*

Structural Fumigation

For purposes of fumigation, a structure refers to the whole or partial physical construction that needs to be fumigated. Farm structures such as grain bins, silos, barns, or storage buildings are common examples.

Any structure can (and almost always needs to) be sealed by tarp, and/or tape-and-seal before introducing fumigant.

Equipment

Sealing Materials: There are numerous sealing techniques, but the most commonly used supplies include plastic sheeting, adhesive tape, adhesive sprays, and expandable foam caulking. When using tarps, you will also need clamps to seal tarp edges and snakes (water or sand-filled) for ground seals.

Cylinders and Hoses: Fumigants are often applied directly into the treatment site as gases from pressurized cylinders (Figure 1) through an introduction hose (also called shooting tubes). Sometimes fumigants get delivered as liquids, with the hose dripping the liquid into an evaporation pan. The rate of introduction of the fumigant is controlled by the length and inside diameter of the introduction hose. The longer the hose and narrower the inside diameter, the slower the introduction rate. When possible, place the cylinders outside the fumigated space to reduce workers' exposure (Figure 2). For large sites, use multiple hoses to rapidly attain equilibrium.

Introduction of Tablets or Pellets: To fumigate a building with phosphine, simply place the required number of tablets or pellets (determined by the volume and commodity) in each room of the building. It's helpful to scatter them on a cardboard tray to contain the spent residue. **Never** place aluminum phosphide on a wet surface or in standing water since it will evolve the gas too fast and could possibly ignite or explode.

For grain bins, you can apply pellets or tablets continuously by hand or by an automatic dispenser on the belt or into the fill openings as the grain is loaded into the bin. You can also use an automatic dispenser to add fumigant into the grain stream in the up leg of an elevator.

Figure 1: When releasing fumigant from a cylinder, wear eye protection and make sure that the hose discharges away from you. (Photo © Betsy Danielson, Iowa State University Extension and Outreach).

Figure 2: It is highly recommended to release fumigant from outside the building to minimize applicator exposure to the fumigant and increase safety. Here, operators get ready for a large fumigant operation with cylinders outside the structure attached to hoses leading inside. (Photo © Douglas Products).

You can use a probe to distribute tablets or pellets more evenly after grain is already in a bin (Figure 3). Insert the probe into the grain pile to the desired depth. Drop in the tablets or pellets. Pull the probe upward in evenly spaced intervals, stopping to drop in more product. Continue until the desired amount of product is used for a single probe. The last tablets or pellets applied through the probe should be about six inches below the surface. Repeat until the total amount of product for the fumigation is applied, distributing the probes evenly throughout the grain pile.

When probing, always wear a safety harness and rope along with your other PPE. Work in teams if possible.

Tarps: If you apply the fumigant on the surface or with probes, you can cover the entire surface of the grain with polyethylene sheeting. Phosphine cannot easily penetrate poly tarps and they will reduce gas loss substantially as well as reduce the amount of fumigant required (because you are not fumigating the empty space above the grain).

Fans: A fan can be used to help introduce the fumigant (Figure 4). You might need multiple fans to spread fumigant evenly and quickly throughout the space or commodity being treated (whether you're using cylinders or solid formulations). The fumigant must move into the structure's cracks and crevices, and into spaces within the stored commodity to contact all pests. Some grain storage structures have built-in aeration or recirculation systems that can aid in circulating and aerating the fumigant.

- When using phosphine, you **must** use non-sparking fans since heat sources can cause phosphine to ignite.

Monitoring Lines and Equipment: Just as you might need multiple introduction lines for a large treatment area, you might also need multiple monitoring lines. If the lines are long (several hundred feet) some labels recommend using a vacuum purge pump, which ensures timely, accurate samples from all areas within the structure.

Burrow Fumigation

Fumigants are sometimes used to control burrowing *vertebrate* pests. Vertebrates are animals with an internal backbone. Typically, you might use fumigants to control rodents like prairie dogs, pocket gophers, and ground squirrels.

Even when labeled for burrows, using fumigants is prohibited within 100 feet of buildings. Labels will contain a statement such as:

> "FOR BURROWING RODENT APPLICATIONS: THE USE OF THIS PRODUCT IS STRICTLY PROHIBITED WITHIN 100 FEET OF ANY BUILDING WHERE HUMANS AND/OR DOMESTIC ANIMALS DO OR MAY RESIDE ON SINGLE AND MULTI-FAMILY RESIDENTIAL PROPERTIES AND NURSING HOMES, SCHOOLS (EXCEPT ATHLETIC FIELDS), DAYCARE FACILITIES AND HOSPITALS."

Other important restrictions might include contacting state or federal agencies prior to fumigating burrows if there is a chance of harming federally protected non-target species (e.g., black-footed ferrets).

Before conducting a fumigation, you must assess whether a fumigation is even possible, and if so, how to conduct it safely and effectively. Make sure to survey the site, identify possible non-target species, and assess the burrow(s).

Figure 3: You can buy commercially made phosphine probes or make them from electrical conduit, plastic pipe, or tubing like the one pictured above. (Photo © Garo Goodrow, Penn State).

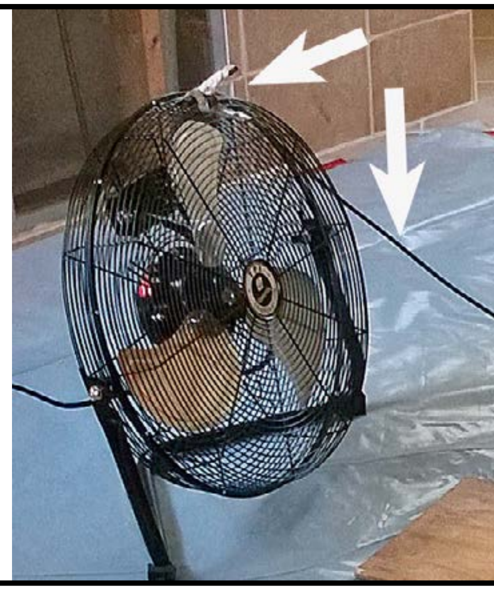


Figure 4: You can use fans to introduce fumigant to the site. Note the fan with attached introduction hose in this picture. Fans are also useful—and sometimes necessary—to make aeration practical, especially under calm conditions. (Photo © Bonnie Rabe).

Currently three types of fumigants are registered by the EPA for use in burrows: ignitable gas cartridges, carbon dioxide, and aluminum phosphide-based tablets/pellets. These are explained in more detail in Chapter 7, "Burrow Fumigation for Vertebrates."

Aeration

Aeration procedures vary according to the fumigant and the type of installation and/or items being fumigated. Always read and follow label instructions for the fumigant and the situation for which it is being used. Because it is difficult to predict wind speed and direction, the fumigator should plan for every possibility. Aeration under calm, cold conditions may take several days.

Factors Affecting Aeration Time

In addition to the characteristics of the fumigant itself, the rate of ventilation and aeration are affected by several factors. The most important are load factor, rate of air exchange, and temperature.

Load Factor

The amount of fumigant sorbed by materials is referred to as the *load factor*. This sorbed fumigant is not available to act as a fumigant but must still be removed during aeration. Some commodities are much more sorptive than others, just as some fumigants are more subject to sorption than others. The greater the sorptive capacity of the fumigant and commodity, the longer the desorption process and the greater the aeration time needed.

The greater the surface area of the commodity, the greater the sorption rate and the longer the aeration period. For example, open machinery aerates more rapidly than bagged flour. Make sure you factor fumigant retention by highly sorptive materials like grain, flour, meals, and jute bags.

Rate of Air Exchange

The rate of air exchange within the structure or area is the most important factor affecting aeration. The exchange rate is proportional to wind velocity through the area, size and arrangement of the fumigated site, and the mixing of gases. The time that it takes the initial concentration of fumigant to be reduced by half is referred to as *half-loss time* (HLT). In atmospheric chambers, an exchange time of one air change per minute is desirable. The most effective practical method is to increase cross ventilation (Figure 5). Loaded areas aerate much more slowly than empty areas. The rate of fumigant lost from an enclosure also depends on leakage and fumigant sorption.

Temperature

Higher temperatures favor diffusion of the fumigant and increase the rate of desorption.

Aeration Procedures

Procedures for aeration and ventilation vary with the fumigant and the structure and/or commodity being fumigated. Make plans for aeration before starting the fumigation. Release free gas and aerate commodities immediately following fumigation.

When outside, you may aerate the structure safely by opening the door slightly at the beginning of the aeration period and turning the blower on. Prop the door partially open so it cannot accidentally close and vent air discharged from the blower outside of the chamber. If the door closes, the partial vacuum created by the blower may damage the chamber.

No one should remain near the door or the exhaust when the blower is turned on. You can fully open the doors after about 15 minutes, but don't let workers enter the chamber until it has been checked with an appropriate detector.

If you must enter the structure before the fumigant concentration has decreased to a safe level, wear an approved respirator, generally a SCBA. At least two trained and certified applicators, wearing supplied-air respirators or gas masks, must work together (check the label for which type of respirator to use and at what levels of fumigant you need them). Also turn on any fans that might assist in aeration. You should leave the structure every 15 minutes or so for fresh air.

Allow no one but a certified applicator with proper PPE into the structure until detectors indicate the fumigant concentration is below the threshold level in all parts of the structure.

Equipment Compatibility and Equipment Failure Concerns

Make sure you use the proper equipment for whatever fumigant you will be using. Labels will tell you if there are materials you should not use with a particular product. For example, phosphine gas, especially in the presence of moisture or ammonia, reacts with silver, copper, and copper alloys. Copper-containing equipment, such as electrical devices, could be severely damaged. Remove or protect electronic equipment to avoid damage from phosphine.

Equipment Failure

Applicators should always be prepared for the possibility of equipment failures and other emergencies. If possible, rehearse the fumigation process, common equipment issues, and emergency evacuation before performing the fumigation. Rehearsals provide the opportunity to detect problems in emergency plans, and to correct them.

- If an equipment failure results in fumigant being released where it shouldn't, always make sure you put on the proper PPE to protect yourself before attempting to make repairs.

Whenever possible, make sure to have standby equipment and/or replacement parts for application equipment, PPE, hoses, clamps, sealing material, gas detectors, and other equipment on hand. In some cases, this is mandated on labels. For example, if a label calls for a SCBA, you must have a second SCBA on hand during each fumigation in case you need to make an emergency entrance into a fumigation enclosure. The second SCBA is for potential use by another trained person who must be on site if you enter the fumigation enclosure.

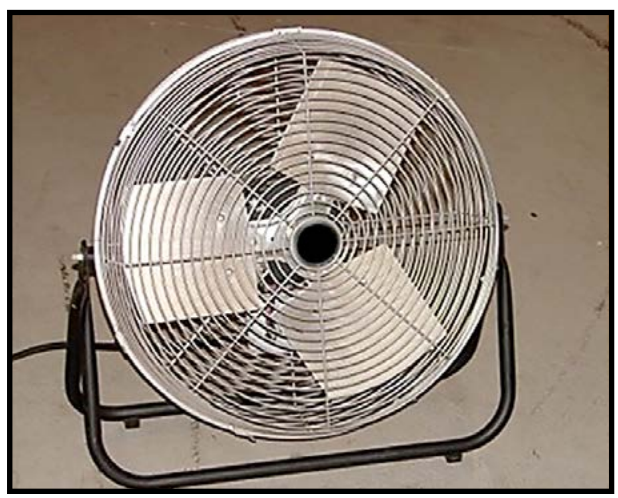


Figure 7: Fans are useful for aerating after a fumigation. Remember to use non-sparking fans to minimize the risk of fire.(Photo © Cardinal Products).

When a Fumigation Goes Wrong

Real-world Examples

What Happened

Applicators were drilling multiple holes into telephone poles and upended a pint bottle with flex tube attachment into the hole, dispensing liquid chloropicrin. In between poles, the applicators were not capping the flex tube. Walking between poles, the applicator tripped and dropped the bottle. The bottle hit the ground and the liquid chloropicrin splashed into the applicator's face and one eye. The applicator was not wearing eye protection, nor was there an emergency eyewash to enable him to flush his eyes.

What Should Have Happened

The flex tubes should have been capped in between poles. The applicator should have worn eye protection and an emergency eyewash should have been present and available.

How It Could Have Been Avoided

The flex tubes should have been capped. Emergency eyewash should have been available. The label required PPE.

What Was the Consequence

The applicator had irreversible eye damage to his left eye.

Burrow Fumigation for Vertebrates

LEARNING OBJECTIVES

- ☑ **Describe the uses of burrow fumigation.**
- ☑ **List any specialized equipment you need.**
- ☑ **Briefly outline potential pests you can control.**
- ☑ **Explain any unique label requirements for burrow fumigation.**

Burrow Fumigation

Typically, you might use fumigants to control mammals such as woodchucks, prairie dogs, Norway and roof rats, mice, ground squirrels, moles, voles, gophers, and chipmunks.

General Principles for Fumigation of Burrows

Fumigants work best when soil moisture is high, such as in early spring, after soaking rains or irrigation. Moisture fills gaps between soil particles, which helps keep fumigant gases contained within the burrow system. Even when using best practices, burrow fumigants seldom achieve 100% control of the animals in treated burrows. You usually need to do follow-up treatments of active burrows. Since fumigants have no residual effect, neighboring animals can move into the treated burrows. To reduce the risk of this, control as much ground as is occupied by the target species. Community-based efforts improve long-term success.

Most fumigant work is used to control vertebrate pests on small acreages, sparse populations, or as a cleanup following use of toxic bait.

Advantages and Disadvantages of Fumigants for Burrowing Pests

Since fumigants have a wide range of application temperatures, they can be used throughout much of the year provided that temperatures are above minimum levels listed on the product label.

Fumigants have a few disadvantages, including cost. Researchers estimate fumigation applications cost 5 to 10 times more in labor/product than toxic baits to treat the same amount of ground. Fumigants also pose risks to applicators as we've discussed throughout this manual, often requiring the use of specialized PPE. Also, fumigants do not target specific pest animals. Any animal in the burrow will be killed, whether it is a targeted animal or not.

Surveying the Fumigation Site

Burrow fumigants are highly toxic to all wildlife. Both target and non-target species may inhabit burrows (even the same burrow). Label instructions contain guidelines designed to reduce the risk of killing non-target animals, especially threatened and endangered species.

The fumigant product you use may require you to survey the proposed treatment area to determine if any non-target animals could be harmed by the treatment. The extent of these surveys varies by label and site. Some simply require a visual inspection (morning and afternoon) of the treatment area 24 hours prior to fumigation. Others may involve intensive multi-day surveys. A good visual inspection includes identifying all burrow openings (main entrance and all emergency exit holes) and burrows/areas that should be avoided, such as those occupied by non-target animals.

Assessing the Burrow

Treatment of empty burrows or burrows occupied by non-target animals is not only illegal, but it also wastes time and money. The appearance of the animal's scat, the size of the burrow entrance, and the burrow's architecture are all factors that must be considered when determining whether a burrow is appropriate for fumigation.

Signs of Target Burrows

Many rodent and wildlife pest species are easily seen during daylight hours. If you encounter a burrow that does not match the typical burrow size of the animal you are targeting, avoid it or make sure to investigate carefully before treating it. Below are typical burrow diameters for target species.

- Ground squirrel: 2 to 4 inches.
- Prairie dog: 4 to 10 inches.
- Woodchuck: 10 to 12 inches.

Signs of Inactive Burrows

Inactive burrows are characterized by the following:

- Burrow is completely or partially collapsed.
- Burrow seems unkempt and lacks evidence of recent digging.
- Burrow area lacks presence of fresh droppings/feces.

Label Restrictions

All products labeled for burrowing pests can ONLY be used in outdoor burrows. Target pest animals must be listed on the label and the pesticide can only be used to control these pest species.

Endangered Species Bulletins

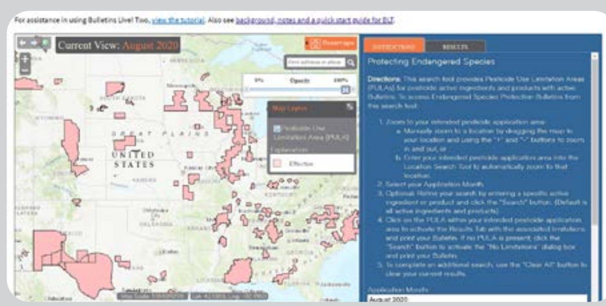
Registered fumigants labeled for use in outdoor burrows require applicators to obtain endangered species bulletins for the area where the treatment will occur. Copies of these bulletins can be obtained from EPA's Endangered Species website. Some labels require you contact the U.S. Fish and Wildlife Service and/or state agencies prior to applying the fumigant. There may also be local ordinances or tribal restrictions prohibiting use of fumigants.

Protecting Endangered Species

When the EPA determines that the normal use of a particular pesticide may harm a listed endangered species or its critical habitat without certain extra use limitations, those extra restrictions are detailed in a bulletin.

Bulletins are required to be downloaded at the EPA's **"Bulletins Live! Two"** website at https://bit.ly/epa-endangered-species-bulletins.

The bulletins list any special restrictions on the use of the product and are usually geographically based. As with any label requirement, these restrictions are legally binding. These bulletins are only valid for 6 months and must be with you during the application.



CHAPTER 8

Specifics about Prairie Dogs

LEARNING OBJECTIVES

- ☑ **Identify the classification and species**
- ☑ **Describe the physical characteristics, biology (diet, reproduction), social habits, and habitat**
- ☑ **Describe nuisance behaviors (signs of infestation) and when they become a problem**
- ☑ **Explain effects on the environment and ecosystem**

In Wyoming, prairie dogs evoke a range of opinions and labels as they are both species of concern and agricultural pests. This chapter includes the background of prairie dogs and how they have impacted Wyoming rangeland landscapes; the classification and species of prairie dogs in Wyoming; and their physical characteristics, biology, social habits, habitat, nuisance behaviors, and effects on the ecosystem.


Henk Bentlage, shutterstock.com

CLASSIFICATION AND SPECIES

Prairie dogs occupy an estimated two million acres in North America. There are two species of prairie dogs in Wyoming. The Cynomys leucurus, or white-tailed prairie dog, is primarily found in western Wyoming, while the Cynomys ludovicianus, or black-tailed prairie dog, is primarily found in eastern Wyoming. Black-tailed prairie dogs tend to have larger and denser colonies and invoke more controversy regarding their impacts on rangeland ecosystems. This manual focuses on the management of black-tailed prairie dogs. They will henceforth be referred to as prairie dogs.

PHYSICAL CHARACTERISTICS

Prairie dogs are relatively large burrowing ground squirrels weighing 1.5 to 3 pounds and are 14 to 17 inches long. They have reddish tan fur, large eyes, short ears, and broad, round heads.

HABITAT

Prairie dogs are a social wildlife species. These burrowing rodents colonize into large groups as a strategy for protection from predator species that rely on them as a food source.

Prairie dogs are primarily active during daylight hours. Unlike other species of prairie dogs, black-tailed prairie dogs maintain these activities all year as they do not typically hibernate in the winter. They split the time spent above ground evenly between foraging, socializing, and watching for predators. In addition to foraging near burrows, they also clip and remove vegetation to increase their ability to visually detect predators.

Burrow mounds are used as vantage points as prairie dogs spend about one-third of their time scanning for predators.

Coterie – colony – complex – ward

Prairie dogs form colonies commonly referred to as prairie dog towns. Colonies are made up of coteries, small family groups. Coteries are generally composed of one adult male, three adult females, and six offspring.

A complex is several closely located colonies, within four miles of each other, with suitable habitat between colonies to facilitate individual movement among colonies.

Susan Natoli, shutterstock.com

If the closely located colonies are separated by barriers of unsuitable habitat that prohibit individual movement among colonies, like water, they are considered wards.

Prairie dogs within a coterie defend their territory within the larger colony. They live in burrows about 10 yards apart, 3 to 14 feet deep, and 10 to more than 100 feet long. A mound 3 to 10 feet across and 6 to 12 inches high at the entrance of the burrow prevents water from rushing in and serves as a lookout station. A density of 35 black-tailed prairie dog mounds per acre is common, although up to 95 mounds per acre have been reported. Burrow systems have one to three entrances.

Prairie dogs are unique from most wildlife species because their populations are estimated by density (number of prairie dogs per acre) of occupied area rather than counts of individuals, which can vary greatly depending on season, region, and climate. Their numbers vary from about 3 per acre in late winter to 89 per acre after the birth of pups in the spring. Population density also depends on site suitability, resource availability, and fatalities from disease outbreaks.

BIOLOGY

Male and female prairie dogs reach sexual maturity at two years of age. Mating occurs on a single day, typically in February and March. Prairie dogs mate with a new individual each year and sometimes mate with different individuals during their single day of mating. The gestation period for a growing pup is 28 to 34 days. Litters are born in the spring with an average size of three pups. The pups will venture above ground when they are five to six weeks old. About half of the pups don't survive their first year due to predation, infanticide, and harsh winter conditions.

Prairie dogs can live up to 8 years. Females typically live 4 1/2 years and males about 2 1/2 years. The differences in lifespan are attributed to the risky activity of young adult males. For example, young males permanently leave their birth home in search of a mate and new food resources in another coterie within the same colony—a process called dispersal. If unsuccessful, males must leave their colony in search of a mate in a separate colony, becoming a target for predators because they do not have a burrow for safety or family members to warn them of approaching predators.

Dispersal of year-old juveniles and a few adults takes place in late spring. Most prairie dogs travel less than two miles, but a few may move up to six miles.

Prairie dogs are active only during the day. Black-tailed prairie dogs do not hibernate but will stay below ground for several days during cold cloudy weather.

Prairie dogs are herbivores whose diet is at least 85 percent grass, primarily blue grama, wheatgrasses, sun sedge, and sand dropseed.

SOCIAL PATTERNS

Communications within a colony are essential for the survival of prairie dogs, as there are many predator risks associated with being above ground. Some prairie dogs will serve as a sentinel or guard of the colony. If the sentinel sees a predator, like a coyote, or a threat, like a human, it issues an alarm call to alert fellow colony members. The alarm call is quickly repeated by other colony members to increase the likelihood all members are notified and escape predation. To the human ear, prairie dog alarm calls might sound simple and unintelligible. However, their sophisticated and complex language can describe many different features about a threat. For example, alarm calls describe if the threat is aerial or terrestrial and the type of predator. This level of information helps prairie dogs decide how much energy to expend in response to the threat.

If a coyote is the cause of alarm, prairie dogs run to their burrow entrance, but stay above ground unless the coyote approaches. However, if a colony is threatened by an American badger, prairie dogs will immediately hide below ground because badgers are capable of excavating their burrows. Similarly, if an agile predator like a hawk or eagle flies overhead, prairie dogs will immediately hide below ground. Once the threat is gone, prairie dogs issue a second call known as the all clear or jump yip. This call is different from the alarm call, both in sound and body language. To make this call, prairie dogs stand on their hind legs with arms in the air and head back, then jump and emit the yip. This call of excitement and relief can be so enthusiastic that prairie dogs fall over backwards when making the jump yip.

HEALTH RISKS

Prairie dogs are hosts for fleas, making them susceptible to plague. Plague may be transmitted to humans via flea bites. Early symptoms of plague in humans include swollen and tender lymph nodes, chills, and fever. Early diagnosis and treatment is imperative. When walking through suspected plague areas, apply an insect repellent to socks and pant cuffs before tucking pants inside boots. Prairie dogs often carry fleas, which carry diseases that can be passed to livestock. One of the most destructive diseases spread by prairie dogs is the silverback plague, also known as the bubonic plague, which is caused by the bacterium Yersinia pestis. That plague maintains an indefinite life cycle in hosts like fleas and mice. However, the bacteria can be transmitted to new hosts through contact with fleas. Prairie dogs have no natural immunity to the plague bacteria. Thus, exposure to plague causes almost 100 percent mortality in both small and large colonies. As a result, the structure and population densities of prairie dog colonies are greatly altered following plague. Plague is also a human health issue because it can transfer from prairie dogs to humans and pets, as evidenced by three cats contracting plague in northeastern Wyoming in 2018.

ECOLOGICAL AND ECONOMIC IMPORTANCE

Prairie dogs are considered ecosystem engineers, foundation species, and keystone species. These designations are all based on the importance of their presence and associated activities that have unique and significant effects on rangeland systems.

The burrowing activity of prairie dogs provides the greatest ecological benefit by decreasing soil compaction, increasing water intake, aerating the soil, and promoting soil formation. Their foraging vegetation and clipping activities can alter the vegetation in the colony by favoring certain grass and forb species. Grass species favored by prairie dogs include western wheatgrass, buffalograss, and grama grasses. Prairie dogs also provide recreation for photographers, hunters, and naturalists.

Prairie dog burrows serve as homes for burrowing owls, cottontail rabbits, rattlesnakes, and other animals. In Oklahoma, 89 vertebrate species were associated with prairie dog towns. Prairie dogs are a major food source for predators, including the endangered black-footed

> Ecosystem engineers—Creates or alters the availability of resources available to other species in the ecosystem.
>
> Foundation species—Its environmental modifications create habitats supporting other species in the ecosystem.
>
> Keystone species—Plays a critical role in an ecosystem such that if the keystones species were to disappear, the ecosystem would be dramatically different or would cease to exist.

ferret, badgers, coyotes, foxes, prairie falcons, ferruginous hawks, and eagles.

EFFECTS ON RANGELAND ECOSYSTEM

Prairie dogs are important to the environment and ecosystem and can have positive impacts when managed correctly. However, when a rangeland area becomes infested with prairie dogs, they create many problems for the plants, animals, and humans sharing the same areas.

One of the ways prairie dogs affect the environment is with forge quantity versus quality.

The role of prairie dogs in reducing available range forage for livestock is not well studied. Several factors can influence forage reduction, including geographic location, rainfall, dominant grass species, and duration of prairie dog habitation.

Recent research suggests effects ranging from 20 to 30 percent less forage to an increase in the percentage of grass species preferred by livestock. However, other studies indicate that reduced forage quantity does not necessarily equate to limited livestock production. Effects of prairie dogs on forage quantity and quality are highly variable across space and time and competition may be evident under dry conditions, but offset under wet conditions. Lower quantities of forage can be partially offset by increased forage quality. Grasses with increased palatability and crude protein are stimulated by grazing. For example, both bison and cattle preferentially graze on the edges of prairie dog colonies. This behavior could be the result of cattle foraging to balance forage quality and forage quantity intake. Grazing animals may utilize areas without prairie dogs primarily for forage quantity like bulk feeding, and use prairie dog colonies to obtain more nutritious forage. In addition, prairie dogs sometimes clip and or eat plants that are toxic to livestock. Many grazing animals appear to prefer feeding in prairie dog colonies over non-colonized grassland.

However, if quantity is reduced to such a level where it does become limiting for livestock, the higher quality may not matter. Simply put, it is important to manage the population of prairie dogs on rangelands in order to maintain a sustainable quantity of forage grasses for livestock.

As stated previously, large populations of prairie dogs will compete with livestock by consuming similar grasses. Since prairie dogs feed earlier in the spring and clip the grass, those grass stands will eventually disappear. The damage to native grasses can take at least a decade to repair. Additionally, those grasses will often be replaced with less palatable grass species with lower nutritional value. Prairie dog activities encourage shortgrass species, perennials, forbes, and species that are resistant to grazing when forage quality is low. This can negatively affect cattle weight gain. A six-year study in the shortgrass steppe of eastern Colorado compared weight gains of yearling steers between pastures with black-tailed prairie dogs and those without prairie dogs. Yearling steer weights decreased by five percent when prairie dog colonies occupied 20 percent of a pasture, and weights decreased by 13 percent when colonies occupied 60 percent of a pasture. Prairie dog effects on cattle weight gain are highly dependent on pasture size. The authors of the shortgrass study suggested economic loss caused by prairie dogs would be greater in more productive systems like mixed grass prairie, where the grasses are generally taller and thus more biomass is diverted from livestock grazing as a result of prairie dog grazing. Forage quantity is therefore reduced when larger prairie dog populations are present. This is due not only to their similar eating patterns, but also their activities. Overall, prairie dogs may remove 18 to 90 percent of the available forage through their burrowing and daily activities.

In the ranching industry, prairie dogs have been long recognized as a native wildlife species that competes with livestock for forage. This competition and reduction of available forage on rangelands is intuitive, as prairie dogs are herbivores whose diet relies heavily on a grass diet that overlaps with livestock grazing. Composition between prairie dogs and domestic livestock, particularly beef cattle, has been estimated at 75 percent, primarily due to the preference of grasses by both species. Their effects are visually apparent as areas within prairie dog colonies may be nearly devoid of vegetation. However, the relationship between livestock and prairie dogs can be complicated.

Some animals, including cattle and bison, show a preference for consuming grass at the edges of prairie dog colonies. At the same time, prairie dogs can reduce available forage and livestock weight gains, particularly during droughts and in times or places where prairie dogs are very abundant. Diet competition between prairie dogs and cattle is likely most pronounced during the summer, as prairie dogs consume relatively more grasses in the summer than in any other times of the year. This is also the season when cattle are moved to public grazing allotments, where prairie dogs most commonly occur since prairie dogs eat the same grasses as cattle and sheep. Having a few thousand extra mouths to feed can ruin a ranch.

Prairie dogs often begin feeding on pastures and rangeland earlier in the spring than cattle and clip plants closer to the ground, keeping the grasses short so prairie dogs

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can see their surroundings. After a prolonged period of prairie dog activity these grasses will disappear, negatively affecting livestock production. Ultimately, when prairie dog populations become too large, their habitats and behaviors become detrimental to the ecosystem.

When a prairie dog tunnels into the ground, it leaves behind deep holes, and if a cow or horse steps into them, the animal may break a leg and have to be put down. The burrows also increase soil erosion and are a potential threat to livestock and machinery as well. Damage may also occur to ditch banks, impoundments, field trails, and roads.

While prairie dogs have shaped Great Plains ecosystems, they are also controversial in ranching communities. It is imperative to maintain a proper ecological balance between prairie dog populations, wildlife, and livestock competition. When prairie dog populations are too large, this can limit livestock productivity, cause damage to the rangeland, and pose danger to other animals and humans. However, when prairie dog populations are too low, this can negatively affect the habitats of plants and animals who depend on them for their livelihood. Striking a balance has been a persistent rangeland management challenge. Interactions among prairie dogs, livestock, humans, and Great Plains ecosystems are complex, and rangeland owners and managers need to have a robust understanding of prairie dog issues in order to make management decisions that align with their goals and objectives.

Prairie dog management tactics

As you learned previously, prairie dogs can be both beneficial and detrimental to the ecosystem; therefore, properly managing prairie dog populations is essential to maintaining balance between the animals and humans who interact with the land. Many techniques have been tested to control or manage prairie dog populations, but the effectiveness defined as decreased prairie dog colony density and economic feasibility remains unclear. Many management techniques can also have direct consequences and secondary effects on non-target species like the federally endangered black-footed ferret, birds, insects, and small rodents, so care is required when employing control techniques.

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MANAGEMENT APPROACHES

Alteration of habitat

Changing the prairie dog habitat can encourage the reduction of their population and natural migration to a different area. Spraying herbicide, piling physical materials like rocks or trees, or providing perches to encourage raptor predation are ways to accomplish this goal. However, it is difficult to determine effectiveness and is expensive to maintain over time.

Contraception

Used to reduce reproductive rates. However, synthetic hormones can accumulate in predators and cause secondary effects.

Trapping

Prairie dogs can be captured using different trapping techniques, including:

- Double-door cage traps baited with a horse sweet feed mix
- Flushed from burrows with soap and water
- Removed from burrows with a large vacuum truck

All three of these methods are expensive and their long-term effectiveness is largely unknown. Survival of prairie dogs flushed from burrows and those relocated to active towns also is unknown.

However, releasing prairie dogs into an established colony likely will increase stress on resident and relocated prairie dogs.

Limitation or postponement of livestock grazing

Because prairie dogs prefer areas that are low in vegetation height, areas intensively grazed by livestock may encourage colony expansion.

Limiting or postponing grazing in certain areas can help to reduce growth of prairie dog colonies.

Predator odors

Pods or spray can be used to deter prairie dog growth by creating a false sense of predators in the area. Must be exercised frequently.

Translocation

Relocate prairie dogs to a different, active colony. The biggest obstacle to prairie dog relocation is finding release sites. A permit is required before prairie dogs can be relocated.

Visual barriers

Placing barriers around the colony will mimic an unsuitable or unstable environment, which will discourage growth and dispersal.

Gas exploding devices

Gas exploding devices can be placed in prairie dog burrows to kill them, but may be illegal in some states.

Recreational shooting

Allow hunters to shoot and kill prairie dogs for sport to decrease population. Many people are opposed to harming these animals for sport.

Rodenticides

- Poison grain baits
- Zinc phosphide
- Anticoagulants

Fumigants

- Carbon monoxide
- Carbon dioxide
- Aluminum phosphide

Vegetation Recovery After Extermination

Prairie dog extermination does not guarantee productive vegetation recovery. Additional steps must be taken to rehabilitate the vegetation in evacuated prairie dog towns.

To speed recovery, level mounds with a land plane, blade, or offset disc set just above the ground surface. To allow grass and root system recovery, exclude livestock from the area for at least one growing season, and reseed the area with grass.

Because prairie dogs do not thrive in tall grass, careful management of grass through proper stocking rates can discourage re-invasion by prairie dogs. Prairie dogs often establish colonies in areas where livestock congregates. To distribute grazing pressure evenly, move watering sites and place salt and minerals in areas that are underused by livestock.

Visual barriers constructed from burlap or windrows of small pine trees have slowed colony expansion. Barriers usually are constructed from a woven plastic material.

The use of visual barriers is limited due to high construction and maintenance costs. Raptor perches, artificial cover for predators, and predator odors generally have been ineffective in reducing prairie dog numbers.

MINIMIZING RODENTICIDE IMPACTS ON THE ENVIRONMENT

Every effort should be made to minimize the impacts on the environment from the rodenticide. Following label directions is the easiest, most effective way to do this. By putting out the recommended rates and methods, the least amount of rodenticide is exposed to the environment.

Cleaning up all spills and properly disposing of rodenticide will minimize these impacts to the environment and also to non-target species.

CHAPTER 9

Commodity and Post-Harvest Fumigation

LEARNING OBJECTIVES

- ☑ **Describe the uses of commodity and post-harvest fumigation.**
- ☑ **List any specialized equipment you need.**
- ☑ **Briefly outline potential pests you can control.**
- ☑ **Explain any unique label requirements for commodity and post-harvest fumigation.**

In this chapter, we will discuss some basic parameters of fumigating structures that contain food, feed, or other commodities and/or commodities themselves. Specifically, we will focus on fumigation of farm structures containing commodities, such as grain bins, silos, barns, or other storage structures, and commodities not enclosed in any structure.

We will also discuss rules governing "quarantine fumigation," which is the fumigation of certain commodities to prevent movement of agricultural pests within (or into) the United States.

Pests Controlled

Possible targets for commodity and quarantine fumigation typically include food- and grain-destroying moths, beetles, and rodents.

Purpose of Commodity Fumigation

Commodity fumigation is used to eradicate pests from products as they are moved between producers, warehouses, and retail markets. The principles are the same as those for structural fumigation: Use or create a confined air space around a commodity that you release fumigant into to eliminate pests.

Fumigants Used

The four primary gases used for commodity fumigation are methyl bromide, liquid and/or packaged phosphine, sulfuryl fluoride, and carbon dioxide.

Fumigation of Grain

Grain, including corn, wheat, oats, and others, are the bulk of fumigated commodities. Fumigant molecules diffuse through the spaces between grain kernels as well as into the kernels themselves, penetrating locations that are inaccessible to insecticide sprays or dusts.

Figure 1: Indian meal moths can leave a large amount of webbing (silk) on top of stored grain as shown in this picture (shiny material). Webbing, like crusted grain, can inhibit the movement of fumigant into the grain. (Photo © Phil Sloderbeck, Kansas State University, Bugwood.org).

Factors Affecting Grain Fumigation

Consider the following factors to ensure that a fumigation will be both safe and effective.

Insect Pest Considerations

There are a great number of different insects that will feed on and damage grain. Fumigants will not, however, provide adequate control if the grain has crusted areas, hot spots of caked grain, or is high in moisture—these conditions must be corrected before a fumigation (Figure 1).

Keep in mind, however, that once the fumigant diffuses out of the grain, no residual protection remains, and the grain is susceptible to reinfestation.

Storage pest problems are usually seasonal in Wyoming. Grains harvested and stored in the heat of summer are more susceptible to pests than grains harvested in fall when temperatures are cooler. As a rule, the longer a commodity is stored at 60°F to 90°F, the greater the chance of pest problems.

Note that concentrations of insect pests can raise the temperature and/or moisture level within stored grain. These conditions can then trigger other problems, such as mold.

Temperature and Moisture Effects

Temperature controls the speed of penetration and release of the fumigant into and out of grain. Low grain temperatures (generally less than 50°F) can slow down gas movement enough so that you will get inadequate control. You may need higher dosages, longer fumigation times, and prolonged aeration when temperatures are less than 60°F. It is best to fumigate when grain temperature is above 70°F. Adjustments for grain temperatures are given on the label.

High moisture and dockage (chaff, broken kernels) in grain slows the movement of the fumigant. The gas is absorbed and held by moist or finely divided pieces of grain, possibly reducing gas concentrations below those required to kill insects. The moisture content of grain also influences the penetration of fumigant gases by altering the rate of sorption. In general, moist grain requires an increase in dosage or an extended exposure period to compensate for the reduced penetration and increased sorption.

When moisture and temperature of the fumigated commodity are high, phosphine fumigation can be completed in less than 3 days. However, at lower ambient temperatures and relative humidity levels, it might require 5 days or more.

Storage Structures

Grain bins are built to not be airtight to prevent grain from spoiling. Typically tape-and-seal is the main way grain bins are fumigated. Often, sheeting is placed directly over the grain inside the bin and a tight seal is made by tucking the plastic under the grain at the edges (this also reduces the amount of fumigant needed because the empty air space above the level of the grain is not being fumigated). Aeration systems, bin eaves, etc. can be taped and sealed to prevent leakages as well.

For some storage buildings, it may be necessary to use tarps over the entire structure. Although there may be label recommendations for fumigation of grain in wooden bins, fumigating these structures often increases costs due to high dosages and poor control.

Sealing
Any structure you fumigate needs to be sealed before introducing a fumigant. Be certain to close all doors and windows, seal vents and other openings, and repair cracks and broken windowpanes. Take special care to seal off adjacent storage or work areas that are not to be fumigated.

Grain Bin Safety

You may need to enter a grain bin either before the fumigation to inspect it, during the fumigation to apply the fumigant, or afterward to aerate and/or evaluate the job. Be aware that grain bins can be very dangerous places (Figure 2) and many people have been covered by grain and suffocated. According to Purdue University, an average of 35 reported grain-handling incidents per year were reported between 2005 and 2015, of which 60% to 70% were fatal. Team inspection, in which one member of the team wears a safety line while inside the bin and the second person handles the line on the outside, can help reduce risk. In addition, place a sign outside the bin to warn others that someone is inside the facility.

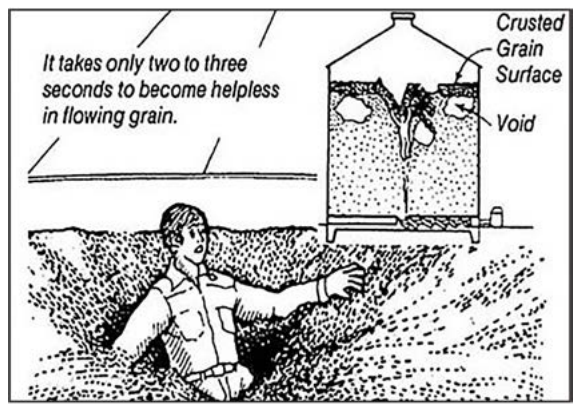


Figure 2: Never inspect grain bins alone. Grain can sometimes form crusts on top that feel stable but hide voids below where you could break through. There are other dangers as well. Your best protection is to use a harness and tether or other safety device anytime you work in a grain bin. (Illustration © U.S. Occupational Safety and Health Administration).

Fumigating Grain with Phosphine

Phosphine-producing fumigants are among the predominant fumigants used for the treatment of bulk-stored grain throughout the world.

Phosphine pellets or tablets can be applied on the conveyor belt or into the fill openings as the grain is loaded into the bin (by hand or by an automatic dispenser). You can also use an automatic dispenser to add fumigant into the grain stream in the up leg of an elevator.

If it takes more than 24 hours to fill a bin, you should not fumigate the grain by continual addition of aluminum phosphide into the grain stream. Instead, fumigate these bins once the bins are done filling. Make sure to lengthen fumigation periods to allow for diffusion of gas to all parts of the bin if the pellets or tablets have not been applied uniformly throughout the grain mass.

Ensure Even Distribution

Distribute aluminum or magnesium phosphide tablets or pellets evenly over the surface; if using probes to introduce tablets deeper into the grain, make sure to evenly distribute them as well. Place the first tablet or pellet in the probe when the probe is down approximately 5 feet into the grain. Raise the probe 1 foot and add the next tablet or pellet. Repeat this procedure until you add the last tablet or pellet into the probe—this should be about 6 inches from the surface of the grain.

Recirculation

Some grain storage structures have built-in aeration or recirculation systems. These regulate the temperature and moisture content of the grain. During fumigation, you can sometimes use them to distribute fumigants throughout the grain mass.

Figure 3: Using a recirculation system when fumigating a grain bin or other storage structure helps the quick and uniform penetration of phosphine throughout the commodity. In some cases, this could result in a reduced dosage. (Photo © Jeffrey Jones.)

It is often desirable to use a low-flow recirculation system for phosphine gas in certain bulk storages (Figure 3). Recirculation usually involves the application of a fumigant to the surface of the commodity. The phosphine gas is then continuously or intermittently drawn out of the top air space and blown into the bottom of the storage using specially designed low-volume fans and ductwork.

Stack Fumigations

Sometimes, it is more feasible to simply cover the commodities themselves and not a whole structure. In these situations, sometimes called stack fumigations, a temporary chamber using tarps or other gas-impermeable sheeting must be used to enclose the commodity.

To ensure a tight seal, place the items on a sufficiently airtight foundation, such as another tarp or on concrete, and cover with a fumigation tarp to ensure a tight seal. Support the tarp over the items to create a gas expansion dome, then seal the bottom edges of the tarp with loose sand or snakes.

Figure 4: Ttop) Timber is being fumigated outside under plastic sheeting. Note that the timber is underlain by plastic sheeting as well, so the fumigant does not dissipate into the soil. (Bottom) Stacked pallets of bagged cocoa beans are fumigated in a warehouse. (Photo credits: (top) © Carl Schnabel; (bottom) © Douglas Products.)

Indoor Stack Fumigations

Indoor stack fumigation helps protect from wind and rain. However, most indoor treatments require you to evacuate the entire building; either way, post warning signs and monitor the area regularly. Some fumigants may allow work to continue in other parts of the building as long as the treatment area remains clear. If the commodity you wish to treat is in an unsuitable indoor site, it may be better to move it to an indoor location. For ease of movement, place all commodities on pallets for fumigation.

Ventilating Indoor Stacks

A well-ventilated site is required for exhausting gas before and when the tarp is removed from the stack. Even in the best conditions, some gas will escape from the tarp. Avoid areas where strong drafts are likely to occur. Most warehouses have high ceilings and several windows and doors that can be used for ventilation. In warehouses, you must provide an exhaust system to the outside of the building and ensure that the exhausted gas does not re-enter the building or endanger people working outdoors.

Outdoor Stack Fumigations

If you are fumigating stacks outside of buildings, try to select a site that is semi-sheltered, such as the leeward side of a building that offers some protection from wind. Placing sand snakes or sandbags over the tarp can help to protect it against wind. If you know it will be stormy or windy, delay fumigation.

Outdoor stack fumigation may require stronger and thicker coverings. Polyethylene should be at least 4 mils thick, but 6-mil sheets are preferred. The color of the tarp also makes a difference. Clear polyethylene tends to become brittle from ultraviolet rays of the sun.

It is also more difficult to obtain a good ground seal outdoors. You may have to lay a tarp on the ground and set the stacked commodities on top of it. You should also place braces over the product under the tarp so that rain will not accumulate in any low spot.

Stored Commodity Pests

LEARNING OBJECTIVES

- ☑ **Discuss the importance of proper pest identification.**
- ☑ **Explain which pest factors determine if the target pest can be controlled with fumigation.**

Stored Commodity Pests

Pests of Stored Products

A large number of beetles, several moths, booklice, and some mites commonly infest a variety of plant material, including spices, flour, vegetable seeds, tea, dried flower arrangements, dried herbs and fruits, chocolate, pet food, grain, tobacco, some rodent baits, straw, bamboo, cigars, and nuts. Some pests also feed on materials of animal origin, such as dried fish and meats, milk powder, and non-food materials like hides, skins, wool, and other fibers. Under optimal temperature and humidity, these pests can develop continually indoors.

Primary and Secondary Feeders

Insect pests of stored agricultural products fall into two groups: primary and secondary feeders. Primary feeders can feed either externally or internally on grain and secondary feeders live in grain storage areas at the same time as the primary feeders.

Primary Feeders

Primary feeders feed on whole, sound grain, reducing its nutritional value and ability to sprout. Damage caused by internal feeders makes grain more susceptible to secondary feeders (insects that feed on grain debris). Adult females of internal feeders deposit eggs on or in whole kernels and larvae develop within the kernels. Some primary insect feeders include the:

- Angoumois grain moth,
- Rice, granary, and maize weevils, and
- Lesser grain borer.

Secondary Feeders

Secondary feeders feed only on damaged grains and seeds. The outer layer of the grain or seed must be cracked, holed, abraded, or broken for them to gain access. This damage can be caused during harvesting, rapid drying, or processing, or by the feeding of a primary feeder. Some common secondary feeders of raw agricultural products include the:

- Indian meal moth,
- Mediterranean flour moth,
- Tobacco moth,
- Drugstore and cigarette beetles,
- Confused and red flour beetles,
- Dermestid beetle,
- Sawtoothed and merchant grain beetles,
- Yellow mealworm beetle, and
- Grain mites.

Pest Identification

The following information is meant to give you examples of **some** of the common pests you might encounter, but is not an exhaustive list, nor is it meant to be a definitive pest identification guide. Consult experts for pest identification and the pesticide label for proper use information.

Moth Pests

Moths are second only to beetles in the amount of damage they cause to stored products. Note that moths only cause damage in their larval stage.

General Moth Characteristics

Adult moths have two pairs of wings that fold over the body when the moth is resting. While wing color and patterns can be helpful in identification, identification can be difficult if wing scales rub off. The antennae of female moths are long and slender, while the male's antennae are often long and feather-like (but this can vary between species). Adults live for a short time, breed, and do not feed on grains. Females die soon after they lay their eggs.

Moth larvae, called caterpillars, resemble small worms with legs. Some species have distinct color patterns that can help with identification. An easy way to tell the difference between moth larvae and beetle larvae is

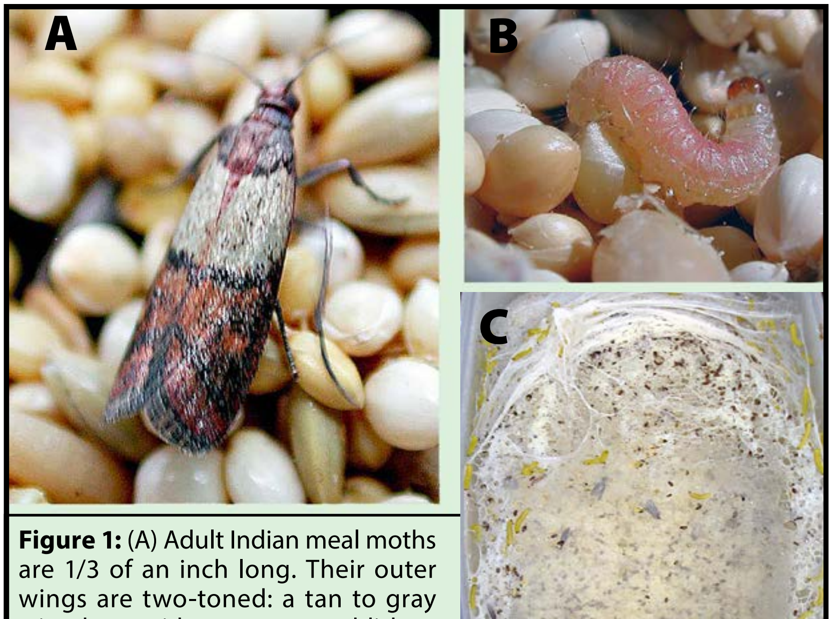


Figure 1: (A) Adult Indian meal moths are 1/3 of an inch long. Their outer wings are two-toned: a tan to gray wing base with a coppery-reddish or bronze outer two-thirds. (B) Mature larvae are cream colored, ½-inch-long caterpillars. The caterpillars have chewing mouthparts and feed on a large variety of commodities, including stored grain, nuts, rice, dog biscuits, dried fruit, bird seed, and much more. (C) The caterpillars can spin large amounts of silk webbing in and over food. (Photo credits: (A and B) © Pest and Diseases Image Library; (C) © Mohammed El Damir. All from Bugwood.org).

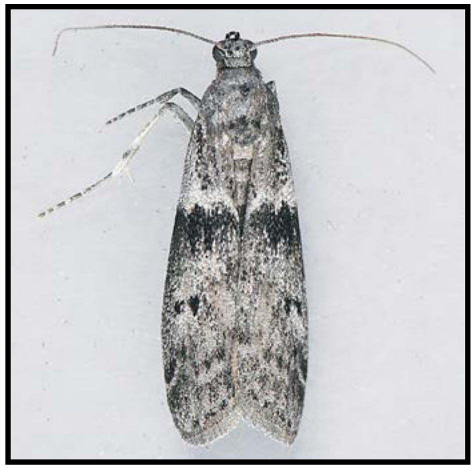


Figure 6: Adult Mediterranean flour moths are about ½ inch long with a wingspan of a little less than an inch. (Photo © Mark Dreiling, Bugwood.org).

to look at the middle of their bodies. Moth larvae have six legs at the area just behind the head and often have fleshy, leg-like appendages called "prolegs" in the middle of the abdomen.

Moths can produce several generations per year, depending on environmental conditions. With warm temperatures and abundant food, they may complete their life cycle in one to three months.

Moth Damage

Moth larvae contaminate and make grain unfit for human consumption by eating, creating webbing, and defecating. Some moths like whole grains, while others prefer milled or ground foods such as flour, cereals, and pet food. Damage usually occurs when these items are stored for an extended period. If larval control is poor, moths may follow a product throughout the manufacturing and distribution process. You can find moth pests in fields, storage bins, mills, delivery trucks, retail stores, and homes.

Indian Meal Moth

Indian meal moths are one of the most common pests of grain storage and processing facilities as well as stored products in homes and warehouses (Figure 1). Larvae often migrate away from the food source to spin a cocoon in bag seams, cracks and crevices, or other sheltered sites (Figure 1-C). Indian meal moths can produce five to six generations a year under ideal conditions (86°F and 70% relative humidity).

There is a low tolerance for these moths because of the potential for food product contamination. People use pheromone traps to detect initial moth activity and trapping to isolate and identify breeding sites.

Indian meal moth larvae feed in the upper few inches of the grain mass and "web" the grain together. If populations are high, the surface will become crusted, which can protect the larvae from surface-applied insecticides or fumigants. Remove the crust and damaged grain before treatment. The webbing from Indian meal moth larvae also can jam and clog equipment in food-processing facilities.

Mediterranean Flour Moth

As larvae, the Mediterranean flour moth is a secondary feeder that prefers flour and meal (Figure 2). Adult moths do not feed and are short-lived. They are pale gray with two distinct black zigzag lines on their wings. When the adult is at rest, the head and abdomen are slightly raised, making the wings look as if they slope downward. Adults fly at night in a very characteristic zigzag pattern. They are less common than Indian meal moths.

Females lay up to 675 white eggs on or near food. In three to five days, pinkish white larvae emerge. Larvae have reddish brown heads, a few small hairs, and a few black spots on their bodies. They spin silken tubes within which they feed and mature. When fully developed, larvae are 1/2 to 2/3 inch long. Larvae are active crawlers. As they move, they spin webbed mats. Like Indian meal moths, these mats can clog processing equipment. They pupate near clean food, away from large amounts of infested material.

While Mediterranean flour moth larvae prefer flour and meal, they also infest grain, nuts, seeds, and other stored foods.

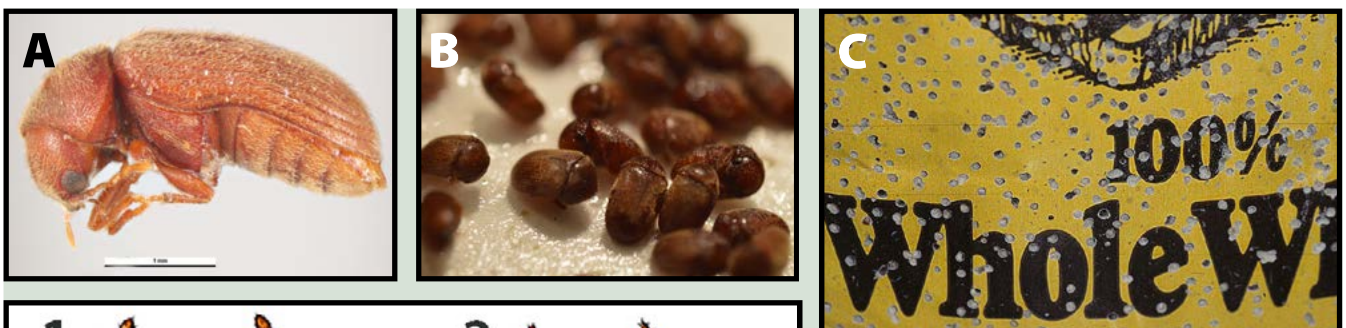
Figure 3: The small size (1/7 of an inch) of the red flour beetle allows these reddish brown beetles to easily penetrate packaging and to hide in cracks in shelving. (Photo © Peggy Greb, USDA Agricultural Research Service, Bugwood.org).

Beetles

Many beetle species are pests of stored grain and food. Adult beetles of all species have two pairs of wings, but the first pair is thickened and hardened into wing covers; these wings meet to form a line down the middle of the back. Beetles undergo complete metamorphosis. Both adults and larvae (also called grubs) have chewing mouthparts. Larvae have three pairs of legs.

Red Flour Beetle

Red flour beetles are a serious issue in grain and have developed resistance to fumigants in some parts of the U.S. The red flour beetle is especially problematic in pasta plants, flour mills, cereal plants, and bakeries, where they infest milled grain products (Figure 3). Large populations discolor and alter the taste and baking quality of flour. Adults live two to three years.



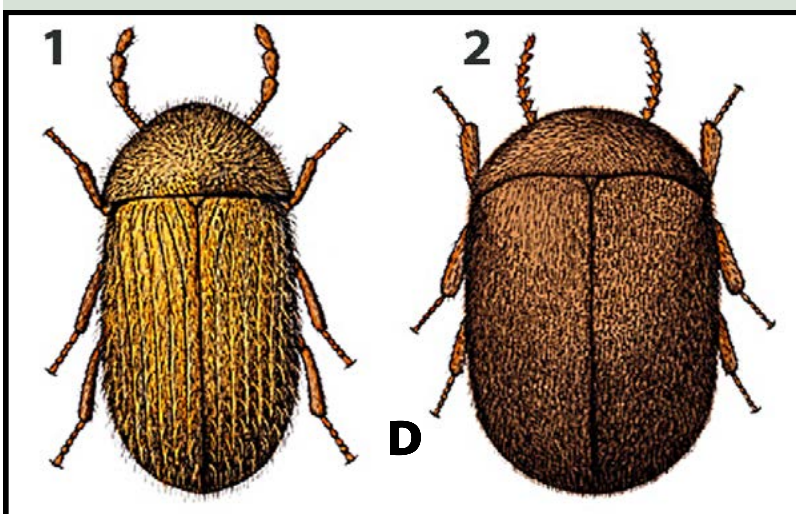


Figure 4: (A) Drugstore beetles and (B) cigarette beetles are small (1/16 to 1/8 of an inch long), cylindrical, reddish brown beetles that have their head tucked so that you cannot see it from above. They can cause damage in a wide variety of materials, including many kinds of food products. (C) They leave behind cylindrical holes in packaging when they emerge. It's important to distinguish the two types of beetle, since control strategies may differ. (D) Although they're similar in size, you can distinguish them by their wing covers and the shape of their antennae. (D-1) The drugstore beetle's wing covers have distinct grooves, and its antennae are clubbed with three broadened segments at the tips. (D-2) The cigarette beetle's wing covers are smooth and lack distinct grooves. Their antennae are serrated. (Photo and illustration credits: (A) © Wood Products Insect Lab, USDA Forest Service; (B) © Brian Little, The University of Georgia; (C) © Gerald Holmes, California Polytechnic State University at San Luis Obispo; all courtesy of Bugwood.org. (D) © U.S. Department of Agriculture).

Beetles are often found in the hard-to-clean areas of food production facilities. Infestations have been traced to grain dust in light fixtures, candy machines, and voids in conveyer belts and other equipment. Flour and similar materials drift and can be found on upper beams, ledges, ducts, and even inside equipment that appears to be sealed.

Pheromone traps help monitor beetle activity. Constant inspection is needed to find problems early and whole-building fumigation might be needed to control flour beetles.

Figure 5: Granary weevils and related species can only breed on whole grain or seeds. (Photo credits: (top) © Clemson University - USDA Cooperative Extension Slide Series; (bottom) © Pest and Diseases Image Library; both courtesy of Bugwood.org).

Drugstore and Cigarette Beetles

The cigarette and drugstore beetles are two of the most common pests of stored products. Both species are found throughout the world (Figure 4) and feed on a wide variety of stored food products as well as non-food items such as leather, wool, potpourri, pinned insects, and other museum specimens. The majority of the feeding damage from both are caused by the larval stages. Adult cigarette beetles do not feed.

Mature larvae are up to 3/16 inch-long, white, C-shaped, and almost cylindrical, with all body segments similar in size. Hairs covering the bodies of larval cigarette beetles are longer and more apparent than those on drugstore beetle larvae. Larvae feed for five to ten weeks before pupating.

Adults live up to six weeks. Adult beetles can penetrate most paper packaging; drugstore beetles can even penetrate wood (Figure 4-C).

Granary Weevils

Granary weevils are ⅛ of an inch long and dark brown with an elongated snout, a key feature of all weevils (Figure 5). Adults cannot fly (however, other weevils that infest food can fly) and infestations are often seen close to rice, whole grain corn, wheat, or sunflower seeds.

Figure 6: Sawtoothed grain beetles can produce up to 6 generations per year. Populations are most successful when the relative humidity is 70% or higher. (Photo © Emilie Bess, USDA APHIS PPQ, Bugwood.org).

Sawtoothed Grain Beetles

The sawtoothed grain beetle is another common stored product pest (Figure 6). It is a flat, dark brown beetle with six saw- like teeth on each side of the thorax. The adult is 1/10 of an inch long.

Dermestid Beetles

The name "dermestids" applies to more than a dozen species of beetles that are destructive (especially as larvae) to hides, skin, fur, wool, other animal-related materials, and stored food. This includes the warehouse beetle (Figure 7), larder beetle, black carpet beetle, and furniture carpet beetle. Adult dermestids are round, dark beetles that are usually about ¼ of an inch long. The larder beetle is ½ of an inch long with a brown band around the middle.

Carpet beetles feed on grains, cereal, dried milk, chocolate, spices, hair, wool, feathers, silk, and dead insects (e.g., cluster flies). They can go extended periods without food and are responsible for extensive damage to wool clothing. Larder beetles are often associated with dead birds and rodents, or high-protein pet food. Carpet beetles can breed in horsehair insulation, bird nests, wasp nests, and grain-based rodent baits. They are slower to breed than most stored product pests.

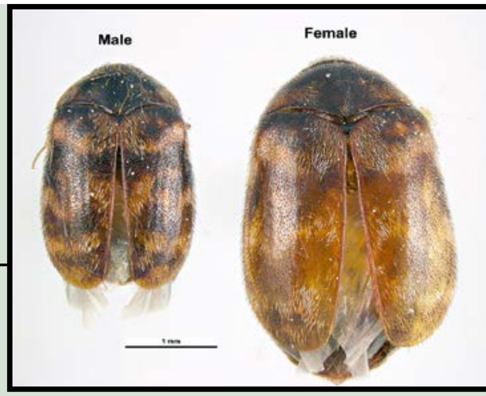
Comparing Beetle and Moth Larvae

The difference between adult beetles and moths is obvious: Beetles have a hard shell while moths have two pairs of fuzzy wings. Their larvae, on the other hand, can be hard to distinguish. Moth larvae have three pairs of true, jointed legs just behind their head. They also have a varied number of non-jointed, fleshy "prolegs" farther down the abdomen. While some beetle larvae have three pairs of jointed true legs behind the head, beetles never have any prolegs (Figure 8).

Grain Mites

Several types of grain mites breed indoors or on food products if conditions are damp. These mites require relative humidities above 80% to survive and drying out a room or building often manages the mite problem. However, drying may not be feasible when you have infestations in high-moisture animal feed. In these situations, fumigation might be the only practical solution (Figure 9).

Animals sometimes refuse to eat grain that has been heavily infested with grain



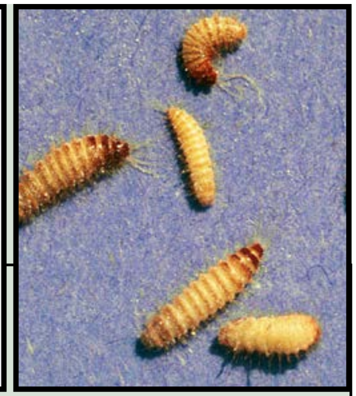


Figure 7: (Left and middle pictures) Warehouse beetles, one type of dermestid beetle, have oval bodies about 1/8-inch long with a brown and yellowish pattern on the wing covers. They feed on a wide variety of foods. (Right) Dermestid beetle larvae are typically golden to dark brown, hairy, and have an elongated shape tapered on both ends. (PPhoto credits: (left and middle) © Pest and Diseases Image Library; (right) © Whitney Cranshaw, Colorado State University. All from Bugwood.org)

mites, even after the mites have been killed. If this is the case, disposing of infested grain might be the most cost-effective solution.

Control of Grain and Commodity Pests

Prevention is key to controlling grain and commodity pests. Start by cleaning in and around product storage areas regularly. Practice good sanitation by removing spilled grain, grain dust, and other stored product inside and outside the storage area. Be sure to clean corners, floors, and walls. Remaining bits of product can harbor insects that can move into new products stored in the same area. Routine cleaning, along with preventive spot fumigation, can reduce or eliminate a need for large-scale fumigation.

Prevention also requires good storage practices. Monitor for insect infestations and heating in stored products and grain. Aerate the storage facility to maintain low moisture levels. Mix and level the grain so fines and other grain debris are evenly distributed throughout the grain.

If an infestation does develop, first attempt to find and destroy all infested products, then treat the location where they were stored. If the infestation is severe, you may need to fumigate.

You can measure the effectiveness of a fumigation by comparing insect activity or presence before and after the treatment. Practice good housekeeping to prevent reinfestation.

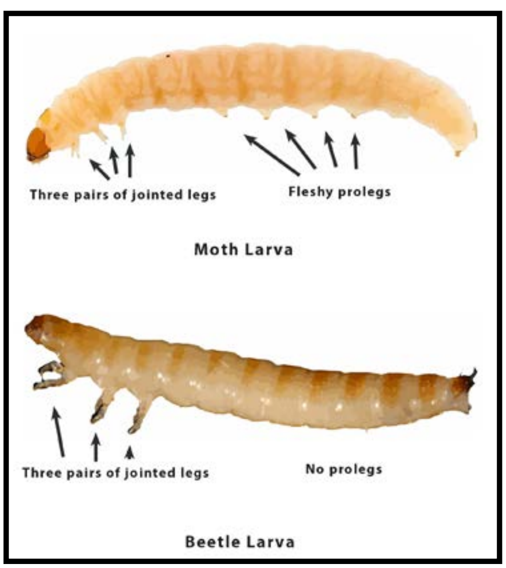


Figure 8: While different species of both moth and beetle larvae vary in appearance, two that can look similar are the Indian meal moth caterpillar (top) and the red flour beetle larva (bottom). The main distinguishing feature is that moth caterpillars will have some prolegs on their abdomen, while beetle larvae never do. (Illustration credit: © UW-Madison Pesticide Applicator Training Program. Photos for illustration (moth larva) © Todd Gilligan, CSU, Bugwood.org; (beetle larva) © John Obermeyer, Purdue Extension).

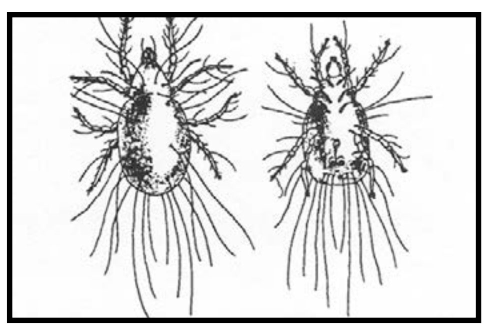


Figure 9: Grain mites (greatly enlarged).

Fumigant Details

LEARNING OBJECTIVES

- ☑ **Understand the different fumigants available.**
- ☑ **Understand the the risks associated with each of the fumigants.**
- ☑ **Understand the different formulations of phosphine and why you would choose one formulation over the other**

Currently, these are fumigants registered by the EPA:
1. Carbon monoxide (CO), including ignitable gas cartridges and CO generators;
2. Carbon dioxide (CO_2), available as both solid (dry ice) or gas;
3. Sulfuryl fluoride;
4. Phosphine.

Carbon Monoxide (CO)

Cartridges contain sodium or potassium nitrate, carbon (usually in the form of charcoal), sulfur, and some other inert ingredients. The gas cartridges come in the form of specially made cardboard tubes. After puncturing one end with a nail in designated areas, applicators insert a fuse into that end. The sodium nitrate accelerates the combustion of charcoal, which in turn forms carbon monoxide, a clear, odorless, lethal gas poisonous to all vertebrates, including humans. There are other commercially available carbon monoxide generators specifically used to control burrowing rodents.

Carbon Dioxide (CO_2)

In 2017, the EPA registered carbon dioxide (CO_2) based fumigants to control burrowing pests. Carbon dioxide in solid form (dry ice) is used specifically for rats and can be put into their burrows. The solid CO_2 evaporates into its gaseous state and essentially suffocates the pest animals. There are also some "forced gas fumigation systems" that pump CO_2 into burrows. Some of the machines are regulated by the EPA as pest control devices.

Uses and Applications

Carbon dioxide can be used to kill insect pests in stored commodities and for burrowing pest control. It is applied from pressurized tanks and does not leave residues on products or structures. To fumigate with CO_2, structures need to be tightly sealed or must take place in fumigation chambers.

Carbon dioxide can kill all life stages of insects, but generally needs a long treatment period. When used as a fumigant, CO_2 needs to be held at a concentration of 35–60% at room temperature for up to 21 days. The concentration of CO_2 and exposure time varies depending on the pest, commodity type, and temperature.

Precautions

Although CO_2 is naturally found in the air we breathe, it is present at a very low concentration (about 0.04%). Carbon dioxide is also lethal to humans at the concentrations required to fumigate pests.

Sulfuryl Fluoride

Sulfuryl fluoride is a colorless, odorless gas. It is nonflammable in all atmospheric concentrations, but will become *corrosive* in the presence of an open flame, electric heaters, or other high heat sources. Fans or blowers are used to introduce, distribute, and *aerate* sulfuryl fluoride. Aeration is quite rapid and the gas desorbs quickly.

Uses and Applications

There are two separate product registrations for sulfuryl fluoride. One is specifically for treating structural pests (i.e., termites, powderpost beetles, old house borers, bedbugs, cockroaches, rodents) and requires the use of chloropicrin as a warning agent. The other product is registered for use in treating commodities. Sulfuryl fluoride is used for structural and commodity fumigations, including dwellings, barns, buildings, vehicles, ships, rail cars, and fumigation chambers. It penetrates dry wood products very well. This fumigant is very effective against insect larvae and adults, but not eggs, at normal concentrations. You should not use sulfuryl fluoride at temperatures below 55°F.

Precautions

Because the gas can get into frost free refrigerators and freezers, you must either seal these appliances or remove their contents from the structure. Do not use sulfuryl fluoride on living plants. Other items that you must remove are non-target animals, tobacco products, and medications. Additionally, items that might trap vapors, such as waterproof mattress covers, must be opened up or removed from the structure.

Chemical Reactivity: Sulfuryl fluoride does not adversely react with a large number of products. However, you must turn off all pilot lights and allow heating devices to cool to prevent formation of a corrosive gas.

Warning Agent: Because sulfuryl fluoride is odorless, a warning agent (such as chloropicrin) is used during fumigation of dwellings.

Phosphine

Phosphine is a gas that can be generated from solid formulations of aluminum phosphide or magnesium phosphide. Phosphine gas is highly toxic and capable of killing many living things, including humans. Due to its lethality, applicators must follow many safety guidelines to ensure safe and effective use, including using gas-monitoring equipment and respirators and writing a detailed fumigation management plan.

Phosphide formulations react with moisture in the air to produce the toxic gas hydrogen phosphide, also called phosphine (Figure 1). Solid aluminum and magnesium phosphide comes in the form of tablets, pellets, ropes, strips, and more. Magnesium phosphide releases phosphine much more rapidly than aluminum phosphide. There are also formulations of phosphine gas in pressurized cylinders either as pure phosphine or mixed with CO_2.

Phosphine is about 20% heavier than air and does not tend to *stratify*. Therefore, in open space situations you do not usually need fans to ensure even distribution of the gas. However, in bulk commodity fumigations, phosphine will not settle downward through grain without the use of fans. Once it does penetrate the grain, it diffuses rapidly because it is not strongly absorbed by grain. Because of this combination of low absorption and great penetration capacity, phosphine tends to leak from structures that are not gas tight.

There is no allowed use of phosphine products in residential areas. When used for outdoor burrow fumigation, applications are strictly prohibited within 100 feet of any building where humans and/or domestic animals do, or might, reside. Labels will contain a statement such as the following:

"The use of this product is strictly prohibited on single and multi-family residential properties, and nursing homes, schools, day care facilities, and hospitals."

Choosing Solid vs. Gas Formulations

The decision to use solid formulations (aluminum and magnesium phosphide) versus cylinders of phosphine gas depends on multiple factors, including the fumigation site, the skill of the applicator, and the label instructions.

When choosing a product, consider the following. Cylinders are basically bottled phosphine, so the target fumigant concentration is reached as soon as the gas spreads through the fumigation site. In contrast, packaged phosphine has about a 24-hour ramp-up period in which the solids react with humidity in the air to convert into phosphine gas.

In a tightly sealed structure, cylinders of phosphine work quickly; however, in a poorly constructed structure, they also lose gas quickly, which can result in not having enough gas to control the pest over the duration of the fumigation.

The biggest advantage of solid formulations versus cylinder applications is primarily the cost. Smaller packaging is available for solid formulations, which is beneficial for small fumigation sites like railcars, containers, fumigation chambers, and storage bins. Many manufacturers offer specific sizes for specific site fumigations to assist in calculating proper dosages.

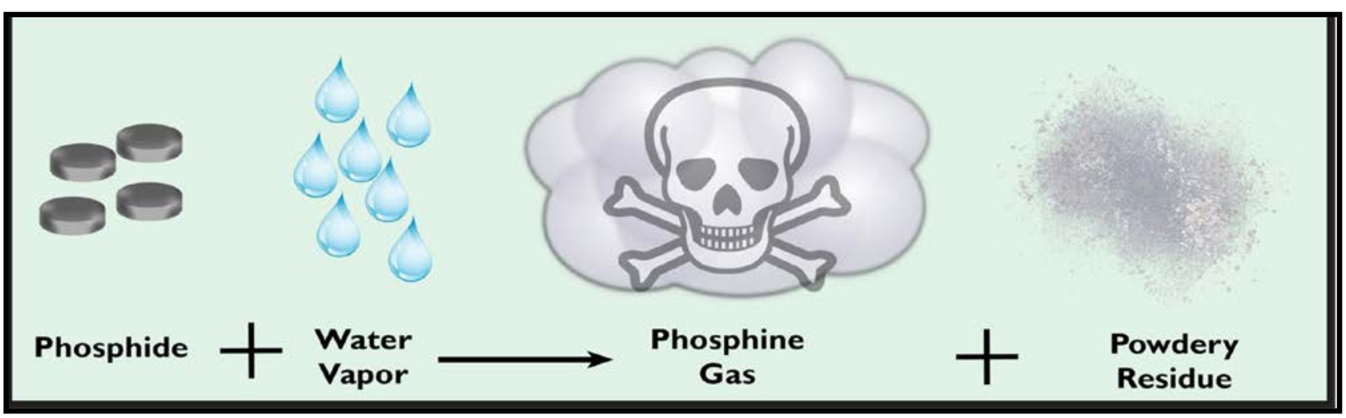


Figure 1: The graphic above illustrates the reaction of phosphide solids (both aluminum and magnesium phosphides) with atmospheric moisture to create phosphine gas. (Illustration © UW-Madison Pesticide Applicator Training Program based illustration by Ruth O'Neill, MSU in the Montana non-soil fumigation manual.)

Odor

Phosphine is a colorless gas that is odorless when pure, but technical grade material sometimes has an odor de- scribed as "fishy" or "garlicky." Because that odor can vary, it **is not** an adequate indicator of phosphine's presence and **does not** provide reliable warning of hazardous concentrations.

Uses and Applications

The concentration of phosphine increases slowly after first application: 12 to 48 hours might elapse before it reaches the desired concentration. The total time needed for a successful fumigation can range from three to ten days, depending upon temperature and other factors. Phosphine will be produced more quickly, and the fumigation completed sooner, under **warm, humid conditions** compared to cool, dry conditions. Chemicals typically react faster as temperature increases and higher humidities means more water is available to produce phosphine.

Phosphine fumigations are usually ineffective at controlling insects at temperatures below 40°F. This is because gas release is slowed, and insects will not inhale a fatal dose.

Aluminum and magnesium phosphide have become widely used for treating commodities in bulk storage and in transit (e.g., railcars and ships), partly because they have no adverse effects on seed germination at normal dosages. However, goods undergoing fumigation with aluminum phosphide in a truck trailer or container, or that have not been completely *aerated*, cannot be transported over public roads or highways. Doing so is illegal.

Precautions Fire and Explosion: If phosphine is produced too rapidly, fire or an explosion can occur. To reduce this risk, manufacturers produce controlled-release forms. Some solid formulations give off CO_2, which helps retard the risk of fire or explosion. Phosphine in pressurized cylinders mixed with CO_2 are not flammable.

Explosions can occur if aluminum phosphide is used improperly. For example, phosphine is explosive at concentrations above 18,000 ppm. If the fumigation is conducted properly, concentrations should not approach this value. Phosphine is also explosive under vacuum conditions—never use it in chamber fumigation. **Note that aluminum phosphide can explode if it comes into extended contact with water.**

Figure 2: (A) Since metal phosphide fumigants react readily with moisture, they must be packaged in gas-tight containers. (B) Small containers usually contain loose pellets or tablets. (C) Another form the fumigants come in is as Prepac bags (also ropes) where the tablets are contained in gas-permeable blister packs. Both prepacs and ropes are then packed in metal containers where they must stay until use. Once removed from their sealed container, they start producing phosphine gas after a short delay. Other formulations may start producing gas immediately. (D) Phosphine can also be applied from pressurized cylinders that contain phosphine, which is sometimes mixed in liquid carbon dioxide. ((A) © Betsy Danielson, Iowa State University Extension and Outreach; (B-D) © Cardinal Professional Products.)

The risk of fire or explosion also applies to magnesium phosphide. Therefore, magnesium phosphide is produced as pellets or tablets, or impregnated onto polyethylene plates and strips covered by a gas-permeable paper. Magnesium phosphide is also packaged in small, gas-permeable blister packs; these can only be used for fumigating equipment.

Chemical Reactivity: Phosphine gas, especially in the presence of moisture or ammonia, reacts with silver, copper, and copper alloys. Copper-containing equipment, such as electrical apparatus, can be severely damaged. Protect or remove electronic equipment before exposing to phosphine.

Residues: Both aluminum phosphide and magnesium phosphide produce residues when they react with moisture in the air. Partially reacted dust is called "green dust" because it remains slightly greenish in color, while the spent residual dust is grayish white. Don't assume that fumigation is complete if you see the residue; some residue may form while the gas could still be releasing. **Do not allow this residue to come in direct contact with any processed food or bagged commodity.** You can prevent the residue from contacting a commodity by placing the phosphides on a tray instead of adding it directly to the commodity. Special packages are available that retain the residue, preventing contamination. Residues must be deactivated and disposed of according to the label. At the end of the fumigation, collect all spent or partially spent aluminum and magnesium phosphide plates, strips, ropes, or prepacs from the treated site.

Glossary

Absorb, Absorbed	(1) The entrance or taking up of a pesticide into a body through the skin, eyes, or mouth. (2) In the case of a fumigant, when the molecules penetrate into a material (commodity, soil, wood, etc.).
Acute effects	Illness or injury that appears immediately after exposure to a pesticide (usually within 24 hours).
Acute exposure	Exposure to a single dose of a pesticide. A one-time event.
Acute toxicity	A measure of the capacity of a pesticide to cause injury as a result of a single exposure.
Adsorb, Adsorption	The process by which a substance sticks to the surface of something else (e.g., when a fumigant binds to the surface of a commodity).
Aeration	In relation to fumigation, it is the process of adding air or allowing air into the space fumigated (or the container that held the fumigant) to allow the fumigant to dissipate to safe levels.
Aerosol	A suspension of fine solid or liquid particles in air. NOT the same thing as vapor or gas.
Air monitoring	The use of sensitive gas monitoring devices during fumigation to accurately gauge the dosage of the fumigant and/or to detect leaks from the application site.
Ambient air analyzer	A type of monitor that uses infrared light to detect and measure gas fumigant concentrations. Also called "IR analyzer."
Applicator's Manual	Most, if not all, fumigant labels direct the applicator to use the product's applicator's manual. That manual is much longer and contains more detailed instructions on use of the product than the label attached to the product. Just as for the label, the manual is a legally binding document and you must follow the instructions explicitly.
Atmosphere-supplying respirator	A device that draws air from outside a fumigation area or uses canisters of pressurized air to supply a worker with breathable air. The latter is also called a self-contained breathing apparatus (SCBA).
Atmospheric chamber	A structure used to conduct a fumigation that is under normal (i.e., ambient) air pressure.
Boiling Point	The temperature at which the vapor pressure of a liquid equals the pressure surrounding the liquid and the liquid changes into a vapor. Or, simply, the temperature at which a liquid becomes a gas.
Buffer zone	A restricted-access area established around the perimeter of an area being fumigated. The certified applicator (and authorized fumigation handlers under their direct supervision) must prohibit entry into the buffer zone by any other person. Note that EPA has adopted the terms "treatment buffer zone" and "aeration buffer zone" to designate the zones in effect during the application and exposure periods (the "treatment" time) and during aeration. These will differ in scope and may differ in location.
Burrow fumigation	A type of fumigation used to control certain vertebrates in outside burrows.
Canister	A device used with a respirator that contains chemical components that absorb specific gases. Each canister is color coded with stripes to indicate limitations and approved uses.
Canister respirator	A respirator that uses canisters to remove toxic fumes from air.
Certified applicator-in-charge	A certified applicator who has supervisory authority over the fumigant application. Note that the EPA uses the term "site supervisor."
Chamber fumigation	The use of a well-sealed structure to conduct a fumigation. Some chambers are specially built for fumigation, while others are modified rooms or buildings.
Chemical reactivity	The tendency of a substance to undergo chemical reaction, either by itself or with other materials. One common example of a chemical reaction is when iron combines with oxygen to make iron oxide, or rust.
Concentration	The amount of a substance in a given weight or volume.
Corrosive	Causing damage by chemical action such as when a substance oxidizes (e.g., rusts) a metal surface, or corrodes like an acid. Some fumigants are especially corrosive to certain metals.
Concentration x Time (CT) Concept	The dosage required to kill the target pest(s) that is accumulated over a period of time and measured in ounce-hours or gram-hours.
Desorb / Desorption	The process of a substance releasing from or through a surface. The process is the opposite of sorption.

Detector tubes	A glass tube that shows a color change in the presence of a specific gas such as methyl bromide. Tubes are specific for different fumigants. Also called "colorimetric tubes."
Detectors	A generic term for any of various monitoring tools used to measure the presence of a substance (e.g., concentration of phosphine in air).
Diffuse / Diffusion	Diffuse: to cause a gas or liquid to spread through or into a surrounding substance by mixing with it. Diffusion: a process by which there is a net flow of matter from a region of high concentration to a region of low concentration resulting from random motion of molecules.
Dosage	The addition of an ingredient or the application of an agent in a measured dose. In terms of fumigation, it is the number of ounce-hours (or gram-hours) accumulated during the exposure period.
Dose	The amount of fumigant introduced into the fumigation space. In the case of the metal phosphides, the weight of solid material is not the dose; the dose is the amount of gas generated from the solid, most commonly listed in grams.
Endangered species	Any species that is in danger of extinction throughout all or a significant portion of its range (i.e., normal area it lives in).
Endangered species bulletin	A part of EPA's Endangered Species Protection Program. Bulletins referenced on the product label that set forth geographically specific pesticide use limitations for the protection of threatened and endangered species and their designated critical habitats.
Equilibrium	Even distribution. A fumigant has reached equilibrium when there is an equal concentration of gas throughout a given space. This can be accomplished through the use of "mixing" fans at the time of initial application.
Fit check	An on-the-spot check to make sure that a fit-tested respirator or self-contained breathing apparatus (SCBA) still fits correctly. A fit check should be done each time the respirator or SCBA is worn.
Fit test	A qualitative test that must be done before you use a respirator or SCBA for the first time and which will determine whether or not the device fits well enough to adequately protect you during use.
Flammability	The ability to support combustion (i.e., the process of burning). A substance that easily catches fire. "Inflammability" has the same definition.
Fumigant	Pesticides in a gaseous state.
Fumigation	The process of treating an area with fumigants.
Fumigation Management Plan	A written plan for a specific fumigation that is prepared before the start of the fumigation.
Gas / gases	A state of matter consisting of particles that have neither a defined volume nor defined shape. As vapors, gases do not leave residues.
Half-loss time	The amount of time it takes to lose half the amount of fumigant from an enclosed space because of leakage, breakdown, or sorption.
Halide leak detectors	A detector for monitoring the presence and approximate concentration of halide gases. Used to measure methyl bromide or sulfuryl fluoride.
Label	The information, including directions for use, restrictions, requirements, and safety procedures, printed on or attached to the pesticide container or wrapper. This information is legally binding.
Labeling	The pesticide label and all additional product information, such as brochures and fliers referred to on the label.
Load factor	The amount of fumigant sorbed by the materials being fumigated.
Metabolism	All the chemical processes that occur within a living organism in order to maintain life.
Molecular weight	A measure of the sum of the atomic weight values of the atoms in a molecule.
Molecule	The smallest particle of a substance that retains all the properties of the substance and is composed of one or more atoms.
Particulate	Microscopic particles of solid or liquid matter suspended in the air. NOT the same as a vapor or gas.
Personal protective equipment	Devices and apparel worn to protect the body from dermal, eye, and inhalation exposure to pesticides or pesticide residues. Commonly abbreviated PPE.

Pesticide	A chemical used to directly control pest populations or to prevent or reduce pest damage (e.g., insecticides, herbicides, fungicides, fumigants).
Pesticide resistance	The genetically acquired ability of an organism to tolerate the toxic effects of a pesticide.
Post-application summary	A written summary of actions taken during the fumigation to comply with label directions.
Quarantine fumigation	A fumigation ordered by a governmental agency to protect domestic agriculture and forestry from pests (i.e., insects, fungi, viruses) capable of causing catastrophic damage. Quarantines are particularly used to prevent the entry and establishment of foreign species that have no natural domestic enemies (e.g., predators, parasites, or diseases).
Respirator	A face mask that either provides a source of clean air (air-supplying respirator) or that filters out particles and/or vapors from contaminated air (air-purifying respirator).
Restored pressure fumigation	A method of vacuum chamber fumigation where the pressure is lowered, fumigant introduced, and then pressure is restored. This is also called "below NAP" (normal atmospheric pressure).
Restricted-use pesticide (RUP)	A pesticide designated as such by the EPA (or a state) because it may generally cause, without additional regulatory restrictions, unreasonable adverse effects on humans, domestic or wild animals, and/or the environment (including injury to the applicator). A restricted-use pesticide may be used only by a certified applicator or handlers under the direct supervision of one (some states and some product labels do not allow direct supervision for RUPs).
Risk	Risk, in terms of pesticide exposure, is a measure of the likelihood that a person will be harmed by the pesticide and its particular use. It is a product of both the pesticide's toxicity and the amount of exposure in terms of volume of pesticide and length of time.
Seal / sealing	To enclose an area so that fumigant gas cannot escape too quickly. A good seal will contain a lethal amount of gas long enough to kill the target pests. Sealing is often done with plastic sheeting, tape, and adhesives.
Self-contained breathing apparatus (SCBA)	A type of respirator that supplies fresh air from an outside or portable source such as a cylinder under pressure. Air enters a mask that tightly covers the entire face.
Solubility	The property of a substance to dissolve in another substance (e.g., salt dissolves in water).
Sorption	A physical and chemical process by which one substance becomes attached to another. The term covers both absorption and adsorption.
Specific gravity	The ratio of the density of any substance to the density of some other substance taken as standard, water being the standard for liquids and solids, and hydrogen or air being the standard for gases.
Spot fumigation	A fumigation technique applied to a restricted or localized space within a larger structure that has no connection to other parts of the structure so that area can be separately sealed and fumigated. Often used in food-processing plants, mills, etc.
Stratify / Stratification	The creation of layers of gas within a confined area most often due to physical characteristics such as temperature, humidity, and the relative weights of different gases.
Structural fumigation	The process of sealing a building and applying a fumigant to control pests.
Supplied-air respirator	A device that supplies air from a compressed air tank that is located outside of the fumigation area.
Sustained-vacuum fumigation	A method of vacuum chamber fumigation where pressure inside the chamber is reduced, fumigant is introduced, and the lower pressure is maintained throughout the fumigation.
Tape-and-seal	A method of sealing an area for fumigation that does not require a tarpaulin. Potential sites for leaks are sealed with polyethylene sheeting and tape.
Tarpaulin / tarp	A large vinyl-coated nylon, canvas, or polyester sheet used to seal a structure or other spaces for fumigation. "Tarp" is the more informal and more often used term for "tarpaulin." The most common material is polyethylene and the least common is canvas.
Thermal conductivity analyzers	An instrument designed to measure the concentration of fumigant gases within a chamber or other enclosure during fumigation. Also called "TC analyzers."
Threatened species	A group of organisms likely to become endangered in the foreseeable future.
Toxic	Acting as, or having the effect of, a poison. A toxic substance is one that can cause harm to organisms or the environment.

Toxicant	A poisonous substance.
Toxicity	A measure of the capacity of a pesticide (or other substance) to cause injury. That injury can occur soon after the exposure (acute) or appearing later than 24 hours following pesticide exposure (delayed and/or chronic effects).
Trigger levels	The air concentration of a fumigant that triggers the requirement for a fumigant handler to use specific respiratory protection in order to continue working in the area being fumigated.
Vacuum chamber	A specially designed structure used to conduct a fumigation where the air can be removed prior to introducing the fumigant.
Vapor	A substance in the gaseous state as distinguished from the liquid or solid state. As a vapor it exists in the air as separate molecules.
Vapor pressure	The pressure exerted by vapor molecules in equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system. The pressure exerted by a liquid or a solid as it volatilizes (becomes a gas).
Vertebrate	Animals that contain a backbone.
Volatile	A substance that vaporizes readily. That means it changes from a liquid (or even a solid) into the gas phase.
Volatility	A measure of how easily a substance vaporizes.
Volatilization	The process or act of vaporizing.
Warning agent	In fumigation, a substance added to the fumigation space to warn or deter people from entering and remaining in the structure during the fumigation. The usual substance used is chloropicrin because of its easily recognized smell and sensory irritation, such as watery eyes.
Warning placard / sign	A sign that must be posted at all external entrances and all sides of a structure warning that the structure is being fumigated. Sometimes “sign” and “placard” are used interchangeably.

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Category 909

Soil and Non-soil Fumigation for Commercial Applicators

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