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Fumigation

For the Commercial/Noncommercial Pesticide Applicator

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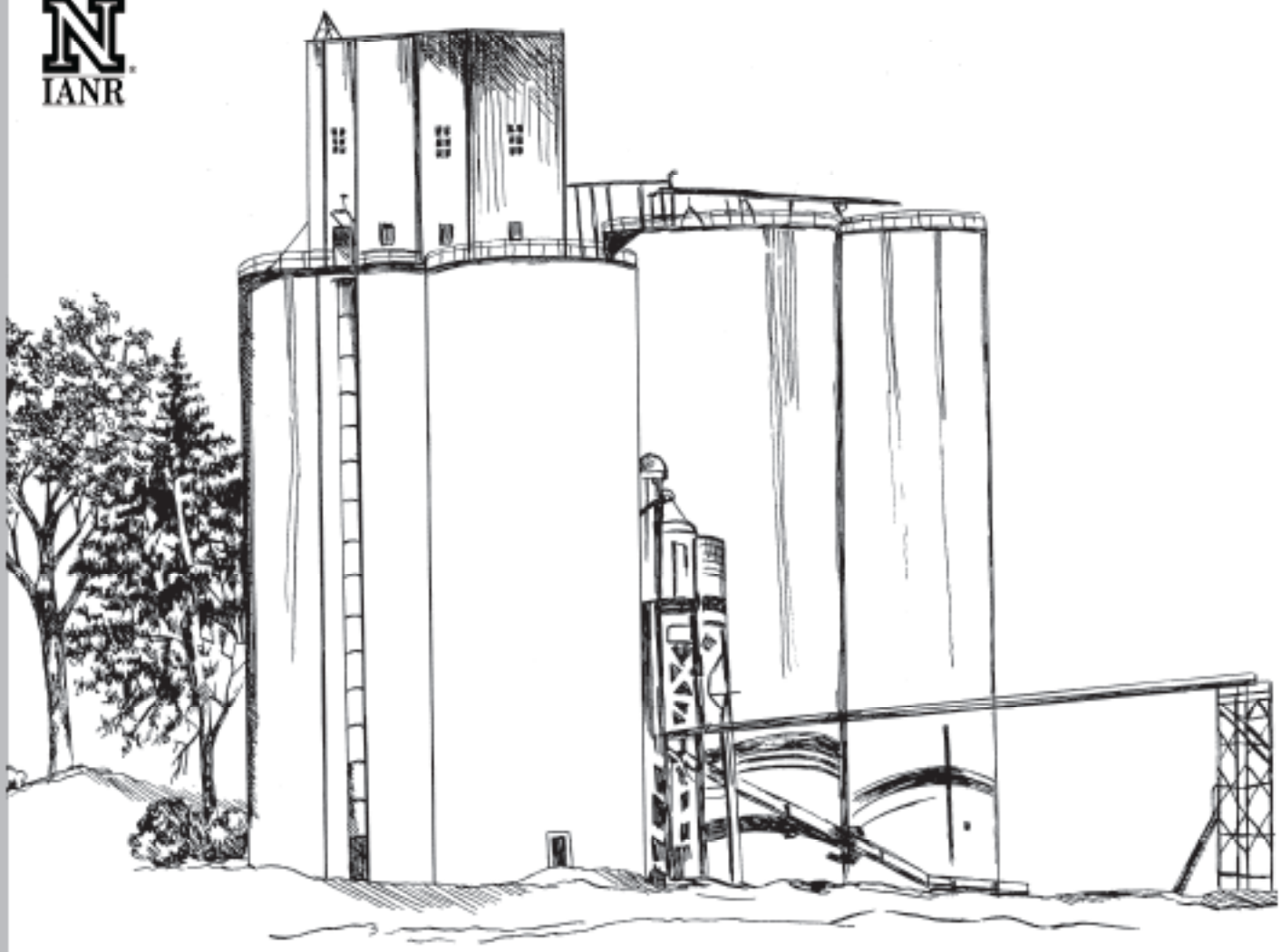

Category 11

Fumigation

Pesticide Safety Telephone Numbers

Nonemergency Telephone Numbers

National Pesticide Information Center **(800) 858-7378**

Chemical Referral Center (weekdays only) **(800) 262-8200**
Referrals to manufacturers on health and safety related to chemicals

Emergency Telephone Numbers

The Poison Center **(800) 222-1222**
For aid in human poisoning cases

Pesticide Accident Hotline (CHEMTREC) **(800) 424-9300**
For help involving spills, leaks, fires

Nebraska State Patrol **(800) 525-5555**
To report chemical spills or releases
To report motor vehicle accidents

Find more pesticide educational information at
Pesticide Education Resources
http://PestEd.unl.edu

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Fumigation

for the Commercial/Noncommercial Pesticide Applicator (Category 11)

Third Edition, 2011

Editor:

Erin Bauer
Extension Associate
Pesticide Safety Education Program
University of Nebraska–Lincoln

Cover Art and Design:

Renee Lanik
Specialist
Communications and Information Technology
University of Nebraska–Lincoln

Layout and Formatting:

Vicki Schroeder
Office Associate
Pesticide Safety Education Program
University of Nebraska–Lincoln

Chapter Authors:

Buzz Vance
Nebraska Department of Agriculture
(Chapter 9)

Technical and Contributing Consultants:

Frank Arthur, PhD
USDA-ARS, GMPRC
Manhattan, KS

Technical and Contributing Consultants Cont:

James Campbell, PhD
Research Entomologist, USDA-ARS, GMPRC
Department of Entomology
Adjunct Associate Professor
Kansas State University
Manhattan, KS

Jim Criswell, PhD
Professor and Extension Pesticide Coordinator
Oklahoma State University
Stillwater, OK

Marv Evert
Evert Pest Management, Inc.
Lincoln, NE

James Kalisch
Extension Associate
Department of Entomology
University of Nebraska–Lincoln

Clyde Ogg
Extension Educator
Pesticide Safety Education Program
University of Nebraska–Lincoln

Preface

This is the third edition of *Fumigation Pest Control for the Commercial/Noncommercial Pesticide Applicator*. This manual provides information for the Nebraska commercial/noncommercial pesticide applicator wishing to become certified in the Fumigation Control category, number 11. To become a certified applicator in this category, a candidate must pass both a general standards exam (information covered in this exam can be found in the General Standards materials) and an examination based primarily on the material presented in this manual. These tests are administered by the Nebraska Department of Agriculture (NDA). Study packets can be purchased from the Pesticide Education Office, University of Nebraska–Lincoln, Web site: http://pested.unl.edu.

Acknowledgments

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Contents

How to Pass the Exam

This training manual has been developed to prepare you for successfully passing the Pesticide Certification Exam for the Fumigation (11) category. This manual includes information that you as the pesticide applicator should know and use when fumigating in and around stored grain facilities.

At the beginning of each chapter, you will notice a set of learning objectives. Questions on the certification exam will be based on these learning objectives.

To successfully pass the certification exam:

- Read and understand the learning objectives at the beginning of each chapter. The learning objectives describe what you should be able to do after reading the chapter.
- Read the chapter in detail, keeping in mind the learning objectives as you read.
    a. After reading the chapter, return to the learning objectives and see if you can respond to each one of them. If you have difficulty responding to a learning objective, locate the section of the chapter that discusses that particular objective. Re-read that section of the chapter and then see if you can respond to the learning objective. Continue this for other learning objectives that gave you difficulty.
    b. Once you are able to respond to all of the learning objectives, you will be prepared to take and successfully pass the certification exam.

Understanding and being able to respond to the learning objectives is the key to passing the exam!

Chapter 1

Introduction

Learning Objectives

After studying this chapter, you should be able to:

- Explain what fumigants are and how they work.
- List what questions should be asked before deciding to fumigate.

Although they are highly toxic, fumigants are often the best and only way to control pests in raw agricultural commodities. By reading this chapter, you will learn what fumigants are and how they work. This chapter will outline the scope and purpose of this manual, and what is included in each chapter.

Terms to Know

Aeration – The process of replacing fumigant-containing air or water with fresh air and/or water that contains little or no fumigant. Aeration must follow all fumigation operations.

Aerosol – Solid or liquid particles suspended in air (such as smoke, fog, or mist).

Commodities – Items produced for trade or commerce.

Fumigant – A pesticide that is a gas, or forms a gas, when applied. In a high enough concentration, this gas (vapor) has pesticidal action.

Molecule –The smallest particle of a substance that retains all the properties of that substance.

Pest – Any living thing that is undesirable or causes harm to people or the environment. An organism may be a pest in one place but not in another; for example, termites in a house vs. those that recycle dead trees in a forest.

Raw Agricultural Commodity–An unprocessed human food or animal feed crop.

The earliest use of fumigants as pesticides dates back to 2500 BC. At that time, people burned sulfur to control insects and mites. Today, we use fumigants to control insects, rodents and other pests. We rely on these chemicals to treat grain bins, boxcars and other railcars, and other stored grain facilities. Fumigation is one of the quickest and most effective ways to eliminate pests from stored grain.

Unfortunately, fumigants are some of the most toxic pesticides in the world. Even small amounts can kill non-target insects, animals and people. Fumigants are often fast acting, odorless and invisible. Many are highly flammable. For these reasons, fumigators require more training and skill than do many other pest control operators. Skill and training are critical for safe application.

What Is a Fumigant?

A fumigant is a chemical that, when released as a gas or vapor, diffuses throughout enclosed areas or penetrates objects in concentrations that are lethal to pest organisms. Fumigants may be odorless, and usually cannot be seen.

Fumigants are different than aerosols (such as a smoke, cloud, fog, or mist), which are solid or liquid particles suspended in air. Fumigant gases or vapors consist of molecules that will mix with the surrounding air. Because the molecules are very small (compared to particles in aerosols), fumigants can spread throughout a space, penetrate into the material being fumigated, and diffuse away afterward. Aerosols cannot do this.

Fumigants can penetrate even seemingly solid items like brick, concrete and wood. However, these items are not as solid as they appear. In a magnified view, it is possible to see the molecules of wood and the spaces between them. Fumigant molecules actually move between the wood molecules to reach the pests. Because fumigants penetrate so well, they must be confined in an enclosed space. As soon as a fumigant escapes from an enclosure, its effectiveness is lost.

NOTE: Fumigants provide no residual protection. Once a commodity has been treated and aerated, new pests can attack at any time.

Scope of This Manual

Fumigation is used to treat a wide range of pests in many locations. It is most often reserved for pests that live in hard-to-reach areas such as soil, stored grain or wood.

This manual covers fumigation of stored products and raw agricultural commodities, such as whole grains and other unprocessed products.

The purpose of this manual is to provide basic information to help you fumigate safely and effectively. It starts by describing the major (the most common and the most damaging) pests of raw agricultural commodities in Nebraska. While the list is long, it is by no means complete. Professional organizations, universities, industries and government agencies produce detailed field guides and other pest identification references. These sources will help you learn more about the pests described here. They will also describe pests not included in this manual.

Many things can be pests. Insects and mites harm stored commodities. This manual will focus on pests that are commonly controlled by fumigation. You will learn about their life cycles and what to look for when scouting. This manual also describes the most vulnerable stage (s) of common pests and the best time (s) for efficient control.

You will also learn about fumigants. Fumigants have many characteristics that can affect how well they work. These include boiling point, molecular weight, water solubility and flammability. External factors such as temperature and humidity can also affect performance. This manual will describe these factors and help you understand how different fumigants will perform in different situations.

This manual describes the principles of Integrated Pest Management (IPM). It explains when and how fumigation fits into a well-planned IPM program. You will also learn several ways to control pest and disease problems without fumigation. These alternatives to fumigation may be cultural, biological or chemical. By using a combination of methods, you may often achieve the best control.

Please note that in Nebraska the commercial control of rodents and birds in/around grain storage facilities is covered by Structural Pest Control, Category 8, not by Fumigation, Category 11. You will need to obtain Category 8 if using baits to control these pests.

You will be introduced to a range of fumigation methods and equipment. You will learn basic techniques used to treat raw agricultural commodities. Each method has its pros and cons. You will learn how to select a treatment method based on the pest, the item infested, and the severity of the infestation. During fumigation, problems often arise. You will learn how to prevent these problems, and how to handle them if they do develop.

Aeration must follow all types of fumigation. For indoor treatments, aeration introduces fresh air to dilute and remove fumigant-filled air. Proper aeration is key to safe fumigation. Procedures for aeration vary with the fumigant, the item treated and the conditions in the treatment area. This manual will describe aeration techniques for a variety of situations.

Pest control decision-making will be addressed throughout this manual. Before fumigating, answer the following questions:

- Is the problem actually caused by a pest?
- If so, what pest?
- What effective and affordable control options are available?
- Is the problem severe enough to warrant fumigation?
- Is the pest in a vulnerable stage in its life cycle?

A good planner makes careful records of pest problems: when and where the problem occurred, solutions and results. He or she also learns how to prevent future problems.

Fumigants are the most hazardous of all pesticides. Small amounts of many fumigants can cause serious illness or death. This manual describes ways to protect the public, your coworkers and yourself from exposure. You should always read the label before applying fumigants. This manual refers to the sticker label and the label booklet (Applicator's manual) as "labeling." Label information must be followed to ensure safe use of the fumigant.

This manual also provides safety checklists for all stages of fumigation. You will learn about special tools and first aid techniques.

Respirators and gas detectors are two of the most important safety tools in fumigation. Respirators provide clean air to workers during fumigation and aeration. Gas detectors monitor and record gas levels before, during and after treatment. This manual will describe several models of each device. You will learn how to select the best model for your situation. You will also learn how to inspect, maintain and use this equipment properly.

Finally, this manual will discuss common fumigants used to treat food products and raw agricultural commodities.

Chapter 2

Pest Identification and Biology

Learning Objectives

After studying this chapter, you should be able to:

- Define primary and secondary feeders.
- Identify stored commodity pests by appearance, behavior, and types of damage.
- Describe each pest's preferred habitat, biology, and life cycle.
- List prevention and control methods for stored commodity pests.
- Explain why sampling stored grain is important.
- Identify and describe three sampling tools.
- Identify and describe three monitoring traps.

This chapter describes some of the most common pests of processed and raw agricultural commodities that are controlled with fumigants. You will learn why these organisms are considered pests, what these pests look like and where they live. Proper identification of pests is essential to choosing the most effective control method. This chapter will also describe techniques used to prevent or control infestations.

Universities, government agencies, industry and other organizations produce detailed field guides and other useful references. These sources will help you to learn more about the common pests described here and additional pests not included in this chapter.

This chapter gives the common and the scientific (Latin) name for the insects described. Scientific names are in italics and placed in parentheses. The first name is the "genus." The second name is the "species." The term "spp" indicates that there are several species within a single genus.

Terms to Know

Abdomen – The hindmost or rear body section of an insect.

Antennae – A pair of jointed appendages on the head of an arthropod. Antennae are usually long and slender. They are used to sense things in the arthropod's environment.

Arachnid – A wingless arthropod with the body divided into two parts. Arachnids have four pairs of legs on the rear body section. They do not have antennae. Mites, spiders and ticks are arachnids.

Arthropod – A animal with jointed legs and a segmented, jointed exoskeleton. Beetles, wasps, crayfish and spiders are arthropods.

Auger – A grain transfer tool used to load and unload grain and other stored products.

Caterpillar – The larval stage of a butterfly or moth.

Cocoon – A protective envelope formed by an insect larva, in which it spends the pupal state.

Contact Pesticide – A chemical that causes a localized injury where it touches a pest. Contact pesticides do not need to be ingested by the pest to cause toxic effects.

Fore Wings – The pair of wings closest to the head of an insect.

Germinal – At an early stage of growth. The germ, embryo or nucleus of a grain kernel.

Grain Elevator – A facility for holding stored grain before shipment.

Grub – The creamy, soft larval stage of some beetles.

Habitat – A specific area or environment in which an animal normally lives.

Hind Wings – The pair of wings closest to the rear of an insect.

Infest – To inhabit or overrun in large numbers.

Infestation – A pest population so large that it is harmful or unpleasant.

Insect – An arthropod with a body divided into three regions: head (front), thorax (middle) and abdomen (rear). Insects have three pairs of legs on the thorax. Usually, adult insects have one pair of antenna and two pairs of wings. Ants, cockroaches, beetles and flies are insects.

Instar – In insect development, a stage between successive molts. For example, the first instar is between hatching and the first molt.

Larva (Plural = Larvae) – An immature stage in the life cycle of an insect with complete metamorphosis. Most insect larvae look like segmented worms with legs. As a rule, the larval stage is an active, feeding stage. Maggots (flies) and caterpillars (butterflies and moths) are insect larvae. In complete metamorphosis, the larval stage is between the egg and the pupa stage.

Life Cycle – The stages of development. The continuous sequence of changes that an organism undergoes during its life, from egg to adult stages.

Mandibles – The jaws used by some insects to bite and/or chew.

Metamorphosis – The change in body form during the life cycle. Some organisms are born looking like small adults. Others change considerably in appearance (in stages) as they develop. Most insects go through some sort of metamorphosis in their life cycle.

Complete Metamorphosis – Insect development involving four different body forms and life stages. A good example of complete metamorphosis is the life cycle of a butterfly or moth. A butterfly life cycle starts with an egg. An active feeding stage called a larva hatches from the egg. A butterfly larva is called a caterpillar. When caterpillars get to a certain size and age, they make a protective case. The next stage, which is called a pupa, does not feed. Inside the case, the pupa changes into an adult.

Gradual Metamorphosis – Insect development in three stages. In gradual metamorphosis, the egg hatches into a nymph. A nymph is a small, immature stage resembling the adult in body form. As the nymph grows, it develops wings and functional reproductive organs. Grasshoppers and cockroaches go through gradual metamorphosis.

Molt – To shed. Arthropods shed their exoskeleton when they molt.

Nymph – The developmental stage of an insect with gradual metamorphosis. Nymphs hatch from eggs and gradually develop into mature adults.

Pheromone – A chemical released by an organism that influences the behavior of other organisms of the same species. Pheromones are often used in traps to attract insects to a specific location.

Pupa (Plural = Pupae) – In complete metamorphosis, the stage of development between the larva and adult. Pupae do not feed. Usually, they are not mobile.

Residual Pesticide – A pesticide that persists and remains toxic after it is applied. Residual pesticides can kill pests over a period of time.

Thorax – The middle segment of an insect's body. The thorax lies between the head and the abdomen.

Who "Dunnit"?

Pests of Stored Products

Stored product fumigation is most often used to manage insect pests.

Insects cause vast losses of stored products worldwide. Stored products include:

- Fabrics
- Rugs and carpeting
- Paper products
- Milled or ground food such as flour, meal, cereals, cake mixes and pet food
- Nuts and dried fruits

- Meats and other animal products such as wool, fur and angora
- Spices, coffee and tea

The type of damage caused varies with the insect and the stored product. Some insects stain and severely damage fabrics and hard goods. Others consume large amounts of stored food, reducing the amount for sale. Still other pests make fresh and stored food products inedible and unmarketable. In all cases, stored-product pests can cause significant financial losses.

Common pests of stored products include moths and beetles. These pests can be controlled with fumigant pesticides in some situations.

The most common pest moths found in stored products include:

- Indianmeal moth
- Webbing clothes moth
- Mediterranean flour moth

The most common beetle pests found in stored products include:

- Rice weevil
- Maize Weevil
- Granary weevil
- Lesser grain borer
- Cigarette beetle
- Drugstore beetle
- Confused flour beetle
- Red flour beetle
- Sawtoothed grain beetle
- Larder beetle
- Warehouse beetle

Pests of Raw Agricultural Commodities

Insects are the most common pests of raw agricultural products. Raw products include whole grains (corn, rice, wheat, etc.), seeds and other unprocessed agricultural goods. They attack these commodities in:

- Grain elevators
- Silos
- Storage bins
- Warehouses
- Storage facilities
- Railroad cars
- Tractor trailers

Often, successful pest management depends on early diagnosis. Effective diagnosis of an infestation depends on several factors:

- Recognition of damage
- Accurate identification of what is causing the problem
- Knowledge of the pest's life cycle and habits
- An assessment of the distribution, density and dynamics of the pest infestation

Determining the type of pest causing damage is often difficult. Many are small and hard to see. Others hide in cracks, crevices or within grain kernels themselves. With no suspect present, your only clue may be the damage itself. Often the damage from one pest can be distinguished from that of another pest. To manage a pest effectively, you must be able to identify it. You must also understand its life cycle and environmental requirements. Treatment of an unidentified pest can lead to poor results. You may also be in violation of state and federal pesticide laws.

Each pest has a set of characteristics that can be used to identify it. This "profile" includes appearance, preferred habitat and food, signs of damage, seasonal life cycle and periods of activity. Some pests look different and/or have different body forms during their life. It is important to recognize the "profile"" for a pest during each stage of its life.

Regular and careful monitoring will detect early warning signs of pest activity. A well-trained pest manager can match symptoms with a probable cause. Knowing the pest's biology will help you decide when and how to manage it effectively and economically. Finally, you will need to study the pest infestation to decide if fumigation is necessary. You will need to know at least three things:

1. How large is the pest infestation?
2. How are the pests in the infestation distributed (for example, randomly or in clusters)?
3. Are numbers in the infestation increasing or decreasing?

Primary Feeders vs. Secondary Feeders of Stored Grain

Insect pests of stored agricultural products can be divided into two groups: primary and second-

ary feeders. The distinction is based on the feeding habits of the pest.

Primary feeders

Primary feeders are capable of destroying whole, sound grain. The most damaging primary feeders are those that develop within grain kernels, commonly referred to as internal feeders. These insects feed on the "germinal" region of the seed, reducing its nutritional value and its ability to sprout. Adult females of internal feeders deposit eggs on or in whole kernels. Larvae develop within the kernels.

Primary feeders include the:

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

Secondary Feeders

Secondary feeders feed only on damaged grains and seeds. The outer layer of the grain or seed must be damaged – cracked, holed, abraded or broken. This may be caused by physical damage during harvesting, rapid drying or by the damage caused by primary feeders. Some secondary feeders live in grain storage areas with primary feeders. The grain trade generally refers to secondary-feeding beetles as "bran bugs" or "bran beetles." Concentrations of bran beetles may raise the temperature and/or moisture level within stored grain. These conditions favor rapid population growth and grain spoilage.

The most common secondary feeders of raw agricultural products include the:

- Indianmeal moth
- Mediterranean flour moth
- Cadelle beetle
- Cigarette beetle
- Confused and red flour beetles
- Flat grain beetle
- Sawtoothed and merchant grain beetles
- Yellow mealworm beetle
- Grain mite
- Warehouse beetle

Both primary and secondary feeders can cause significant financial losses in facilities with raw agricultural products. You can control these pests with fumigant pesticides in some situations.

Common Pest Descriptions

Following are descriptions of some of the most common pests of raw agricultural commodities and stored products. Each section includes a description of the pest, its life cycle, its habitat preferences and the damage it causes. For information about pests not included in this manual, consult your local Extension office.

Moth Pests

Moths are second only to beetles in the amount of damage they cause to stored products. Only the larval stage causes damage.

Damage

Moth larvae damage grain by eating and contaminating it so that is it is not fit for human consumption. Some moths prefer whole grains. 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 control is poor, moths may follow a product throughout the manufacturing and distribution process. You can find moth pests in storage bins, mills, and delivery trucks.

Life Cycle

To control moths, you must understand their life cycle. Moths are close relatives of butterflies. They develop by complete metamorphosis. Female moths lay eggs singly or in small groups. An adult female can produce several hundred eggs during her brief life. The caterpillars, or larvae, hatch from the eggs and feed on nearby food. Each caterpillar grows and sheds its skin several times. After feeding for several weeks, the caterpillar spins a cocoon. In the cocoon, it transforms into a pupa. The adult moth emerges several weeks later. Adults live for a short time and do not feed on grains. Females die soon after they lay their eggs. Moths may produce several generations per year, depending on the temperature and food source. In good conditions (warm temperatures and abundant food), they may complete their life cycle in one to three months.

Identification

Adult moths have two pairs of wings that fold over the body when the moth is resting. Like butterflies, some moths have color patterns on their wings.

Others have solid-colored wings. The antennae of female moths are long and slender. The male's antennae are long and brushlike or featherlike.

Moth caterpillars resemble small worms with legs. Some species have distinct color patterns or spots that can help with identification. It is easy to confuse moth larvae with beetle larvae. An easy way to distinguish between the two is to look at the middle of their bodies. Moth larvae usually have fleshy, leg-like appendages called "prolegs" on several of the middle segments of their bodies. Prolegs are not present on the middle sections of beetle larvae.

There are many types of pest moths. The following are some of the most common and troublesome to raw agricultural commodities and stored products.

Angoumois Grain Moth
Sitotroga cerealella

Adults have four wings and about a 1/2-inch wingspan. The fore wings are buff to pale yellowish brown. Hind wings are gray and pointed, resembling a pointed finger. Both sets of wings are fringed with long hairs. Adults are nonfeeding, short-lived and attracted to light. In the spring, they often fly out to fields and lay eggs on the grain kernels while they are still on the plant.

Each female lays 40 to 400 eggs directly on grain kernels. The eggs are white when first deposited but soon turn red. Emerging larvae are white with yellowish heads and reddish brown mouthparts. Each larva bores into a whole grain kernel, spinning a silken web over the hole through which it enters. Once inside the kernel, the larvae feeds until maturity and then pupates inside the kernel. When the adult emerges, it leaves a distinctive round flap over the hole in the grain.

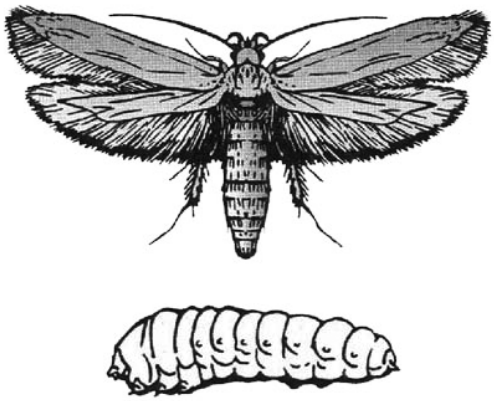


Figure 2.1 Angoumois grain moth adult and larva

Angoumois grain moths are primary feeders that attack only whole kernels or caked material. Barley, rye, corn, oats, rice, wheat and various seeds are common targets. Larvae attack grain in the field as well as in storage. They cause a reduction in grain weight and quality. Heavily infested grain smells bad and is less attractive for consumption. In bins, only the top few inches of grain will be infested. The Angoumois grain moth prefers damp grain to dry grain. Adult moths cause no damage.

Indianmeal Moth
Plodia interpunctella

Adult Indianmeal moths have four wings spanning about 3/4 inch. You can distinguish the moth from other species by the color pattern of its front wings. The outer two-thirds of the front wings are reddish brown and the bases are grayish white. The hind wings are pale gray. The head and thorax are reddish. Adult Indianmeal moths are weak fliers. They are usually active for only a few hours in the evening. Most of the time, they remain close to the infested material.

Female adult Indianmeal moths lay from 100 to 400 eggs singly or in groups directly on food material. The small, pale yellow eggs hatch in about three days.

Figure 2.2 Indianmeal moth adult and larva

Larvae emerge and feed on nearby grain products. They are usually dirty white but may have a greenish or pinkish tint. Full-grown caterpillars are about 1/2 inch long with a brown head. Caterpillars spin silk thread as they crawl. Heavily infested materials are often covered with a fine, mesh of silk webbing. Mature caterpillars usually crawl away from their food to spin a cocoon and pupate. Sometimes you will find Indianmeal moth caterpillars crawling across ceilings or walls far from the source of infestation. The pupal stage can last for several months, making control more difficult.

In agriculture, the Indianmeal moth is one of the most common pests of grain storage and cereal processing facilities. It is a secondary pest that feeds on cracked corn and grain that is damaged by other insects. It attacks grain and grain products, seeds, nuts, a variety of dried fruits and other commodities. Because of its preference for corn, the Indianmeal moth is common in the corn-growing and corn-storage areas of the United States.

In stored products, Indianmeal moth larvae are one of the most common pests of stored flour products, ground meal, birdseed and dry pet food. They also feed on other dry foods including dried fruit, seeds, powdered milk, chocolate and candy. Adult Indianmeal moths cause no damage.

Mediterranean Flour Moth
Ephestia kuehniella

Adult moths are about 1/2 inch long with a wingspan of a little less than an inch. The fore wings are pale gray with wavy black lines running across them. The hind wings are dirty white. 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. Adults are also nonfeeding and short-lived.

Adult 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, and apparent hairs and 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 profusely spin silken threads that mat food particles together. These mats can clog processing

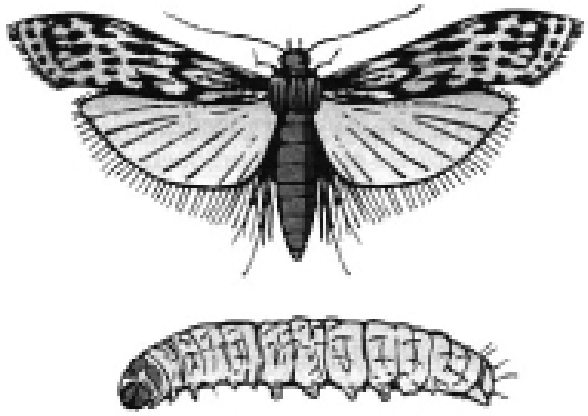


Figure 2.3 Mediterranean flour moth adult and larva

equipment. Pupation occurs near clean food, away from large amounts of infested material.

The Mediterranean flour moth is a secondary feeder that prefers flour and meal. However, it also infests grain, nuts, seeds and other stored foods. Adult Mediterranean flour moths do not cause damage.

Webbing Clothes Moth
Tineola bisselliella

Casemaking Clothes Moth
Tinea pellionella

The adult webbing and casemaking clothes moths look very similar. Adult clothes moths have four very narrow wings and a 1/2-inch-long wing spread. Their fore wings are light gray and sometimes mottled with brown scales. The hind wings are small and pale. Both sets of wings are fringed on the back margin. To distinguish between the species, look at their fore wings. The casemaking clothes moth has three dark spots on its fore wings. These spots are absent on the webbing clothes moth.

Clothes moths mate and begin laying eggs two days after they emerge as adults. Females lay 40 to 50 eggs directly on food. Whitish larvae, less than 1/2 inch long, emerge in one to three weeks. The head and first segment of the larval body are brown. In exposed areas, larvae spin a silk tube or mat to cover their body. When they pupate, the larvae leave these empty cases and mats behind. The presence of silk tubes or mats is a sure sign of infestation.

Larvae feed on wool, feathers, bristle brushes, fur and other items made of animal fibers. They will also infest synthetic fabrics that are interwoven with

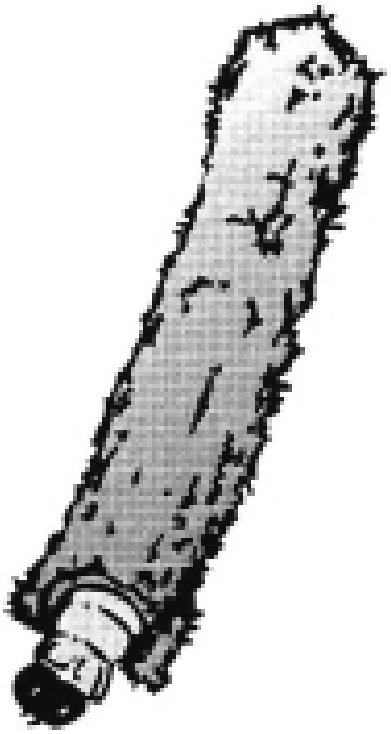


Figure 2.4 Casemaking clothes moth larva in a case

animal fibers. Sometimes, clothes moths spin silken tunnels on infested woolens. Damage is most extensive to the surface of fabric. In addition, the larvae will infest food ingredients that have high animal protein content such as dried meat, and powdered liver or egg. Adult clothes moths cause no damage.

Control

To control moths attacking food and fabrics, prevention is key.

Food Products – Routine cleaning of all food handling equipment, with preventative spot fumigation, may reduce or eliminate the need for large-scale fumigation. Good sanitation involves removing spilled flour, meal, dust and other stored product in and around the holding area. Be sure to clean corners, floors and walls. Bits of product remaining can harbor insects that can move into the new products stored in the same area. Also, make sure that grain and feed in adjacent buildings are not infested. Moths can fly from one building to the next.

If an infestation does develop, first find and destroy infested materials. Then treat the location where they were stored. Thoroughly clean the area to remove spilled food products. Practice good housekeeping to prevent reinfestation.

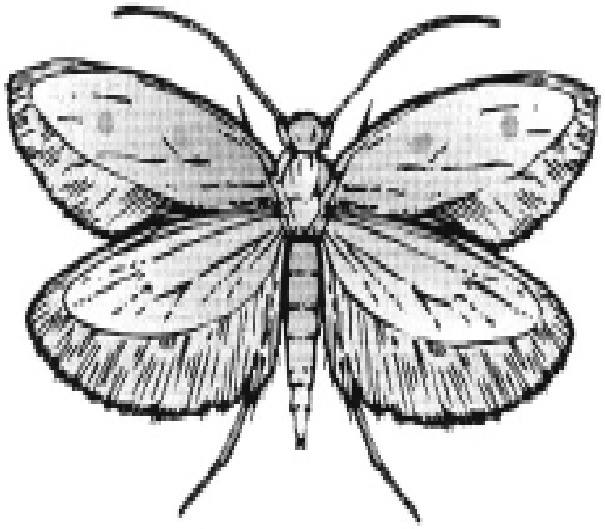


Figure 2.5 Casemaking clothes moth adult

Fabrics – Control small infestations by cleaning fabrics and storing them in tight containers with moth crystals. Large infestations such as in a warehouse may require fumigation. However, the problem must be severe enough and/or the products must be valuable enough to justify the expense of fumigation. Practice good housekeeping to prevent reinfestation. Use fumigation as a last resort.

Prevention also involves following good grain storage practices. Monitor for insect infestations and heating in stored grain. Aerate to maintain low moisture levels in the grain. Mix and level the grain so fines and other grain debris are evenly distributed throughout the grain. For more information on proper grain storage, see Chapter 4.

If an infestation does develop, find and destroy infested materials. Then treat the location where they were stored. Thoroughly clean the area to remove spilled product. Practice good housekeeping to prevent reinfestation.

Beetle Pests

There are hundreds of thousands of beetle species in the world. Fortunately, only a few attack raw agricultural and stored products. Those that do, however, can cause serious damage and large financial losses if left uncontrolled.

Damage

Beetles attack a wide range of agricultural and stored products. Most species infest a specific commodity or type of commodity. For example,

cigarette beetles prefer dried plant materials such as cured tobacco, herbs and spices. Rice, granary and maize beetles attack stored grains. By knowing which pest(s) attack(s) which product(s), you can more quickly pinpoint the source of damage.

Life Cycle

Like moths, beetles develop by complete metamorphosis: egg, larvae, pupae and adult. Female beetles lay eggs singly or in small groups on a variety of foods. The larva, or "grub," that hatches from the egg will feed on the available food. The grub stage may last 14 to 16 months. Full-grown grubs build cocoons out of scraps of food. They pupate inside these cocoons. After several weeks, adult beetles emerge. Adults live for several months or as long as one year. Both adult beetles and grubs are active feeders, damaging a range of stored products. In warm climates or heated buildings, beetles can produce six or more generations a year.

Identification

Beetles are very diverse in appearance. However, there is one feature common to most beetle species. Adults have a pair of thin inner wings covered by a pair of shell-like outer wings. These outer wings are called "elytra" or "wing covers."

The following are a few of the most common beetle pests of raw agricultural products.

Cadelle Beetle
Tenebroides mauritanicus

Cadelle beetles are one of the largest stored- products pests. Adults measure 1/3 to 1/2 inch in length. They are long, flattened and shiny black. They have brown antennae and legs. Adult cadelles are long-lived, often surviving for more than a year.

The adult female cadelle lays about 1,000 eggs over several moths. Emerging larvae are grayish white with a black head and thoracic shield. When larvae are mature, they measure about 3/4 inch long. Larvae have a distinctive black plate with two hornlike projections on the upper side of their last abdominal segment.

Cadelle beetles are secondary pests. They attack grain in rice mills, flour mills and storage bins on farms. The larvae and adults feed by moving from grain to grain and devouring the germinal region.

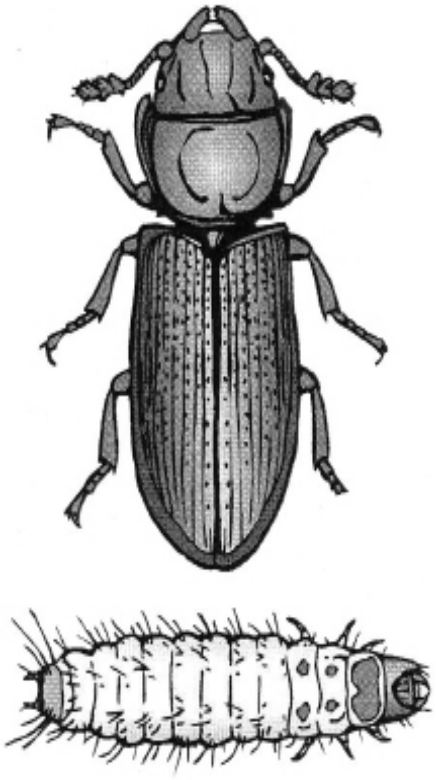


Figure 2.6 Cadelle adult and larva

Cadelle larvae also cause damage by boring into the floor and walls of wooden storage bins. They sometimes burrow into empty bins as larvae and remain dormant until fresh grain is stored. A seemingly clean bin may hold thousands of insects. Cadelle larvae and adults are large and can go without food for 52 (adults) to 120 (larvae) days. Since they live for nearly one year, they are more common in old grain bins and flour mills.

Cigarette Beetle
Lasioderma serricorne

Drugstore Beetle
Stegobium paniceum

Adult cigarette and drugstore beetles are small, oval insects. They usually measure 1/16 to 1/8 inch long. They look hump-backed because their heads are bent at an angle under their thorax. Their bodies are covered with small hairs that give them a silky, yellowish brown to reddish color. You can distinguish the two beetles by their antennae, wing covers and flight habits. Adult drugstore beetles have enlarged terminal segments of their antennae. They seldom fly and their wing covers have, longitudinal lines of punctures or pits. On the other hand, cigarette beetle antennae are sawlike. They often fly and they

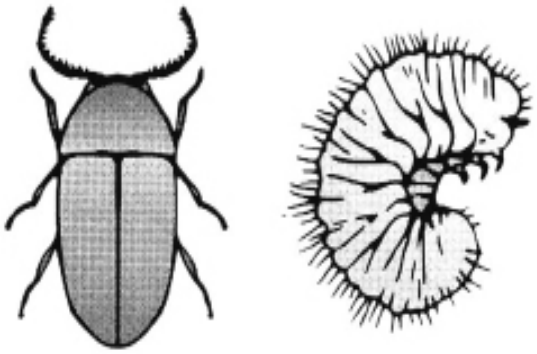


Figure 2.7 Cigarette beetle adult and larva

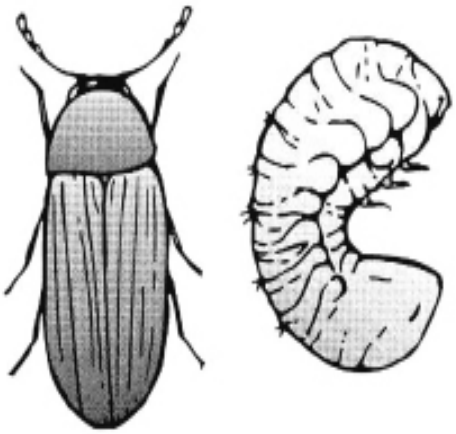


Figure 2.8 Drugstore beetle adult and larva

have scattered punctures over their smooth wing covers.

Adults of both species are nonfeeding. The cigarette beetle female lays her eggs in groups of 30 to 40 eggs. Female drugstore beetles lay eggs singly. Both deposit their eggs on or near food sources. When the eggs hatch, tiny, C-shaped larvae emerge. The larvae are creamy white with yellow heads and brown mouth parts. Mature larvae are about 1/6 inch long. Larvae are often covered with the material they infest.

As its name implies, the cigarette beetle is primarily a pest of dried tobacco. It can infest stored, bundled leaves as well as finished products like cigars and cigarettes. However, this beetle can also feed on a variety of stored food products including cereals, ginger, raisins, dates, pepper and dried fish.

The drugstore beetle feeds on a variety of foods and spices, including dried bread products, pepper, ginger, and paprika. They also attack vitamin supplements and some medicines. Drugstore and cigarette beetles can penetrate most paper packaging materials.

Confused Flour Beetle
Tribolium confusum

Red Flour Beetle
Tribolium castaneum

Adult confused flour beetles and red flour beetles are long, flat, shiny, reddish brown insects. They measure about 1/7 inch long. The head and upper parts of the thorax are densely covered with minute punctures or "pits." The wing covers are ridged lengthwise. You can distinguish between the two beetles by their antennae, compound eyes, and ability to fly. The antennae of the confused flour beetle gradually enlarge toward the tip, producing a four-segment club. The red flour beetle's antennae enlarge abruptly at the last few segments, giving the antennae a knobbed appearance. The eyes of the confused flour beetle are almost cut in half by a ridge on the edge of the head; whereas, with the red flour beetle the eyes are almost intact. The red flour beetle is a strong flier. The adults are very active, especially in the evening hours. The confused flour beetle cannot fly.

Female flour beetles lay an average of 450 eggs directly on the food source. Eggs are small and clear white. The female covers the eggs with a sticky secretion to which bits of the food adhere. Small, brownish

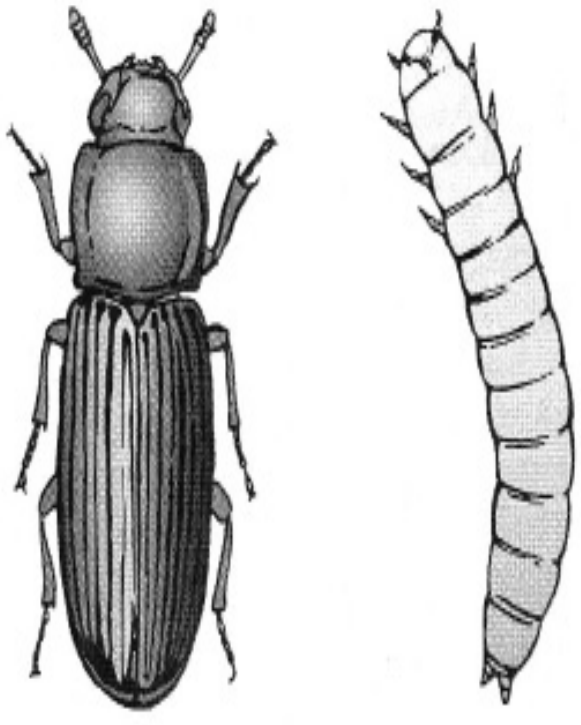


Figure 2.9 Confused flour beetle adult and larva

white larvae hatch in five to twelve days. They are full grown in one to four months. A full-grown larva is about 3/16 inch long and tinged with yellow. Larvae feed on broken kernels, flour, meal and other starchy materials. They are often hard to detect because they cover themselves with bits of the food they infest. They may appear as tiny lumps in the flour. The larvae pupate and transform into adults.

Confused and red flour beetles are serious pests in flour mills. They do not penetrate whole grain kernels or undamaged grain. Instead, these secondary feeders cause damage by scraping the surface of foods or eating finely ground material. Their preferred foods include grains and grain products, peas, beans, flour, dried fruits, shelled nuts, spices and other commodities. These beetles may leave a bad odor that affects the taste of infested products.

Flat Grain Beetle
Cryptolestes pusillus

The adult flat grain beetle is tiny, flat and brown. It measures 1/16 inch long. You can distinguish it from other stored-product pests by its long antennae, which often grow two-thirds the length of the insect's body.

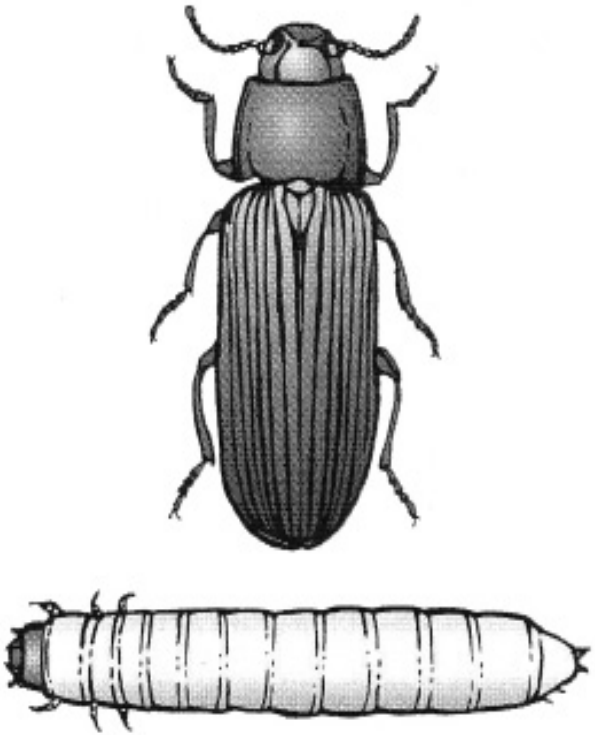


Figure 2.10 Flat grain beetle adult and larva

Female flat grain beetles lay small white eggs in the crevices of grain. When they emerge, larvae are slender and pale, with dark-colored legs and a dark head. Each larva has a pair of black, spinelike "tail horns" at the end of its body. Mature larvae form cocoons to which food particles stick.

The flat grain beetle is a widely distributed secondary pest. It primarily feeds on the germinal region of stored grains, especially wheat. It prefers damaged grain with a high moisture content.

Lesser Grain Borer
Rhizopertha dominica

The adult lesser grain borer is 1/8 inch long and shiny dark brown or black. It has a slender cylindrical form. Its body surface is somewhat roughened, and its head turns down under its thorax. Lines of small pits occur on the wing covers. Powerful jaws allow the lesser grain borer to bore into grain. The last three segments of the antennae are enlarged on one side. Adult lesser grain borers are strong fliers and long-lived.

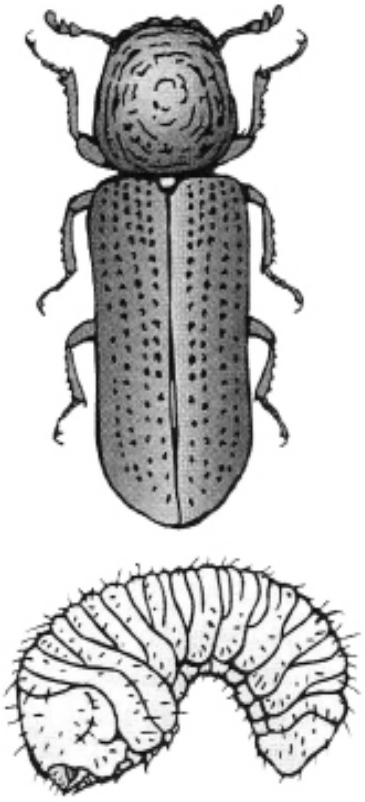


Figure 2.11 Lesser grain borer adult and larva

Adult female lesser grain borers lay up to 500 eggs singly or in clusters in loose grain. When

the larvae emerge, they are C-shaped and white with dark heads and claws. Larvae burrow into and feed on the interior of nearly all types of stored grain. When mature, the larvae measure about 1/8 inch. They complete development by pupating inside grain kernels. It is often difficult to detect infestations of lesser grain borers because the adults and larvae are usually together inside the infested grains.

Lesser grain borers occur worldwide. They are primary feeders that attack cereal and coarse grains, especially whole corn and wheat kernels. Both adults and larvae are voracious feeders and can penetrate packaging. Grain infested with the lesser grain borer has a characteristic sweet and slightly acrid pungent odor. This odor contains a male-produced pheromone that has proven to be an effective lure for traps.

Rice Weevil
Sitophilus oryzae

Granary Weevil
Sitophilus granaries

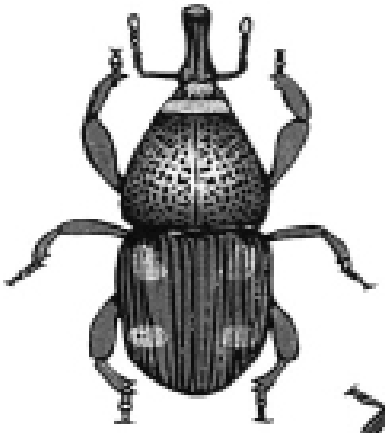
Maize Weevil
Sitophilus zeamais

Weevils are among the most destructive pests of grains, seeds and grain products. Most are primary feeders that attack the inside of grain kernels.

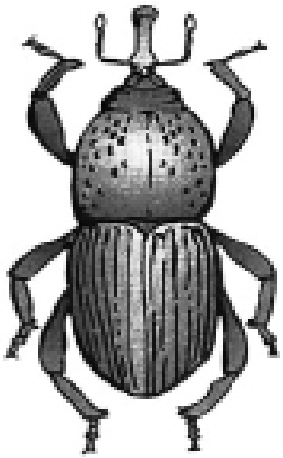
Adult rice and granary weevils vary in size but average about 1/8 inch long. The bodies of rice and granary weevils are reddish brown to black with ridged wing covers. Their thoraxes are densely pitted. Their mouthparts form elongated snouts, characteristic of all weevils. You can distinguish between the granary and rice weevils by the shape of their pits, the color of their bodies and their ability to fly. Adult rice weevils are dull in color and readily fly. They tend to have round pits covering the thorax. They also have four pale reddish to yellow marks on the corners of the wing covers. Adult granary weevils have oval pits, a polished uniform coloration, and they cannot fly.

The maize weevil and the rice weevil are so close in appearance that identification should be left to the experts. Maize weevils are slightly smaller than rice weevils, and they are more heat-tolerant.

Adult rice and maize weevils live for four to five months. Each female lays 300 to 400 eggs. Adult granary weevils can live for seven to eight weeks.

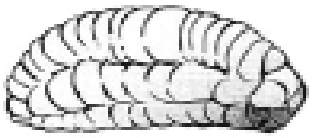


Rice weevil adult



Granary weevil adult

Figure 2.12



Rice/granary weevil adult

Each female lays 50 to 200 eggs. Females of all three species use their strong mandibles to chew a small hole in a grain kernel. There they deposit a single egg and seal the hole with a gelatinous fluid. The small, white, legless larvae hatch, feed and develop inside kernels of grain. Since rice and maize weevils can fly, infestations may develop in the field before harvest. Because granary weevils cannot fly, you most often find them only where grain is stored.

Granary weevils are tolerant of low temperatures and cold climates. Within grains, larvae can survive at least ten weeks at 41°F. Adults easily overwinter in unheated buildings and bulk grain. Adult rice and maize weevils do not normally overwinter in cold climates unless the grain heats up due to a high moisture content.

Rice, granary and maize weevils are primary feeders that attack grain before harvest and in storage. They feed on both unbroken and broken grain kernels. Wheat, corn, oats, rice, sorghum and buckwheat are just some of their preferred foods. These pests

also infest grain products such as spaghetti and macaroni. Both the adults and larvae damage agricultural products.

Sawtoothed Grain Beetle
Oryzaephilus surinamensis

Merchant Grain Beetle
Oryzaephilus mercator

Adults of these two beetles are 1/8 inch long, slender, dark brown and flat. They have sawtoothed-like projections on each side of the thorax. The larvae are yellowish white and less than 1/8 inch long. They become covered with the food they ingest and appear as small lumps in flour. Merchant grain beetles are known to fly, whereas sawtoothed grain beetles do not fly.

Adults of these two beetles usually live six to ten months, but some may live as long as three years. The female lays 50 to 300 eggs in flour, meal or other stored products. The eggs hatch in flour, meal or other stored products. The eggs hatch in about four days, and the larvae begin feeding immediately. When the larvae are full grown, they construct cocoons out of fragments of foods. Within these cells, the larvae change to pupae and then to adults.

Sawtoothed and merchant grain beetles are secondary feeders that attack nearly all foods of plant origin. Although they are not able to attack intact kernels, they do cause a considerable amount of damage to grains by infesting slightly damaged pieces. Sawtoothed and merchant grain beetles also feed on grain products such as flour, granola, cake mixes, meal, cereal and macaroni, as well as nutmeats, candy and dried fruits. Since these beetles are very flat, they easily hide in cracks and crevices and often penetrate improperly sealed packaged foods. The sawtoothed grain beetle prefers areas of high temperature and humidity.

Yellow Mealworm or "Mealworm Beetle"
Tenebrio molitor

Adult mealworm beetles are about 1/2 inch long. Their bodies are shiny dark brown or black. Tiny punctures occur in rows along the wing covers. The antennae are slightly clubbed at the tip. Yellow mealworm beetles have well- developed wings and are strong fliers.

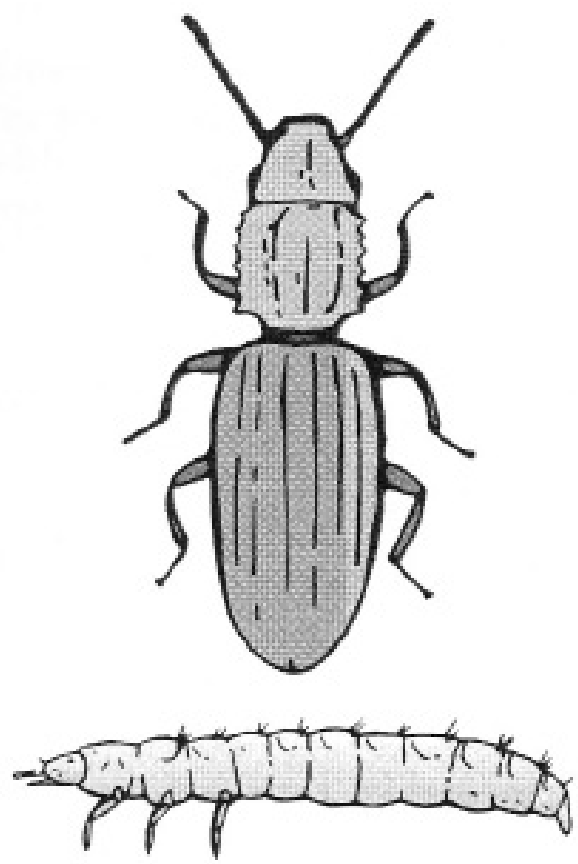


Figure 2.13 Sawtoothed grain beetle adult and larva

Adult mealworm beetles lay their eggs in grain or food products. Each female produces up to 500 bean-shaped eggs. The eggs are white and sticky, quickly becoming covered with food particles. Larvae are pale brown to yellow, smooth and hard bodied. When fully developed, they measure 1 1/4 inches long. Larvae develop slowly, living at least one year. They pupate near the surface of the food.

The mealworm beetle is a minor pest, but common in spoiled grain, grain dust and debris. Yellow mealworm infestations typically indicate poor sanitation. You may find them in grain spillage, neglected corners where grain dust has accumulated or under bags of grain. They also occur in poultry houses, where chicken droppings mix with grain.

Larder Beetle
Dermestes lardarius

Adult larder beetles are 1/4 to 3/8 inch long, oval and elongated. They are dark brown to black with a broad pale yellow band across the front third of their wing covers. The band is speckled with darker spots. Also noticeable are the short, clubbed antennae.

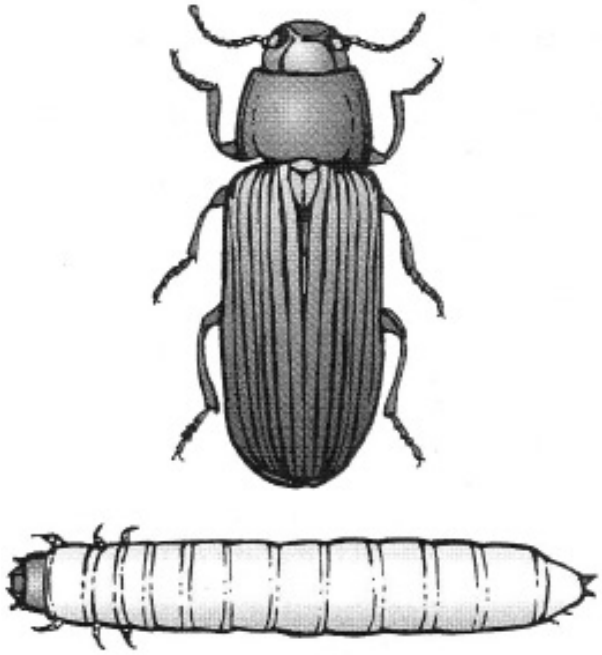


Figure 2.14 Yellow mealworm beetle and larva

Adult females lay 100 to 800 eggs on food or in cracks where food is stored. Brown, hairy larvae emerge in 12 days. They range in length from 3/8 to 5/8 inch. To pupate, larder beetle larvae bore into solid materials such as wood, plastic, and insulation. After three to five days, adults emerge.

Adults and larvae feed on a variety of animal products including dried fish, ham, bacon, meats, cheese, dried pet food and rawhide chew toys, and chew bones. They will also attack dried museum specimens such as insects, hides, feathers, horns and hair. Larvae cause most of the damage, but adult feeding can also cause problems. Larder beetles are often found with masses of dead insects in walls or gathered at windows.

Warehouse Beetle
Trogoderma variabile

The adult warehouse beetle is oval, 1/8 inch long and brownish black with yellowish wavy patterns on the wing covers. The larva is worm-like and somewhat hairy, with denser pads of hair on the segments at the end of the body.

As a carpet beetle species, warehouse beetles feed on fabrics, hair, feathers and wools, but they also have expanded their diet to include grains and grain-based products. They have a preference for substances containing higher levels of protein and often consumer germinal portions of grain.

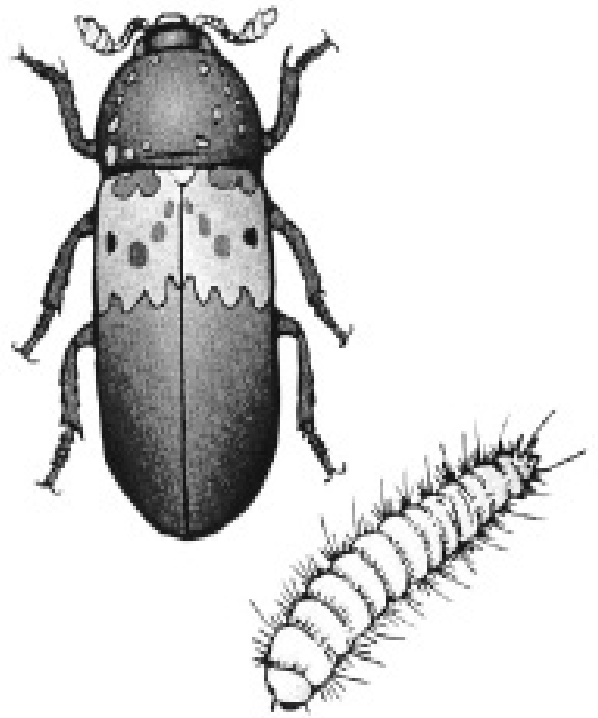


Figure 2.15 Larder beetle and larva

An adult female warehouse beetle can lay around 90 eggs in her life span, which can range from nine to 100 days. The complete life cycle can take two to four months.

Eggs are laid on the food surface, with larvae feeding on damaged grain or fines and later infesting whole grains. Cast skins left by molting larvae, as well as adult insects are good indication of infestation by the warehouse beetle.

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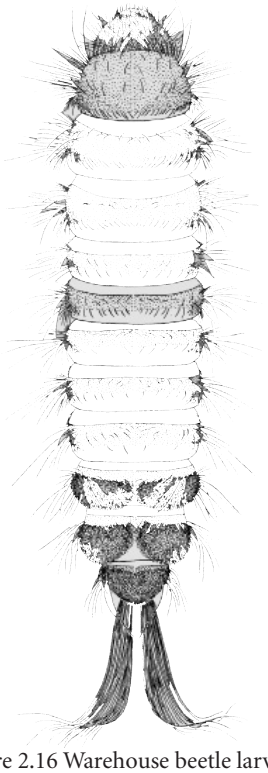


Source: USDA, Illustrator: Candy Feller

Figure 2.16 Warehouse beetle larvae

Warehouse beetles are found in both processed and unprocessed food, and food ingredients, including yeast, whole wheat flour, barley, wheat, cereals, egg noodles, meal, animal feeds, pet food, dried spices, and powdered milk. They often can

Source: USDA, Illustrator: A Cushman

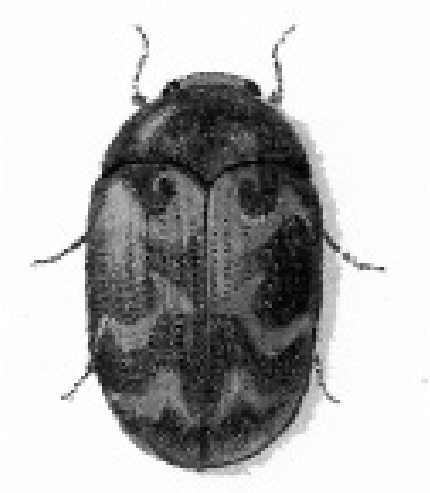


Figure 2.17 Warehouse beetle adult

be secondary pests, having been attracted to dead insects already present in stored foods.

Control

Controlling beetles in stored products is much the same as controlling moths. Prevention is key.

Food Products – Clean in and around storage areas regularly. Good sanitation involves removing spilled flour, meal, dust or other stored product in and around the holding area. Be sure to clean corners, floors and walls. Bits of product remaining can harbor insects that can move into new products stored in the same area. Apply nonfumigant pesticides to areas that are hard to reach. Routine cleaning, with preventative spot fumigation, may reduce or eliminate the need for large-scale fumigation.

If an infestation does develop, first find and destroy infested materials. Then treat the location where they were stored. If the infestation is severe, you may need to fumigate. Practice good housekeeping to prevent reinfestation.

Animal Products – Practice good sanitation to prevent larder beetle infestations. This involves keeping areas free of hair, dead insects, spilled animal food and other items in which larder beetles commonly nest. When small infestations develop, find and remove infested items. If you cannot identify the source of infestation and the problem is severe, fumigation may be necessary. Fumigation may also be needed when an individual item, such as an animal hide, is attacked. This is true if other control options such as chemical sprays would damage the item, or other types of pesticides are not able to penetrate the item and kill the beetles.

Prevention also involves following good storage practices. Monitor for insect infestations and heating in stored products and grain. Aerate the storage facility to maintain low moisture levels in the grain. Mix and level the grain so fines and other grain debris are evenly distributed throughout the grain. For more information on proper grain storage, see Chapter 4.

Other Pests

Grain Mites
Acarus siro

Mites are not insects. They belong to a group of arthropods called "arachnids." This same group includes spiders. Mites look and behave much like insects with a few differences. Adult mites have eight legs and two body segments. Insects have six legs and three body segments.

Mites go through three stages of development: egg, nymph and adult. Some references refer to the first nymphal instar as a larva, but it is technically a nymph. Adult and nymphal mites have eight legs and are similar in appearance.

Adult grain mites are pearly white with pale yellow to reddish legs. Their bodies are oval, measuring about 1/128 to 1/64 inch long. Long hairs trail from the rear of the body. Grain mites are not hard shelled.

Mites develop by gradual metamorphosis. An adult female can lay up to 800 eggs in her lifetime. She deposits white, oval eggs one at a time directly in food material. When the larvae hatch, they feed and grow quickly for about three days, and populations can explode rather quickly. Fungi on unbroken grain weaken the hull, allowing mites access to the germ where they feed and reproduce. Fungi attract the mites to the food source.

Also called "flour mites," grain mites occur worldwide. They infests grain and flour with a high moisture content. They are responsible for "mite dust" on the surface of cheese or on the floor near bags of flour or wheat. These mites also attack cereals, animal feeds, dried fruits and other vegetable materials. The grain mite occurs in fields, barns, bird nests, grain elevators and other areas. By attaching itself to insects, birds and other animals, the grain mite can

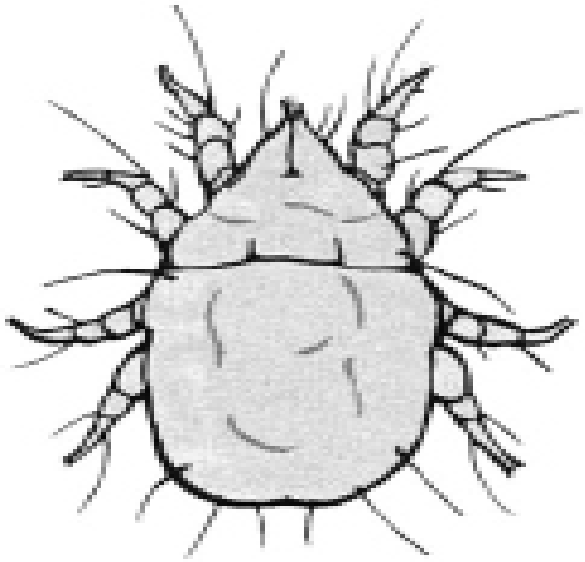


Figure 2.18 Grain mite

disperse widely. Large populations leave a characteristic minty odor. Grain mites can cause a type of dermatitis in humans known as "grocer's itch."

Mites cannot survive when the humidity drops below 60 percent. Their life cycle takes 17 to 28 days.

Control of Grain Mites and Mold

The best way to control grain mites and the mold that attracts them is to monitor the humidity and moisture level in and around stored products. Ventilate storage areas well. Keep the relative humidity below 60 percent. It is also important to move susceptible products and clean storage areas periodically.

When small infestations develop, remove and destroy the infested product. Clean the area thoroughly. Apply a nonfumigant pesticide to kill remaining mites and their eggs. Large infestations usually require fumigation.

Accurate identification of pests is vital for control methods of any type to be effective. Once you decide fumigation is the best way to control the pest, your knowledge of methods and application procedures comes into play.

Monitoring and Sampling in Raw Agricultural Products

Inspect for pests before they become a problem, and you will save time and money. Sampling will tell you the physical condition of your commodity, and which and how many pests are present. Table 2-1 indicates the number of live insects required to consider a commodity as infested. These Grain Inspection Standards for insect counts in sieved grain, as well as the grade criteria for insect damaged kernels (IDK) can help determine the need to fumigate. To find out more information about the United States Department of Agriculture's (USDA) U.S. sample grade criteria, please consult the references section at the back of this manual. It will also help you evaluate the effectiveness of previous control programs and allow you to take corrective measures before fumigation is required. Be thorough and use appropriate sampling equipment. Know where, how and at what intervals you should sample.

Grain	Insect Density Per Kilogram of Grain
Wheat, rye, triticale	• More than one live weevil, or • One live weevil plus any other live insect pest, or • No live weevils, but two or more other live insect pests
Corn, barley, oats, sorghum	• More than one live weevil, or • One live weevil plus five or more other live insect pests, or • No live weevils, but ten or more other live insect pests

Table 2-1. Number of live insects required for Federal Grain Inspection Service designation as "infested"
NOTE: Reference to 'weevil' includes weevils, and other live insects injurious to grain, such as the lesser grain borer.

Detecting Pest Problems – Raw Agriculture Products

To manage stored-grain insects effectively, always examine the grain before it is unloaded and moved into storage. Check grain for insects, moisture content and sour or musty odors. Use manual or hydraulic probes to withdraw grain samples from incoming loads. Sift and check these samples for insects.

Once grain has been stored, it is important to inspect bins regularly. Sample stored grain at 30-day intervals until it cools to less than 60°F. By taking samples, you can measure the grain temperature and moisture and detect any new insect problems. If there are "hot spots" (temperatures greater then 10°F higher than the rest of the grain), collect samples from these areas. Hot spots indicate a high moisture content

that favors insect and fungus activity. Determine the moisture content of your commodity and the presence of any insects. It is especially important to check for insects in samples from the grain surface and from areas where fines have collected. Infestations often begin in these locations.

Table 2-2 lists the minimum number of samples you should take when monitoring round bins. If temperatures are unusually high in certain spots, collect samples from those areas. Determine the moisture content and presence of any insects.

Sampling Tools

Several types of probes are available for sampling grain. Industry suppliers can give you instructions for using these devices.

- Partitioned grain trier ("probe") – This tool captures insects in stacked compartments. Suppliers sell 3-, 5-, 10- and 12-foot models. Always sample the center surface of the storage bin and at least two other locations near the surface. To operate the grain trier, insert it into the grain at a 10° angle with the compartments closed and facing upward. Once the trier is in the grain, open the compartments to take a grain sample. Then, shut the compartments and remove the trier from the grain. Place the samples from each section in a plastic bag or other container. Sieve each sample and check for insects.
- Deep-bin or deep-cup probes – Use these probes to collect samples from greater depths within a grain mass. They extend up to 15 feet below the surface. The sample cup is attached to the end of a metal probe and inserted closed into the grain mass.
- Vacuum samplers or power probes – These tools allow you to collect samples from depths greater than 10 to 15 feet. A modified shop vacuum can collect samples from depths as great as 20 to 30 feet. Hydraulic or mechanically powered probes can collect samples from depths as great as 100 feet.

Bin Height	Temperature Probes		Moisture and Insect Determinations	
	Shallow*	Deep*	Shallow*	Deep*
Less than 24 feet	2	3	3	5
Greater than 24 feet	2	5	3	10

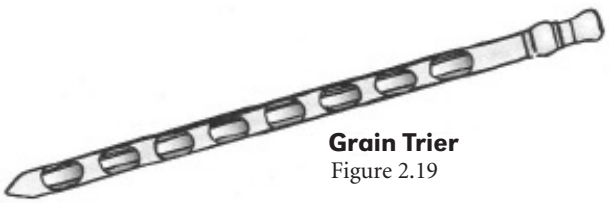
Table 2-2. Minimum number of samples for determining temperature, moisture and insect levels in round bins

**Take shallow samples at or just below the surface of the grain. Take deep samples from various depths determined by the sampling equipment and your ability to probe the grain mass. Be sure to take one shallow sample and one deep sample from the center of the grain mass. This is especially important if fines are concentrated in the central core.*

Traps

Traps are another way to monitor insect activity in stored grain. Because traps depend on insect movement, they are not effective when grain or air temperatures are below 50°F. At these temperatures, insects are not active.

- Plastic probe or pitfall traps – These traps consist of a long, clear plastic cylinder with perforations drilled through the upper part. Insects crawl through the perforations and drop through a funnel into a lower catch-tube. See product literature for more complete instructions. Pheromones and food baits often enhance collections in these traps.
- Corrugated cardboard trap – This trap holds an oil lure that attracts and kills insects that are active where the trap is placed. You can use these traps on the surface of a grain mass to detect insect presence. They are also effective around bagged seeds or feeds in warehouses.

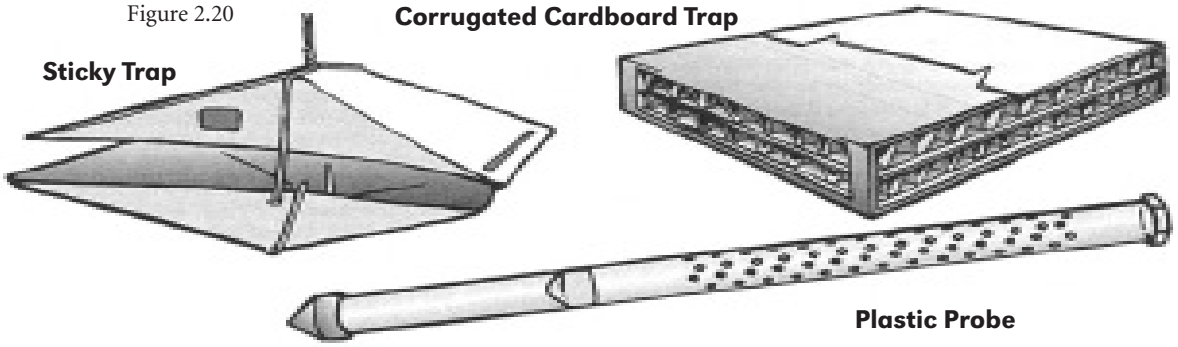


Grain Trier
Figure 2.19

- Paper sticky traps – Baited with attractants, paper sticky traps allow you to monitor for the presence of the Indianmeal moth, lesser grain borer, cigarette beetle, and several other pests in warehouses and processing plants.

If you need help with insect identification contact your local Extension office.

Figure 2.20



Chapter 3

Pest Management Options

Learning Objectives

After studying this chapter, you should be able to:

- Define Integrated Pest Management (IPM).
- Describe five strategies or characteristics that are useful in IPM decision making.
- Identify six alternatives to fumigation.
- Identify four non-fumigant pesticides.
- Explain the advantages and disadvantages of using fumigants.
- Outline the six criteria to consider when determining if fumigation is necessary.
- Describe six ways you can improve the effectiveness of pesticides and prevent pesticide resistance.

This chapter describes the principles of Integrated Pest Management (IPM). It explains how you can use fumigation as one aspect of a well-planned IPM program. You will learn several advantages and disadvantages of fumigants. You will also learn several ways to manage pest and disease problems without fumigation. These "alternatives to fumigation" may be cultural, biological or chemical. By using a combination of methods, you may often achieve the best control.

Terms to Know

Action Threshold – A pest population level that triggers a management response. Sampling and regular observation are necessary to assess threshold levels.

Aeration – *Fumigant application*: The process of replacing fumigant-containing air with fresh air that contains little or no fumigant. Aeration must follow all fumigation operations.

Aeration – *Grain storage*. The process of passing air through a stored product such as grain to regulate temperature and moisture content.

Auger – A grain transfer tool used to load and unload grain and other stored products.

Binning – Placing grain or another raw product into a storage bin.

Biological Control – The use of natural enemies (predators, parasites or pathogens) to control pests and pest populations.

Fines – Broken kernels and pieces of small foreign material within a load of grain.

Harborage – Shelter, a home or refuge for an organism.

Headspace – The open area between the stored product and the ceiling of the storage facility.

Hot Spot – An area in stored grain that is much warmer (10°F or more) than the surrounding grain. A hot spot indicates that the grain has a higher than normal moisture content, possibly caused by insect or fungus activity.

Insecticide – A pesticide used to control or repel insects or to reduce the unwanted or harmful effects of insects.

Integrated Pest Management – A pest management system that uses all appropriate strategies to reduce pest populations.

Pesticide Resistance – The ability of an organism to tolerate a specific pesticide. There are levels of resistance. For example, some insects may be sensitive, weakly resistant or strongly resistant to a specific insecticide. Total resistance is immunity.

Plenum – An enclosure in which air or other gases are at a pressure greater than the atmospheric pressure outside the enclosure.

Skinning – Superficial injury, such as to the surface of a grain kernel during harvesting, transport and storage.

Topdressing – A material such as a pesticide applied to or mixed into the upper surface of grain or soil.

Volatile Liquid – A fumigant that exists as a liquid under atmospheric pressure but evaporates under normal temperatures.

IPM and Decision-Making

There are many ways to control pests of raw agricultural products. Your job is to select the best method for the situation at hand. Pesticides and other control methods often provide good to excellent control temporarily. However, for consistent, reliable, long-term control, you will need to use Integrated Pest Management (IPM).

IPM is an ecological approach to pest control. It is based on the habitat and life cycle of the pest. It combines all of the most appropriate pest control strategies into a unified, site-specific plan. IPM plans may include both nonchemical and chemical management methods. IPM is dedicated to managing causes rather than simply treating symptoms. IPM balances the level of control needed with any associated risks. The goal of an IPM program is to reduce pest numbers to an acceptable level in a way that is practical, cost-effective and safe for people and the environment.

Prevention

The first strategy of an IPM program is prevention. Prevention of pests in stored products and raw agriculture commodities relies on sanitation, proper storage, and monitoring the condition of the commodity before and during storage. Prevention may help you exclude pests or provide them with unsuitable living conditions. Stopping a pest problem before it occurs saves time and money.

Sampling and Observation

IPM also relies on sampling and regular observation. This will help you determine if treatment is needed and/or if previous control measures were effective. Check commodity storage areas regularly. When sampling and observing stored products, check their physical condition. Look for signs of new infestations. Determine what pests are present, how many of each kind are in the area and how much damage they are causing.

Thresholds

Use information from sampling and observation to make management decisions. Follow the action thresholds that indicate at what point pests need to be controlled.

Thresholds are the basis for IPM. "Damage thresholds" indicate how many pests must be present to cause a problem, such as economic damage or a safety threat. "Action thresholds" indicate the number of pests that must be present for a problem to be severe enough to warrant a control action. If a certain number of insects in a grain sample exceed the action threshold, the grain needs treatment.

Stored Product Histories

Knowing the history of a stored product is also useful when developing an IPM plan.

When an Infestation Occurs

When an infestation does occur, identify the pest. Learn how it causes damage and when it is most vulnerable. Then, develop a control plan. Consider all appropriate control options. Your strategy should be economical and effective, while minimizing harm to people and the environment. Follow-up site inspections are critical. Did the control tactic work? Is re-treatment needed? Continue to monitor areas for long-term control.

Fumigation is only one option of an IPM program. It can be costly and dangerous. Use it only as a last resort when nothing else works. For stored products, sanitation, proper grain storage and nonfumigant pesticides can often control pests without the help of fumigants.

Alternatives to Fumigation

Many pests of raw agricultural commodities and stored products can be controlled without fumigants. The key is prevention. Prevention involves sanitation, proper grain storage and maintaining before and after it is placed into storage. In this way, you can keep pests away or reduce the number of pests that are able to develop.

Other management strategies such as biological control, aeration, spot treatments, empty bin sprays, grain protectants, topdressing, and pest strips help to reduce existing pest populations.

Prevention

Sanitation

The first step in preventing insect infestations is sanitation. By keeping bins and the areas around them clean, you can greatly reduce insect populations. Old grain and grain products provide food and habitat for insects. These residues can occur inside and around bins, in combines and in grain transfer equipment. Before storing fresh grain, clean the inside and outside of storage bins and buildings. Clean aeration ducts, augers and sidewalks. Use both a broom and vacuum. Dispose of all spilled or leftover grains and grain dust. Open the aeration ducts and augers to be sure they are clean. Clean bins immediately after they are emptied and again at least two to three weeks before adding grain. You should also clean bins before applying "empty bin sprays." (See "Empty Bin Sprays" later in this chapter). Always wear a dust mask when cleaning these and other storage areas. Mow regularly around bins to reduce harborage for rodents and insects.

Proper Grain Storage

Harvesting grain does not end the danger of pests. You must also store it properly. Good grain storage can prevent infestation and the need for fumigation. Producers may store grain for a few weeks to a few years. The profitability of such storage depends on grain quality and marketing. Grain is usually stored so that it can be sold when market prices are higher than they are during the harvest season.

Grain Type and Storage Time	Maximum Moisture Content for Safe Storage (% wet basis)
Shelled corn and sorghum	
Sold as #2 grain by spring	14-15
Stored 6 to 12 months	13-14
Stored more than 1 year	12-13
Wheat, oats, and barley	
Stored up to 6 months	12-13
Stored 6 to 12 months	11-12
Stored more than 1 year	10-11

Table 3-1. Maximum moisture contents for safe aerated grain storage in Nebraska.

Grain Condition

The physical condition of grain when it is placed into storage influences its susceptibility to pests. Only high-quality, undamaged grain with a low moisture content can be stored successfully for long periods. Never mix new grain with old grain in storage. See Table 3.1 for maximum moisture content for safe grain storage.

Drying Grain Before Storage

Grain is dried to prevent spoilage and to deter insect infestation. Most small grains are dried to 12 to 13 percent moisture. The moisture level may be 1 to 2 percent higher if the producer plans to hold the grain during the cooler part of the year only.

Drying methods may influence grain quality. High-speed, high-temperature drying produces more stress-cracked corn than low-temperature drying. Kernels with stress cracks break readily during handling. Broken kernels are more likely to spoil.

Broken Kernels and Fines

Many insects that infest stored grain are not able to penetrate the seed coat of unbroken kernels. These pests depend on the presence of broken kernels and foreign material called "fines." Broken kernels are also more likely to spoil and mold than are unbroken kernels. Fines decrease the airflow from aeration fans. This can increase aeration time up to 50 percent. Fines also tend to accumulate in the center of the bin. Fines hold moisture, further increasing the chance of insect damage or mold, which can cause respiratory illnesses in some individuals exposed to it. This is especially true when fines are concentrated in certain parts of the storage.

Grain Cleaning

Cleaning grain before "binning" is the best way to minimize problems with fines. Rotary screen and aspiration cleaners work best. Rotary screen cleaners use a rotating screen to remove fines and foreign material from the grain as it is transferred to a dryer or storage bin. Avoid using perforated or screened sections in the auger. These usually do a poor job of cleaning the grain. They may even reduce grain

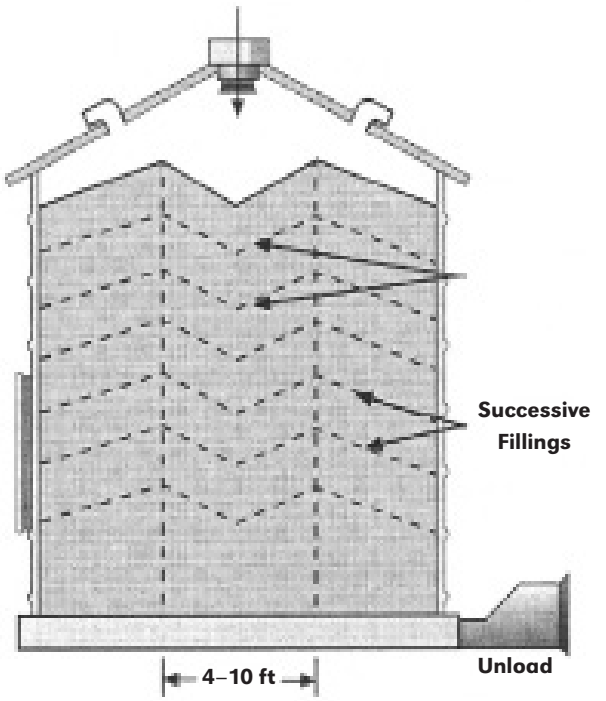


Figure 3.1 Withdrawals during filling remove most fines from the core of fine material

quality by "skinning" or causing superficial damage to the kernels.

If you cannot clean the grain ahead of time, remove fines during bin loading. When grain is loaded into the center of a round bin, most of the fine material will collect in a center "core" under the spout. Eliminate this problem in one of two ways. First, try using a grain spreader. Grain spreaders distribute fines and grain evenly throughout the bin. This method retains the fines, which may have value as animal food. However, they tend to pack the grain, reducing airflow within the load. You can also remove the core of fine material periodically as the bin is filled. To do this, remove the grain from the bottom of the center core. Mix it with other grain and put it back in the bin.

Peaked Grain

Peaks occur at the top of a grain pile just below the loading spout. There are several problems with leaving grain peaked in a bin. First, it is impossible to achieve uniform aeration. This is because air moves toward the nearest open areas, the sides, leaving the center core unaerated. (See "Aeration" later in this chapter for more information on how it affects stored grain.) Second, when grain is loaded without a spreader, the fines tend to accumulate in the center under the spout. Fines are particularly prone to insect and fungal attack. They are also difficult to aerate. (See "Broken Kernels and Fines" earlier in this chapter for more information on how they affect stored grain.) In addition, it is very difficult to enter a bin to sample the grain or to apply a top-dressing if the grain is peaked and filled to the top of the bin. It is easier to walk on level grain than on sloped grain. There may also be insufficient headspace. Be sure to level the surface of stored grain so that it is not peaked.

Storage Facilities and Packaging

Grain should always be stored in a steel bin. Be sure the bin is weather-tight, rodent-proof, and mounted on a moisture-proof concrete base. It should have a grain spreader, a perforated floor aeration system, an adequate fan and a weather- and rodent-proof roof vent. Caulk the seams of older bins and inspect them annually for moisture leaks. Buildings used to store other types of commodities should be dry and designed to exclude rodents, birds and flying insects. There should also be a minimum of harborages for pests. Move or eliminate unnecessary equipment, wood, rocks and other popular pest hideouts in and around storage facilities.

Storage Time

Storage pest problems tend to be seasonal. Grains harvested and stored in the heat of the summer are more susceptible to pests than grains harvested in the 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. If a producer needs to store a commodity for more than one year, or if conditions are more likely to be favorable to pests, he or she should increase monitoring and pest prevention efforts.

Aeration

Proper aeration can control insects in many ways. Aeration is the movement of air through grain to regulate moisture and temperature. By preventing moisture from building up and moving through a commodity, aeration helps to limit mold growth. This, in turn, reduces the food supply for fungus-feeding insects. Aeration also controls "hot spots." Hot spots are sites that are much warmer (10°F or more) than the grain in the rest of the storage bin. These areas indicate that the grain has a higher than normal moisture content and may harbor insects or fungi. In addition to addressing hot spot areas, it

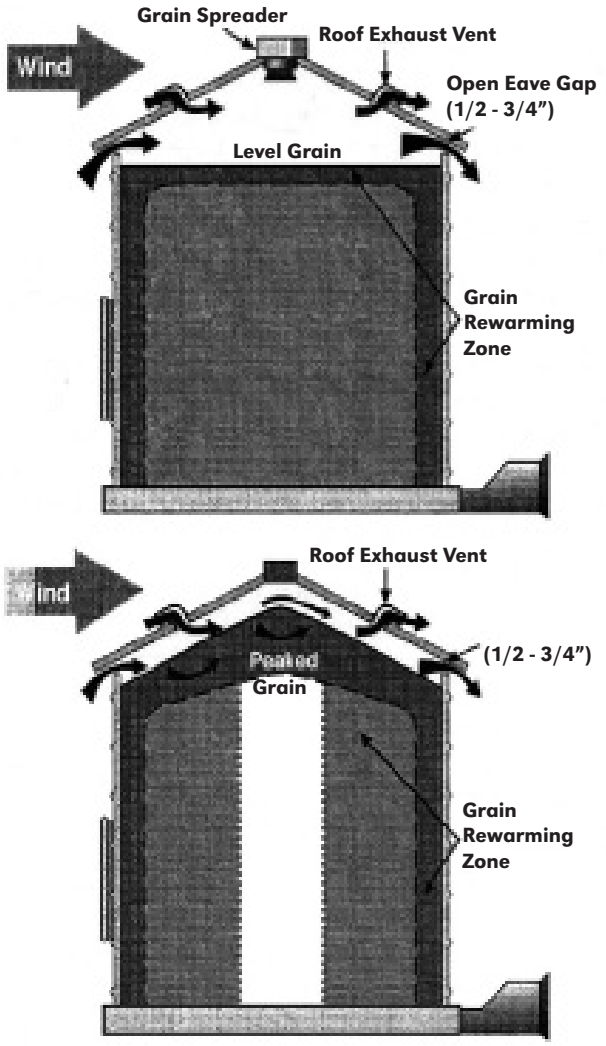


Figure 3.2 Peaked grain vs. level grain surface in storage bins.

may be beneficial to cool the overall average temperature of the whole grain mass.

Aeration procedures are the same for all types of stored grains. In the fall, aerate to lower the grain temperature below 60°F. At this temperature, most insect and mold activity will decrease. In the fall, winter and spring, aerate to control moisture migration and to create a uniform temperature throughout the grain mass. If you plan to store grain through the summer, you may need to aerate to control moisture during this season as well. However, most grain is sold before summer to make room for the next crop.

Biological Control

Biological control is the use of natural enemies (predators, parasites or pathogens) by humans to control pests and pest populations. These natural enemies, also called biocontrol agents, can sometimes reduce the number of pests in raw agricultural commodities and stored products. Predatory or parasitic insects are the most common biocontrol agents used to control insect pests in these products.

Unfortunately, it may be difficult to effectively use biological control in an IPM program. This is because beneficial insects require some host insects to become established. It is difficult to keep these pest insects from reaching damaging levels. Stay informed about new developments in biocontrol that may help prevent infestation.

Non-Fumigant Pesticides

Note: In Nebraska the use of liquid treatments, dusts and rodent or bird baits are not included in the Fumigation category. Those pesticide uses may require certification in the Structural Health Related Pest Control Category (Category 8).

Empty Bin Sprays

Another management strategy is to coat empty bins with insecticidal sprays. These pesticides will kill eggs and insects missed during cleaning. Treat bins as soon as they are clean. Try to delay treatment until the weather is warm and the insects are active. Insecticides are most effective at this time. If treatment occurs more than three months before the bin will be filled, repeat the application at least two weeks before storing the grain. Apply the spray to as many surfaces as possible. Be sure to hit all joints, seams, cracks, ledges and corners. Spray the

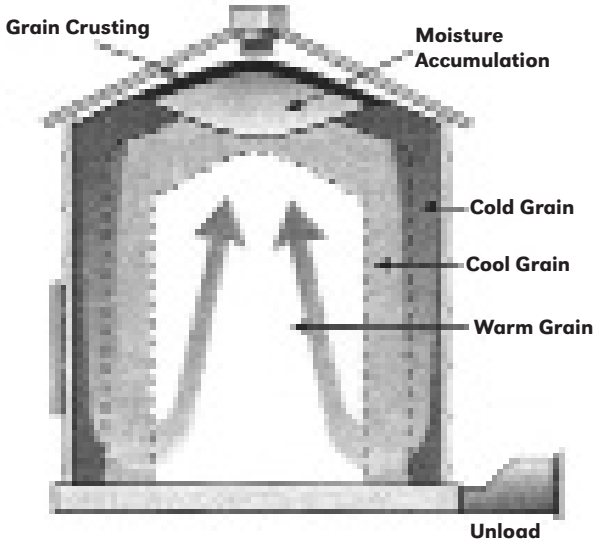


Figure 3.3 Example of moisture migration in grain stored several months without aeration.

ceiling, walls and floor to runoff. Spray beneath the bin and its supports. Treat the outside surfaces in a similar fashion. Then apply the insecticide in a six-foot border around the outside foundation. For increased protection, treat harvesting equipment, elevators, augers, trucks and wagons. Be sure these items are thoroughly cleaned. Insecticides will kill most insects emerging from cracks and crevices.

Unfortunately, empty bin sprays do not work for every type of storage bin. More and more producers are using metal bins with perforated floors. These floors aid in grain drying and aeration. They also permit broken grain and grain dust to gather in the subfloor plenum. This is an ideal area for insects to thrive. Additionally, subfloors are often difficult to remove. It may be difficult to inspect, clean or apply insecticides under them. In these cases, fumigation may be your only practical method of pest control.

Grain Protectants

You can prevent or reduce insects by applying insecticides directly to the grain. These "grain protectants" are usually applied as grain is moved into storage. Grain protectants are intended to protect the grain, not to eradicate an existing infestation. For eradication, use a fumigant.

If a producer plans to hold grain for more than one month and the grain temperature is likely to be above 60°F, treat the grain with a protectant. To apply liquid protectants, use a gravity drip, compressed air or wipe-on applicator to apply the insecticide as the grain is augured or elevated into the bin. Mixing of the insecticide and the grain will occur during the bin-filling process. Use the auger diameter, angle and speed as well as the type of grain to determine the application rate.

Grain protectants are also formulated as dusts. You can apply dusts to grain in trucks before transfer. Spread the dust evenly over the surface of the grain and mix it in with a shovel. Complete mixing will occur as the grain is loaded into the bin.

Unfortunately, insecticides tend to break down faster in areas with high temperatures and moisture. If the moisture level of grain is greater than 13 percent and its temperature exceeds 90°F, a treatment may last for only a couple of weeks. When treating warm grain, be sure to aerate and cool it as soon as possible after it is introduced into the bin. Aeration will not remove the insecticide from the grain.

Most grain protectants are not registered for use on all types of grain. Be sure that you use the correct insecticide for the product you intend to treat. Consider all types of registered protectants including synthetic pesticides, naturally produced toxins, abrasives and growth regulators.

Topdressing

Some areas of a grain bin, such as the headspace at the top, are likely to remain hot and humid. These conditions cause some grain protectants to break down quickly at the grain surface. The headspace is also the area where reinfestation tends to recur after fumigation. This is because chemical protectants break down more quickly, and the moisture content of the grain in this area makes it more favorable to insect pests. Treat the surface of the grain beneath the headspace with an insecticide registered as a topdress treatment. Both sprays and dusts work well. Mix half of the treatment with the upper three to six inches of grain. Be sure the grain is dry and less than 90°F. The bin should be insect-tight below the treated surface. Once the insecticide is in place, do not disturb the treated surface. It acts as a protective barrier over the entire load of grain. Topdressings can be especially useful against moths, such as the Indianmeal moth, which tend to stay near the grain surface.

Topdressings will kill insects on the surface and in the upper few inches of grain. They can also prevent new insects from entering the grain load from the top surface. However, they will not control existing infestations deeper in the bin.

Pest Strips

You can also hang resin strips in the headspace in the top of the bin to help control adult moths. Use one strip per 1,000 cubic feet of air space. Replace them once every three months. For resin strips to be effective, you must temporarily seal the top of the bin, including the roof vent. Aeration will prevent this treatment from working.

Fumigation

Sanitation, proper grain storage, aeration and non-fumigant pesticides can go a long way toward

preventing or reducing pests in stored products and raw agricultural commodities. For some situations, however, fumigation may be the only answer. Fumigants control pests by diffusing through the spaces between grain kernels as well as into the kernels themselves. They often work better than non-fumigant pesticides because they can penetrate into places that are not accessible with insecticide sprays or dusts. They can also kill all stages in an insect's life cycle.

When deciding whether to fumigate stored products, weigh these advantages and disadvantages.

Advantages of Fumigants

- Depending on the specific situation and fumigant, fumigants are effective against insects, mites, and most other living things.
- Most fumigants are fast acting. They are the quickest way of controlling many pests.
- In some cases, they can provide total eradication.
- Human exposure is limited. Areas are evacuated during treatment and must be aerated before reentry.
- Most fumigants, when used properly, do not leave residues on surfaces.
- There are several ways to apply fumigants.
- They penetrate and treat spaces in commodities like grain that cannot otherwise be reached.
- When treating raw products, you can apply them without disturbing the commodity.
- They usually are readily available.
- You can use some fumigants in or near food without leaving harmful residues, tastes or odors.

Disadvantages of Fumigants

- They are highly toxic to most living things, including humans. Breathing even small amounts of some fumigants can be fatal.
- They may require special protective equipment, such as a self-contained breathing apparatus (SCBA) and gas detectors.
- They require highly trained applicators.
- They offer no residual control. Once an area or item is aerated, traces of fumigant do not remain to help control future pests.
- They must be confined in a tightly sealed area to be effective.
- Some may injure seeds and reduce germination. Others may leave toxic residues, tastes or odors if used incorrectly.
- Because they are fast acting, response to problems and emergencies must be quick. Spills, leaks and equipment failures usually call for immediate action.
- They usually require warm temperatures to be effective. Temperature requirements may be hard to meet, especially in the winter.
- Some are expensive.
- Some are corrosive.
- Some are flammable and explosive.
- Some fumigants are hard to remove from treated material.

Before using a fumigant to control pests in stored products and raw agricultural commodities, make sure you need it. Monitor pest populations through out the storage period. Do not hold grain or other raw agricultural products in storage for longer than necessary. Use all possible cultural and non-fumigant chemical controls to maintain pest populations below damaging levels. Before you decide to fumigate, make sure that pest populations are high enough to warrant fumigation.

Determining Need for Fumigation

Several criteria should be considered in determining the need and suitability of fumigation for pest control. These include:

1. Characteristics and habits of the pest
2. Life stages of the pest
3. Characteristics of the treatment area
4. Hazards located in the treatment area
5. Available pest management alternative
6. Established pesticide residue tolerances

Pesticide Resistance

One of the biggest problems with pesticide use is "pesticide resistance." Pesticide resistance develops when a group of pathogens or insects is able to tolerate doses of a specific pesticide that would kill a normal population of the same species. Surviving pests reproduce and pass their resistant traits to their offspring. Preventing resistance is of great importance for the pests of stored commodities. New laws and regulations have drastically reduced

the number of insecticides approved for use against stored-product pests. As a pest control operator, you can protect the effectiveness of pesticides by:

- Using IPM
- Using alternative controls and nonchemical controls whenever possible
- Using pesticides only when necessary
- Avoiding repeated use of the same pesticide
- Doing a thorough job when applying a pesticide (do not leave behind pests that can develop resistance and reproduce)
- Fumigating only when nothing else works

Chapter 4

Characteristics and Effects of Fumigants

Learning Objectives

After studying this chapter, you should be able to:

- Describe multiple characteristics of fumigants and how they affect fumigant use.
- List multiple factors to consider when choosing a fumigant.
- Describe multiple factors that can affect fumigant performance.
- Discuss five pest characteristics that can influence the timing and effectiveness of fumigation.
- Identify the three ways to seal a structure or commodity and why a quality seal is important.

Like all pesticides, several factors can affect how well a fumigant will work. These range from characteristics of the fumigant itself (boiling point, molecular weight, etc.) to external factors such as air movement, temperature, and applicator knowledge and skill. This chapter will focus on how these characteristics and factors effect fumigant performance. See Chapter 8 for discussion on specific fumigants.

Terms to Know

Absorption – When fumigant molecules penetrate into a commodity or other item being fumigated.

Adsorption – When fumigant molecules stick to the surface of a commodity or other item being fumigated.

Aeration – Fumigant application: The process of replacing fumigant-containing air with fresh air water that contains little or no fumigant. Aeration must follow all fumigation operations.

Boiling Point – The temperature at which a liquid becomes a gas.

Desorption – The liberation or removal of a fumigant from treated surfaces and/or substances.

Diffuse – To spread or distribute, to move in all directions.

Dosage – The concentration of a fumigant (ounces, etc.) times the exposure time (hours, minutes, etc.). The dosage requirements depend on the pest, the fumigant, the temperature, the rate of leakage (some leakage is inevitable), and many other factors.

Equilibrium – Even distribution. For example, a fumigant has reached equilibrium when there is an equal concentration of gas throughout a given structure.

Inert – Not reactive.

Metabolism – All chemical reactions that take place in a living thing. For example, insects metabolize food to produce energy.

Molecular Weight – The sum of the atomic weights of all the atoms in a molecule. All fumigants have a unique molecular weight.

Molecule – The smallest particle of a substance that retains all of the properties of the substance.

Pesticide Resistance – The ability of an organism to tolerate a pesticide. There are different levels of resistance. For example, some insects may be sensitive, weakly resistant or strongly resistant to a specific insecticide. Total resistance is immunity.

Seal – 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.

Solubility – How readily a substance will dissolve in a liquid.

Sorption – Adsorption and/or absorption.

Stratification – When fumigants rise or fall, making layers of gas within a confined area. Diffusion is incomplete, leaving some areas untouched by the fumigant. Stratification results in an incomplete treatment.

Vapor Pressure – The pressure exerted by a liquid or a solid as it volatilizes (becomes a gas).

Vaporize – When a solid or liquid turns into a vapor (gas).

Volatility – How readily a substance transforms from a solid or liquid into a gas.

Chapter 1 defined a fumigant as a pesticide in gas form. At a high enough concentration, this gas can kill insects.

Fumigants kill pests by interfering with their respiratory functions. Most fumigants interfere with the enzymes necessary for normal respiration. Other fumigants such as carbon dioxide smother (asphyxiate) the pest by displacing oxygen in the surrounding air. The killing action of a fumigant is influenced by its concentration in the atmosphere, the length of time it stays in the atmosphere, and the temperature and humidity of the area at the time of fumigation. Fumigants enter cracks, crevices and other areas where target pests may occur, such as between kernels of corn. This is why fumigants are so effective in certain situations. Fumigants must be applied in enclosed areas. Fumigation has no residual effect, and reinfestation may occur after the fumigant has diffused from the area.

Characteristics of Fumigants

There are many fumigants on the market. Your job is to select the best product for the pest and situation at hand.

Boiling point, molecular weight, specific gravity, solubility, flammability and other characteristics are different for all fumigants. Each characteristic makes a fumigant act a certain way under certain conditions. Understanding how these factors affect application will help you select the best product for the job. See Table 4-1 for more on physical and chemical properties of fumigants. Always consult the label information for each product that you consider.

Molecular Weight and Specific Gravity

All substances, including air and fumigants, have a "molecular weight." The molecular weight of air is about 29. Fumigants with a molecular weight lower than 29 are lighter than air and may rise. Those with a molecular weight higher than 29 are heavier than air and may sink.

All substances also have a "specific gravity." The specific gravity of air is 1. Fumigants with a specific gravity greater than 1 are heavier than air and may sink. Fumigants with a specific gravity less than 1 are lighter than air and may rise.

Gases are unique in that their specific gravities are related to their molecular weights. For example:

$$\text{Specific Gravity of a Fumigant} = \frac{\text{Molecular Weight of a Fumigant}}{\text{Molecular Weight of Air}}$$

NOTE: This relationship is valid only when the temperature and pressure of the fumigant and air are the same.

The molecular weight and specific gravity of a fumigant can help you determine how well it will distribute throughout an area. Even distribution is referred to as "equilibrium." Most fumigant gases are heavier than air. For example, the molecular weight of methyl bromide is 94.95, making its specific gravity 3.28. This means methyl bromide is 3.28 times heavier than air. When the molecular weight of a fumigant is greater than or less than air, you may need to use fans and/or other tactics to achieve equilibrium during fumigation.

Boiling Point

Boiling point is the temperature at which a fumigant becomes a gas. Most fumigants reach their boiling point between -125.9°F and 233.6°F. "Low-boiling" fumigants become gases below room or moderate outdoor temperatures (68° to 77°). To stabilize these chemicals, manufacturers keep them as liquefied gases under pressure in cylinders or cans. Fumigants with boiling points higher than 68°F, "high-boiling" fumigants, are initially liquids at normal fumigation temperatures. While these chemicals have slow evaporation rates, they will eventually vaporize during treatment. To use these products, you may need to wait for a warm day or increase the temperature within the area you plan to treat.

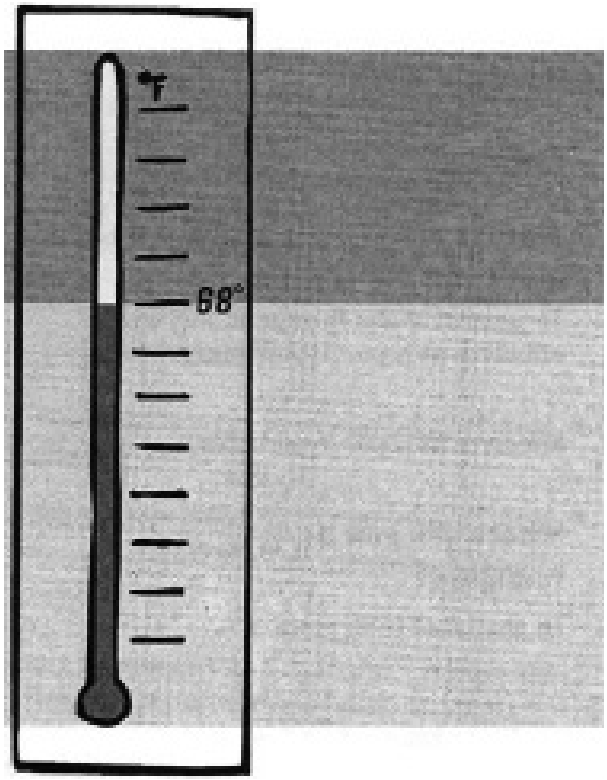


Figure 4.1 Low-boiling fumigants become gasses usually at 68°F or below. High-boiling fumigants need higher temperatures to become gasses.

Boiling point also indicates the vapor pressure of a fumigant. In general, the higher the boiling point, the lower the vapor pressure, and the slower a fumigant will change to a gas.

Solubility

Solubility tells you how readily a fumigant gas will dissolve in certain materials, depending on their moisture content.

Some fumigants are soluble in water, oil or other liquids. These pesticides may dissolve in commodities that have high moisture or oil contents. For example, methyl bromide is soluble in oil. If you use this fumigant to treat commodities with high oil content, such as soybeans, it may dissolve in the oil. to aerate. This is particularly a problem when multiple treatments of these commodities are necessary.

Flammability

Some fumigants, such as phosphine, are extremely flammable. Formulations of flammable fumigants may contain fire retardants. For example, some products that produce phosphine also produce ammonia and carbon dioxide. However, the best way to prevent fire hazards is to apply and dispose of fumigants properly. Always read the labeling to learn which conditions favor fire or explosions. The labeling will describe how to avoid these problems.

Volatility

Volatility is the tendency of a chemical to evaporate and become a gas or vapor. Volatility increases as temperature rises. Some "gaseous type" fumigants, such as methyl bromide, are normally a gas at room temperature. Other fumigants exist as a liquid (chloropicrin) or solid (paradichlorobenzene, naphthalene) at room temperature. Also, many of the "solid type" fumigants, such as aluminum and magnesium phosphide, are not fumigants themselves but react with moisture to form a fumigant gas (phosphine or hydrogen phosphide).

Vapor pressure

The vapor pressure of the fumigant affects the concentration of the fumigant in the air (in a confined space). Fumigants with high vapor pressure will be more concentrated and therefore have better fumigant qualities.

This can be explained by the concept of equilibrium. When a volatile liquid or solid chemical is first put into a confined space, molecules come off the surface of the liquid or solid and move into the surrounding air. The concentration of molecules in the air is low at first. But as the volatilization process continues, more molecules do this and

Fumigant	Molecular Weight	Boiling Point (°F)	Specific Gravity*	Flammability (in air)
Carbon dioxide	44.01	-109.3	1.52	nonflammable
Methyl bromide	94.95	38.4	3.28	nonflammable
Phosphine	34.00	-125.9	1.17	flammable
Sulfuryl fluoride	102.07	67.00	3.52	nonflammable

Table 4-1. Physical and chemical properties of fumigants commonly in use at the time this manual was printed.

* Specific gravity = the molecular weight of a fumigant divided by the molecular weight of air (29).

the concentration continues to increase. However, volatilization appears to stop at some point and the concentration stabilizes. This is the point of equilibrium, when every molecule evaporating from the liquid or solid is replaced by a molecule condensing out of the air.

Diffusion potential

Diffusion potential is a measure of how fast gas molecules disperse through the atmosphere. After a while, the molecules become evenly distributed. The speed with which molecules disperse is affected by the molecular weight of the gas. Gases that are heavier diffuse more slowly and it may be important to disperse these types of gases with fans or blowers.

Latent heat of vaporization

Latent heat of vaporization (the extra heat required to change the liquid to a gas) must be considered when using fumigants that have boiling points below room temperature. Unless sustained by warming from an outside source, the temperature of an evaporating liquid constantly drops. This is shown by the cooling effect of evaporating water on the skin.

The factor of latent heat has important practical significance. High pressure fumigants, such as methyl bromide, volatilize and lose heat rapidly on release. Unless the lost heat is restored, the temperature of the fumigant may fall below its boiling point, causing the gas to no longer evolve. Also, as the liquid changing to gas is led through metal pipes and tubes or rubber tubing, the drop in temperature may freeze the fumigant in the lines, preventing further passage.

In many applications, it is wise to apply heat to the fumigant as it passes from the container into the fumigation space. Fumigants that are liquids at normal temperatures and are volatilized from evaporating pans or vaporizing nozzles also lose heat. These applications may require a source of heat, such as a hot plate, so that full concentrations will take place rapidly.

Chemical reactivity

Chemical reactivity of some fumigants with other chemicals in the environment may limit some fumigant uses. 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 (used in electrical wiring, motors and plumbing) to cause serious corrosion. High temperatures around an open flame may cause some fumigants to form corrosive acids. Certain fumigants may make photographic film and paper unusable because of chemical reaction.

How to Choose a Fumigant

When choosing a fumigant, consider all that will control the pest and allow you to do the job as efficiently as possible. The fumigant product you choose must be labeled for the specific fumigation job and you must be prepared to comply with all of its relevant labeling.

Consider such factors as:

- Toxicity to the target pest
- Volatility and ability to penetrate
- Corrosiveness, flammability, and potential for explosion
- Warning properties and detection methods
- Effect on seed germination and finished product
- Quality
- Residue tolerances
- Availability
- Ease of application
- Cost

Factors That Affect Fumigation of Raw Agricultural Commodities and Stored Products

A variety of factors affect the use and success of fumigants. Some of the most important factors are:

- Pest characteristics
- Sorption of the fumigant when it contacts materials
- Temperature of the commodity or area you plan to treat
- Moisture in the commodity or area to be fumigated and in the air surrounding/within it
- Air movement and diffusion within the area you fumigate
- Construction of the structure within which you treat an item
- Quality of the seal enclosing the area to be fumigated
- Applicator knowledge and skill

Pest Characteristics

Several aspects of the pest's biology can influence the effectiveness and timing of a fumigant treatment. These include:

- **The insect's stage of growth.** Pupa and eggs are the hardest to kill because they are not active. Adults and young larvae are most susceptible.
- **The activity level of the insect.** Active adults and larvae are easier to kill than are inactive or hibernating adults and larvae. This is because active insects have a higher metabolism, allowing them to process the fumigant faster. Therefore, whenever possible, wait until the insects are mature and active before fumigating.
- **The feeding habits of the insect.** Insects that develop outside grain kernels are usually more susceptible to fumigants than species that develop inside grain kernels.
- **The size of the infestation.** Heavy infestations are more difficult to control. Masses of insects generate large amounts of dust, damaged grain, webbing and cast skins. These materials interfere with fumigant penetration and increase sorption.
- **Some insects have "resistance" to fumigants.** Resistance is the ability of an organism to tolerate a pesticide. There are various levels of resistance. For example, some insects may be sensitive, weakly resistant or strongly resistant to a specific fumigant. Total resistance is immunity. Frequent fumigation at dosages too low to kill all insects promotes problems with resistance.

Although this information is true for most insects, application recommendations vary with the pest. Use the information from Chapter 2 to help you identify the most susceptible stage(s) of development and activity level(s) of the pest that you wish to control.

Sorption

When a fumigant gas contacts materials, gas molecules undergo the process of "sorption." There are two types of sorption: adsorption and absorption. Adsorption occurs when fumigant molecules stick to the surface of a treated material. Absorption occurs when the molecules penetrate into the material. Both types of sorption reduce the effectiveness of fumigants by removing molecules from the air. These bits of fumigant are no longer able to move freely and kill the target pest(s). Sorption also slows aeration, the process by which fumigant is released after treatment.

Some fumigants are more subject to sorption than others are. Read the labeling for sorption information about each product you consider.

Commodities and the structures that house them also vary in their "sorptive" capacity. 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.

Knowing how sorptive certain chemicals and commodities are is critical. This information will help you determine how much fumigant to use, how long to contain the fumigant and how long to aerate the treatment area or product. When sorption levels are high, you will need to use more fumigant. You will also need to increase the treatment time because diffusion is slower. When treatment is complete, aeration periods must be long enough to allow the fumigant to slowly "desorb" from the commodity. If aeration is too short, traces of fumigant may remain sorbed to the product. This can cause toxic residues, off- flavors or odors in the treated material.

As a rule, sorption is greater at cold temperatures. For example, if the temperature inside a warehouse is cool during fumigation, the commodity(ies) will absorb or adsorb the fumigant at a higher rate. You will need to use more fumigant. The same is true

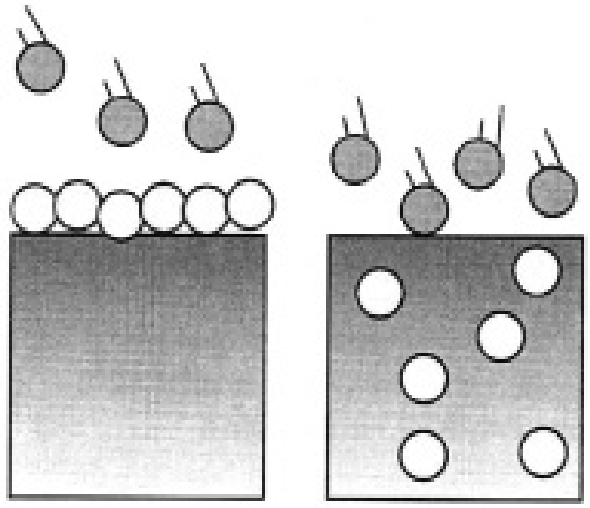


Figure 4.2 Adsorption vs. absorption

for aeration. Aeration normally takes longer when temperatures are low or when products are cold.

Adsorption is usually greater with fumigants of high molecular weights and low vapor pressures.

Temperature

"Temperature" refers to the temperature;

- Of the commodity that you plant to treat
- Under the tarp or within the structure where treatment will occur

Temperature affects both the dosage and exposure period needed for pest control. As a rule, the higher the temperature, the less fumigant you will need. This is because as temperature increases, insect metabolism increases. As metabolism increases, insects breathe faster, absorbing more fumigant. Less fumigant is needed to kill the pest. As the temperature drops, the reverse is true. Insect breathing slows. You may need to add fumigant to get the same level of control. Below 40°F, fumigants may not be effective at all.

Higher temperature also increases the volatility of fumigants. The higher the volatility, the faster a fumigant disperses and penetrates. Sorption by the material being treated decreases and less fumigant is needed.

Finally, temperature can cause a fumigant to "stratify." Stratification occurs when 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.

For best results, fumigate when temperatures are above 60°F.

A difference in temperature between the outside air and the temperature of the commodity can greatly influence the movement of some fumigants throughout the structure.

Moisture

As the moisture content of a commodity increases, sorption increases. This makes it more difficult for a fumigant to penetrate a commodity. Therefore, products with high moisture content require higher doses of fumigant. High moisture content also increase the potential that residues will exceed legal limits due to the increased sorption and slow desorption.

Another problem in grain can be condensation. Condensation is greatest during periods of high humidity or falling temperature. High humidity may be due to a recent rainfall or because of high humidity of the commodity. Condensation can cause several problems, such as interfering with the fumigant and damaging commodities by staining, spotting, and surface corrosion. If possible, dry out commodities or areas having high moisture before beginning a fumigation.

On the other hand, some dry fumigant formulations (such as phosphine tablets and pellets) need humidity to generate gas. These are called "moisture-activated" fumigants. If the air is too dry or the moisture content of the commodity is too low, these fumigants will stay in solid form.

Air Movement

To be effective, a fumigant gas must diffuse (spread) evenly and quickly throughout the commodity or space that you are treating. The gas must enter small crevices, cracks or spaces so that a lethal concentration contacts every pest. Even distribution is called "equilibrium." The ability of a fumigant to reach equilibrium depends on several things. In general, gases diffuse more quickly at higher temperatures and lower air pressures. Fumigants also spread faster when their initial concentration is high and the penetration distance is short.

Some fumigants require air circulation to diffuse quickly. Without air circulation, the air and fumigant may stratify. Fans, ducts and blowers are often necessary. Select equipment that fits the job. Fans are usually sufficient to stir the air in open areas. Confined areas with tightly packed commodities may require blowers or ducts to move the fumigant from one place to another. However, once the fumigant reaches equilibrium, the problem of stratification decreases.

Construction of the Structure

Fumigant label information lists a range of dosages from which to choose. Each dosage fits a specific situation. The most important factor in selecting a

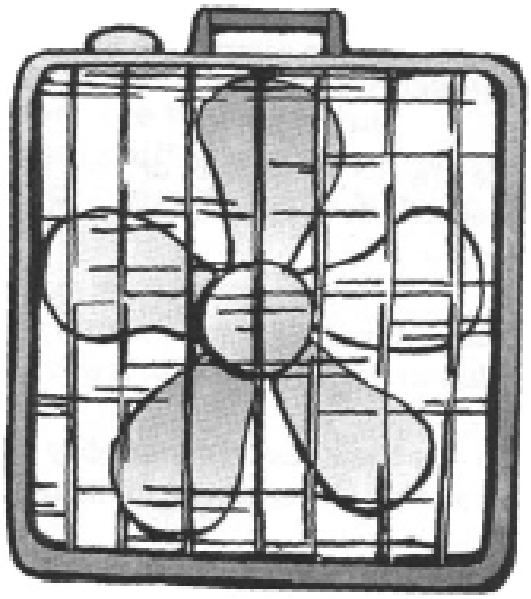


Figure 4.3 Sometimes you will need help to distribute a fumigant throughout a treatment area.

dosage is the tightness of the structure. The ability of a building to hold a fumigant directly affects the amount of gas needed to sustain a lethal concentration throughout. Higher dosages are needed for structures that are of "loose" construction. For example, warehouses tend to have gaps around windows, doors and wall joints. Lower doses may be adequate for "tightly" constructed structures such as boxcars and fumigation chambers.

For loosely built structures, it is often better to "seal" the area than to increase the amount of fumigant you use.

Seal

A tight seal around a structure or commodity ensures effective fumigation and the safety of those nearby. You can seal a structure or commodity in one of three ways:

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

The quality of a seal is important. It can affect:

- The amount of fumigant needed (the tighter the seal, the less gas that will escape, and the less fumigant that will be needed)
- The length of time necessary to kill the target pest (the tighter the seal, the more constant the fumigant concentration, and the less time needed to achieve control)

A fumigation chamber is an example of a tight seal. Little gas escapes from a well-constructed chamber. On the other hand, placing a gas-tight tarp over commodities or structures can provide a poor-to-excellent seal depending on:

- The condition of the tarp
- The tightness of the seams
- The type of ground seal

Structures in sandy soils or with dirt crawl spaces may lose gas through the soil. Commodities sitting on concrete floors may lose gas through the concrete. To prevent these problems, always tarp the top and bottom of structures and items on porous bases.

Some structures may be too large to tarp, such as warehouses or large grain bins. In these situations, a tape-and-seal job may be required. Always seal doors, windows and vents. This will prevent heavy loss through large gaps. In grain bins, you should also seal unloading augers, roof exhaust vents and eave gaps (openings where the roof meets the sidewalks). Although tape-and-seal fumigation can prevent many leaks, the fumigant can penetrate untarped walls, even when the walls are made of solid materials like brick and concrete. You will usually need more fumigant to replace what is lost through untarped walls.

Also, consider the condition of the structure and the type of construction. A wooden structure, even when sealed, will not retain fumigants as well as one of brick, concrete or steel. This is because wood is more porous than the other materials. For example, round steel bins retain fumigant better than flat grain-storage bins, which are usually made of wood. In addition, wooden structures are often not built as "tightly" as structures made with other materials. For these reasons, it is often necessary to tarp wooden structures during fumigation.

Applicator Knowledge and Skill – Raw Product Fumigation

In the end, you, the applicator, are the most important variable in raw agricultural commodity and stored product fumigation. Your education and training will directly affect the success and safety of your operation. Know and understand the properties of every product you plan to use. Consider how different factors will affect treatment. Understand the site – its limitations and its strengths. Choose your dosage and application methods accordingly.

Chapter 5

Methods of Fumigation

Learning Objectives

After studying this chapter, you will be able to:

- Describe three methods of fumigation used to treat raw agricultural commodities.
- List the three types of vault fumigation and explain the advantages and disadvantages of each.
- Describe how to prepare for a tape and seal fumigation.
- Describe three types of sealed structures.
- Identify the advantages and disadvantages of tarpaulin fumigation.
- Identify two types of tarpaulins.
- Describe how to obtain a good ground seal.
- Describe indoor, outdoor, and entire structure tarpaulin fumigation.
- Describe the basic procedures for doing a spot fumigation and its advantages and disadvantages.
- Explain the importance of proper aeration.
- Identify three factors that affect aeration time.
- Describe the aeration procedures used for five different structures.
- Determine volume for structures of various shapes and sizes.

This chapter describes the most common methods used to fumigate raw agricultural commodities and stored products. Each method has advantages and disadvantages. You will learn what these are and how to use this information to select the best type of fumigation for a particular situation. You will learn how to implement each method. You will also discover basic safety considerations associated with each method. With this information, you can make educated decisions. This chapter also discusses the importance of proper aeration. You will learn about factors that affect the speed and success of aeration, and how to perform these procedures yourself. This chapter will also discuss the importance of equipment calibration, and how to calculate the volume for structures of various shapes and sizes.

Terms to Know

Air Wash – A method of aeration used in vacuum fumigation. Air washing involves drawing a second vacuum after the exposure period is complete and then breaking this vacuum with fresh air.

Billowing – When air or gas causes something to bulge outward. In tarpaulin fumigation, this occurs when gusting winds cause a tarp to bulge away from the item or structure that it is covering.

Blower – A machine that generates and directs an air stream in a particular direction.

Boxcar – A large, roofed container with enclosed sides used to transport freight. Boxcars usually have sliding doors on each side. Trains usually transport boxcars.

Desorption – The liberation or removal of a fumigant from other substances.

Diffusion – The process of spreading out or distributing evenly in a space.

Dosage – The concentration of a fumigant (ounces, ppm, etc.) x the exposure time (hours, minutes, etc.). The dosage requirements depend on the pest, the fumigant, the temperature, the rate of leakage (some leakage is inevitable), and many other factors.

Fumiport - A special opening in a transfer line, small bin or food processing machine through which you can apply fumigants.

Fumigation Tape – Strips of adhesive material used to seal doorways, windows and other areas where gas might escape during fumigation. You can also use fumigation tape to join together two or more tarps during tarpaulin fumigation. Fumigation tape has a plastic or vinyl coating that reduces fumigant penetration.

Gas Detector – A device used to check the concentration of fumigant in the air.

Gastight – Something that does not allow gas to enter or pass through. Gasproof.

Ground Seal – The sealing of tarps to the ground to prevent fumigant loss during fumigation.

Liquefied Gas – A fumigant that must be kept under pressure in order to remain a liquid. These fumigants change from liquid to gas when released from their pressurized containers.

Nonsparking Fan – A machine that safely recirculates air in potentially explosive environments.

Parts Per Million (PPM) – The number of parts of a substance in one million parts of another substance. For example, if a gas detector reads "5 ppm," it means that there are five parts of fumigant to every one million parts of air.

Permeable – Having pores or openings that permit liquids or gases to pass through.

Prepac – Aluminum phosphide fumigant tablets that are packed in a gas-permeable material.

Seal – To enclose an area so that fumigant gas cannot escape too quickly. A good seal will contain a lethal amount of gas for long enough to kill the target pests.

Ship Hold – The area or deck of a ship commonly used to transport cargo.

Sorption – The process of taking up or holding a chemical either by adsorption or absorption.

Tarpaulin (tarp) – A semipermeable material used during fumigation to confine fumigant in a specific area during the exposure period.

Once you pinpoint a pest problem and decide fumigation is necessary, you are ready to choose a treatment method. There are several types of fumigation. Each has its pros and cons. Your job is to select the best method for a given situation. Your decision will be based on:

- The pest you need to control
- The item or area you need to treat
- The location of the product
- The product you need to treat
- Your client's budget
- The proximity of the area to other people
- Weather conditions
- The severity of the infestation

All methods of fumigation have one thing in common: they must achieve and maintain an adequate concentration of toxic gas long enough to kill the target pest(s).

Remember, fumigants are highly toxic and dangerous. They are reserved for only the most severe infestations. Be sure fumigation is the best option for your situation.

Fumigation Methods

Raw agricultural products are stored in bins, silos and other structures. They may also be kept in boxcars or other railcars, trucks or in ship holds for short periods during transportation. Because fumigants can move through tiny cracks and crevices, fumigation must occur in structures that are relatively airtight. Some buildings and boxcars are naturally well-sealed. Others may need fumigation tape, polyethylene sheeting or other materials to make them airtight. Still other structures, particularly those that are leaky, may need to be tarped. Fortunately, several fumigation methods are available.

The most common methods used to fumigate raw agricultural commodities are:

- **Vault Fumigation** – Vault fumigation uses atmospheric or vacuum chambers to treat infested products. Other structures such as truck trailers, boxcars or other railcars, grain bins, silos and other storage structures can be vaults if they are well-sealed.
- **Tarpaulin Fumigation** – Tarpaulin fumigation places commodities under a tarp or covers an entire structure. Fumigant is released beneath the tarp and held until pest control is complete.
- **Spot (Local) Fumigation** – Spot fumigation is used to treat small items or areas with light to moderate infestations. Spot fumigation is also used routinely to prevent infestations from developing or recurring.

Vault Fumigation

Vault fumigation treats infested commodities within an airtight or sealed structure. These structures or "vaults," such as truck trailers, boxcars or other railcars or ship holds, may serve dual purposes. Others, like vacuum chambers, are specially designed for fumigation. Sealed silos and grain bins are also fumigation vaults. Although you must take basic safety precautions, fumigation in atmospheric vaults and vacuum chambers poses fewer risks than other methods of fumigating agricultural products. These structures are better designed to deliver, contain and exhaust the fumigant.

For simplicity, this chapter will discuss three types of vault fumigation:

1. Fumigation in atmospheric chambers
2. Fumigation in vacuum chambers
3. Fumigation in sealed structures

Fumigation in Atmospheric Chambers

An atmospheric chamber can be any airtight structure under normal air pressure. It is usually a small building located away from other structures. Some are specially built for fumigation. Others are modified from existing structures.

You can construct a suitable, low-cost atmospheric chamber using a gastight room with an appropriate door. A minimum of equipment is required. You will need tools to apply, distribute and remove the gas. Heating may also be necessary. Steam pipes are best and should be able to heat the area to 70°F during treatment. Locate the chamber so that you can easily move goods in and out of it. Also, be sure to minimize hazards to workers and the environment. Atmospheric chambers should not be within or connected to other structures where fumigant passage may occur.

Advantages of Atmospheric Chambers

Once atmospheric chambers are built or modified for fumigation, you can use them again and again. Commodities can be moved in and out of the vault without special preparation. Vaults have a constant volume, so you do not have to compute the volume for each treatment. You can permanently install special equipment to monitor fumigant levels.

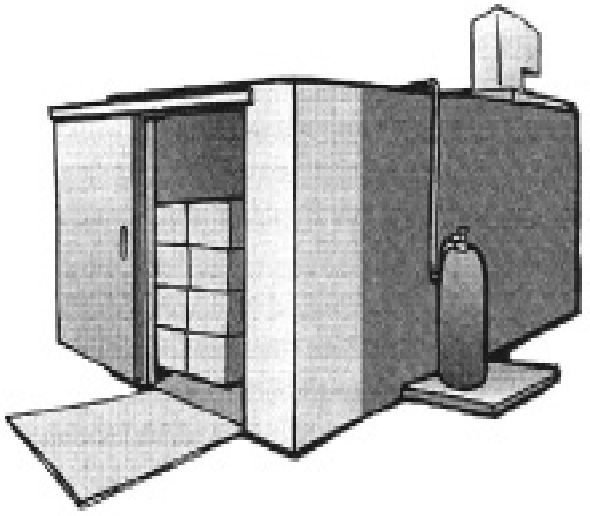


Figure 5.1 Atmospheric vault

Disadvantage of Atmospheric Chambers

Atmospheric chambers are costly to set up, and they hold a limited amount of product. It also takes time and money to move commodities into and out of the chamber.

Fumigation in Vacuum Chambers

Vacuum chambers are large steel structures. Unlike other vaults, treatment occurs in a "vacuum" rather than at atmospheric pressure. In a vacuum, the air pressure is lower. This does two things. First, it denies oxygen to the pest. Under a vacuum, the oxygen level inside a chamber decreases. Pests become stressed and are easier to kill. Second, the vacuum helps the fumigant penetrate the commodity. This may reduce fumigation time from 24 hours to 4 1/2 hours depending on the fumigant used. In addition, by adding an "air-wash cycle" (breaking the vacuum and drawing a second vacuum), aeration after treatment is also fast. Beware that some fumigants (such as phosphine) explode under vacuum conditions. Always read the labeling to be sure your product is safe to use in a vacuum chamber.

Vacuum fumigation is used to treat densely packed items and other materials that are difficult to penetrate at atmospheric pressures. It is also useful for plant quarantine and products that need to be treated quickly. Do not treat tender plants or produce in a vacuum. Fresh fruits, vegetables and other such items cannot withstand the reduced pressures.

There are two main ways to conduct vacuum fumigation: sustained-vacuum fumigation and restored pressure fumigation. The "sustained vacuum method" starts when you reduce the pressure inside the chamber and introduce the fumigant. The slightly reduced pressure (vacuum) is held until the end of the treatment. In the "restored pressure method," you would lower the pressure, introduce the fumigant and then restore the pressure in one of four ways.

4. **Gradual Restoration** – Release the fumigant and then slowly introduce air until the air pressure returns to normal. This usually takes two to three hours.
5. **Delayed Restoration** – Hold the vacuum for about 45 minutes following discharge of the fumigant. Then, allow air to rapidly enter the chamber.
6. **Immediate Restoration** – Just after releasing the fumigant, rapidly let air into the chamber by opening one or more valves.
7. **Simultaneous Introduction of Air and Fumigant** – Use special metering equipment to release a mixture of air and fumigant into the chamber.

These four techniques to restore pressure are listed in order of effectiveness – number one being the most effective for most situations. The "sustained-vacuum method" falls between methods two and three.

"Air-washing" must follow all vacuum fumigation procedures. This process removes the fumigant/air mixture, then flushes the chamber with clean air several times until it is safe to open the door for unloading. Air-washing is more intensive than aeration. Because vacuum fumigation forces the fumigant into a commodity, sorption of that chemical is strong. Without forcing fresh air into the chamber, the fumigant may remain within the commodity.

Vacuum fumigation requires the same safety precautions as do other fumigation methods. These may include wearing a respirator and using monitoring tools to test for leaks. See Chapters 6 and 7 to learn more about personal protective equipment.

Portable Vacuum Fumigation Chambers

When you need to fumigate small amounts of product in several locations, a portable vacuum fumigation system brings added flexibility. A portable unit consists of:

- A vacuum such as "shop vac" or other high-capacity vacuum cleaner
- Two pieces of heavy-duty vinyl sheeting that you can clamp or zip together (similar to food storage bags)
- Fumigation dispensers
- Connecting hoses
- A security lock
- A gas concentration monitoring valve
- A carrying case
- A gas discharge standpipe

Portable systems allow you to develop a vacuum between the layers of vinyl. The vacuum pulls the vinyl tightly around the commodity. Once the vacuum reaches the optimal level, you can apply the fumigant.

Advantages of Vacuum Fumigation

Commodities fumigated in vacuum chambers require much shorter exposure times. The fumigant can penetrate dense commodities. Vacuum chambers have most of the other advantages of atmospheric chambers.

Disadvantages of Vacuum Fumigation

Vacuum fumigation in chambers takes a large initial investment. Commodities must be moved into and out of the chambers. You cannot use phosphine or other fumigants that are explosive under a vacuum. In addition, more fumigant is required, and the amount of product that can be fumigated in vacuum chambers is limited.

Fumigation in Sealed Structures

Fumigation by sealing, also called "tape-and-seal" fumigation, works by turning an entire structure (grain bin, warehouse or boxcar) into a temporary fumigation chamber. To do this, it helps if the structure is airtight. Tape-and-seal fumigation accomplishes this by working only with structures that are in good repair. Workers find and seal all leaky spots with fumigation tape. The goal is to create a "vault" that is as close to airtight as possible.

Tape-and-seal fumigation allows you to treat commodities stored in many structure types. You can

fumigate products in brick and concrete structures that are in good repair if you tape and seal the roof if it is likely to leak. Monitor the fumigant concentrations to ensure that an adequate dosage is achieved to kill the target pest. In addition, when treating commodities in large structures, you must run gas detectors throughout the structure to monitor fumigant levels in different areas. This will ensure that all areas receive an equal amount of fumigant.

Advantages of Tape-and-Seal Fumigation

Nontarget pests such as rats and mice are usually controlled along with the insects. In addition, little material is needed to make the structure relatively airtight. Unfortunately, this advantage is usually offset by the labor required to find and seal leaks.

Disadvantages of Tape-and-Seal Fumigation

Building occupants must leave the structure during treatment. You must also remove items that the fumigant may damage. Tape-and-seal fumigations are notoriously leaky. It is easy to overlook vents, cracks, conduits and other areas that may permit gas to escape. The fumigant may diffuse through interior walls, making it hard to maintain the required concentrations of gas. Insects in the exterior walls and eaves may survive if gas levels are too low to penetrate these sites.

Preparing for Tape-and-Seal Fumigation

Once you decide that tape-and-seal fumigation is necessary, do a thorough on-site inspection. Frequently, the success of a fumigation operation will depend on what you learn, what you decide and how you plan. Ask yourself a number of questions.

General:

- Can you move the infested commodity and treat it elsewhere?
- If removing the infested commodity is not practical, can you fumigate it in place without treating the entire structure?
- What is the volume (cubic feet) of airspace or volume (cubic feet) of the commodity?
- What is the cubic footage of the building?

Information on how to calculate volume will be covered later in this chapter.

Inside the Building:

- Are there any broken windows that you need to replace?
- Are there cracks in the ceiling, walls or floor that you will need to seal?
- Are there floor drains, sewer pipes or cable conduits that may leak? Many fumigation attempts have failed because floor drains under stacked commodities went unnoticed. In another case, a fumigant leaked into a telephone cable tunnel that led to an occupied building. A number of people became ill.
- How will you handle ventilation fans, air conditioning ducts and flues?
- Will interior partitions interfere with fumigant circulation?
- Are the interior partitions gastight?
- Can you rely on them to keep the fumigant from entering other parts of the structure?
- Are there parts of the building that are not under the control of your customer?
- Can you shut down these operations during treatment?
- Will the fumigant damage anything in the building?
- Can you remove these items during fumigation?
- If not, can you protect them?
- Where are the gas shut-offs?
- Where are the pilot lights?
- Where are the electrical outlets?
- What is their voltage?
- Will circuits be live during fumigation?
- Can you use the outlets to operate you circulating fans?
- Does the building contain any high-priority items that may have to be shipped within a few hours notice?

Outside the Building:

- From what materials is the structure built? (Fumigants readily pass through certain materials such as wood.)
- Can you make the structure relatively airtight through sealing?
- How far is it to the nearest building?
- Does that building have air conditioning?
- Does it have air intakes that might draw the fumigant inside, particularly during aeration?

- How will you aerate the structure after fumigation?
- Are there exhaust fans?
- Where are the fan switches?
- Are there windows and doors that you can open for cross ventilation?
- Is the structure to be fumigated located where your operations may attract bystanders? If so, consider asking police to assist your own guards.
- Where is the nearest medical facility?
- Do you have the telephone number of a poison control center?

Once you are confident that you have covered everything, prepare a list of things to do and record these as part of your Fumigation Management Plan (see chapter 9). Make a second list of materials that you will need. See Chapter 6 and Appendix A for sample checklists. Do not rely on your memory. With the checklists in hand, ask yourself one final question:

- What have I overlooked?

Types of Sealed Structures

Silos and Grain Bins

Treating grain in silos and grain bins is one of the most common types of raw agricultural commodity fumigation. Well-built silos and grain bins may only require sealing to be gastight. Others, especially those made of wood and other permeable materials, may need to be tarped.

When sealing grain bins and silos for fumigation, be sure you find and seal all potential leaks. Proper sealing will often mean the difference between success and failure of a treatment. There are many places in a bin where gas can escape. These include along walls, roof-wall junctures, seams, roof ventilators, bin doors, aeration fans, and through other gaps. When sealing these gaps with fumigation tape, it is often helpful to apply tape primer first. Tape primer coats the surface you plan to seal with a tacky substance. This helps the fumigation tape adhere better. Both brush-on and spray-on primers are available.

Figure 5.2 Grain storage recirculation system

Unlike other types of grain storage structures, wooden bins are often too leaky for tape-and-seal fumigation. The loose construction of wooden bins and the permeable nature of wood can cause gas to escape despite your best sealing efforts. Instead, wooden bins may have to be tarped to retain enough gas for the treatment to be effective. See "Tarpaulin Fumigation" later in this chapter for information about this treatment option.

Once a grain bin or silo is sealed, you are ready to release your fumigant. Some fumigants are heavier than air. These chemicals often require special recirculating equipment such as blowers to adequately distribute them throughout a grain mass. Before releasing such fumigants, be sure your blowers are working properly. First, turn them on to establish airflow. Then, introduce the fumigant on the high-pressure side of the blowers. Run the recirculating system until the fumigant is thoroughly distributed.

Some grain storage structures have built-in aeration or recirculation systems. These devices regulate the temperature and moisture content of the grain. During fumigation, you can use them to distribute fumigants throughout the grain mass. Other storage structures may not have such sophisticated systems.

In most cases, if you use fumigants that have good penetrating and distributing power, you will not need special recirculating equipment. Simply apply the fumigant directly into the grain. You can do this while the grain is being stored or as the silo or bin is being filled. If the fumigant comes as pellets or tablets, use a special probe to insert them into the grain mass. If you add the pellets to the grain during filling, use an automatic pellet/tablet dispenser. Fumigant manufacturers often supply these probes and dispensers.

No matter which type of fumigant you use, always wait for a still day to fumigate. Winds around a grain storage structure create pressure gradients across the grain surface. This can result in rapid loss of fumigant. In some cases, using polyethylene or plastic-coated nylon to cover the top of the grain after treatment will help to ensure an effective treatment.

As with other types of fumigation, the fumigant, formulation, dosage and equipment vary depending on the commodity, the storage facility and other factors. Make sure the fumigant is labeled for the intended use. Follow all instructions in the labeling exactly.

Wheeled Carriers

NOTE: It is illegal to transport goods over public roads if those goods are undergoing fumigation or have not completely aerated.

Fumigating products inside wheeled carriers such as truck trailers, boxcars and other railcars is a form of vault fumigation. This method saves time and labor. It avoids extra loading and unloading. It controls the pests in the commodity and ensures that live pests do not remain after unloading. In addition, fumigation of incoming loads prevents the introduction of pests into uninfested areas.

Boxcars and other railcars, and truck trailers are ideal vaults for fumigation. Wheeled carriers must be airtight for fumigation to be successful. Fumigation must stay inside the truck or boxcar long enough to control the pests. Well-built structures can be made relatively airtight by sealing them with fumigation tape or liquid adhesive. Structures with large holes or cracks, or structures made of permeable materials such as wood, may need to be tarped. See "Tarpaulin Fumigation" later in this chapter to learn about this type of fumigation.

First, inspect and clean the wheeled carrier while it is empty. Look for small holes or cracks that may allow fumigant to escape. Use fumigation tape, liquid adhesive or caulking to seal any gaps. Then seal the door that will not be used for loading. Secure a precut 2- or 4-mil polyethylene sheet over the entire door. Compute the volume of the container to determine the dosage. Information about how to calculate volume can be found at the end of this chapter.

Next, apply the fumigant. Every product is different. Read the labeling to determine how best to apply the product you are using.

Next, cover the last door with polyethylene before closing and sealing it with fumigation tape. As required by law, place a warning sign on each door. Return any unused fumigant to a locked chemical storage area. Dispose of empty fumigant containers according to the directions in the labeling. See Chapters 6 and 8 for more information on the safe use and disposal of fumigants.

Ship Fumigation

Like fumigation of wheeled carriers, ship fumigation treats goods while they are still on board. This avoids extra loading and unloading. It controls the pests in the commodity and ensures that live pests do not remain after unloading. Fumigation of incoming loads also prevents the introduction of pests into uninfested areas. This is particularly important for products arriving from overseas.

Ship fumigation involves many people. Close cooperation with the responsible ship officer, ship agent, USDA official and Coast Guard inspector (if involved) is essential. You may also need to notify the port authority and the local fire and police departments.

Shipboard fumigation is highly specialized. The problems encountered and techniques used in ship fumigation are unique. In many cases, you may want to hire a company that specializes in ship fumigation.

Tarpaulin Fumigation

Tarpaulin fumigation treats single pallets of goods or entire structures. It works by placing a semi-permeable tarp over an infested product or struc-

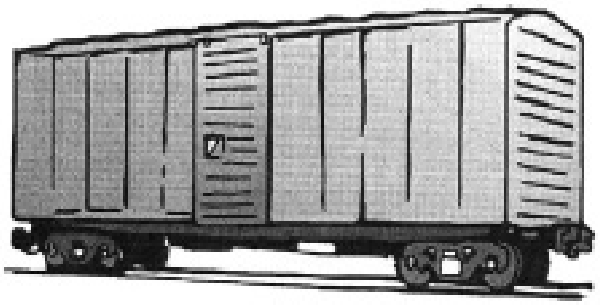


Figure 5.3 Boxcar

ture, sealing the edge and then releasing fumigant beneath the tarp. Sometimes, you may need to treat an entire building.

Advantages of Tarpaulin Fumigation

You can use tarpaulin fumigation to treat a variety of items. It is particularly useful when only single pallets or groups of commodities are infested. Instead of fumigating an entire warehouse full of goods, tarpaulin fumigation allows you to treat only those items that are infested. This saves time and money. In addition, you can tarp and treat individual items or groups of items where they stand, if it is permitted by the labeling. This also saves time and money. Because you can clamp together many sections of tarp, there is no limit to the size of the stack or structure that can be covered.

Disadvantages of Tarpaulin Fumigation

The biggest problem with tarpaulin fumigation (when covering entire structures or treating products outdoors) is the weather. Weather conditions can delay fumigation. If there has been a recent heavy rain, the roof of a structure may be too slippery for safe work. Structures with wood roofs or concrete block houses can absorb enough moisture to cause problems after the tarps are placed on the building. In addition, if the temperature is below the labeled minimum, you must delay treatment until the structure and commodity within it are warm enough to comply with the label instructions.

Types of Tarpaulins

An important aspect of tarpaulin fumigation is the type of tarp you select. Some tarps are specially made for fumigation, such as impregnated nylon. Others are more generic but equally effective, like sheet polyethylene. Each material has its pros and cons.

Impregnated nylon tarps are strong. They resist ripping and are reusable. In addition, you can clamp or tape together many sections of impregnated nylon tarps. This allows you to cover structures and commodity loads of almost any size. Unfortunately, impregnated nylon tarps are expensive. They are also heavier, which makes them more difficult to use.

Polyethylene sheeting comes in a variety of thicknesses. Some are reusable and some are not. Thinner sheets (3 mil or less) can be used once and are for indoor treatments only. Outdoors, you can use 4- and 6-mil polyethylene. Six-mil sheets can be reused if they are not worn or ripped excessively. To join together sections of polyethylene, use fumigation tape instead of clamps. Thinner sheets of polyethylene are often preferred to nylon tarps because they are less expensive and disposable. However, because they can tear easily, you must use them with care.

Ground Seals

In addition to proper tarp selection, also consider the type of ground seal you will need. If they are smooth, concrete and asphalt surfaces provide the base for a good ground seal. Wood surfaces do not. With wood, and frequently with soil surfaces, it is necessary to place a section of the tarp beneath the product to be fumigated as well as over the top of the product. Otherwise, gas may escape through the wood or soil.

There are several ways to obtain a good ground seal. First, cover the infested product, allowing at least 18 inches of tarp to skirt out from the base. Then, lay loose sand, sand snakes or water snakes to hold the skirt to the ground surface. Snakes are tubes of cloth or plastic filled about three-quarters full with sand, gravel or water. All types of snakes should overlap each other about 1 1/2 feet.

Figure 5.4 Clamping two sections of tarp together

Sometimes you can attach adhesive fumigation tape directly to the floor. However, you still need sand, gravel or water snakes to prevent the tarp from blowing off during treatment. Occasionally, you may need to treat an item that is too close to a wall to obtain a good ground seal. In this case, move the item and seal the tarp properly to the floor.

Tarping Individual Items

Frequently, only single pallets or groups of commodities need treatment. With tarpaulin fumigation, you can cover and fumigate these items in place or at a nearby location.

Basic Procedures

First, erect tarp supports one to two feet higher than the stacked commodity. This will create an air dome. An air dome ensures adequate gas circulation during fumigation. Secure gas introduction tubes above the commodity. Place polyethylene sheeting under the outlet of the gas introduction tube. This will protect the commodity from any liquid fumigant that may accumulate during discharge. Next, pad all corners to prevent the tarp from tearing. The lighter the tarp material, the greater the chance for rips.

If the stack is large, use nonsparking fans to ensure adequate gas circulation. Turn on the fans for 30 minutes to one hour after introducing the fumigant. Run tubing from various positions in the stack (usually one located high in the stack, one at an intermediate location and one at a low location) to the point where you will sample gas concentrations. Then place and seal the tarp to the floor. Determine the volume of the space beneath the tarp to calculate the amount of fumigant to use. See how to calculate volume at the end of this chapter.

Indoor Tarpaulin Fumigation

Tarpaulin fumigation is easiest and most effective indoors. Protection from wind and rain is critical. However, most indoor treatments require you to evacuate the entire building. Some fumigants may allow work to continue in other parts of the building as long as the treatment area remains clear. Of course, you must post warning signs and monitor the area regularly.

If the commodity you wish to treat is in an unsuitable indoor site, it may be better to move it to another indoor location than to fumigate outdoors. Make this decision when you first inspect the structure. For ease of movement, place all commodities on pallets for fumigation.

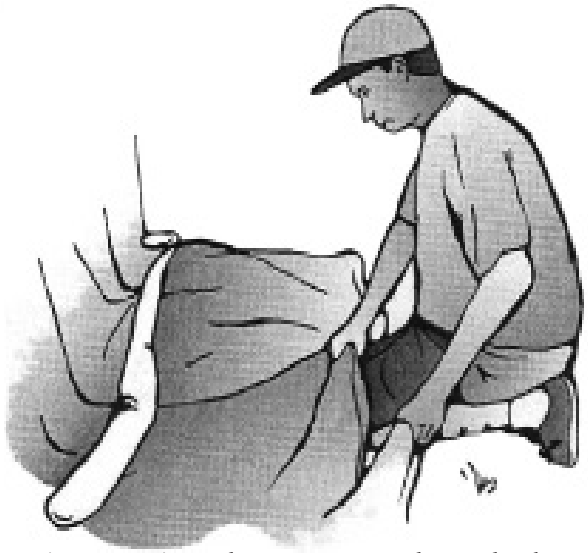


Figure 5.5 Using snakes to ensure a good ground seal

Outdoor Tarpaulin Fumigation

The same procedures outlined for indoor treatments apply to fumigation outdoors. The difference is that outdoor tarps must be stronger and more durable. If you use polyethylene, it must be at least 4 mils thick. Six-mil sheets are better. The color of the tarp also makes a difference. Clear polyethylene tends to become brittle from ultraviolet rays of the sun. In some cases, rays of sunlight can concentrate through water drops on clear tarps and cause fires. If you plan to keep the polyethylene tarp in place after fumigation is complete or if you will reuse it, consider black polyethylene. It is more resistant to sunlight and is not transparent. However, there are some dangers with black tarps. For example, if the tarp spans several stacks, it may conceal gaps between the stacks or other voids. Persons working on

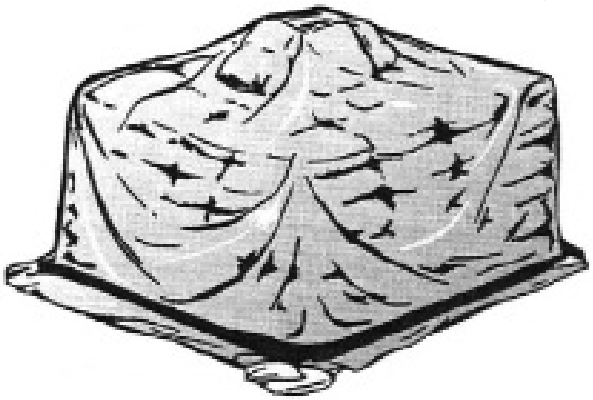


Figure 5.6 Using tarp to fumigate commodities on a pallet

top of the tarp must be careful not to fall through. Once fumigation begins, a fall could be fatal.

There are several challenges with outdoor fumigation. First, it is more difficult to obtain a good ground seal outdoors. Sand and water snakes are often less effective because the ground is usually porous and uneven. Instead, place a layer of loose sand on the tarp skirt to obtain a good seal. You will also need to plan for bad weather. If you know it will be stormy, delay fumigation. Place braces over the product (but under the tarp) so that rain will not accumulate in any low spot. Also, place sand snakes or sand bags over the tarp to protect it against wind.

Tarping an Entire Structure

Sometimes, you may need to treat a commodity by tarping an entire structure. This type of tarpaulin fumigation is normally used to treat flat grain storage buildings or any extremely leaky, poorly constructed structure that cannot feasibly be sealed.

Basic Procedures

When fumigating an entire structure, good preparation is critical. Remove all items that the fumigant may damage or that the label requires. Evacuate the building for the entire fumigation and aeration period. Turn off pilot lights, flames, electrical heating elements and electric motors. If the commodity you plan to treat is packaged in bags or other containers, be sure these materials will allow the fumigant to penetrate and treat the commodity.

Place tubing to draw air samples from several places within the structure. Use these tubes to administer the fumigant and test its concentration during the treatment and aeration. It is best to introduce the fumigant at several locations. Place electric fans so that the fumigant will circulate throughout the structure and achieve rapid equilibrium. Local fire authorities may require the use of nonsparking fans.

If landscape plants are too close to the structure to permit a good ground seal, move the plants. Pad all edges of the structure that may puncture or tear the tarp. To be safe, ask all workers to wear shoes with nonskid surfaces. Slips or falls can be very dangerous during fumigation. All ladders should be strong and braced. Use these to carry tarp sections to the rooftop. If you use impregnated vinyl or nylon tarps, roll together the edges of two tarp sections. Place clamps approximately 8 inches apart (4 inches apart if windy) along the seam. Drop the tarp over the sides of the structure. Complete any additional clamping or taping at this point.

Excessive "billowing" of a tarp can speed the loss of fumigant from a structure. Billowing occurs when air beneath a tarp causes the tarp to bulge outward. Prevent this by keeping the tarp tight against the structure. For example, if the building top is flat, use sand snakes to hold down the tarp. If the roof is peaked, throw weighted ropes over the tarp. Draw the tarp as close to the building as possible. One technique involves a high-capacity electric fan. Place the fan in one doorway and direct it outward. This may create a partial vacuum that will draw the tarp against the structure. Then, you can gather and tape down the excess material at the corners of the structure.

As in any fumigation, the ground seal is very important. The ground should be level and free of vegetation. If the soil is porous or dry, soak the soil around the perimeter of the building with water. This will help prevent fumigant from escaping through the soil. Make sure the tarp skirt is at least 24 inches and weighted down by loose sand, water snakes or sand snakes. If you use water or sand snakes, double or triple them in windy weather.

Spot (Local) Fumigation

Spot fumigation is the short-term treatment of machinery and small storages with toxic gases. It is used to control pests that infest whole foods and food particles that remain within processing equipment. Spot treatments work by interrupting the life cycles of insect pests. Since one or more stages of the insect (egg, larvae, nymph, adult) may survive, you must repeat spot fumigation regularly to maintain control. Use spot fumigation to control stored product pests in:

- Bins, silos and holding tanks
- Elevator boots, heads, filters, conveyers, spouting and purifiers
- Food processing equipment such as sifters, rollers and dusters
- Related equipment in mills, food and feed processing plants, breweries and similar industries

Advantages of Spot Fumigation

Insect infestations are usually not uniform. They concentrate in specific locations within equipment and storage areas. Spot fumigation allows you to treat only those areas where insects exist. This saves time and money, and it puts less fumigant into the environment.

Disadvantages of Spot Fumigation

Spot fumigation is often labor intensive. Without fumiports or similar devices, you must cut up and insert prepackaged fumigant, such as phosphine Prepacs, into the machinery at several locations. In addition, when treatment is complete, you must retrieve each Prepac or risk contaminating product during future processing. Spot fumigation can also be time-consuming. Calculating the volumes of several small locations is cumbersome. Finally, disposal of spot fumigants like phosphine is difficult because you must deactivate the chemical before transporting it off site.

Basic Procedures

Several things can affect the success of spot fumigation. Most important is your understanding of the equipment you treat and the airflow patterns within a warehouse. Always review diagrams of the facility and inspect the machinery. Determine whether you can make the site sufficiently gastight. Next, develop a Fumigation Management Plant (FMP). Details about fumigation management plans are described in Chapter 9. Be sure your plan includes:

The necessary staff and supplies.

- An application route. This route should be quick and efficient. It should also minimize applicator exposure.
- Security provisions during treatment. Post appropriate signage and notify the facility's personnel. Do not allow unauthorized persons to enter the treated area(s) prior to aeration.
- A procedure for sealing the equipment before treatment. Repair machinery, transfer lines, bins or other equipment before treatment. This may improve the equipment's ability to retain gas.
- Dosage rates and application points.
- Safety provisions. Respiration protection is often required during spot fumigation. Always preplan ways you and other applicators can reduce your exposure to the fumigant. These methods may include wearing respiratory protection, working near an open window or using fans or forced ventilation.
- A record or log detailing the procedure. The log should include dates, dosage rates and application points.
- Recommendations for the permanent installation of fumiports. Place fumiports inside the equipment to eliminate the possibility of contamination.
- A procedure for monitoring fumigant concentrations. Using an approved gas detector, take readings at regular intervals. Note fumigant concentrations during application to be sure fumigant levels get high enough for long enough to kill the pest. Note fumigant concentrations during aeration. Allow reentry only when gas levels are safe.
- A procedure for recovery, deactivation and disposal of the fumigant when using phosphine. This plan must include emergency monitoring procedures.

Clearly mark all application points, particularly those that may not be visible from the floor level. Also, mark points where ladders are needed to reach overhead areas. Prepare a checklist or chart for each facility. Show the location and number of application points on each floor. As you treat each point, check off the appropriate location on the chart. In this way, you can be sure you did not miss any points before moving to the next floor.

Before treatment, run the machinery to empty the process stream. In mills, turn off the feed and allow the mill to run for 30 to 45 minutes. During this period, use rubber mallets to tap on the spouting, elevator legs and sifters. This will help to loosen product that is trapped inside. Check outlet channels in the sifters to be sure they are not blocked or choked.

Next, seal the equipment. This will prevent fumigant from escaping. Eliminate drafts inside the equipment by closing off sections that have openings. Then, seal these openings with tape, caulk, tarps or other materials. Seal dust collector vents with polyethylene sheeting or large plastic bags. Close dust collectors and filter vents to keep the fumigant within the machinery. Thermal currents and drafts can cause a spot fumigation to fail. Gas may escape before reaching a lethal concentration within the machinery.

While spot fumigation is less intensive than other methods of fumigation, proper safety is equally important. During application, open windows in rooms that house equipment to allow ventilation. When possible, use a fan or hood to reduce your exposure. Read the labeling of each product you use to determine what personal protective equipment (PPE) is required. Approved respiratory protection is required for many spot fumigations. See Chapters 5 and 6 to learn more about fumigant safety and respiratory equipment.

Aeration After Fumigation

Aeration follows both vault and tarpaulin fumigation. It is the process by which fumigated air is replaced with fresh air. This can occur in a large warehouse or in an individual piece of equipment. Sometimes aeration involves opening doors and windows. Other times you can use fans and ventilators. Aeration procedures vary according to:

- The fumigant you use
- The area in which you fumigate
- The commodity(ies) that you treat

Every situation is different.

Proper aeration is important for your safety, the safety of your crew and the safety of your clients. Read and follow the instructions in the labeling for your product exactly.

Factors Affecting Aeration Time

The rate of aeration is affected by several factors. Three of the most important factors are:

- The rate of air exchange
- Air temperature
- Sorption and desorption

Rate of Air Exchange

The rate of air exchange within a treated area is the most important factor affecting aeration. The faster air flows through a structure, the faster aeration can occur. Exchange rates are proportional to wind speed and to the size and layout of the fumigated area. In atmospheric chambers, an exchange rate of one "air change" per minute is desirable. An air change occurs when 100 percent of the air in a given space is replaced by fresh air. Nonsparking fans are useful for this purpose. They also help to stir up the air in "pockets" or "dead spaces." Areas loaded with product aerate more slowly than empty areas.

Temperature

Temperature can also affect the speed of aeration. As temperature increases, the rate of aeration increases. This is because higher temperatures increase the rates of diffusion and desorption of fumigants. For example, when you aerate areas during colder months, you may use cold outside air. These lower air temperatures will slow desorption. The rate of diffusion will also decrease. A longer aeration time will be needed. It may be necessary to close the area and heat it to 76°F (the optimal aeration temperature for most fumigants). Then repeat the aeration process to adequately remove the fumigant.

Sorption and Desorption

As you learned in Chapter 3, sorbed fumigant cannot control pests. It is adsorbed and/or absorbed by materials in the treated area. Still, you must remove it during the aeration process. Some commodities are more sorptive than others are. Some fumigants are more subject to sorption than others are. The greater the sorptive capacity of the fumigant and the product you are treating, the longer it will take for the product to completely aerate.

To determine how sorptive a fumigant is, read the labeling. Then follow these two rules of thumb:

1. Generally, the lower the boiling point of a fumigant, the lower the sorption rate, and the more rapid the aeration.

2. The greater the surface area of the commodity(ies) being fumigated, the greater the sorption rate, and the longer the aeration period needed for desorption. For example, the surface area of wheat grain is high. (A load of wheat grain consists of many small pieces, each with a surface area. Together, these add up.) Because of its high surface area, the desorption rate of wheat grain is slow. It is usually advisable to hold wheat grain an additional 24 hours after the satisfactory aeration period. Other highly sorptive materials include clover seed and milo (grain sorghum). You will need to increase aeration times when treating these materials as well.

Aeration Procedures

Procedures for aeration vary with the fumigant, the area and the product(s) being fumigated. Read the labeling for aeration procedures specific to each product that you use. Follow the instructions exactly.

Aeration of Fumigation Chambers

The way you aerate a fumigation chamber depends on whether the chamber is indoors or outdoors. When a fumigation chamber is within a building where people are likely to be present, install intake and exhaust pipes for safe aeration. These pipes lead to the outside. The intake pipe will draw fresh air in while blowing fumigant-treated air out. Turn on air circulation equipment in the chamber to exchange air between the chamber and the outside.

When a fumigation chamber is outside, aeration is straightforward. Simply open the door slightly and turn on the blower. Be sure to prop open the door so it does not accidentally close. If the door closes, the partial vacuum created by the blower may damage the chamber. Channel the air from the blower to the outside of the chamber.

Do not stand near the chamber door or exhaust when the blower is on. Check gas levels regularly during aeration. Be sure to use a gas detector that is approved for the product you are using. If fumigant levels are too high, stay out of or away from the treated area unless you are wearing the appropriate respiratory protection.

Aeration of Grain Bins and Silos

Aeration of grain in bins and silos depends on the type of fumigant you use. When aerating chemicals that require recirculation systems, disconnect the return air duct and operate the ventilation system until the exhaust air is free of fumigant. Check fumigant levels with an approved gas detector. Do not use detectors that rely on an open flame around grain bins. When grain gases and dust approach a fire, an explosion can result.

If recirculation systems are not required, simply open all vents and doors. Use nonsparking fans to move fresh air into the structure and pull the fumigant out. Always check gas levels with an approved gas detector before reentry.

Aeration of Wheeled Carriers

To aerate wheeled carriers such as truck trailers, boxcars and other railcars, open all doors and vents to promote as much air circulation as possible. Allow the structures to air out for at least 30 minutes. Be sure to wear respiratory protection during aeration as directed by the labeling. Always check gas levels with an approved gas detector before reentry.

Aeration of Buildings

After fumigation, aerate buildings by opening doors and windows and turning on ventilators. First, open ground floor windows and doors from the outside. Allow buildings to air out for at least 30 to 60 minutes before entry. Then open other windows and doors. Check detectors to be sure fumigant levels are safe. Read the label information for other aeration requirements.

At the beginning of the aeration procedure, enter the building only for short periods. Always enter in pairs and wear approved respirators. Once inside, open doors and windows on the first floor first. Target windows that provide thorough cross-ventilation. Then return to the outside. If ground floor ventilation occurred before entry, work upward floor by floor. Open windows. Turn on nonsparking fans and allow them to run until aeration is complete. Take concentration readings to determine if exposures are within allowable limits.

After the building has been partially aerated, reenter with a partner wearing approved respirators. Open as many of the remaining windows as needed to complete aeration.

When the building has completely aerated, begin testing gas levels. Using approved detectors, test confined spaces with poor airflow, stacked commodities and other items to make sure that no gas is remaining. Aerating the building and its contents is extremely important. Follow the directions in the labeling closely. The first rule of reentry is to "check it first."

Tarpaulin Aeration

Safe tarpaulin aeration can be trickier than it seems. When aerating loads under tarps on still, humid days, follow these steps. Place a blower on one end

of the load. Make an opening on the opposite end by lifting the tarp. Then turn on the blower and discharge the fumigant. If a breeze or steady cross-ventilation is available, a blower may not be necessary. If you choose not to use a blower or cross-ventilation, aerate the commodity by lifting the tarp at the corners. Then, slowly raise the sides until the tarp is completely removed.

If aeration occurs outside and there is a breeze, pay attention to which way the breeze is blowing. Always lift the end or side of the tarp opposite the direction of wind movement first. Then lift the portion of the tarp on the windward side. If the first opening is on the windward side, fumigant vapors will be forced backward and may endanger workers.

Wear a respirator or gas mask during all phases of tarpaulin aeration. Evacuate occupants other than fumigation workers before aerating tarped products.

After all types of aeration, collect all empty fumigant containers, packaging materials and solid residues (such as those from metal phosphide fumigants). Transport these materials to an appropriate site for further deactivation and disposal. Follow the disposal instructions outlined in the labeling.

For fumigation and aeration to be safe and effective, you must select the appropriate fumigation method and follow the procedures outlined in this chapter. You should also know how to select and use the equipment described in Chapter 7.

Calculating Use Rates

The first step in deciding how much fumigant must be released to achieve the desired concentration is to measure the length, width and height of the area to be treated and figure its volume. (Volume measurements on fumigant labels are given in cubic feet.) Some examples of volume calculations you may encounter can be found at the end of this chapter.

If the commodity, container or structure to be fumigated is to be tarped, the total volume inside the tarp must be determined, not just the volume of the structure or commodity. This must account for spaces caused by over-hangs, eaves, and other irregular shapes.

Fumigant labels are the best source of information on calculating the proper amount of fumigant to use for specific situations. Always read and follow label and Applicator manual instructions.

Physical or environmental conditions may influence the amount of fumigant that must be applied to achieve the required dosage. Factors that must be considered include:

1. Temperature and temperature fluctuation during fumigation.
2. Sorption qualities of the commodity or items in the target site.
3. The type and condition of the sealing method.
4. Texture and moisture content of the soil beneath the fumigation site.
5. Wind velocity during the fumigation period.
6. The volume of the area being fumigated.

Many fumigant manufacturers furnish calculators, charts, or slide rules to help figure dose adjustments for these factors.

Volume Calculations

There are several important factors to consider when preparing for a fumigation. One of the most important is calculating the volume of the space you plan to treat.

Calculating the Volume of Rectangular Structures

In simple terms, to determine the cubic content of a rectangular structure multiply the length by the width and then multiply the result by the height. Use this calculation for truck trailers, boxcars and other simple structures. Measure the inside of these structures if the structure will be sealed and treated on the inside. Measure the outside of the structure if the structure will be tarped. The entire area enclosed by the tarp must be calculated.

Calculating the Volume of Buildings

Calculating the volume of a flat grain storage building or similar structure is usually more involved. Most buildings are irregular in shape. They also may have peaked or gable roofs. To calculate the cubic content of such structures, first determine the area (square feet) of the space you plan to treat. Then multiply the area by the average height (feet).

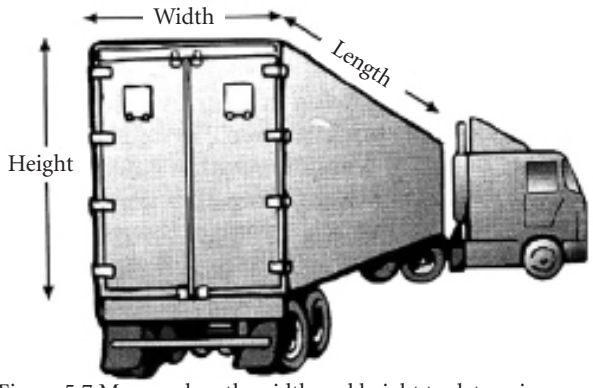


Figure 5.7 Measure length, width and height to determine area to be treated and figure its volume.

Example 1: The rectangular building shown in Figure 5.8 is 80 feet long and 20 feet wide, with an average height of 25 feet. Calculate the volume (cubic content) of the building.

Area = length x width
= 80 ft x 20 ft
= 1,600 sq ft

Volume = area x average height
= 1,600 sq ft x 25 ft
= 40,000 cu ft

This is a very basic example. A fumigator must be able to calculate the cubic content of buildings much more complicated than this. He or she also must understand how to determine average height. The building in Figure 5.9 is still simple, but a little more complicated than Figure 5.8. A lean-to has been added to the main structure, and there is a crawl space and subarea.

Example 2: To figure the volume in Figure 5.9, (cubic content) of this structure, use the same procedure outlined in Example 1, but calculate the volume of each section separately. Section 1 is the main section, not including the loft and subarea. Section 2 is the lean-to, not including the loft and subarea of that section. Section 3 is the loft area of the main structure. Section 4 is the loft area of the lean-to, and section 5 is the combined subareas below the main structure and the lean-to.

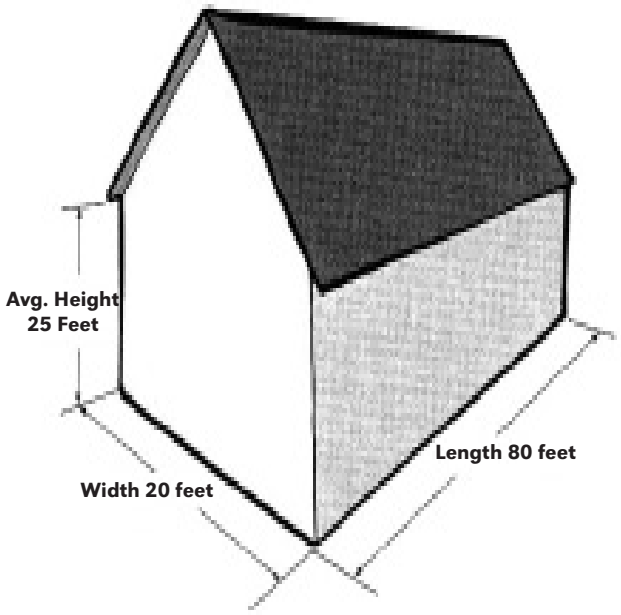


Figure 5.8

Volume of Section 1:
40 ft x 30 ft = 1,200 sq ft
1,200 sq ft x 8 ft = 9,600 cu ft

Volume of Section 2:
30 ft x 10 ft = 300 sq ft
300 sq ft x 6 ft = 1,800 cu ft

Volume of Section 3:
40 ft x 30 ft = 1,200 sq ft
1,200 sq ft x 3 ft (1/2 of loft height)
= 3,600 cu ft

Volume of Section 4:
30 ft x 10 ft = 300 sq ft
300 sq ft x 1 ft (1/2 of loft height)
= 300 cu ft

Volume of Section 5:
40 ft x 30 ft = 1,200 sq ft
30 ft x 10 ft = 300 sq ft
1,200 sq ft + 300 sq ft = 1,500 sq ft
1,500 sq ft x 2 ft (height of subarea)
= 3,000 cu ft

Total volume would be the sum of all area volumes:

9,600
1,800
3,600
300
+3,000
Total square feet = 18,300

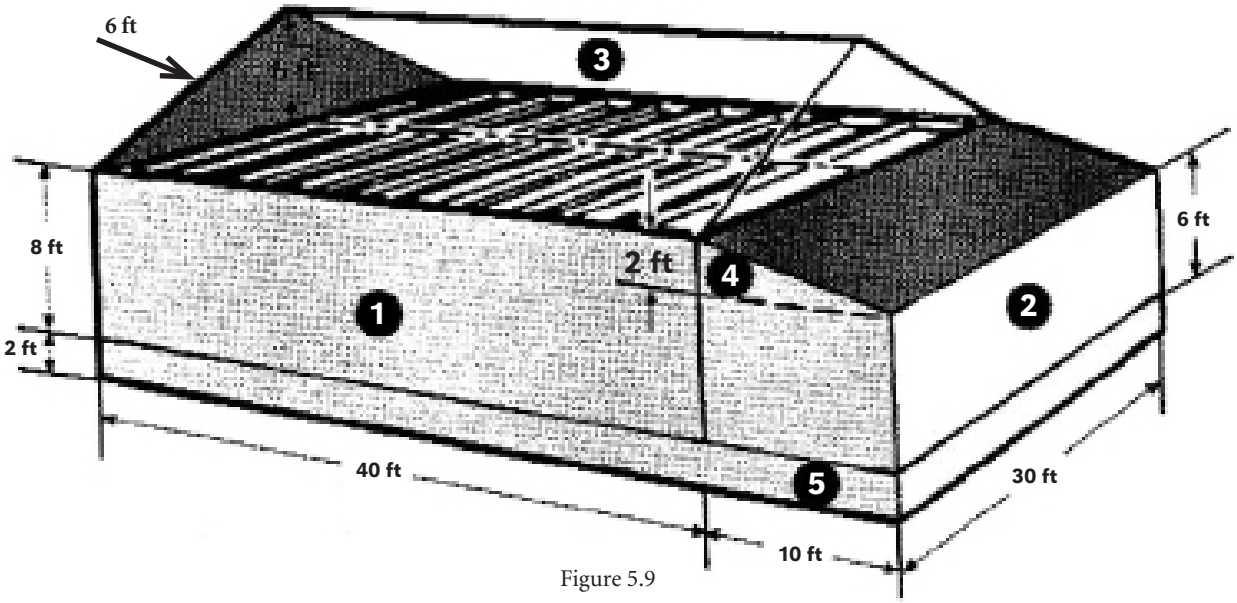


Figure 5.9

Calculating Average Height

Calculating the average height of a building is a critical step in figuring volume. Several methods are available. To figure the average height of a building with a gable roof, multiply one-half the distance from the ground-floor ceiling to the peak of the roof by the number of square feet in the loft Another method is to multiply the maximum height at the peak by the number of square feet and divide the result by two.

If the building has a simple roof, without dormer or extra gables, as in Figure 5.10, you can calculate the average height of the total building by adding the wall height and one-half of the attic height.

To measure the average height of the building in Figure 5.11, find the midway point between roof peak and eave. From there, measure to the ground. If the terrain is sloping or access to the outside is difficult, it is useful to measure the roof from inside while making the inspection.

Average height = 8 ft + 6 ft/2

= 8 ft + 3 ft
= 11 ft

Calculating the Volume of Grain Bins

Grain bins are usually cylindrical, with cone-shaped caps. To calculate the volume (cubic content) of a grain bin, you must know how to figure the volume of a cylinder and a cone:

Volume of a cylinder = $3.14 \times r^2 \times h$

Volume of a cone = $\frac{3.14 \times r^2 \times h}{3}$

r = radius (1/2 of the diameter of the circular base of the bin)
h = height of the cylindrical part of the bin

3.14 is a constant often called "pi" and represented as π.

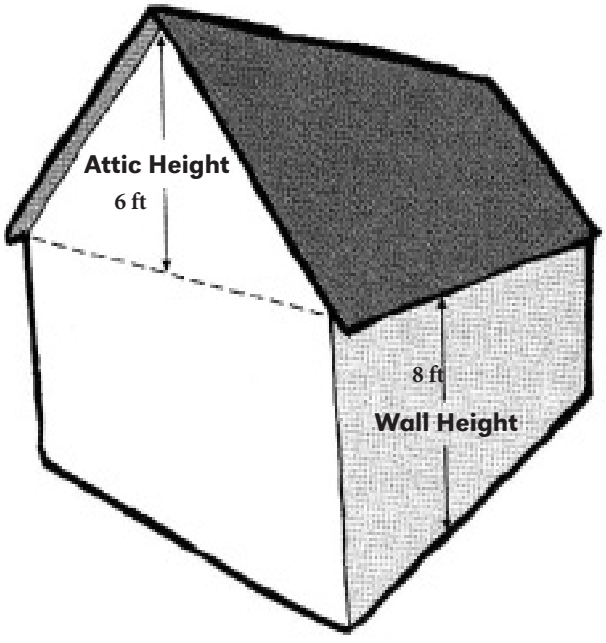


Figure 5.10

Example: Figure 5.12 shows a basic grain bin. The height of the cylindrical part of the bin is 25 feet. The diameter of the circular base of the bin is 20 feet. The height of the cone-shaped cap is 5 feet. With these dimensions, calculate the total volume (cubic content) inside the bin.

Volume of the cylindrical portion of the bin
= 3.14 x $(10 \text{ feet})^2$ x 25 ft
= 7,850 cubic ft

Volume of the cone-shaped cap
= 3.14 x $(10 \text{ ft})^2$ x 5 ft
= $\frac{1{,}570 \text{ cubic ft}}{3}$

= 523.3 cubic ft

Total volume
7,850.0 cubic ft
\+ 523.3 cubic ft
Total cubic ft = 8,373.3

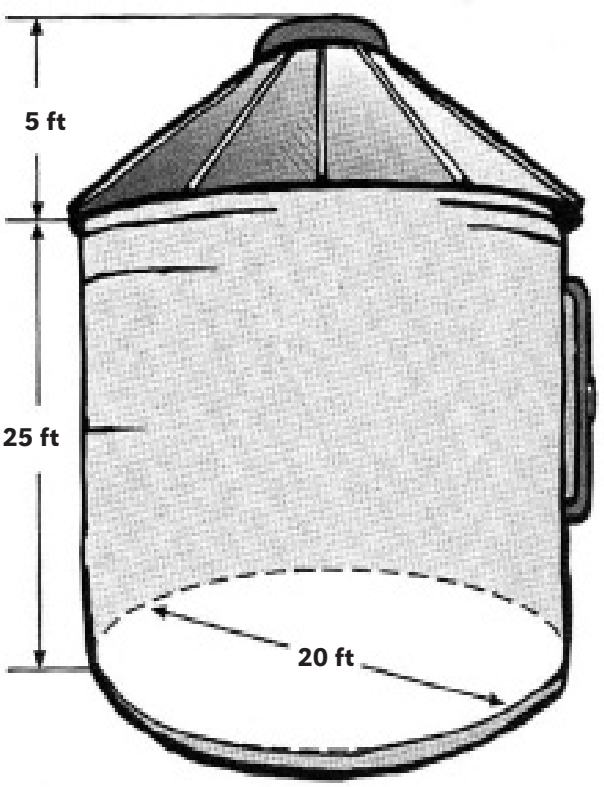


Figure 5.12

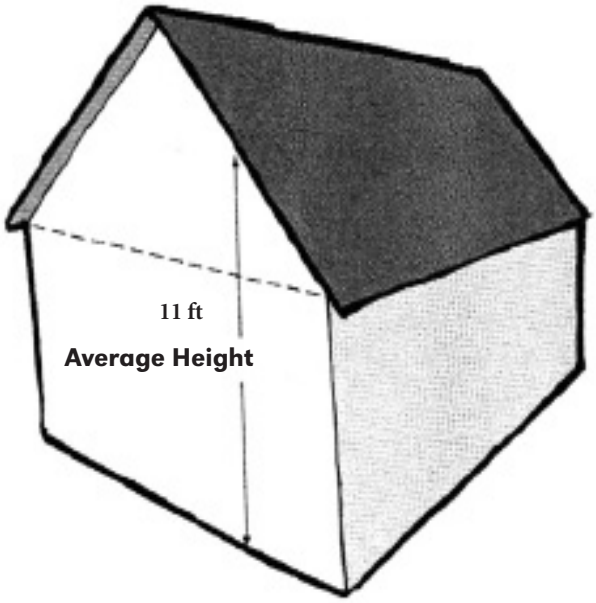


Figure 5.11

Chapter 6

Public, Personal and Environmental Safety

Learning Objectives

After studying this chapter, you should be able to:

- Identify multiple hazards of fumigants.
- Name the agencies that regulate the use of fumigants.
- Describe six ways to protect people and animals from fumigant exposure.
- Explain why fumigators should always work in pairs.
- Identify the routes of fumigant exposure.
- Describe three types of personal protective equipment (PPE) required when using most fumigants.
- Identify three appropriate tools to make fumigation safer.
- List what should be included on safety checklists for use before, during, and after a fumigation operation.
- Identify the signs and symptoms of fumigant exposure.
- Explain how to administer basic first aid in the event of fumigant exposure.
- Describe multiple procedures to follow if someone has suffered inhalation exposure from a fumigant.
- Describe multiple procedures to follow if someone has suffered skin exposure from a fumigant.

The Nebraska Pesticide Applicator Certification Core Manual is a comprehensive guide to pesticide safety. The Core Manual discusses basic safety considerations for all applicators.

This chapter covers safety practices specific to raw agricultural commodity and stored products fumigation. By reading it, you will learn how to reduce or eliminate fumigant exposure to yourself and to the public. It will teach you about personal protective equipment (PPE), warning gases and exposure limits. You will discover the importance of posting warning signs and writing an application plan. Later in this chapter are several safety checklists. It is critical to use these checklists before, during and after every fumigation.

Terms to Know

Aerate – To replace fumigant-containing air with fresh air that contains little or no fumigant. Aeration must follow all fumigation operations.

Antidote – A remedy that may counteract the effects of a pesticide.

Exposure – When a person or organism comes in contact with a pesticide by inhalation, ingestion, skin contact or any other method.

Overexposure – When a person or organism comes in contact with enough pesticide to cause harm.

Material Safety Data Sheet (MSDS) – A printed report that details information on the fumigant manufacturer, identity of hazardous ingredients, physical and chemical characteristics, fire and explosion hazard data, reactivity data, precautions for safe handling and use and control measures.

Permissible Exposure Limit (PEL) – An OSHA standard that designates the maximum exposure permitted as an 8-hour time-weighted average (TWA).

Personal Protective Equipment (PPE) – Clothing or devices used to protect the human body from exposure to pesticides and pesticide residues.

Rinsate – a pesticide-containing water (or other liquid) that results from rinsing a pesticide container, pesticide equipment or other pesticide-containing materials.

Threshold Limit Value-Short Term Exposure Limit (TLV-STEL) – The concentration of fumigant to which most workers can be exposed continuously for a short period without suffering from: irritation, chronic or irreversible tissue damage, narcosis (drunkenness) that may increase the chance of accident or injury. Exposures to concentrations at the STEL should not be longer than 15 minutes and should not occur more than four times per day. The STEL is expressed in parts per million (ppm) or milligrams per cubic meter (mg/m^3).

Threshold Limit Value-Time Weighted Average (TLV-TWA) – The average concentration of fumigant to which most workers may be repeatedly exposed 8 hours a day, 40 hours a week without adverse effect. The TLV-TWA is expressed in parts per million (ppm) or milligrams per cubic meter (mg/m^3).

Warning Gas – A chemical that can be added to certain odorless fumigants to help workers detect the product. Warning gases give off strong smells or have an irritating effect.

Fumigants are the most hazardous of all pesticides. They are highly volatile, penetrating and poisonous. Even experienced fumigators can cause injuries or damage because of these hazards:

- Fumigants can kill humans.
- Fumigants can kill rodents, bats, birds, pets and other animals that are on site during treatment.
- Fumigants can cause severe burns and damage internal organs.
- Fumigants can cause fires and explosions.
- Improper fumigant use can result in illegal residues in/on foods.
- Some fumigants can inhibit the germination of seeds.
- Some fumigants can corrode metals.
- Some fumigants react with certain materials to produce bad odors and flavors.
- Most fumigants can kill plants.

Three agencies regulate the use of fumigant pesticides – the Environmental Protection Agency (EPA), the Nebraska Department of Agriculture and the Occupational Safety and Health Administration (OSHA). Each agency administers regulations that concern pesticide handling.

You must follow all directives issued by the EPA, NDA and OSHA, and the instructions in the fumigant labeling. These agencies may fine you for misusing a fumigant or for failing to properly use and maintain your protective equipment.

This chapter discusses safety issues, general precautions and emergency procedures related to fumigation. It will describe how to protect the public, your coworkers and yourself from exposure. It will also provide safety checklists for all stages of fumigation. However, no publication can cover all situations for all products. Follow the instructions in the labeling specific to each product that you use. Remember that there is no substitute for good common sense.

Protecting the Public and the Environment

Because fumigants are some of the most toxic pesticides available, their safe use and handling requires skill and care. As mentioned in previous chapters, fumigants control pests on items or in areas with which people and animals may have direct contact. Your ability to apply fumigants safely is critical. You must protect the public and the environment from exposure.

There are several important ways to protect others from fumigant exposure. These include:

- Reading and following the labeling
- Posting warning signs
- Monitoring for the fumigant
- Safely transporting, storing and disposing of fumigants and their containers
- Following tolerance levels
- Properly aerating the treatment area
- Preparing and planning well before application

Read the Labeling

As mentioned in Chapter 1, the most important thing you can do to ensure personal and public safety is to read a fumigant's labeling. Follow its instructions to the letter. It is the law.

The labeling will tell you how and where to use the product. It will give you detailed application and aeration instructions. You will discover how to store the chemical properly. The labeling may note specific sites that you should avoid or application methods that are not permitted. It will also describe

Figure 6.1 Always read the labeling before using a fumigant.

specific safety precautions. Read all of the labeling completely before using any fumigant for any purpose.

See Chapter 9 concerning situations where Nebraska law is more restrictive than the label.

Signage for Fumigated Areas

Warning signs or "placards" protect the public during and after fumigation. They are also posted during transportation and storage of a fumigant. A warning sign provides a barrier between people and the fumigated site or item. Federal and state laws require you to post warning signs at all accesses leading to areas or commodities under fumigation. Only authorized fumigators wearing the proper personal protective equipment (PPE) may enter treated areas before and during aeration.

Follow labeling directions regarding posting warning signs before and during fumigation. Most fumigant labels have specific directions regarding signage:

- What the sign should say
- How many signs to use
- Where to post the signs
- How long to leave the signs in place

Posting warning signs will help to keep unauthorized persons away.

On structures, all entrances should be locked during fumigation and access allowed only to authorized persons, and even then only in an emergency. Use secondary locks on all doors to further guard against unauthorized entry. Areas that cannot be locked or secured must have someone present throughout the fumigation and aeration period to block unauthorized entry. Always make sure to inform people who regularly use the building about the fumigation.

Warning placards may not be removed and the commodity may not be processed or fed until a certified applicator uses an appropriate gas detection device to determine that gas concentrations have dropped below specified levels for the fumigant, and that the treated equipment and surrounding area have been completely aerated. This follow-up monitoring is a practice recently required under newer regulations.

Monitoring for the Fumigant

There is always a risk that fumigant gas will escape from a treatment area. Monitoring for these leaks is critical. When treating commodities that are next to work areas, be sure to take air samples during treatment. Use appropriate gas detectors to verify that fumigants are not leaking. This is particularly important during indoor treatments. See Chapter 7 for more information about gas detectors.

Transporting Fumigants

Transporting a fumigant is dangerous. Leaks and spills caused by accidents are sometimes beyond

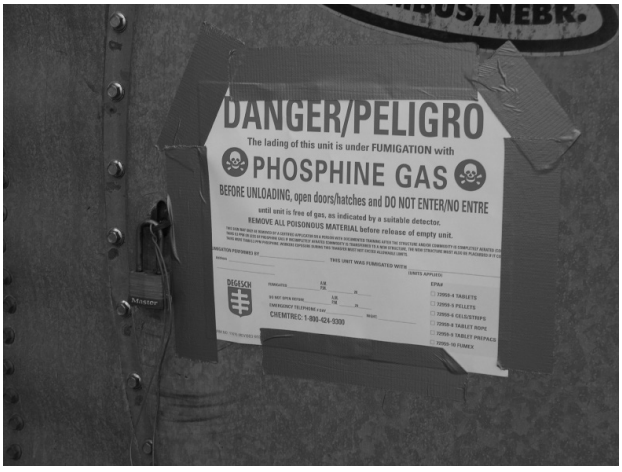


Figure 6.2 Warning placard for phosphine gas

your control. However, by taking the following precautions and using common sense, you can prevent many accidents.

- Do not use public transportation (buses, trains or taxis) to transport fumigants.
- Do not transport fumigants and people together in a closed vehicle.
- Be sure you have the required driver's license with any appropriate endorsements for the specific fumigant you plan to transport.
- Read the labeling and/or the Material Safety Data Sheet (MSDS) to determine the signage requirements for transporting each fumigant that you use. You can also contact the fumigant manufacturer for more information on placarding for transportation.
- Be sure cylinders are upright and secured during transport.
- Mount cylinders so they are protected from rear end collision.
- Do not remove protective valve covers until just before use.

It is illegal to transport goods over public roads or highways if those goods are undergoing fumigation or have not been completely aerated.

Always follow federal and state department of transportation regulations when transporting fumigants and/or their containers.

Storage and Disposal of Fumigants

Storage of fumigants is hazardous. Whenever possible, buy them just before you need them to shorten the storage period. Store all fumigants on sturdy shelves in an area apart from feed or seed. A separate building that is well ventilated or has a mechanical exhaust system is best. Be sure that all fumigant storage areas are locked and posted as pesticide storages. Warning signs should indicate the presence of fumigants.

Fumigants can escape from faulty valves or damaged or corroded cans. Leaks can cause dangerous concentrations to build up in closed storerooms. Check valves and containers regularly for leaks. Before entering any storage area, run an exhaust fan to remove vapors that may have built up inside.

Do not risk contamination of water supplies. Dispose of all empty containers, residues and rinsates according to state waste management procedures. Keep all pesticides and their empty containers out of the reach of children.

Tolerance Levels

Fumigants should not change or impair treated material in any way. Nor should they leave any residues on raw agricultural products that could be hazardous during processing. The EPA has determined the amount of pesticide residue that may safely remain in or on agricultural products. This is called the "tolerance level." Be sure fumigant residues never exceed these levels by following labeling directions to the letter. Consult the labeling or the registrant for tolerance levels specific to the product(s) you use and commodity(ies) you treat. Tolerance levels come from the Code of Federal Regulations.

Proper Aeration

Proper aeration is important for your safety, the safety of your crew and the safety of your clients. Poor aeration is one of the most common problems associated with fumigation. Read and follow the instructions in the labeling exactly. When treating raw agricultural products, be sure the rate of air exchange during the aeration phase will adequately remove the fumigant. If necessary, use fans or other ventilation equipment. Also, check air temperatures. The treatment area should be warm enough to allow the fumigant to completely desorb from the treated agricultural product. Heat the area or increase the aeration time if necessary. Finally, check the sorptive capacity of the commodity you are treating. Highly sorptive materials require longer aeration periods. Adjust your aeration time as needed. See Chapters 5 and 8 for more information on aeration procedures.

Preparation and Planning

Preventing public and environmental exposure also relies on how well you prepare. How well have you sealed an area? Have you inspected all equipment thoroughly? Are you applying the fumigant at or below the label rate? Have you set aside enough time to completely aerate the site or item? Have you set up fences and posted warning signs to keep people, livestock and pets out of the treatment area? Details about proper application methods are described in Chapters 5 and 8. Use this information to develop a FMP. Review the FMP several times. (Chapter 9

contains a sample FMP.) Then use the checklists later in this chapter to be sure nothing has been overlooked. The Appendix contains safety checklists that you can copy and use.

Remember, you, the applicator, are the most important variable in fumigation. Your education and training will directly affect the safety and success of your operation.

Personal Safety

Safety is always a concern for you as a fumigant applicator. You must consider your own safety, as well as that of your coworkers, your clients and the people who will use the areas you treat.

> Human safety is addressed throughout the Nebraska Core Manual. Chapter 5 (Pesticide Hazards and First Aid) and Chapter 6 (Personal Protective Equipment) are devoted to human health and safety issues. Chapter 5 describes the signs and symptoms of pesticide injury or illness. It also tells you how to respond to a poisoning emergency. Chapter 6 discusses how to select, use and care for protective clothing and equipment. Review these sections of the Core Manual for basic pesticide safety information.

Besides taking the precautions outlined in the Nebraska Core Manual, you must also consider the specific risks associated with fumigants.

Always Work in Pairs

One of the most important things you can do to protect yourself during fumigation is to always work with another person when applying fumigants. This person can assist you immediately if you become injured or incapacitated while working around these products. In fact, many fumigant labels require fumigators to work in pairs during application or gas monitoring.

Routes of Exposure

As a fumigant applicator, you may be exposed to fumigants in several ways. Fumigants can enter your body through your lungs (inhalation), your eyes (ocular exposure), your mouth (ingestion) and even your skin (dermal exposure). The most dangerous and common type of fumigant exposure is inhalation. Most fumigants are highly toxic. Breathing even small amounts of some fumigants can cause serious illness or death. To protect yourself, read the labeling. Find out what personal protective equipment (PPE) the manufacturer requires. Then, learn what to do in case of exposure. See "First Aid for Fumigant Poisoning" later in this chapter for details about how to handle different types of fumigant exposure.

PPE

Personal protective equipment (PPE) is the name given to clothing and devices that minimize your exposure to pesticides. The labeling for each product lists the minimum PPE required for using that pesticide. Federal and state laws require pesticide users to follow all instructions on the product label, including wearing the appropriate PPE.

Respiratory protection is the most important piece of PPE for fumigators. When you are surrounded by toxic gas, respirators provide you with clean air to breathe or filter the contaminated air. There are several types of respirators. Each one has its pros and cons. Respirators must be "fit-tested" to each user to ensure that they are sized correctly and will work properly. Users must also pass the appropriate medical tests to ensure that they can wear and use a respirator safely. Read the labeling to determine which type of respirator you will need. If you have questions about respirators, contact your county Extension office. See Chapter 7 to learn more about the selection, use and maintenance of respirators.

Figure 6.3 Respiratory equipment

Fumigation also requires other types of PPE. These include protective clothing and gloves. Requirements vary with the fumigant. Read the labeling carefully to learn which items are required for the product(s) you plan to use.

To protect your skin, some fumigants recommend that you wear loose-fitting clothes, long-sleeved shirts, long pants and socks. Other products say nothing about clothing.

The need for gloves also varies. For example, some solid fumigants require fumigators to wear gloves because of possible skin irritation. Read the labeling to be sure you use the right kind of glove. Other fumigants, particularly liquid products, do not require gloves. Some may even prohibit you from wearing gloves.

Other Tools for Personal Safety

Because inhalation exposure poses the greatest risk during fumigation, several tools are available to reduce or prevent this type of exposure. These include:

- Warning gases
- Exposure limits
- Gas detectors

NOTE: The safe and effective use of gas detectors is covered in Chapter 7.

Warning Gasses

It may be helpful to add warning chemicals to certain odorless fumigants. Read the labeling to determine if you can add a warning gas. These products give off an odor that can help you detect the presence of harmful gas. However, you should never rely on warning gases alone. Keep the following facts in mind:

Figure 6.4 Some fumigants require you to wear gloves during fumigation. Others do not.

- Individuals vary in their ability to detect and quantify odors.
- Odors only indicate whether the fumigant is present. They do NOT tell you the concentration of the fumigant.
- You may suffer olfactory fatigue. Over time, you may lose the ability to smell a particular warning agent.

Warning gases serve a useful purpose, but they are not foolproof. Use them as one of many safety tools.

Exposure Limits

You can also reduce your risk of inhalation overexposure by monitoring fumigant concentrations during treatment and aeration. Be sure your exposure stays below established exposure limits.

An exposure limit is the highest level of fumigant that you may be exposed to without being required to use any controls to reduce your exposure. The American Conference of Governmental Industrial Hygienists (ACGIH), OSHA and the National Institute of Safety and Health (NIOSH) are all agencies that establish these limits. Each agency uses different terms to refer to long-and short-term exposure limits. Refer to the fumigant label information to find out what the different exposure limits are for each product you use.

The three most common terms used to express the exposure limit of a fumigant are the:

- Threshold limit value-time weighted average (TLV-TWA)
- Threshold limit value-short term exposure limit (TLV-STEL)
- The permissible exposure limit (PEL)

TLV-TWA or "TWA" is an ACGIH term that refers to the average concentration of a fumigant to which most workers may be repeatedly exposed 8 hours a day, 40 hours a week without adverse effects. Concentrations at or below the TWA represent conditions that you may be exposed to on a daily basis. These levels are considered safe. Concentrations above the TWA may lead to "overexposure" to a fumigant. This can cause discomfort, sickness or even death. These levels are considered unsafe. The TWA is usually expressed in parts per million (ppm) or milligrams per cubic meter (mg/m^3).

By monitoring fumigant levels throughout treatment and keeping your exposure level below the TWA, you can prevent injury and illness caused by overexposure. However, people's susceptibility and response to fumigants varies widely. For example, a small number of workers may experience discomfort or minor irritation from fumigant concentrations at or below the TWA. Others may suffer more serious health effects – even death – due to a preexisting condition. Even when the TWA is low, observe your self and your coworkers for any signs or symptoms of exposure.

For short-term exposure, look for the TLV-STEL on the product label. Like the TLV TWA, this ACGIH term is often shortened to "STEL." Specifically, STEL is the concentration of fumigant to which most workers can be exposed continuously for a short period without suffering from:

- Irritation
- Chronic or irreversible tissue damage
- Narcosis (drunkenness) that may increase the chance of accident or injury

Exposure to concentrations at the STEL should not be longer than 15 minutes and should not occur more than four times per day. The STEL is expressed in ppm or mg/m^3.

PEL (Permissible Exposure Limit) is an OSHA standard that designates the maximum exposure permitted as an 8-hour TWA. OSHA sets PELs to protect workers against the health effects of exposure to fumigants.

Usually, OSHA PELs are not as conservative as are ACGIH TLVs. With this in mind, it is always wise to comply with the most stringent exposure limit. This will ensure the highest degree of safety and health. In the absence of any exposure limits, you should always strive to minimize your exposure.

Safety Checklists

Keep safety foremost in your mind when planning any fumigation operation. Focus on protecting lives and preventing fires. Plan ahead, especially when working in a remote location. Know how to get help if something goes wrong.

The following checklists will help you organize the many aspects of fumigation. Printable versions of these checklists can be found in the Appendix.

This information is general. It does not apply to all fumigants in all situations. Always read the labeling first. Become familiar with the dangers of the product(s) you intend to use. Some manufacturers provide checklists specific to their products. Use these lists as well.

Safety Checklists – Raw Agricultural Commodity and Stored Product Fumigation

Preliminary Planning

- Draw or locate a sketch of the structure you plan to fumigate. Indicate the layout of the structure, connecting structures and escape routes above and below ground.
- Seal all spouts, conveyors, conduits, heating ducts, pipes, cracks, crevices, broken windows and other possible openings leading from the areas that you plan to treat.
- Record the number and names of everyone who routinely enters the area. Note the proximity of other nearby people and animals. Keep children, unauthorized persons and pets away from the application site.
- If you plan to treat a commodity, learn about it. Find out its mode of storage and its condition. If possible, get a previous treatment history.
- If you plan to treat a commodity within a structure, learn about the structure. What does it consist of: wood, brick, concrete? Note the locations of doors, windows and dividing walls. Check airflow patterns.
- Study the pest(s) you plan to control. When is it most vulnerable to fumigants? Where are its numbers the highest?
- Check and adjust all safety and application equipment. Be sure the components can withstand the corrosiveness of the fumigant(s). When applying compressed gas, use pressure-approved components. Seal them tightly.
- Locate connections and shut-offs for electricity, water and gas. Test these shutoffs to be sure they are working. Find the nearest telephone or communication device.
- Obtain and have handy telephone numbers for local health, fire, police and medical emergency services. Know how to contact the parties responsible for the structure and/or commodity you plan to fumigate.
- ONLY select a fumigant registered by the EPA and NDA.

- Read and reread the labeling. Study the directions and precautions. Make sure the fumigant is labeled for the required work (site, commodity, etc.).
- Notify the local health and fire departments, police and security personnel and hospital. Give them the following information: the location, the chemical name(s), the date and time of application, the type of respirator and other safety equipment required, the fire hazard rating and literature about the safety measures you plan to use.
- Inform the occupants of the structure where treatment will occur. Also, notify the occupants of neighboring structures.
- Arrange for standby equipment and replacement parts for application equipment and PPE. Outline an alternate plan of action.
- Review your treatment plan with all workers. Explain the potential hazards to life and property. Identify the safety measures and emergency procedures that are required by the labeling.
- Prepare warning signs to post near treated areas. Arrange for someone to monitor all entrances and exits during treatment.
- Have first aid equipment (including antidotes and plenty of fresh water) handy.
- If possible, plan for application from outside the structure.
- When necessary, obtain fans to evenly distribute the fumigant.
- Preplan how you will aerate the area after treatment.
- Identify areas where you can store any excess fumigant(s). Be sure conditions in the storage area match those required by the labeling.
- Make sure no open fires, motors or hot surfaces (heat pipes or electric fixtures) are within the space that you plan to treat.
- Know how to operate the gas detection devices.
- Have on hand all the PPE you would need to enter a treated area in an emergency. Check to be sure that this equipment is working properly.

Pre-Application Safety

- Open all doors, cabinets, and drawers inside the area you plan to treat.
- Turn off pilot lights and gas lights. Disconnect electrical equipment.
- Make a final check. Be sure all occupants, pets and livestock have been removed from the structure.
- Place warning signs at all entrances and exits.
- Assign someone to observe all entrances and exits.

During Application Safety

- Apply all fumigants according to the directions in the labeling.
- Apply the fumigant from outside where appropriate.
- Consider the weather. You may need to delay or cancel outdoor treatments on windy or stormy days.
- Do not enter the area where fumigant gas is being discharged, except in extreme emergencies.

Post-Application Safety

- Aerate according to structural limitations.
- Turn on ventilation fans where appropriate.
- Before reentering a treated area, use a suitable gas detector to determine the fumigant concentration. Some fumigants do not provide an adequate odor warning. Others aerate slowly.
- Remove warning signs only when aeration is complete.
- Dispose of or return empty containers per the manufacturer's instructions.
- When using metal phosphide fumigants, return any unused, solid chemicals to clearly labeled containers. Store them properly.

Personnel Safety

To protect yourself and others, be sure you and your supervisor(s) always:

- Know the location of all entrances and exits.
- Know the location of all fumigant containers and aerating fans.
- Rehearse the fumigation plan so that each worker knows what to do.
- Remove all rings, jewelry and watches as required by the label.
- Have current health records for all employees. All workers that take part in fumigations must have a physical exam at least once a year. During fumigation, no worker should have a cold or other condition that may impair breathing. Nor should any worker be undergoing medical or dental treatment, unless a physician certifies that they may work with fumigants.
- Survey workers to make sure they have abstained

from alcoholic beverages 24 hours before and will abstain 24 hours after a fumigation job.
- Instruct all workers about first aid, emergency procedures, antidotes and decontamination.
- Work in pairs, especially when entry into a fumigated area is necessary. Stay in sight of one another while inside a treatment area.
- Report any accidents to your employer or supervisor.
- Report any signs of illness or discomfort, regardless of how minor they may seem. This includes dizziness, diarrhea, nausea, headaches and lack of coordination.
- Teach all workers how to select, operate and maintain protection devices. Warn them about the hazards that they may encounter if the chemicals are misused.
- Have and use the necessary PPE. Inspect all PPE for defects. Know where emergency equipment is located.
- Make sure there is enough water on site to wash or flush skin and eyes if an accident should occur.

Symptoms of Exposure to Fumigants

Most reactions to fumigant poisoning differ from those of exposure to other pesticides. For instance, many fumigant reactions simulate drunkenness. Symptoms of fumigant exposure can include:

- Slowed body movements
- Slurred/slowed speech
- Dizziness
- Numbness of hands or feet
- Coughing
- Sneezing
- Dryness/irritation of nose and throat
- Breathing difficulty
- Nausea
- Abdominal pain.

First Aid for Fumigant Poisoning

Even when you take all of the proper precautions, human exposure can still occur. Be prepared. Know what to do for all types of fumigant poisonings.

First, read the labeling. It is often your best source of first aid information. Additional first aid information appears on the product's MSDS.

First aid information listed within the labeling is usually specific to the product. Therefore, you must also be familiar with basic first aid procedures for fumigant exposure.

Basic First Aid

First aid is just that: it is your first response to fumigant exposure. First aid is not a substitute for medical help. To protect yourself and your coworkers, know when medical attention is needed and seek it right away.

How you respond to a fumigant poisoning depends, to some extent, on whether you or someone else is the victim. In either case, however, you must follow the same basic principles.

If you have been exposed to a fumigant or if you begin to feel ill, remain calm. Get to a doctor right away. Even when the fumigant is less toxic than others are, you may need medical attention, particularly if you were exposed to a large amount of the chemical.

Do not go alone. Have someone take you to the doctor. Be sure to give the label information to the doctor. Keep an extra copy of the label and MSDS on file for each fumigant that you use. You can take this information to the hospital in case of an emergency without risking container transport.

If you are with someone who has been exposed to a fumigant, begin first aid right away. When possible, get help. First, decontaminate the victim. Take him or her to fresh air. Remove any contaminated clothing. Be careful not to contaminate yourself in the process. If the victim needs medical attention, either call a doctor or take the victim directly to a doctor.

Before, during and after the fumigation process, watch for unusual behavior of yourself and others. It could be a sign of exposure. If you feel sick, do not stay to finish the job. Get to fresh air immediately and get help. If you are with someone who has been exposed to a fumigant, and if his or her breathing stops or is labored, give artificial respiration. Never give anything besides air by mouth to an unconscious person.

Specific first aid treatment varies according to the type of exposure. Learn all of the appropriate proce-

dures. You will not have time or the opportunity to look them up during an emergency.

The two main types of fumigant exposure are inhalation and skin contact.

Inhalation Exposure

The greatest risk during fumigation is inhalation exposure. Inhalation exposure occurs when someone breathes fumigant gas. Mild exposure by inhalation can cause a feeling of sickness, ringing in the ears, fatigue, nausea and tightness in the chest. Exposure to fresh air will usually relieve these symptoms. Moderate inhalation poisoning can cause weakness, vomiting, chest pain, diarrhea, difficulty breathing and pain just above the stomach. Symptoms of severe poisoning may occur within a few hours to several days after exposure. Severe poisoning may result in fluid in the lungs. This can lead to dizziness, blue or purple skin color, unconsciousness and even death.

Do not attempt to rescue someone in an enclosed area if you are not wearing the proper respiratory protection. If you are with someone who is suffering from inhalation exposure, carry him or her to fresh air immediately. Do not let the victim walk. Then do the following:

- Call for help – 911.
- Loosen all tight clothing.
- If breathing has stopped or is irregular, give artificial respiration.
- Keep the victim as quiet as possible.
- Prevent chilling by wrapping the victim in blankets. Take care not to overheat the victim.
- If the victim is convulsing, protect his or her head from striking the floor or wall.
- Watch for breathing irregularities that may require CPR. Keep the victim's chin up so that the air passage remains free. Do not put anything in the mouth of an unconscious person.
- Do not give alcohol in any form to the victim.
- Get medical attention right away. Take the victim to a doctor or emergency facility. Take the fumigant's label information with you.

Skin Exposure

Skin exposure occurs when a pesticide contacts the skin. Liquid and solid pesticides are most often the cause of this type of contamination. However, some fumigant gases can also injure the skin. Skin exposure usually occurs when clothing or jewelry holds the gas tight against the skin. This can cause skin to burn or blister. Fumigants may also be absorbed through the skin and pass into the bloodstream, causing systemic effects.

Blisters caused by fumigant exposure

To prevent skin exposure, most fumigant labels suggest that you remove all jewelry and wear loose-fitting clothes. Some labels prohibit the use of gloves. Always consult the label to determine what precautions you should take.

If skin exposure does occur, take the following steps:

- Get to fresh air.
- Remove contaminated items (clothing, jewelry, gloves, shoes, bandages, etc.) immediately.
- Drench the skin with water.
- Wash the skin, hair and fingernails with soap and water.
- Rinse thoroughly and wash again.
- Dry and wrap the affected skin in a blanket.
- If exposure causes a burn, cover the area loosely with a clean, soft cloth. Avoid using ointments, powders and other medications.
- Do not wear contaminated clothes again until you wash them and air them out for several days.

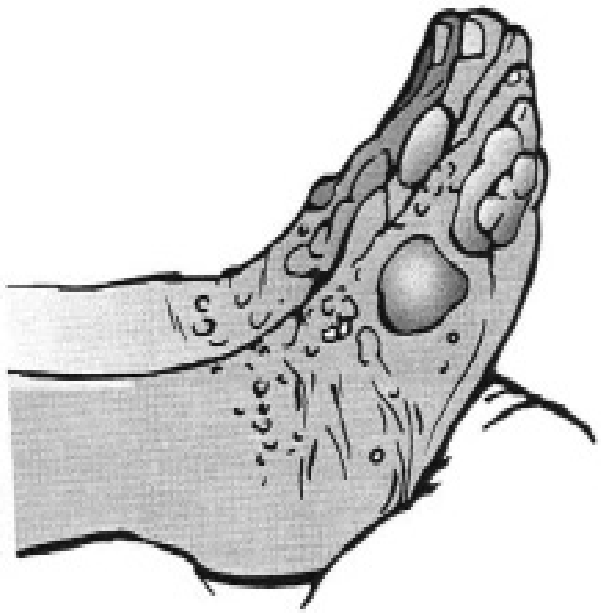


Figure 6.5 Blisters caused by fumigant exposure

You can never entirely eliminate the risks associated with fumigation. However, if you take precautions, you can significantly reduce them. Take steps to protect the public, yourself and your coworkers. Use the checklists from this manual. Read the labeling. Learn about the specific risks of each product you use. Find out what PPE your product requires. Chapter 7 will teach you how to select, use and maintain respiratory and gas detection equipment.

Safety Equipment

Learning Objectives

After studying this chapter, you should be able to:

- Identify the importance of a formal respiratory protection program and what it should include.
- Describe the two main types of air supplying respirators and how they work.
- Describe how air-purifying respirators work.
- Explain the factors that influence how long a canister will last.
- State the general rules for canister use.
- Describe the proper care for a respirator.
- Explain how to test and fit a respirator.
- Describe multiple procedures to follow before each use of your respirator.
- Identify four procedures to follow after using your respirator.
- Describe five types of gas detectors and how to operate them.
- List four examples of other detection devices.

Fumigants are some of the most toxic pesticides available. Even moderate exposure can be lethal to you and others. Proper use of safety equipment is critical.

This chapter describes some of the basic safety equipment used in commodity fumigation. By reading it, you will learn how these devices work and how to use them properly. If safety equipment fails, consequences can be deadly. This chapter will help you prevent these failures by properly selecting and maintaining equipment.

Terms to Know

Air-Purifying Respirator – A device that uses special filter media to remove toxic vapors, gases and particles from the air. The filter media come in the form of cartridges, canisters or pre-filters. These fit on a facepiece and are specific for one type of chemical (for example, organic vapors). Air-purifying respirators are also called gas mask/canister combinations.

Ambient Air Analyzer – A gas detection device that measures the amount of infrared light absorbed by a gas at a selected wavelength. This tells you what gas is present and its concentration.

Air-Supplying Respirator – A device that draws air from outside a fumigation area or uses cylinders of pressurized air to supply a worker with breathable air.

Calibrate – To measure and adjust a gas detector so that it reads accurately for the fumigant you use.

Facepiece – The part of a respirator that fits over your nose, mouth, face and/or entire head.

Fumiscope® – A type of thermal conductivity analyzer that measures the concentration of specific fumigants. It is lightweight, portable and operates on 115 volt alternating current (AC) or battery power.

Neutralize – To counteract the effect of a harmful substance such as a pesticide.

Parts Per Million (PPM) – The number of parts of a substance in one million parts of another substance. For example, if a gas detector reads "5 ppm," it means that there are five parts of fumigant to every one million parts of air.

Respirator – A device that protects the respiratory tract from irritating and poisonous gases, fumes, smokes and dusts.

Self-Contained Breathing Apparatus (SCBA) – A type of air-supplying respirator that supplies fresh air from a cylinder that is carried by the user. Air enters a mask that tightly covers the entire face.

Supplied-Air Respirator (SAR) – A type of air-sup-

plying respirator that supplies air from a compressed air tank that is located outside of the fumigation area.

Thermal Conductivity Analyzer (TCA) – An instrument designed to measure the concentration of fumigant gases within a chamber or other enclosure during fumigation.

Respiratory Protection Equipment

A respirator is as important to a fumigator as a parachute is to a paratrooper. Both are critical to on-the-job safety. If either device is not regularly inspected, maintained and used correctly, results could be deadly. Remember that fumigants are some of the most toxic pesticides. Breathing even small amounts of these chemicals can be fatal.

Training is crucial for the safe and effective use of respirators. To use respirators during fumigation, you or your employer must establish 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 include written operating procedures for the maintenance, cleaning and storage of the respiratory equipment. This program must also contain guidelines for educating respirator users. The information in this manual is not a substitute for the OSHA requirement.

There are two main types of respirators used in fumigation: air-supplying respirators and air-purifying respirators.

All respirators used by fumigant applicators must be approved by NIOSH (National Institute of Safety and Health). The specific type of respirator required may vary depending on the health of the applicator, the type of fumigant you use and the conditions of its use.

Air-Supplying Respirators

Air-supplying respirators draw air from outside a fumigation area or use canisters of pressurized air to supply a worker with breathable air.

Fumigators use two main types of air-supplying respirators: the self-contained breathing apparatus (SCBA) and the supplied-air respirator (SAR). Training is critical for the use of any SCBA or SAR.

Self-Contained Breathing Apparatus (SCBA)

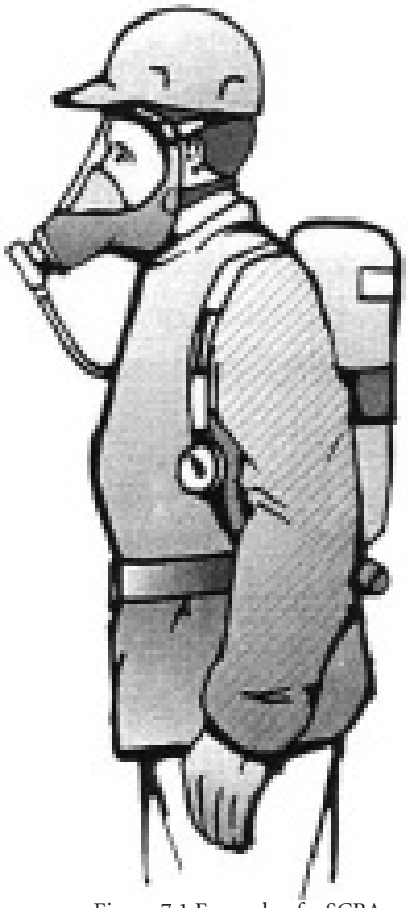


Figure 7.1 Example of a SCBA

An SCBA consists of a full-face mask attached to a tank of air carried on the back of the worker. The cylinder of compressed air supplies air to a regulator. The regulator reduces the pressure and delivers breathable air to the facepiece. SCBAs also have an alarm to warn the user when the air supply is low. Because you carry your air, you do not need to be connected to a stationary source of air. This gives you the mobility of a canister mask (described later in this chapter) and does not restrict movement. However, the weight and bulk of an SCBA often makes strenuous work difficult.

Do not confuse SCBA with SCUBA (self contained underwater breathing apparatus). These systems are very different. You cannot interchange their uses.

There are two types of SCBA respirators: a demand regulator and a positive pressure regulator.

Demand Regulator

A demand or negative pressure regulator supplies air to the facepiece when the wearer inhales. This creates a vacuum. Facepieces must fit snugly or contaminated air may leak in.

Positive Pressure Regulator

A positive pressure regulator allows continuous airflow into the facepiece. The constant positive

pressure in the facepiece forces any leaks out of the facepiece.

Supplied-Air Respirators (SAR)

Like SCBAs, supplied-air respirators are equipped with a full-face mask that delivers air to the fumigator from a compressed air tank or from an ambient air pump. With supplied-air respirators, however, the air tank or pump is located outside the fumigation area.

The most common supplied-air respirator by fumigators is the "airline respirator." Airline respirators supply compressed air from a stationary source through a long hose. Airline respirators have demand, pressure demand or continuous-flow designs. Air is supplied to a facepiece, helmet, hood or a complete suit depending on the level of protection needed.

The demand or pressure-demand airline respirator operates much like a demand SCBA respirator The difference is that an airline system supplies air through a hose connected to a stationary air source, whereas the fumigator carries the SCBA air supply.

Figure 7.2 Supplied-Air Respirators

Continuous-flow airline respirators provide breathing air continuously rather than on demand. These are much like the positive pressure SCBA respirators. Instead of a regulator, however, these respirators have an airflow valve that partially controls the airflow. In addition, air is supplied by a stationary source, whereas SCBA air tanks are portable.

There are several advantages to airline respirators. Unlike SCBA respirators, airline respirators provide long, continuous use. They are lightweight and offer minimal breathing resistance and discomfort. Airline respirators also have a moderate initial cost and a low operating cost.

Unfortunately, there are drawbacks to airline respirators as well For example, if something cuts, burns, kinks or crushes the hose, the wearer has no air. Also, compressors may fail or the storage tank may become empty. For these situations, there are airline respirators with auxiliary air supplies. Airline respirators can also restrict movement. Because the wearer is attached to a long hose (200 feet maximum) there are limits to how far and in what direction he or she can move.

Air-Purifying Respirators

Air-purifying respirators combine a tight or loose-fitting facepiece with a specific filter media. When you breathe in, you draw air from outside the respirator, through filter media and into the mask. The filter media absorb impurities as the air passes through. Air-purifying respirators are also called "gas mask/canister combinations."

The three most common types of filter media used with air-purifying respirators are canisters, cartridges or prefilters. For simplicity, we will refer to all three types of filters as "canisters" for the remainder of this manual.

Many air-purifying respirators have tight-fitting full facepieces. These are similar to the facepieces used for SCBAs and SARs. However, the valves and gaskets for facepieces used with atmosphere-supplying respirators are very different than those used for air-purifying respirators. Do not use them interchangeably. You can also use half-mask air-purifying respirators in some fumigation situations.

Another option is the "powered air-purifying respirator." Some powered air-purifying respirators

Figure 7.3 Gas mask/canister combination respirator

do not include a gas mask at all. Instead, they use a small electrical motor to pull air through a pre-filter and cartridge. The motor then moves the filtered air through a hose to a helmet where the air blows down over the face of the wearer.

Gas mask/canister combinations are approved only for specific fumigants. There are many different types of canisters. Each one is color coded with stripes. The stripes indicate limitations and approved uses for quick and easy recognition. For example, a gray stripe around the top of a canister indicates the presence of a filter that removes dust and other particles. Other color combinations identify canisters for specific fumigants.

Before using any air-purifying respirator, make sure you have been fit-tested and approved by a licensed health care professional. In addition, be sure that all parts and replacement parts meet manufacturer specifications.

How long a canister will last depends on several things:

- The type of canister
- The size of the canister
- The type and concentration of gas in the surrounding air
- The length of exposure
- The rate of breathing
- Whether there is more than one gas present
- The temperature and humidity at the time of use

Never use a canister after the expiration date. An expiration date is usually listed somewhere on the canister. OSHA requires you to develop a cartridge change-out schedule when the canister does not have an end of service life indicator (ESLI). This schedule must be specific to the treatment site, the type of fumigant you use, the concentration of the fumigant, the exposure time, the temperature and humidity in the treatment area and other factors.

General Rules on Canister Use

Discard any canister that has been used for more than 30 minutes (total time) in a fumigant atmosphere.

- Discard any canister whenever an odor of fumigant is detected as coming through. (The absorption material isn't working).
- Discard any canister used for less than 30 minutes if it's more than one year old.
- Discard canisters that have reached their expiration date or that have been manufactured more than two years earlier (even if unused), unless the instruction sheet specifically says otherwise.
- DO NOT use a canister-type gas mask to enter a recently fumigated or oxygen-deficient area.

How Air-Purifying Respirators Work

When properly assembled and fitted, air-purifying respirators protect against the gases or vapors listed on the canister label. Powered air-purifying respirators pull air through the canister, which then neutralizes or absorbs harmful gases and vapors. For other types of air-purifying respirators, inhalation by the wearer pulls air through the canister. The purified air then passes through corrugated rubber tubing into the molded channels of the facepiece. Some of these channels direct the purified air to the lenses to reduce fogging.

When you exhale, air is expelled from the facepiece through a valve designed to permit normal conversation. This valve also serves as a drain for moisture produced by breathing. An inhalation valve at the bottom of the canister prevents the exhaled air from passing out through the canister.

Always read the labeling to determine which type of respirator to use. Wearing the proper personal protective equipment (PPE) will protect you and your coworkers. It is also the law.

Care of Respiratory Protection Equipment

All applicators should have their own respirator and canister. Do not share your canisters with others. In fact, it is best if you do not reuse canisters at all. If you must reuse a canister, keep a written record of the date used, length of time used and gas concentration. Destroy or mutilate the tops of canisters that are no longer usable. Never reuse a canister if it has been used in an emergency.

Clean and disinfect your respirator after each use and at least once a month. To sanitize masks, prepare a solution of cleaner-sanitizer (available through your respiratory protection supplier) and warm water. Immerse the mask in this solution. Scrub the interior and exterior of the mask with a sponge. Rinse the mask with warm water and air dry. If you are not able to sanitize the mask immediately, wipe out the interior with a clean cloth. Use soap and warm water if possible.

During cleaning, inspect the mask. Look for any loose connections and rubber deterioration. Check the integrity of the facepiece seal. For air-purifying respirators, inspect the inhalation valves, exhalation valves and straps. Keep a record of all cleanings and inspections.

After cleaning and inspection, place the mask in its carrying case to protect it against dust, sunlight, heat, extreme cold, moisture or damaging chemicals.

If your respirator needs repairs, be sure to use parts designed specifically for that respirator and approved by the manufacturer. Only experienced persons should repair a respirator. Air-supplying respirators must be sent to the manufacturer for repair.

Fitting and Testing the Respirator

Respirators come in different sizes. Be sure yours is the right size for you. In addition, respirators must be fit-tested to their user. For a firm and comfortable fit of your facemask, adjust the headbands in this order:

1. Make sure the straps lie flat against your head.
2. Tighten the lower or neck straps.
3. Tighten the head cradle straps.
4. Place both hands on the headband or head cradle and position it on the crown of the head.
5. Repeat steps one and two.
6. Tighten the forehead or front strap a few notches.

The mask should feel comfortable, while forming a tight seal against your face. Facial hair will prevent a tight seal. Workers with beards and/or large mustaches must shave. OSHA requires that respirators fit properly and that you test their facepiece-to-face seal.

There are two types of "fit tests," qualitative and quantitative. Qualitative fit tests rely on subjective sensations – taste, irritation and smell – of the respirator wearer to a particular test agent. Quantitative tests use measuring instruments to measure face seal leakage. The type of test you should use depends on many things.

Once you find a respirator with a good fit, testing is not over. You must also check the respirator each time you wear it. Here are two quick field tests. These are called "user seal checks."

Negative Pressure Test

The negative pressure test allows you to check full-face and half-face tight-fitting respirators for proper fit before each use. First, pinch off the breathing tube or cover the inhalation valves with the palm of your hand. Then, inhale to create "negative pressure." The facepiece should collapse. Hold your breath for 10 seconds. A respirator with a tight seal will remain collapsed while you hold your breath. If it is leaking, check the cartridge connections, valves and straps and repeat the test.

Positive Pressure Test

The positive pressure test is usually included in the manufacturer instructions. First, place the palm of your hand or thumb over the exhalation valve. Then, exhale gently into the respirator, causing "positive pressure" inside the facepiece. If you do not feel any air leaking out of the facepiece, the respirator fits properly. If it is leaking, adjust the straps and test again. If the leak persists, inspect the respirator for problems. Check the hoses and connections to make sure they are tight and in good

condition. A new rubber washer for the mask hose is supplied with each new canister. This washer must be in place when attaching the hose to the canister. Otherwise, vapors can enter through the mask hose. Be sure to check for this washer. If the leak still exists, try installing a new corrugated breathing tube. If this takes care of the leak, destroy the defective breathing tube. If, after removing your hand from the canister inlet, you find you cannot breathe, the canister has a blockage. Destroy and replace the canister. If the respirator is an air-supply type, check the facepiece and breathing tube. If the respirator is an SCBA, check the air tank for amount of air, leaks and valve efficiency. For SARs, test the valves, connections and hoses.

Use of Respiratory Protection Equipment

No matter what type of fumigation you are performing, your respirator should be ready to use at all times. When it is not in use, have it on hand for emergencies. Keep the following list nearby. It will help you to inspect and use your mask properly.

- Monitor the air quality. If the air contains less than 19.5% oxygen, it is deficient. Use an air-supplying respirator and not a gas mask/canister combination. When in doubt, always use an air-supplying respirator.
- Before using any air-purifying respirator, make sure that all parts and replacement parts meet manufacturer specifications.
- If you use an air-purifying respirator, check the canister for an expiration date. If canisters are used more than once, be sure enough time remains. When in doubt, use a new canister.
- Select the proper canister for the fumigant you plan to use. The canister label will indicate for which fumigant(s) it is approved.
- If you use a new canister, install the new washer that comes with it. Remove the tape that covers the intake port on the bottom of the canister.
- Connect the mask and canister.
- Put the mask on while you are in fresh air.
- Check for proper fit and leaks.
- Check the time. Note when you should be out of the fumigated area.
- Enter the contaminated area slowly. Return to fresh air immediately if you notice irritating gases, odors or symptoms of distress.

After completing the job:

- Clean and inspect the respirator.
- Record the date of cleaning. If you plan to reuse the canister, record how long you used it. Also, note the fumigant and its concentration.
- If you used all of the canister's time, mutilate the top so that it cannot be reused and then discard it.
- Return the respirator to its carrying case and store it properly.

Gas Detection Equipment

Gas detectors monitor and record gas concentrations before, during and after treatment. They are a part of every fumigator's operational and safety equipment for treatments within enclosed spaces and structures.

You can use detectors to eliminate some of the common hazards associated with fumigation. Use them to:

- Indicate fumigant levels during treatment
- Detect excessive leaks in a building or poor tarp seals, and determine the dosage requirements for future fumigation

Detectors also measure the success of aeration by monitoring the presence or absence of fumigant vapors.

Be sure the accuracy and range of your detector is suitable for the fumigant you plan to use. Some detectors are more sensitive than others are. Calibrate your detector for each fumigant you use. Be sure you know how to read it.

There are several gas detectors from which to choose. The following are some of the most commonly used in fumigation.

Halide Gas Detectors

The halide gas detector indicates the presence and approximate concentration of halide gases – gases that contain any of five nonmetallic halogen elements: fluorine, chlorine, bromine, iodine and astatine. It is most commonly used to measure levels of methyl bromide. It reliably measures gas concentrations of 50 parts per million (ppm) or greater. Refer to labels and company information sheets that

provide more detailed use of these detectors. Halide detectors consist of:

- A fuel tank
- A valve assembly (to regulate fuel flow), a burner head assembly (where the fuel and air mix and unite)
- The reaction plate or cone assembly (where the visible flame reacts to halogen gases)

An attached search hose feeds the air mixture to the burner head assembly for testing. The fuels used include kerosene, alcohol, acetylene, and propane. These are available at refrigeration supply dealers.

To operate a halide detector, hold a lit match in the window opening of the burner tube. Turn the valve slowly to the left. After the copper plate or cone turns red, adjust the flame to the smallest size to maintain that color. The detector is now ready to test the air. Hold the open end of the search hose on, in or near the article or area to be tested. As air passes over the heated plate or cone, the flame color will change if a halogen gas is present. The color and intensity of the flame indicates the concentration of the gas. A color chart with corresponding gas concentrations comes with each detector.

If you use a halide detector at night, the flame will have a bluish cast. You must consider this when reading the results.

Unfortunately, no halide detectors are accurate for determining exactly how much gas is present. They will only give you an estimate.

Because halide detectors have an open flame, you must adhere to all safety precautions. 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. Always read the labeling to determine the flammability of the product you are using.

Halide detectors need little maintenance. The burner head orifice is very small. Prevent dust and other debris from clogging it. Occasionally, you will need to replace the reaction plate or cone.

The halide gas detector has been used for many years. It is an operational as well as a safety device. By detecting leaks, it can help you to reduce harmful gas levels outside the treatment area. This will increase the safety and efficacy of your operation. As a precaution, use a halide detector regularly in rooms that house fumigation chambers. This is particularly important when the building also contains offices or other work areas.

Do NOT use a halide detector to determine whether fumigant levels are safe for reentry. While the halide detector is useful for detecting low levels of halogenated fumigants, it should NOT be used to detect harmful concentrations of these fumigants. The reentry threshold concentrations for a number of fumigants are lower than the detection limit of the halide detector.

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® is one of the most common TCAs. It is primarily used to measure methyl bromide concentrations. The Fumiscope® is lightweight, portable and comes in a compact cabinet. It operates on 115 volt AC (alternating current) or battery power. In a Fumiscope®, electrical currents pass through a wire exposed to the sampled air. The temperature of the wire is affected by the composition of the air around it. The hotter the wire, the higher the fumigant concentration. The fumigant concentration is displayed on the Fumiscope® meter.

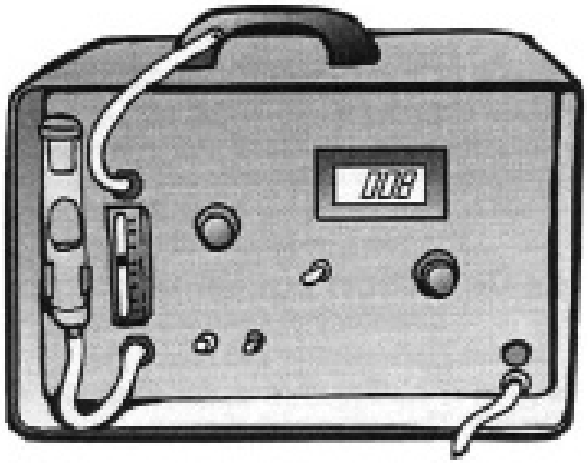


Figure 7.4 Fumiscope®

When using TCAs, keep in mind that most of them are sensitive to several gases, not just the one for which you are testing. For a true reading, you must eliminate other gases. For example, carbon dioxide (CO_2) may occasionally be a problem. If a prefumigation test indicates high levels of CO_2, place a tube of sorbing material such as sodium hydrate in the sampling line. It will absorb CO_2, allowing the TCA to give you a more accurate reading.

When you run long sample lines into the fumigated area, use a small pump to draw air from the test point to the end of the line. This speeds up the readings.

Like the halide detector, TCAs should NOT be used to determine whether fumigant levels are safe for reentry. They cannot measure gas concentrations below 5 ppm.

Glass Detector Tubes

Glass detector tubes or "color diffusion detector tubes" are another gas detection option. Unlike other detectors, glass tubes are disposable. You can only use them once. Glass detector tubes are often more sensitive and more specific than halide detectors and TCAs. They can detect specific fumigants at lower levels than other gas detectors. When measuring fumigant levels after fumigation, it's important to take readings from several locations. Often fumigants may become trapped in localized pockets. Different materials will also desorb at varying rates, a process called offgassing. This can allow toxic levels of the fumigant to occur in scattered locations.

Glass detector tubes are "fumigant specific." That means you will need to purchase a different set of tubes for each type of fumigant you use. Their operation is simple. Place one tube in the area you wish to test. Break the seal. Use a manual pump to draw a measured amount of air through the tube. Different pumps and tubes require a different number of pump strokes. Follow manufacturer recommendations. A color reaction will occur indicating the fumigant concentration. A color chart with corresponding concentrations is printed directly on the tube.

Detector tubes are available for many fumigant gases. Both high-range and low-range tubes are available for some fumigants. Use the high-range tubes to determine gas concentrations during fumigation. Use the low-range tubes to assure safe working conditions after aeration and before reentry.

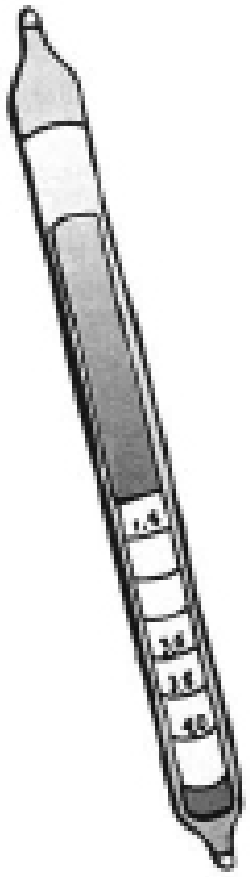


Figure 7.5 Glass detector tube

Ambient Air Analyzers

Some ambient air analyzers or "infrared detection systems" use infrared spectrophotometers to detect and measure gas concentrations. This is how they work. When infrared radiation strikes a gas, certain wavelengths of the radiation are absorbed. The spectrophotometer measures this absorption. The amount of radiation absorbed indicates 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.

Portable units weigh about 18 pounds. They are equipped with both AC and battery power. Each unit has two scales. The lower scale is accurate from

0 to 15 ppm. Use it to check fumigation sites before reentry. The upper scale functions as a leak detector during fumigation. It detects concentrations from 0 to 150 ppm.

Gas Analyzers

Gas analyzers detect leaks during fumigation. They also determine if a site is ready for reentry. Several models are available. The most popular are lightweight and battery powered. Most are designed to monitor concentrations of a particular gas. One model uses a pump to draw an air sample through a tiny furnace. Any fumigant present passes through a sensor that detects how much gas is present. Readings are given in ppm.

Other Detection Devices

Some more sophisticated detectors are now also available. These include infrared detectors, photoionization, flame ionization and electron capture devices.

Many of these devices provide different types of or more sensitive readings then other detection devices. Photoionization detectors, for example, can often detect gas concentration of sub parts per billion to 10,000 ppm.

Read the manufacture information to learn more details about each of these devices and what they can detect. Also read and follow the fumigant label to determine what gas detectors are best to use with that fumigant.

Other Protection Equipment

Whenever possible, provide two-way radio communication between workers applying fumigants and those outside. Also, keep on hand:

- An emergency air-supplying respirator, especially if canister-type respirators are being used
- A safety harness or rescue belt
- Basic first aid equipment

Common Fumigants

Learning Objectives

For each fumigant discussed in this chapter, you should be able to:

- Identify the four fumigant types and:
- Describe their formulations.
- Describe when and where each would be used.
- Describe what protective clothing and respiratory equipment is required.
- Describe basic application techniques.
- Identify precautions for using it.
- Describe proper aeration techniques.
- Identify which detection equipment best measures its concentration.
- Describe how to dispose of its residues and empty containers in a safe and legal manner.

This chapter discusses some of the most common fumigants used to treat raw agricultural commodities and stored products. By reading it, you will understand how each of these fumigants works and how to use it effectively. This chapter will explain basic application and aeration procedures. You will learn the risks each chemical poses. You will discover how to protect yourself and others from exposure. Selection and use of detection equipment is discussed. This chapter will also outline how to properly dispose of fumigant residues and empty fumigant containers.

Terms to Know

Aeration – *Grain storage*. The process of passing air through a stored product such as grain to regulate temperature and moisture content.

Bonnet – The cap that covers the valve and safety cap on a fumigant cylinder. The bonnet protects the valving system from damage and prevents accidental release of the fumigant.

Corrosive – Able to weaken or destroy something gradually.

Deactivate – To make something ineffective. For example, by deactivating fumigant residue, you would neutralize its toxic effects.

Exposure Period – The period of time after placement of fumigant during which the fumigant is allowed to diffuse through the material being treated in order to maximize "exposure" of the target pest(s) to the fumigant.

Formulation – The specific mixture of active ingredient(s), other additives, and a carrier in which a pesticide is offered for sale to the user. Examples include emulsifiable concentrations, pellets, etc.

Germination – The process by which a spore or seed begins to grow or sprout.

Inert – Having no chemical activity. Not reactive.

Liberate – To set free. To release.

Prepac – Aluminum phosphide fumigant tablets that are packed in a gas-permeable material.

Residue – Traces of fumigant that remain after treatment.

SCBA - Self-contained breathing apparatus.

Self-Contained Breathing Apparatus (SCBA) – A type of respirator that supplies fresh air from an outside or portable source. Air enters a mask that tightly covers the entire face.

Threshold Limit Value (TLV) – The maximum amount of fumigant that can be in the air before conditions are considered unsafe. The TLV is expressed in parts per million (ppm). It is used to monitor short-term exposure.

Threshold Limit Value-Time Weighted Average (TLV-TWA) – The average concentration of fumigant for a normal 8-hour workday and a 40-hour workweek to which workers may be repeatedly exposed without adverse effect. The TLV-TWA is expressed in parts per million (ppm). It is used to monitor long-term exposure.

Disclaimer

Just because a fumigant appears in this manual does not mean that it is legal to apply. Laws and regulations governing pesticides change often. Fumigants described here may no longer be legal. Always check current laws and regulations before using any fumigant for any purpose. For example, at the time of this writing, methyl bromide has been labeled an ozone-depleter. As a result, this widely used fumigant may soon be banned. Keep up-to-date on the state and federal laws and regulations that apply to you.

There are a limited number of fumigants on the market. Each has its own advantages, disadvantages, uses and limitations. This manual does not intend to indicate a preference toward any one fumigant. You must make your own choice based on the label information, the pest and the commodity that is infested. Also note that PPE requirements vary among fumigants. See the grey boxes for details about specific fumigants.

Phosphine

Aluminum Phosphide and Magnesium Phosphide

There are two main types of phospine fumigants: aluminum phosphide (such as PhosFume) and magnesium phosphide. These "metal phosphides" are formulated as solids that react with moisture in the air to produce hydrogen phosphide (phosphine gas). Phosphine also comes as a bottled product (phosphine dissolved in liquid carbon dioxide).

Phosphine gas is colorless and highly toxic to all stages of insect and animal life. It has a distinct garlic or carbide odor that is readily detectable at levels below worker protection limits (0.3 ppm). The odor is due to an impurity rather than the phosphine gas itself. However, odor is not a reliable indicator of the presence or absence of phosphine. This is especially true when phosphine has been in contact with a commodity for a considerable length of time.

Aluminum phosphide and magnesium phosphide at a glance (also called hydrogen phosphide and PH3):

Required clothing:

- Dry cotton gloves if you contact the pellets, tablets or dust

Respiratory protection:

- Respiratory protection is required if exposure is likely to exceed the 8-hour TWA of 0.3 ppm during application, or is above 0.3 ppm at any time after application is complete
- Concentrations less than 0.3 ppm: no respiratory protection required
- Concentrations 0.3 to 15 ppm: NIOSH-approved full-face chin gas mask and canister labeled for phosphine
- Concentrations 15.1 to 1,500 ppm: NIOSH-approved full-face chin gas mask and canister labeled for phosphine for escape only
- Concentrations greater than 15 ppm or when concentrations are unknown: NISOH-approved SCBA or supplied-air respirator

Uses:

- What: Raw agricultural commodities such as grains, nuts, seeds, and wool. Animal feeds and feed ingredients, processed foods and nonfood items
- Where: Boxcars, containers, ships and other transport vehicles, bins, silos, barges, under tarpaulins, in small sealable structures and enclosures, mills, food processing plants, and warehouses.

Formulations

Both aluminum phosphide and magnesium phosphide fumigants are available in a number of formulations. These include pellets, tablets, Prepacs, bags and plates. Since metal phosphide fumigants react readily with moisture, they must be packaged in gastight containers. Phosphine can also be applied from cylinders that contain phosphine in liquid carbon dioxide.

Most aluminum phosphide formulations yield about 1/3 of their weight in phosphine. Aluminum phosphide is available in 0.6-gram pellets and 1.0-gram tablets.

Magnesium phosphide comes as Prepacs and in polyethylene plates and strips.

Pellets: Pellets weigh 0.6 gram. They yield 1/3 (0.2 gram) of their weight in phosphine. They are available in resealable flasks.

Tablets: Each tablet weighs 3 grams and releases 1 gram of phosphine. Tablets are available in resealable flasks. Tablets are also used in Prepacs and Prepac Ropes.

Packaged Fumigants: Packaged fumigants are available in several forms. These include bags, Prepacs and plates. In all cases, the metal phosphide is encased in a gas-permeable material, which is overpacked in gastight containers. Bags that contain a powdered aluminum phosphide formulation are also available. Each bag will release 11 grams of phosphine. Many of these packaged fumigants are not resealable. Once opened, you must use the entire contents.

Uses

Use metal phosphides to treat raw agricultural commodities such as grains, nuts, and seeds. You can use metal phosphides to treat spaces and commodities. Commodities treated with phosphine include processed foods, nonfood items, animal feed and feed ingredients.

Aluminum phosphide is the main form used to treat raw agricultural commodities. Magnesium phosphide is more reactive than aluminum phosphide. It is preferred when rapid release is desired and when

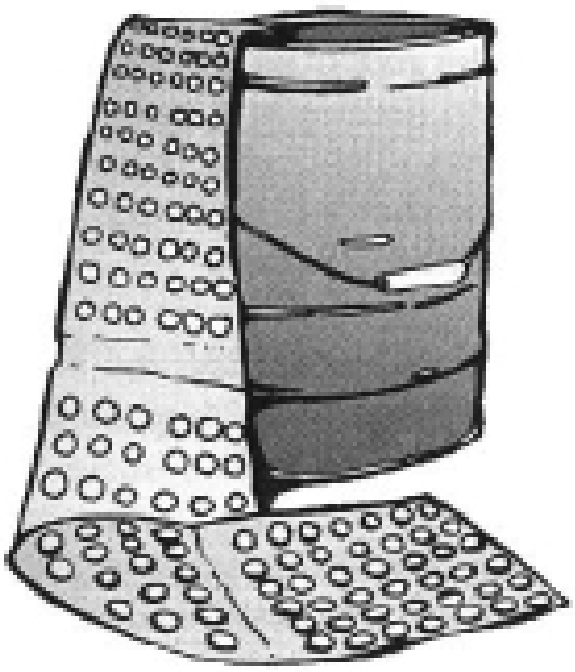


Figure 8.1 Phosphine Prepacs

treatment is performed at lower temperatures and humidities.

Aluminum phosphide for use in protecting bulk grain needs to be evenly distributed to provide adequate fumigant levels. Pellets should be inserted deeply within the grain mass, at least five feet, and no more than 50 pellets or 20 tablets should be inserted per probe. Applicators should also wear cotton gloves so that perspiration doesn't contact the pellets or tablets and start the release of phosphine gas. The applicator not using the probes should periodically monitor fumigant (hydrogen phosphide/phosphine) levels.

Application

One advantage of metal phosphide products is that they are easy to use. Start by calculating the cubic volume of the space you intend to treat. (See Chapter 5 for information on calculating volume.) Then, count out the required number of pellets, tablets, plates, Prepacs or bags. Place the pellets, tablets or bags onto a tray or sheet of cardboard. Slip the tray under the fumigation tarp or inside the fumigation chamber or structure. The moisture in the air will liberate phosphine in about one day, depending on the temperature and humidity.

To treat raw agricultural commodities such as grain, scatter phosphide tablets or pellets over the surface

of the grain. Spread the fumigant evenly over the surface. You can also use a probe to insert the tablets or pellets directly into the grain stream as the grain is moved into storage or as it is "turned" (recirculated).

Fumigation with phosphine takes time. Buildup of the fumigant is slow. It may take 12 to 48 hours to reach the desired concentration of gas. If the atmosphere or commodity is very dry, the process may take even longer. In areas where the relative humidity is low, you can increase the speed of gas liberation by placing a pan of water under the fumigation tarp. You can also spray water onto the floor or dirt. Be very careful. Do not to allow any water to contact the phosphine. An explosive mixture may result.

Normal exposure periods can take 3 to 5 days. If gas concentrations are lower than required after 72 hours, extend the fumigation period.
Magnesium phosphide releases phosphine faster than does aluminum phosphide. Therefore, you are more likely to need respiratory protection when applying magnesium phosphide.

Phosphine is not effective at temperatures below 40°F. Be sure to keep aluminum phosphide and magnesium phosphide products dry during storage. Since magnesium phosphide is more reactive than aluminum phosphide, it is usually recommended for fumigation in cool and/or dry conditions.

Pure phosphine is about 17 percent heavier than air. However, since it is given off slowly, it does not tend to stratify. Fans are not needed to ensure even distribution except when treating bulk commodities. Because of its low sorption and good penetration capacity, phosphine tends to leak from bins that are not gastight. Phosphine will go where the airflow goes.

Precautions

Phosphine is very toxic to humans. Even limited exposure can potentially harm human tissues such as the liver, heart, lungs, and central nervous system.

Always wear approved respiratory protection if the concentration of phosphine in the work area is likely to exceed an 8-hour TWA of 0.3 ppm. A gas mask/canister combination may be used at concentrations up to 15 ppm. Above this level, or when the concentration is unknown, you must wear an SCBA.

After the application, you must wear a respirator whenever the concentration of phosphine is unknown or exceeds 0.3 ppm. The TWA applies only during application. "Application" is the period covering the opening of the first container, applying the appropriate dosage of the fumigant and closing the site to be fumigated. At all other times, anyone exposed to fumigant concentrations exceeding 0.3 ppm must wear respiratory protection.

Always wear gloves when handling aluminum phosphide pellets, tablets, and the residue that remains after fumigation. Air out used gloves and other contaminated clothing in a well-ventilated area before washing them. Packaged metal phosphides such as bags and Prepacs do not require gloves.

Wash your hands thoroughly after handling phosphide materials.

Phosphine is extremely flammable. Never open metal phosphide containers near an open flame or in a flammable atmosphere. Fire or an explosion can occur if the phosphine concentration is too high. It is better to open containers outdoors or near a fan. Phosphine may also ignite spontaneously at concentrations above 18,000 ppm. If you conduct the fumigation properly, however, concentrations will not approach this level. Phosphine is also explosive under vacuum conditions. Never use it for vacuum fumigation. Finally, do not stack or pile phosphine pellets or tablets. This can create a fire hazard.

To reduce the risk of fire, some phosphine products contain ammonium carbamate in their formulation. This helps to produce a gaseous mixture that will not burn or explode at normal application rates.

Both aluminum phosphide and magnesium phosphide can react violently if they contact water.

Never allow aluminum or magnesium phosphide or their residues to directly contact any processed food. To prevent this, place phosphide pellets or tablets on a tray or use packaged phosphine such as Prepacs, bags or plates. Do not add metal phosphide directly to any processed food. Aerate foods and feeds that have been treated with phosphine for 48 hours before giving them to the consumer.

Phosphine gas, especially at high temperatures and humidities, will corrode silver, copper and copper alloys. Copper-containing equipment, such as com-

puters, telephones and other electrical devices, may be severely damaged. Protect or remove items that contain these metals during treatment.

Aeration

Areas treated with phosphine aerate quickly. To be safe, open all doors and windows first to assure good ventilation. Then, while wearing respiratory protection, open the fumigated space or remove seals from the edges of a tarp. Some aerations will be complete in one to two hours. Others will require much longer aeration periods. Take gas readings to be sure concentrations are .3 ppm or below.

Detection

Several reliable gas detectors are available to measure phosphine gas. Glass detector tubes used in conjunction with the appropriate and-operated air sampling pumps are widely used. These devices are portable, simple to use, do not require extensive training and are relatively rapid, inexpensive and accurate. Electronic devices are also available for both low level (~0.1 to 40 ppm) and high (~50 to 2,000 ppm) phosphine gas readings.

Disposal

Metal phosphide fumigants leave a white powdery residue. This residue contains a small amount of unreacted phosphide that may or may not need to be deactivated. The deactivation process differs somewhat for aluminum phosphide and magnesium phosphide.

If the fumigant residue is grayish green, the metal phosphide is only partially spent. Extend the fumigation period until the residue turns white, or use extreme care during the deactivation process.

To deactivate unreacted and partially reacted aluminum phosphide, prepare a deactivating solution. Fill a small to large container with water. Fifty-five-gallon drums work well for large amounts of aluminum phosphide. Add enough nonsudsing detergent to create a 2% solution. Fill the container to within a few inches of the top with the deactivating solution. Then, stir in the phosphide residue. Do not add more than about 45 to 50 pounds of phosphide to 15 gallons of water-detergent mixture.

To deactivate unreacted and partially reacted magnesium phosphide, no detergent is needed. Instead, fill a container to within a few inches of the top with water ONLY. Add the phosphide residue until it sinks to the bottom. Because unreacted or partially reacted magnesium phosphide reacts vigorously with water, be sure to add the residue slowly.

Always deactivate metal phosphide fumigants outdoors. Wear the appropriate respiratory equipment. Never place residue in enclosed containers. It could cause a fire hazard. After deactivating phosphide residues, dispose of the rinsate in a landfill or by other approved methods. Always check with local authorities for disposal regulations. Where permissible, bury the solid or spread it out on the ground.

Methyl Bromide

Methyl bromide is a colorless gas at standard temperatures and pressures. At normal concentrations, it is odorless, tasteless and has no irritating qualities to indicate its presence. However, at concentrations higher than those normally used in fumigation, methyl bromide has a sickly sweet odor. Methyl bromide is toxic to all stages of insect life, as well as to many microorganisms and weeds. It is usually stored under moderate pressures so that it can be handled as a liquefied gas.

Methyl bromide gas is 3.3 times heavier than air and tends to stratify, settling out in low places. In such cases, you will need fans to ensure thorough mixing of the gas with air. With fans, methyl bromide penetrates most commodities well.

Uses

Use methyl bromide to control pests in processed food or feed. There are established tolerances for methyl bromide residues on many commodities. Pure methyl bromide is not labeled for use in empty structures. It is strictly for the treatment of raw or processed commodities and some nonfood products. When mixed with chloropicrin, do not use methyl bromide on processed foods; in dairy, cheese or meat plants; or where there are living plants. Instead, apply these mixtures to treat empty grain bins and warehouses.

There are several materials that should not be exposed to methyl bromide. Some react with the gas and create long-lasting odor problems. Others may be damaged by the gas. Whenever possible or practical do not use methyl bromide to treat the following items:

- Iodized salt
- Full fat soya flour
- Items that may contain reactive sulfur compounds such as some soap powders, some baking sodas, and some salt blocks used for cattle licks
- Sponge rubber
- Foam rubber, as in rug padding, cushions, and mattresses
- Reclaimed rubber, such as rubber stamps
- Furs
- Horsehair
- Pillows (especially feather pillows)
- Leather goods (particularly white kid or any other leather goods tanned with sulfur processes)
- Woolens
- Viscose rayons (rayons produced or manufactured by a process that uses carbon bisulfide)
- Paper (especially silver polishing paper and writing paper cured by the sulfide process)
- Photographic materials used in darkrooms
- Cinder blocks

It is also important to remove all charcoal products before fumigating with methyl bromide. Charcoal can absorb methyl bromide, reducing its effectiveness.

You can also use methyl bromide to control pests in raw foods (including grains, fruits and vegetables), and animal feed. There are established tolerances for methyl bromide residues on many commodities.

Commodity Fumigation (formulations of 100 percent methyl bromide)

To treat raw products with methyl bromide, first seal the space in which the commodity is stored. Then release the fumigant in one of several ways depending on the location of the commodity. If the commodity is in a chamber or vault, introduce methyl bromide by:

- Releasing it in front of a blower or fan
- Passing it through a vaporizer
- Allowing it to evaporate from a shallow pan

Keep all controls outside the treatment chamber.

For vacuum fumigation, release methyl bromide through an appropriate heating unit. This will ensure vaporization of the product as it travels to the treatment chamber. When treating commodities in vehicles, containers and buildings use "shooting

Methyl bromide at a glance:

Required clothing:

- Loose-fitting or well-ventilated long-sleeved shirt and longs pants
- Shoes and socks
- Full-face shield or safety glasses with brow and temple shields when performing direct contact tasks
- – Do not wear goggles.
- – Do not wear jewelry.
- – Do not wear gloves, chemical protective clothing or rubber boots.
- – Do not wear contact lenses

Respiratory protection:

- Air concentrations less than 5 ppm: no respiratory protection required

Formulations

- For commodity fumigation, you can use formulations that contain 100 percent methyl bromide.
- Methyl bromide is available as a compressed liquid in 1 1/2-pound cans or in cylinders that contain from 50 to 1,500 pounds.
- Air concentrations greater than 5 ppm or when air concentrations are unknown: NIOSH-approved SCBA or combination supplied-air/SCBA respirator required

Uses:

- Where: Structures that contain commodities: warehouses, grain elevators and other buildings storing raw products. Chambers and vaults: vacuum chambers, tarpaulin fumigation, boxcars, trucks, vans, ships and trailers. Structures – warehouses, grain elevators, food processing plants, restaurants and other empty buildings.

NOTE: These apply where not restricted by other regulations.

lines" (polyethylene tubing or other compatible tubing) to introduce methyl bromide.

Methyl bromide works quickly. Exposure times of 24 hours or less are normal. Read the label to find out what the required exposure time is for your application.

Precautions

If the concentration of methyl bromide is unknown or exceeds 5 ppm, each person in the exposed area must wear an SCBA or combination supplied-air/SCBA respirator. When applying formulations that contain chloropicrin, you must wear an SCBA if the air concentration of chloropicrin is greater than 0.1 ppm. Regardless of the fumigant concentration, respiratory protection must be available at the treatment site in case it is needed.

If the cylinders are outdoors, you do not need to wear a respirator while introducing methyl bromide unless a leak develops and the air concentration of methyl bromide is greater than 5 ppm. Check the label for specific requirements. Always have an SCBA ready and available.

Never transport methyl bromide containers in the passenger section or trunk of a vehicle.

Do not wear jewelry, gloves, goggles, tight clothing, a chemical protective suit or rubber boots when using methyl bromide. The gas can be trapped inside your clothes and cause skin damage. If liquid methyl bromide splashes on your clothes, shoes or socks, remove them immediately. Place them outdoors until they aerate completely. Discard any absorbent items that have been drenched or heavily contaminated. Leather will absorb methyl bromide and may aerate slowly.

Do not use methyl bromide to control insects in/on a commodity when the temperature of the commodity or the space is less than 40°F. Heat the fumigant when temperatures are below 60°F.

Methyl bromide is not a fire hazard. In fact, it once was an ingredient in fire extinguishers. Still, you must extinguish all open flames and pilot lights before using methyl bromide. It produces corrosive acid when it reacts with moisture near a heat source. In addition, while methyl bromide does not corrode most metals, it can react with aluminum or magnesium in the absence of oxygen to form an explosive mixture. Therefore, never connect aluminum or magnesium tubing to a methyl bromide cylinder. Be sure neither metal is present during vacuum fumigation with methyl bromide.

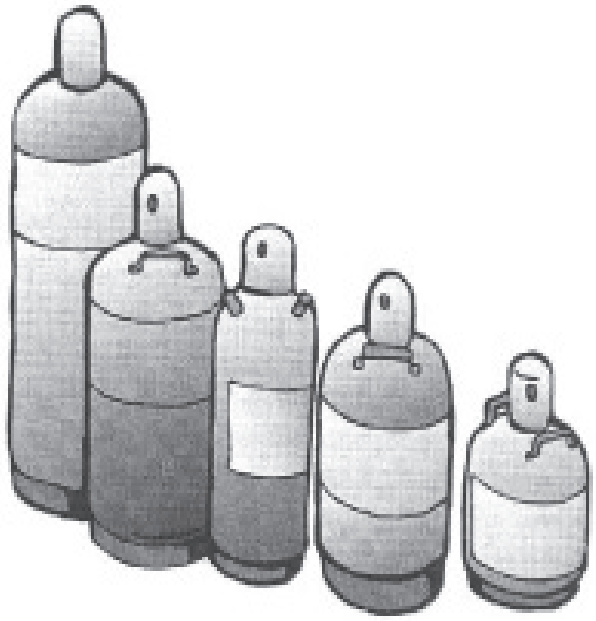


Figure 8.2 Cylinders of Methyl Bromide

Nebraska Department of Agriculture has indicated only three uses for methyl bromide are available:

- Application under critical use situations. Critical uses must meet the location limitations and critical conditions limitations spelled out in the Montreal Protocol. Refer to the table of approved critical uses in Appendix L of 40 CFR Part 82, Subpart A. Most of these uses are limited to food processing facilities with severe insect pest infestations or sensitive electronic equipment subject to corrosion.
- Use for quarantine and preshipment (QPS) for the rapid treatment of imports or exports to meet official quarantine or sanitary requirements in other countries.
- Other applications using methyl bromide produced before 2005 and stockpiled. Once the existing stocks of old product are used up, these "other uses" of methyl bromide will cease.

There are several materials that should not be exposed to methyl bromide. Some react with the gas and create long-lasting odor problems. Others may be damaged by the gas. Be sure to read the label information before treating any item with methyl bromide.

Aeration

To aerate fumigated commodities, open doors and windows and/or remove the tarp to allow air exchange. You may use fans to speed the exchange of air. During fumigation with methyl bromide, commodities may contain inorganic bromide residues. Aeration does not remove these compounds. After repeated treatments, residues may exceed legal tolerances. The Food and Drug Administration (FDA) may seize the product. If this occurs, the last fumigator may be held responsible. Always check past fumigation records before treating any product. Be sure your treatment will not increase residue levels past legal limits. For help, contact the fumigant manufacturer.

Detection

You can measure methyl bromide concentrations in air with halide gas detectors, color diffusion detector tubes and thermal conductivity analyzers (TCAs) such as the Fumiscope®. More sophisticated detection systems now include infrared, photoionization, flame ionization and electron capture detectors. Always consider the sensitivity of the detection device when making your selection. For example, the halide gas detector and Fumiscope® only provide an indication of methyl bromide presence. They do not indicate concentration. Use these devices to detect leaks. Halide detectors and TCAs do not read low enough to detect gas levels for reentry purposes. To check fumigant levels before reentry, use color diffusion detector tubes.

Always read the label information to be sure you select the appropriate detection device. Follow all detection device instructions.

Disposal

Dispose of methyl bromide containers according to label directions. Return empty or partial cylinders to the manufacturer. Cans are not returnable. Aerate empty cans in a well-ventilated, secure location for 12 hours before disposal. If local authorities allow, you may be able to recycle the cans. Otherwise, dispose of them according to local regulations.

Controlled Atmospheres (CAs)

Controlled atmospheres (CAs) are low-oxygen mixtures of relatively inert gases such as nitrogen (N_2) and carbon dioxide (CO_2). CAs have three major advantages over other fumigants.

1. CAs leave no harmful residues on the treated commodities.
2. If a CA leaks from a treatment area, it will be diluted by normal air and reach nontoxic levels quickly.
3. CAs do not change the end-use processes (for example, baking, brewing, germination, etc.) or biochemical properties (for example, taste, odor, etc.) of commodities.

As a result, CAs have fewer government regulations than do other fumigants.

Unfortunately, CAs also have several disadvantages. The biggest problem is cost. Fumigation with CAs is usually more expensive than with other fumigants. It may not be cost-effective in many situations. Other disadvantages with CAs include the long exposure times and high concentrations required for effective control of many stored product pests. CAs also become much less effective at lower temperatures. Sixty degrees Fahrenheit is the lower limit for adequate pest control. Although CAs are often thought of as nontoxic, low-oxygen atmospheres are very hazardous to humans. They can cause unconsciousness and death quickly. Even when diluted with oxygen, CO_2 has some toxicity, as evidenced by an Occupational Safety and Health Administration (OSHA) worker exposure limit of 10,000 ppm (1%) during an 8-hour TWA.

Because the atmospheric gas most commonly used as a fumigant is CO_2, this manual discusses only CO_2 fumigation.

Carbon Dioxide (CO_2)

CO_2 is a colorless, odorless and tasteless gas. It is about 1.5 heavier than air, and it is noncombustible. Although it is safer than other fumigants, a single breath of CO_2 in the high concentrations used for

fumigation can cause a person to faint or fall. The main advantage of CO_2 is that it leaves no toxic residues and no odors or flavors. CO_2 also does not affect the germination of seeds.

Formulations

CO_2 is commonly stored and transported as a liquid at 0°F and under a pressure of 300 psi. One pound of CO_2 produces 8.7 cubic feet of gas.

For most fumigants, you will need a large amount of CO_2. Bulk containers range from 4 to 50 tons. These amounts are usually delivered by tanker truck and transferred to an on-site receiver. The liquid CO_2 is then vaporized and passed as a gas through the stored commodity. The CO_2 supplier is usually involved in the delivery and vaporization of CO_2.

Uses

You can also use CO_2 to treat raw agricultural commodities in bins, storage bins, tanks and railroad cars if you are able to seal the structures tightly enough to contain the fumigant. At high concentrations, CO_2 triggers increased respiration in insects. This can cause dehydration and death. The most effective concentration of CO_2 is about 60 percent. Lower than 60 percent, CO_2 levels are less effective.

Concentrations higher than 60 percent provide little or no added benefit.

Carbon dioxide at a glance:

Required protective clothing:

- None

Respiratory protection:

- Entry into any CO_2-treated areas: NIOSH-approved supplied-air respirator or SCBA.

Uses:

- What: Raw agricultural commodities such as cereal grains.
- Where: Silos, trucks, trailers, bins, tanks and sealed railroad cars and ships.

Do not use CO_2 as a pesticide on fresh produce. Insecticidal concentrations are too high and may damage the produce.

CO_2 may also be useful for organic operations.

Application

There are two methods available for treating stored products with CO_2:

1. The top-down purge method.
2. The lift method.

The top-down purge method adds CO_2 at the top of a structure. The CO_2 displaces the air in the structure as it settles downward. The lift method adds CO_2 at the bottom of the structure. In this case, the CO_2 displaces the air in the structure as it moves upward.

The application method you choose will depend largely on the type of structure you intend to treat. Use the top-down purge method in concrete commodity elevators where you can place the injection hose in the top of a well-sealed tank. Bottom injection (the lift method) works best in stand-alone steel bins where major leaks occur at the top around eaves and hatches. In either application, you must vent the storage during the initial purge so that air pressure will allow the normal air to escape.

To determine when the purge is complete, measure CO_2 concentrations at the commodity surface or headspace (for the lift method) or at the base of the commodity mass or aeration floor (for the top-down purge method). When CO_2 levels reach 60 percent, seal the structure to prevent leaks and outside air from entering. Make additional injections of small amounts of CO_2 when concentrations within the commodity have dropped below 50 to 60 percent. Because CO_2 is heavier than air, it can settle into the bottom of the storage. You can use recirculation systems to improve the efficiency of CO_2 fumigation.

CO_2 application in commodity storages requires a pressure regulator to drop pressures from 300 psi in storage tanks to 10 to 40 psi at the injection hose. Use a flowmeter and globe valve to measure and set the flow of CO_2 to the desired rate, usually measured in pounds per hour. You will also need a vaporizer to speed the conversation of CO_2 from liquid to gas.

The effectiveness of CO_2 depends on several factors Principal among these are commodity temperature and the insect species you target. Adjust the duration of treatment accordingly. If commodity temperatures are less than 60°F, CO_2 fumigation is usually not effective because fumigation times become extremely long. As commodity temperatures increase, however, fumigation time drop. For example, when grain temperatures are near 80°F, most insects that live outside of the grain kernel will die if they are exposed to CO_2 for 4 to 5 days. Internally developing insects, such as weevils, require longer exposure periods of 10 to 14 days.

NOTE: While insect eggs are often resistant to chemical fumigants, they are more susceptible to CO_2 and other CAs.

Precautions

While CO_2 leaves no toxic residues in treated commodities, it is poisonous at high concentrations in enclosed spaces. The concentration of CO_2 in the atmosphere is about 0.03 percent. The threshold limit value (TLV) for CO_2 exposure is 1.0 percent. When concentrations of CO_2 reach 2 percent, human breathing rates increase by 50 percent above normal. At 5 percent CO_2, human breathing is three times more rapid than normal. Such levels can cause strain, fatigue and exhaustion. High concentrations of CO_2 not only reduce available oxygen, they also trigger additional respiratory stress.

Always monitor CO_2 concentrations when applicators enter a fumigated structure. Also check enclosed work areas adjacent to the structure.

Gas mask/canister respirators do not provide protection in high-CO_2, low-oxygen atmospheres. Although the canister may absorb the fumigant, it cannot supply the necessary oxygen. Only an SCBA or supplied-air respirator provides adequate protection.

As a rule, do not enter an area undergoing fumigation with CO_2 except under emergency conditions. Then, you must wear an SCBA or supplied-air respirator.

Aeration

Structures fumigated with CO_2 must be aerated before unprotected workers may enter. CO_2 is known to sorb into commodities and may desorb slowly. Read the label information for specific aeration instructions.

Detection

Check CO_2 concentrations throughout the treatment process. Monitor low concentrations of CO_2 to provide information for worker safety. Monitor high concentrations of CO_2 to determine the need for continued injection of CO_2 into the structure. Use vacuum pumps and tubing to draw gas samples during fumigation. Test these samples with gas detector tubes. Use separate tubes to detect low and high levels of CO_2. Thermal conductivity sensors capable of measuring a range of CO_2 concentrations are also available.

Disposal

Dispose of CO_2 containers according to the label information.

Common Fumigants

Sulfuryl Fluoride

Sulfuryl fluoride (example: ProFume®) is a colorless, odorless and tasteless toxic gas. It is heavier than air and tends to initially settle in low areas. It is nonflammable. However, heaters, pilot lights and open flames must be extinguished, as temperatures above 752°F will cause decomposition products to be formed which can be corrosive and can etch glass and metal. Refer to ProFume fumigation manuals and labels before usage and for any changes in use that may have occurred from the registration process. Sulfuryl fluoride is toxic to most living organisms including humans. In case of over exposure, get medical attention immediately.

Formulations

Sulfuryl fluoride comes in pressurized cylinders (containers). ProFume is a restricted use product. Cylinders are under pressure, 303 psi at 90°F, and must not be stored near heat or open flame. Exposure to temperatures above 158°F will cause a fusible plug to melt and the contents will be released. Always store and transport cylinders in a secure up-

right position. Cylinders of sulfuryl fluoride should be stored in a dry, cool, well-ventilated, secure and locked area. Post as pesticide storage area.

Uses

This fumigant is very effective against insect larvae and adults, but requires higher doses for insect eggs. Do not use for insect control when temperature at the site is below 40°F.

ProFume Uses

- What – For control of insects pests for the commodities listed on label, such as confused flour beetle, red flour beetle, sawtoothed grain beetle, warehouse beetle, Indianmeal moth, Mediterranean flour moth, granary weevil, rice weevil and other moths and beetles. The area around the fumigation must be monitored using a detection device such as INTERSCAN gas analyzer or MIRAN vapor analyzer to ensure that workers without respiratory protection are not exposed to concentrations of sulfuryl fluoride exceeding 1 ppm.
- Where – Non-residential structures (for the food commodities listed on the label) such as mills, warehouses, stationary transportation vehicles (railcars, trucks, etc., excluding air craft and passenger railcars), temporary and permanent fumigation chambers and storage structures. For use in food-processing establishments containing only those commodities listed on the label. Not for use in other food-handling establishments.
- Do not use ProFume without the Fumiguide Program for ProFume Gas Fumigant. The ProFume Fumiguide is part of labeling for ProFume and must be used to calculate the dosage. Never allow untrained individuals to apply ProFume gas fumigant.
- Read product label for any usage changes and further definition of uses or prior to fumigation.

Application

Sulfuryl fluoride does not adversely react with other compounds. However, all flames, must be extinguished. All electrical heating elements must be turned off or unplugged.

Sulfuryl fluoride at a glance:

Required protective clothing:

- Use splash-resistant goggles or full-face shields when handling the liquid, such as opening the cylinder to introduce gas into a structure. Liquid sulfuryl fluoride can freeze the eye tissue.
- Wear loose-fitting or well-ventilated long sleeve shirt, long pants, shoes and socks.
- Do not wear gloves.
- Do not wear rubber boots.

Respiratory protection:

- For ProFume use in commodities, concentrations of 1 ppm or less require no respiratory protection. Concentrations above 1 ppm require NIOSH/MSHA approved SCBA or combination air-supplied respirator/SCBA. If (emergency) re-entry into a structure under fumigation, prior to complete aeration, with sulfuryl fluoride is required, the proper respiratory protection (SCBA) must be used.

Introduce sulfuryl fluoride from the outside through tubes. The tubing should have a minimum burst pressure of 500 pounds per square inch (PSI). Place fans throughout the fumigation area. Run the fans during introduction and for at least 60 minutes afterward. For ProFume, Dow recommends leaving the fans running for the duration of the fumigation. Fans aid in the introduction, distribution and the aeration process for sulfuryl fluoride. Fans will circulate the gas ensuring good distribution. If desired, use a remote shutoff such as a timer to turn off the fans.

Do not use sulfuryl fluoride at temperatures below 40°F. To prevent damage, do not apply sulfuryl fluoride directly to any surface.

Precautions

If the concentration of sulfuryl fluoride is unknown or exceeds 1 ppm for ProFume, all persons in the exposed area must wear a self-contained breathing

apparatus (SCBA) or a combination air-supplied/ SCBA respirator.

Always wear (safety) splash resistant goggles or a face shield while releasing sulfuryl fluoride. However, you should not wear rubber boots or gloves when introducing sulfuryl fluoride. These may trap the liquid against your skin and cause injury.

In transit fumigation, including aeration, of any vehicle is prohibited on public roads or waterways.

Product labels require that the structure be posted with specific warning signs on all entrances and all sides during the exposure and aeration period until the building is cleared for reentry by the fumigator.

Aeration

Aeration is rapid. Sulfuryl fluoride desorbs quickly. Follow the aeration procedures in the label information to determine your aeration time.

Detection

Use the Fumiscope® to monitor sulfuryl fluoride levels during application. The Fumiscope® can detect sulfuryl fluoride at levels greater than 240 ppm.

When measuring gas concentrations for reentry, however, you will need to use a different type of gas detector. Only approved detection devices of sufficient sensitivity, such as specific types of gas analyzers or infrared detection systems (ambient air analyzers), can be used to confirm a concentration of sulfuryl fluoride of 1 ppm or less. At the time of this writing, the sulfuryl fluoride product label requires the use of an INTERSCAN or MIRAN analyzer, or similar approved device to measure gas concentrations for reentry.

Disposal

When a sulfuryl fluoride cylinder is empty, close the valve, screw the safety cap onto the valve outlet and replace the protection bonnet. Return the empty cylinder promptly to the distributor. Do not use the cylinder for any other purpose.

As with any Restricted Use Pesticide, carefully read and follow all label instructions. When using Pro-Fume Gas Fumigant, the fumigator must also read and follow the ProFume Gas Fumigant Fumigation Manual as it is part of the label. All persons desiring to use sulfuryl fluoride as Profume must comply with Dow AgroSciences product stewardship policies.

Use Common Sense

It's essential that fumigators understand and follow the technical instructions that promote safe and effective fumigation of stored grain. It's just as important that fumigators remember to use good common sense when using fumigants and planning and carrying out a fumigation. Although it may be impossible to "teach" good common sense by writing instructions in study materials, the following comments are offered as reminders to exercise good judgment and to think ahead.

- Read and understand the labeling. Demand information from the manufacturer and distributor. Do not use a fumigant without adequate training and confidence in your ability to do the job properly.
- Supply local medical personnel with fumigant and poison treatment information before using the fumigant.
- Plan the entire job. Think through every step, and plan your reactions to possible problems and emergencies. Record this plan, incorporating the elements required for a Fumigation Management Plan, when needed.
- Always work in pairs.
- Use, or have available, proper safety equipment. Make sure all equipment fits well and that all applicators are trained in and familiar with the use of necessary safety equipment.
- Do not take shortcuts; follow through with well- planned and thorough application practices.
- Do not become complacent. Each job is a new challenge and a new situation in which an emergency may require rapid and proper reaction.

Pesticide Laws and Regulations

Learning Objectives:

After studying this chapter you should be able to:

- Identify the characteristics of fumigants that make them RUPs.
- Identify an example of how Nebraska's Pesticide Act is stricter than the federal label.
- Identify who is responsible to follow label directions.
- Detail the requirements for keeping records of fumigant use.
- Explain the purpose of a written Fumigation Management Plan.

Terms to Know

60-Day Rule: A provision in the Nebraska Pesticide Act that allows a person who needs to be certified a once-in-a-lifetime 60-day exemption from licensing. The uncertified person must work under a licensed applicator during this period and turn in an application to the Nebraska Department of Agriculture within 10 days of the first pesticide use which requires an applicators license.

Fumigation Management Plan (FMP): A written document that outlines procedures for performing a fumigation. FMP's must be completed prior to conducting the fumigation.

Mandatory Label Statement: Statement on the label that gives specific application instructions, such as "do not," or "must." These statements have significant legal weight.

Restricted Use Pesticide (RUP): A pesticide formulation that can cause potential health effects, danger to non-target organisms, or pollution of water supplies. Due to their risks, RUPs can only be purchased and used by applicators who are certified and have paid the necessary licensing fees.

Suggestive Label Statement: Statement on the label that gives suggestive statements such as "it is recommended" or "may." It is considered good advice rather than a legal requirement.

Pesticides (insecticides, herbicides, fungicides, desiccants, growth regulators, fumigants, repellents, etc. are extremely valuable to our state's agriculture. These products are regulated by law in an effort to minimize injury to humans, animals, non-target plants and our state's water resources.

In the United States, there are laws which regulate pesticide manufacturing, labeling, sales, storage, transportation, use, and ultimately their disposal. The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) is the primary federal law regulating pesticides. The Nebraska Pesticide Act, modeled after FIFRA, is the state law in Nebraska which regulates pesticides. It is important to note that concerning the use of fumigants, Nebraska's state law is more restrictive than the federal law and the federally-approved product label.

Before a pesticide may be manufactured and sold in the U.S., it must be reviewed by the Environmental Protection Agency (EPA). Each formulation of a pesticide which is reviewed by EPA is assigned a unique number called the EPA Registration Number. Multiple experiments are run on each formulation to determine the formulation's potential adverse effects. Based on this research, the label for the product is written in a way that assures that the product, when used according to directions, will not present any unreasonable harm to the applicator, other species or the environment. In 2004, fumigant labels and Applicator's Manuals were revised to standardize language and to require written Fumigation Management Plans, safety training and documented air monitoring.

Some product formulations pose enough risk that the EPA classifies the formula as a restricted use pesticide (RUP). The RUP status may be based upon a formulation's potential health effects, potential danger to non-target species, or potential pollution of our water supply. In some instances, the presence

of a particular active ingredient will cause a product to be listed as restricted use. In other instances, the classification may be based off of approved use sites, percent active ingredient, approved rates, or the presence of inert ingredients which enhance the activity of the product. Almost all fumigants are classified as RUPs due to their acute toxicity if inhaled.

Just as prescription drugs are not sold without the signature of a trained medical doctor, so RUPs are not sold to persons without proof of adequate training (state certification and licensing). The labels for all RUPs include a text box on the front of the label with the following language: "Restricted due to (acute toxicity/non-target/groundwater) concerns. For retail sale and use by certified applicators or persons under their direct supervision". In Nebraska, the only persons who may purchase and/or use a restricted use product are those who have received training in the safe use of pesticides and/or who have passed exams demonstrating a competency to use these products and have paid the necessary licensing fees.

Certification and Licensing

The Nebraska Pesticide Act is administered by the Nebraska Department of Agriculture (NDA). Under the Nebraska Pesticide Act, the NDA certifies and licenses three kinds of pesticide applicators; private, commercial and non-commercial. The minimum age for a person to be certified or hold a Nebraska pesticide applicator license is 16.

A private applicator is a person who uses or supervises the use of an RUP on property personally owned or rented by them for the production of agricultural commodities. The private applicator license does allow for the treatment of grain storage bins and the use of toxicants for the control of certain wildlife, as long as the use sites are owned or rented by the license holder for agricultural reasons. The current fumigant labels require the writing of a Fumigation Management Plan (FMP) and monitoring of air near the treatment site. Because farmers may not be able to perform the air monitoring as required by the labeling, the NDA encourages producers to hire a commercial applicator to fumigate stored commodities.

A commercial applicator with the Fumigation category is a person who uses or supervises the use of a fumigant for hire to a grain bin, flat storage, mill, warehouse, railcar, container, truck, barge or rodent burrow. Note that the commercial license may be used both on a for-hire basis and for personal use to grain holding sites owned or rented by that person for the production of agricultural commodities.

A non-commercial applicator with the Fumigation category is a person who uses or supervises the use of a fumigant to grain storage sites, railcars, etc. owned or controlled by his/her immediate employer. Examples of non-commercial applicators would be employees of a cooperative applying a fumigant to the cooperative's elevator or railcars on a not-for-hire basis.

According to the Nebraska Pesticide Act, certification in the Fumigation category is required for any person who "uses" an RUP fumigant. "Use" includes all worksite activities where a person is performing a task that would require a person to wear personal protective equipment (PPE). "Use" includes opening a fumigant flask, handling/placing the fumigant, handling unaerated commodities, performing tasks at the treatment site when gas levels are unknown, monitoring gas levels, etc. Familiarity with the product label, the Applicator's manual, and the use of label-directed PPE would be required for all persons using a fumigant.

Nebraska's state Pesticide Act is more restrictive than federal law, the products' applicator manuals, and the pesticide laws in many other states. An example of this difference can be seen in the product applicator's manual which allows for one licensed applicator to supervise an unlicensed (but trained) person in certain situations where two people are required to be involved in a fumigation. In Nebraska, each person who is involved in the "use" of the fumigant must be certified. Nebraska law does NOT allow for one certified applicator to supervise an unlicensed trained assistant, except for the 60-day once-in-a-lifetime exemption explained later.

To become certified as a commercial or non-commercial applicator in the Fumigation category, a person initially must pass two exams: the NDA General Standards exam and the Fumigation category exam. Once both exams are passed a person is considered certified. Once certified, a person may become licensed by paying the appropriate licensing fee to the NDA ($90 for commercial applicators, no fee for noncommercial applicators). Licenses are valid through April 15 of the third year following

the year a person became certified. Renewal of an existing Fumigation license can be accomplished by attending an NDA-approved training meeting prior to the license expiration date and paying the appropriate licensing fee. If a non-commercial applicator changes jobs and the non-commercial status no longer applies, the license may be converted from the non-commercial status to a commercial status by paying the required licensing fee.

The 60-day rule

The Nebraska Pesticide Act does allow a person who needs to be certified a once-in-a- lifetime 60-day exemption from licensing. This provision allows employers the opportunity to provide in-house training and get a new person working prior to their completion of state certification exams. Employees wanting to take advantage of this exemption must complete and submit to NDA an application form (available from NDA at 877-800-4080 or www.agr.ne.gov/forms/89.pdf) within 10 days of making the first pesticide application. This form should include the name and license number of a qualified supervisor. The qualified supervisor must be licensed in the same category of work, and be willing to provide training and supervision for the unlicensed individual. Training must be verifiable and include coverage of the Applicator's manual, and use of PPE (www.agr.ne.gov/division/bpi/pes/training_verification.pdf). The NDA will provide the new employee a letter that is to be carried like a learner's permit. During this unlicensed period the supervisor shares legal responsibility for the actions of the unlicensed person.

Legal Uses of a Pesticide

A person must read and become familiar with the product labeling for the products being used because the labeling establishes the legal conditions under which a product may be used.

Every product label approved by EPA will have the following statement printed in a Directions For Use section, "It is a violation of Federal law to use this product in a manner inconsistent with its labeling." Note that it is also a violation of the Nebraska Pesticide Act to use a product in Nebraska in a manner inconsistent with its labeling.

For fumigants, it is customary for the product container to have a small label and for the bulk of the directions for use to be printed in an accompanying Applicator's manual. The label states that the product must be used in accordance with the Applicator's manual; and the manual instructs the applicator to, "Read and understand the entire labeling and applicator's manual. All parts of the labeling and applicator's manual are equally important for safe and effective use of the product." For simplicity, this manual has been referring to the sticker label and the Applicator's manual together as "labeling."

The labeling contains several sections intended to guide the applicator toward personal safety and use for effective control of pests. Some of this guidance is very specific and actually mandatory. Other guidance appears as suggestive statements. Mandatory statements give specific instructions, often using words like "do not," or "must." These mandatory statements represent portions of the label which have significant legal weight. In contrast, suggestive statements may include words like "should", "it is recommended," etc. and can be considered good advice rather than legal requirements.

The following are examples of common mandatory label statements:

- "NIOSH/MSHA approved respiratory protection must be worn during exposure to concentrations in excess of permitted limits or when concentrations are unknown"
- "Aerate used gloves and other clothing that may be contaminated in a well-ventilated area prior to laundering"
- "At least two persons . . . must be present during fumigation of structures when entry into the structure for application of the fumigant is required"
- "All entrances to the fumigated structure must be placarded"
- "PhosFume Tablets must be stored in a dry, well-ventilated area away from heat, under lock and key"

The following are examples of common suggestive label language:

- "It is permissible and often desirable to use a low-flow recirculation system for phosphine gas"
- "The following table lists a range of recommended dosages which can be used as a guideline for various types of fumigation"
- "Spent residual dust may also be collected and disposed of at a sanitary landfill"

It should be understood that there is a lot of research behind the language that appears on a product label approved by EPA, and the approval process is conditioned upon the ability to guarantee with a reasonable amount of certainty that, when the product is used according to label directions, the applicator, other species and the environment will not be harmed. When a pesticide product label is approved, both the manufacturer and EPA consider the applicator to bear full responsibility for proper application.

Storage and Disposal

The secure storage of pesticides, especially RUPs, has become a topic receiving a lot of attention. Most of the fumigants in use today are required to be stored under lock and key in a well-ventilated area. To protect your investment from being stolen and to prevent accidental poisonings, be sure to keep fumigants in the back of your vehicle under lock and key.

The best legal method for disposing of excess pesticide is to apply the product to a site approved on the label. Unreacted or partially reacted phosphine is acutely hazardous and should be deactivated using the "wet method" described in the Applicator's manual. Spent residual may be disposed of at a sanitary landfill.

Aluminum flasks and other fumigant containers are to be emptied, cleaned and/or recycled according to directions in the Applicator's manual.

Record Keeping

RUPs are tracked all the way from their manufacturing facility to their ultimate use and disposal. Manufacturers are required to keep records of all products sold to dealers or applicators. Dealers are required to keep records of sales to licensed applicators. The applicator is required to keep records of quantities used and the disposal of leftover product.

Records of commercial and non-commercial applications of RUPs must be made within 48 hours of the pesticide application. Records are to be maintained for a minimum of three years (The Applicator's manual says 2 years, but Nebraska requires 3 years). These records should be kept at the principal place of business and include the following information:

- Name and address of the person for whom the pesticide was applied
- Name, address and license number of the person making the application
- Location of the pesticide application
- Target pest(s)
- The site of the application (structure, commodity or burrow)
- Date of the application
- Initial starting time of the application
- Trade name and EPA registration number of the pesticide applied
- Rate of application applied per unit of measure
- Total amount of pesticide applied to the site
- Total area or size of treated site
- Method of disposal of unused pesticide, or if no unused pesticide remains, this should be recorded

In addition to state-required records, the Applicator's manual for most fumigants will require the applicator to draft a written procedure for the fumigation to be performed. This written document is called a Fumigation Management Plan (FMP). The FMP can vary considerably from simple to complex, depending on the site to be treated. Details of what must be included in this written plan, who must be contacted and provided copies of the plan, etc. can be found in the product Applicator's manual. Following a written plan provides assurances that a fumigation will be performed with reasonable certainty of not harming the applicator(s) or others. Several sample FMPs have been posted on the internet at *http://www.agr.ne.gov/division/bpi/pes/fmp.htm* and are also included at the end of this chapter. In Nebraska, FMPs are to be retained for a period of three years along with the state-required records listed above.

Contact Information

For additional information concerning laws and regulations governing the use of pesticides in Nebraska, contact the:

Nebraska Department of Agriculture
301 Centennial Mall S.
Lincoln, NE 68509
(402) 471-2394
http://www.agr.ne.gov/division/bpi/pes/pest1.htm

FUMIGATION MANAGEMENT PLAN

(SAMPLE – not applicable for all situations)

The purpose of this Fumigation Management Plan is to assist _____ in _____, NE to insure the safety of their employees, community and the environment. It is also designed to ensure an effective fumigation and to assist the company in meeting phosphine label requirements.

Owner/Manager of Responsibility:

Name: _____ Address: _____

Day Telephone Number: _____ City: _____ Zip: _____

Night Telephone Number: _____ Email: _____

Certified Applicators in Charge:

Name: _____ Address: _____

Day Telephone Number: _____ City: _____ Zip: _____

Night Telephone Number: _____ Email: _____

Company: _____ Phone: _____

Certification # _____ Date of Expiration: _____

Name: _____ Address: _____

Day Telephone Number: _____ City: _____ Zip: _____

Night Telephone Number: _____ Email: _____

Company: _____ Phone: _____

Certification # _____ Date of Expiration: _____

Emergency Telephone Numbers:

Local Police: _____ Local Fire: _____

Local Hospital: _____ Sheriff's Office: _____

Chemtrec: 1-800-424-9300 Poison Control: 1-800-222-1222

Attach a copy of an EMERGENCY PLAN.

- Include procedure for belt and/or auger lockout.
- Include planned escape routes above and below ground.
- Identify utility service connections for emergency shut-off of electricity, water, gas.
- Include a written procedure with instructions of who to contact and how.

Consulted with facility officials in developing FMP & worker safety plan on _____

Consulted with facility officials in procedures for notifying local authorities to notify nearby residents in the event of an emergency on _____

Consulted with facility officials in having required safety equipment on _____

Date of Site Inspection:_____or referred to previous FMP dated: _____

Consulted with facility officials in developing monitoring plan on _____

Consulted with facility officials in placement of placards on _____

Reason for Fumigation [pest(s), buyer requirements, etc.] :

Previous Fumigation history:

Description of Fumigation site (silo, warehouse, corrugated steel, etc.) :
Attach detailed drawing (identify doors, catwalk entrances, ends of tunnels, vents, etc.)
(identify potential hazards – augers, emergency shutoffs)
(identify emergency helps - telephones, PPE, etc.)

Work to be performed:

Site to be fumigated Refer to site diagram	Volume of treated area	Temperature of commodity	Moisture of commodity	Dosage	Fumigation time

Sites to be Sealed: List and/or indicate on site diagram

Sites to be Placarded: List and/or indicate on site diagram

Workplace Sites to be Monitored: List and/or indicate on site diagram.

Site	Number of Readings	Date Time	Phosphine Reading(s)

Perimeter Sites to be Monitored:

Site	Wind Speed	Wind Direction	Date Time	Phosphine Reading

Attach written instructions for aeration (where to start, where to finish)

Site(s) and date cleared of phosphine: List below and/or indicate on diagram.

Site	Date Cleared	Phosphine Reading

Personnel Training for parties who will be in immediate area during/after fumigation:

_____ **Instructed Fumigators on product Label on** _____
_____ **Instructed Fumigators on Applicator's Manual on** _____
_____ **Instructed Fumigators on required PPE on** _____

_____ **Conducted Safety Meeting for elevator employees on** _____
_____ **Explained emergency plan including emergency phone numbers on** _____
_____ **Explained established meeting area for personnel in case of an emergency on** _____
_____ **Personnel were notified of planned fumigation on** _____
_____ **PPE was confirmed in place on** _____
_____ **Provided owner/safety manager with a copy of FMP on** _____
_____ **Notified local authorities on** _____

_____ **Notified receiver of in transit vehicle on** _____
Receiver: _____
Contact information: _____
_____ **Removed warning placards on** _____
_____ **Notified appropriate people when it is safe to reenter treated sites on** _____

References

Gorham, J. Richard, ed. *Insect and Mite Pests in Food*. Washington, DC: U.S. Government Printing Office, 1991. 2 vol [United States Department of Agriculture, Agricultural Research Service and United States Department of Health and Human Services, Public Health Service, Food and Drug Administration, Washington, DC, Agriculture Handbook No. 655]

Reed, C.R. (2006). *Managing Stored Grain to Preserve Quality and Value*, St. Paul, MN: AACC International.

United States Department of Agriculture (2007). *Grain Inspection Handbook-Book II; Grain Grading Procedures*, Table No. 5, p. 13-12. Retrieved September 4, 2009, from USDA Grain Inspection, Packers & Stockyards Administration Web site: http://archive.gipsa.usda.gov/reference-library/handbooks/grain-insp/grbook2/complete-bk2.pdf

Sample Safety Checklists

Safety Checklist for Raw Agricultural Commodity and Stored Product Fumigators

The following safety checklists will help you organize the many aspects of fumigation. They are organized so that you can photocopy them directly from this manual. This information is general. It does not apply to all fumigants in all situations. You can modify these checklists to meet your specific needs. Some manufacturers provide checklists specific to their products. Use these as well.

Preliminary Planning

- ☐ Draw or locate a sketch of the structure you plan to fumigate. Indicate the layout of the structure, connecting structures and escape routes above and below ground.
- ☐ Seal all spouts, conveyors, conduits, heating ducts, pipes, cracks, crevices, broken windows and other possible openings leading from the areas that you plan to treat.
- ☐ Record the number and names of everyone who routinely enters the area. Note the proximity of other nearby people and animals. Keep children, unauthorized persons and pets away from the application site.
- ☐ If you plan to treat a commodity, learn about it. Find out its mode of storage and its condition. If possible, get a previous treatment history.
- ☐ If you plan to treat a commodity within a structure, learn about the structure. What does it consist of: wood, brick, concrete? Note the locations of doors, windows and dividing walls. Check airflow patterns.
- ☐ Study the pest(s) you plan to control. When is it most vulnerable to fumigants? Where are its numbers the highest?
- ☐ Check and adjust all safety and application equipment. Be sure the components can withstand the corrosiveness of the fumigant(s). When applying compressed gas, use pressure-approved components. Seal them tightly.
- ☐ Locate connections and shut-offs for electricity, water and gas. Test these shut-offs to be sure they are working. Find the nearest telephone or communication device.
- ☐ Obtain and have handy telephone numbers for local health, fire, police and medical emergency services. Know how to contact the parties responsible for the structure and/or commodity you plan to fumigate.
- ☐ ONLY select a fumigant registered by the EPA and NDA.
- ☐ Read and reread the label information. Study the directions and precautions. Make sure the fumigant is labeled for the required work (site, commodity, etc.).
- ☐ Notify the local health and fire departments, police and security personnel and hospital. Give them the following information: the location, the chemical name(s), the date and time of application, the type of gas mask and other safety equipment required, the fire hazard rating and literature about the safety measures you plan to use.
- ☐ Inform the occupants of the structure where treatment will occur. Also, notify the occupants of neighboring structures.
- ☐ Arrange for standby equipment and replacement parts for application equipment and PPE. Outline an alternate plan of action.
- ☐ Review your treatment plan with all workers. Explain the potential hazards to life and property.
- ☐ Identify the safety measures and emergency procedures that are required by labeling.
- ☐ Prepare warning signs to post near treated areas. Arrange for someone to monitor all entrances and exits during treatment.
- ☐ Have first aid equipment (including antidotes and plenty of fresh water) handy.
- ☐ If possible, plan for application from outside the structure.

- ☐ When necessary, obtain fans to evenly distribute the fumigant
- ☐ Preplan how you will aerate the area after treatment.
- ☐ Identify areas where you can store any excess fumigant(s). Be sure conditions in the storage area match those required by the labeling.
- ☐ Make sure no open fires, motors, or hot surfaces (heat pipes or electric fixtures) are within the space that you plan to treat.
- ☐ Know how to operate the gas detection devices.
- ☐ Have on hand all the PPE you would need to enter a treated area in an emergency. Check to be sure that this equipment is working properly.

Application Safety

Pre-Application

- ☐ Open all doors, cabinets, and drawers inside the area you plan to treat.
- ☐ Turn off pilot lights and gas lights. Disconnect electrical equipment.
- ☐ Make a final check. Be sure all occupants, pets and livestock have been removed from the structure.
- ☐ Place warning signs at all entrances and exits.
- ☐ Assign someone to observe all entrances and exits.

During Application

- ☐ Apply all fumigants according to the directions in the labeling.
- ☐ Apply the fumigant from outside where appropriate.
- ☐ Consider the weather. You may need to delay or cancel outdoor treatments on windy or stormy days.
- ☐ Do not enter the area where fumigant gas is being discharged, except in extreme emergencies.

Post Application

- ☐ Aerate according to structural limitations.
- ☐ Turn on ventilation fans where appropriate.
- ☐ Before reentering a treated area, use a suitable gas detector to determine the fumigant concentration. Some fumigants do not provide an adequate odor warning. Others aerate slowly.
- ☐ Remove warning signs only when aeration is complete.
- ☐ Dispose of or return empty containers per the manufacturer's instructions.
- ☐ When using metal phosphide fumigants, return any unused, solid chemicals to clearly labeled containers. Store them properly.

Personnel Safety

To protect yourself and others, be sure you and your supervisor(s) always:

- ☐ Know the location of all entrances and exits.
- ☐ Know the location of all fumigant containers and aerating fans.
- ☐ Rehearse the fumigation plan so that each worker knows what to do.
- ☐ Remove all rings, jewelry and watches as required by the label.
- ☐ Have current health records for all employees. All workers that take part in fumigations must have a physical exam at least once a year. During fumigation, no worker should have a cold or other condition that may impair breathing. Nor should any worker be undergoing medical or dental treatment, unless a physician certifies that they may work with fumigants
- ☐ Survey workers to make sure they have abstained from alcoholic beverages 24 hours before and will abstain 24 hours after a fumigation job.

- ☐ Instruct all workers about first aid, emergency procedures, antidotes and decontamination.
- ☐ Work in pairs, especially when entry into a fumigated area is necessary. Stay in sight of one another while inside a treatment area.
- ☐ Report any accidents to your employer or supervisor.
- ☐ Report any signs of illness or discomfort, regardless of how minor they may seem. This includes dizziness, diarrhea, nausea, headaches and lack of coordination.
- ☐ Teach all workers how to select, operate and maintain protection devices. Warn them about the hazards that they may encounter if the chemicals are misused.
- ☐ Have and use the necessary PPE. Inspect all PPE for defects. Know where emergency equipment is located.
- ☐ Make sure there is enough water on site to wash or flush skin and eyes if an accident should occur.