Iowa Commercial Pesticide Applicator Manual

Category

7C

Fumigation

IOWA STATE UNIVERSITY
University Extension

CS-27 | Revised | December 1998

File: Pest Management 7-1

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Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Stanley R. Johnson, director, Cooperative Extension Service, Iowa State University of Science and Technology, Ames, Iowa.

Iowa Commercial Pesticide Applicator Manual

Fumigation

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This manual has been developed for individuals wishing to become certified in commercial pesticide applicator Category 7C, Fumigation. It contains specific information that an individual must know before becoming certified in Category 7C. This manual has been designed to supplement the general information contained in the *Iowa Core Manual* (IC-445) and should not be used for certification preparation without referring to the *Iowa Core Manual*.

No endorsement is intended by Iowa State University Extension of companies or their products mentioned nor is criticism implied of similar companies or their products not mentioned.

Contents

Introduction

This manual has been prepared as a study guide for persons wishing to qualify to apply fumigants in Iowa either as a commercial or private applicator. The information presented is intended to help you learn to fumigate effectively, safely, and in compliance with federal and state regulations. This manual is not offered as an endorsement of any particular product or type of product. It is not designed to promote pesticide use or to oppose alternative methods of control. In fact, other methods of control such as biological control are strongly encouraged when applicable. Nevertheless, training for proper pesticide use is the designated objective of this manual.

Fumigants are used to control insects, rodents, and other pests. They are used to rid food and feed plants of insects and mites, kill insects in stored grain, control wood-destroying insects in structures, and decontaminate railcars. Small quantities of contaminated product can be treated in a fumigation chamber or under a plastic tarp. Fumigating whole structures requires thorough sealing or tarping. Fumigants are often the quickest and most efficient way of eliminating pests from food products, wooden articles, and entire structures. When used correctly, they leave little, if any, residue and can solve pest problems that other methods cannot solve.

Fumigation requires more extensive training and skill than any other form of pest control. The effectiveness of fumigants is greatly influenced by temperature and humidity. Each fumigant requires different dosages depending on the pest to be controlled, the site or type of storage being fumigated, and the commodity being treated. Some fumigants, such as methyl bromide, react with objects such as iodized salt, cinder blocks, rubber goods, blueprint papers, and photographic chemicals. Proper sealing or tarping of commodities is necessary to confine the fumigant in sufficiently toxic dosages for the required length of time. An understanding of how to properly work with each fumigant product is necessary.

Fumigation makes use of some of the most toxic chemicals known to modern civilization. Fumigants are toxic to all forms of life; a handling error on your part can kill you or the person working with you. Consequently, the Environmental Protection Agency (EPA) drastically changed the way fumigants are to be handled. Some products such as ethylene dibromide (EDB) and carbon disulfide are no longer registered for use and the remaining fumigants have been classified as restricted use pesticides. A minimum of two trained people must be present if entry of a structure is necessary during fumigation or if you must reenter a partially aerated structure. Approved respiratory protection is required when working in areas where the fumigant concentration is at or above the threshold limit value (TLV), or when the fumigant concentration is unknown. Monitoring equipment is needed to determine fumigant concentrations prior to entry into a structure under fumigation and before warning signs are removed. The full-face, canister-type respirator, in most cases, can be used only when fumigant concentrations are below certain levels.

In preparing for the certification exam, persons wishing to certify commercially should study all sections of this manual. Farmers wishing to certify as private grain fumigators should study pages 6–31 and pages 43–54. Although this manual is comprehensive and can serve as a useful reference, realize that no one publication covers all aspects of pest identification and control.

Characteristics of major insect groups

With over 1.5 million species of insects, it would not be realistic to expect any individual to be able to identify all of them. There are, however, a limited number of structural and stored commodity pests that you should be able to identify. If you do not recognize a pest, take it to someone who can help with the identification, such as your supervisor, local biology teacher, or county extension agent. Specimens also may be submitted to the Insect Diagnostic Clinic located at Iowa State University, Department of Entomology, 109 Insectary, Ames, Iowa 50011. Proper identification is important to good pest management.

To properly identify a pest, you must be familiar with and be able to recognize certain physical features of insects. The type of mouthparts (chewing or sucking), the number and type of wings, and the type of development (simple or complete metamorphosis) are used in classifying insects. With these characteristics, insects are divided into 24 or more groups or orders. This manual discusses only the common groups that are found as structural or stored commodity pests, and uses the common names that are most familiar to you.

Wood-infesting beetles

There are more species of beetles than any other organism in the world. It is not surprising, then, that many beetles have developed a "taste" for wood. Some species feed only on dead or dying trees and cannot reinfest sound, seasoned lumber. Some species can and do destroy structural timbers, fine furniture, flooring, and older wooden objects by repeatedly attacking and breeding in wood. Because the larvae and adults of wood-infesting beetles are seldom seen when damage is found, the pest control technician must identify the insect by examining the wood itself and by using emergence holes, types of sawdust present, and age and species of wood as clues. Because control methods and potential wood damage differ for the common families of beetles found in wood, improper identification can lead to problems. Even the most destructive beetles work slowly so there is time to make the proper identification and consider treatment alternatives.

There are a number of wood-infesting beetles that attack dead or dying trees. These insects help decompose wood and are very beneficial in recycling nutrients and preventing the forest floor from being littered with dead wood. These beetles do not usually attack healthy trees and do not infest lumber after it has been milled. When these insects are found in the home they are usually associated with firewood stored indoors or they have recently emerged from new lumber. The important point to remember is they cannot reinfest wood in the home or building, and need to find a new source of dead or dying trees to continue their life cycle.

Bark beetles

Bark beetles (family Scolytidae) attack only standing trees. Females are attracted to trees that have suffered from drought stress or fire, or that have been killed from some other cause. They chew their way through and under the bark and the females lay their eggs. The larvae feed laterally just under the bark and can girdle the tree and cause death. Feeding tunnels leave characteristic wormlike galleries. Because of the superficial feeding, bark beetles do not weaken the structural integrity of wood. When adults emerge from the tree, they cut a small, round hole (about the size of a BB) in the bark. Small, gritty sawdust is sometimes kicked out from these emergence holes.

Adult bark beetles are small ($1/6$ inch in length), cylindrical, and reddish brown to black, with short, elbowed, clubbed antennae. Adults fly toward windows where they can pile up and become readily noticed. They do not attack seasoned wood or wood products. They can, however, be serious nuisance pests and can inflict monetary loss to individuals owning log cabins, wood furniture, and decorative items made from wood that still contain its bark. Insecticides sprayed on the outer bark of infested wood are not effective in killing the larvae and adults beneath the bark. The most common source of bark beetles in a home is from infested firewood. Such firewood should be stored outdoors.

Another group of bark beetles, called ambrosia beetles, bore directly into tree wood and feed on fungi that grow on the walls of the bored tunnels. These tunnels become stained black, brown, or blue. This insect is incapable of infesting seasoned wood. The small ($1/16$ to $1/8$ inch in length), round emergence holes resemble the emergence holes of powderpost beetles. The tunnels, however, are free of sawdust, and if you put a pin or thin wire into them you should notice that most tunnels are bored at an angle to the surface of the wood. True powderpost beetle emergence holes would be at right angles to the surface. This distinction is important because ambrosia beetles have already left the seasoned wood, whereas powderpost beetles can reinfest it. Control is not needed to prevent structural weakening from bark beetle or ambrosia beetle attack.

Wood borers

Metallic wood-boring beetles (family Buprestidae) attack standing timber and firewood. Like the bark beetles, these beetles are highly attracted to heat and smoke and attack stressed or dying trees. Females have even been known to lay eggs on recently scorched trees after forest fires. The larvae are called flatheaded borers and have a very distinctive, enlarged, and flattened area behind the head. Larvae feed for 1 to 3 years in both the sapwood and heartwood of trees. The larvae pack their tunnels with a coarse frass (sawdust). Adults are medium to large ($1/4$ to 2 inches in length), brightly colored, streamlined, and metallic-colored.

Metallic wood-boring beetles found indoors are most often associated with firewood. One or two adults may emerge from structural lumber within the first 2 to 3 years after new construction. These beetles were already in the tree when it was milled into lumber and cannot reinfest seasoned wood.

Longhorned wood-boring beetles (family Cerambycidae) also attack only dead and dying timber or recently cut logs. Adults have very long antennae that are at least as long, or 2 to 3 times longer than the body. They range from ⅓ to 4 inches in length and come in a variety of colors. Some of the smaller brown species are occasionally mistaken for cockroaches. Larvae of this beetle family are called roundheaded borers and are very common in firewood. Their rate of development is influenced by moisture and temperature, and development may extend for more than 3 years. There is only one species in this family, the old house borer (*Hylotrupes bajulus*), that is capable of reinfesting wood. This species has not been found in Iowa.

It has been fairly common for cerambycids to emerge from finished logs, timbers, or structural lumber in the home. The practice of salvaging timber after a forest fire or other natural catastrophe has lead to the milling of beetle-infested lumber. Sometimes individual larvae can be heard "chewing" at night. At other times large amounts of very coarse sawdust may be pushed out from rough beams or logs. One genus of cerambycids, the pine sawyers, is commonly found in spruce and pine logs. No matter how severe the infestation, these insects do not reinfest wood and do not compromise the structural integrity of the wood. Most infestations run their course within 24 months of construction. Fumigation is rarely justified.

Powderpost beetles

There are three families of beetles that are sometimes referred to as powderpost beetles: true powderpost beetles, anobiid beetles, and false powderpost beetles. They are all capable of reinfesting sound lumber and collectively can attack both softwood and hardwood. Although many infestations are determined solely by the presence of emergence holes and are referred to as being from the "powderpost beetle complex," it is important to be able to identify and separate these three families.

True powderpost beetles are in the family Lyctidae. In the United States, lyctids are second only to termites in their destructiveness of wood. They have been given their name due to the extremely fine, flourlike fecal matter that is pushed out of infested wood. This material is as fine as talcum powder and is often the first noticeable sign of a problem. The powder is pushed out by emerging adults and can be found on flooring, in dresser drawers, on furniture, or underneath infested beams. Because this dustlike powder is loose in the feeding tunnels, it may continue to sift out long after the adults have emerged and even after the infestation has died out.

True powderpost beetles attack only hardwoods and prefer pourous wood, such as ash, oak, mahogany, hickory, maple, walnut, bamboo, and wicker. In nature, they attack old, well-seasoned, dried wood. Most infestations occur in sapwood. Two- to 4-year-old oak firewood is a common source of infestations in the home. Powderpost beetles may be found indoors in hardwood flooring, timbers, plywood, barn board, and hardwood articles such as tool handles, crating, furniture, antiques, gun stocks, and picture frames.

Adult beetles resemble the red flour beetle. They are small (1⁄12 to ⅕ inch in length), elongate, flattened, reddish brown to black and, when viewed from above, their head is visible. They have short, 11-segmented antennae with a 2-segmented terminal club. Adults are attracted to light and often appear at window sills in infested rooms. Lyctids are generally brought into buildings in wood that contains their eggs or larvae. There are six common species found in the United States.

A true powderpost beetle infestation begins when the female beetle deposits her eggs in the surface pores of wood or when adult beetles crawl into old emergence holes. Once the pores are covered with shellac, paint, varnish, sealer, wax, or even whitewash, the females cannot successfully lay their eggs. Eggs hatch within 10 days and the larvae tunnel through the sapwood, usually following the grain. In the southern United States, the larval stage may be completed in as little as 2 months but normally takes from 9 to 11 months to complete in Iowa. As the larva matures, it chews to within ½ inch of the surface of the wood and prepares a small pupal chamber. Adults emerge 2 to 3 weeks later and are most commonly seen in the spring. Emergence holes are round and 1⁄32 to ⅛ inch in diameter. A large quantity of fine sawdust is packed in these holes. Mature larvae are less than ¼ inch in length, curved, wormlike, and enlarged at the thorax. They differ from the other wood-borer larvae in that they have distinct 3-segmented legs that do not have a claw, and they have a last abdominal breathing pore (spiracle) that is six times larger than the other pores found on the abdomen.

The success and potential damage of a lyctid infestation are related to both the starch and water content of wood. Female lyctids do not lay eggs in sapwood that has a starch content of less than 3 percent; the higher the concentration of starch, the better they survive. True powderpost beetles can live in wood with a water content between 8 and 32 percent. Because green wood is commonly about 50 percent water, infestations are generally confined to partially or wholly seasoned wood. The most activity is found in wood with a moisture content between 10 and 20 percent. Over time, the starch content in sapwood naturally declines so that wood becomes less susceptible to attack. The most seriously damaged structures in Iowa are unheated buildings because of the increased moisture and humidity found within them.

It normally takes years for serious structural damage to occur from powderpost beetles. For high-value articles such as furniture or antiques, even one emergence hole cannot be tolerated. The first problem is to determine if the infestation is still active. The presence of adult beetles, new emergence holes, and powderlike frass indicates an active infestation. If powder is seen only when the wood is jarred, the infestation may not be active. It is sometimes useful to mark existing emergence holes and check 3 to 6 months later for the appearance of new holes. Placing a dark-colored cloth under infested beams and checking for piles of powder over a period of time also verifies activity. If part of the wood can be sacrificed, remove small sections of wood and look for adults or larvae.

The second problem is to determine where the infestation came from and when it started. Often, an infestation in new construction can be associated with an oak baseboard, a fireplace mantel, or a mahogany-covered door. Adult beetles typically begin to emerge from these sources within the first 12 months following construction. In these cases, infested wood was built into the home. Wood with more than 30 exit holes per square foot contains, or did contain, established beetle populations. Kiln drying kills insects present in the wood, but powderpost beetles can reinfest wood in storage after drying.

If the infestation is widespread throughout flooring, cabinetry, or structural timbers, fumigation may be necessary. Methyl bromide is the preferred material because it kills all insect life stages, including eggs. This treatment is very expensive and the cost must be balanced against the replacement value of the wood. Proper fumigation kills all insects present but does nothing to guarantee or prevent the wood from becoming reinfested. Infested lumber can be tarp fumigated. Small articles or furniture can be treated in a fumigation vault or chamber.

There are over 260 species of deathwatch beetles (family Anobiidae) in the United States. Two species, the cigarette beetle (*Lasioderma serricorne*) and the drugstore beetle (*Stegobium paniceum*), are important pests of stored food products. Several other species attack and reinfest seasoned wood. Attacks often start in poorly heated or unventilated crawl spaces and spread to other parts of the house. Anobiids attack the sapwood of both hardwoods and softwoods and can extend into the heartwood. In nature, these beetles develop in old, dried limbs of trees.

Adult anobiids range from 1/25 to 1/3 inch in length and are usually reddish brown to gray. They have a distinctive hoodlike, bell-shaped thorax that conceals the head. Unlike with lyctids, you cannot see the head of an anobiid from above. There is no club on the end of the antennae, but the last three segments are usually longer and broader than the other eight segments.

Female beetles lay eggs in cracks in wood or in old emergence holes. There is a strong preference for rough-sawed lumber, and females may be inhibited from laying eggs on smooth or finished wood. Anobiids have a high moisture requirement and eggs do not hatch at humidities below 60 percent. Larvae are grayish white with black jaws and can be distinguished from true powderpost beetle larvae because they have a 5-segmented leg that ends in a claw. Anobiid larvae also have a double row of small brown spinules (spiny hairs) along the upper body. There is no enlarged spiracle on the last abdominal segment. Larval development may take from 1 to 10 years or more, depending on the species of beetle and the nutritional content of the wood. There are some documented cases of anobiids taking 25 years to emerge from an oak table.

The obvious sign of an infestation is the accumulation of powdery sawdust and tiny pellets underneath infested wood. Fresh powder is bright and light colored, similar to freshly sawed wood. Small, 1/85-inch-long oval pellets may fall from infested channels or old emergence holes. These pellets give the sawdust a gritty quality and are loosely packed in the tunnels. If sawdust is yellowed and partially caked on the surface where it lies, the infestation has died out. Emergence holes are round and from 1/16 to 1/8 inch in diameter.

It normally takes 10 or more years for anobiid beetles to increase in number before an infestation is noticed. As mentioned, high-moisture conditions are attractive to adults and allow for shorter generation times. Wood with a moisture content between 13 and 30 percent is most susceptible to attack. Old, unheated buildings, livestock housing, and homes with earthen basements or damp crawl spaces are prime targets. Anobiids are much more likely to infest old lumber and wood than are the other species of wood-infesting beetles. Old barn board that is used as paneling is often a source of infestation.

Infestations should be checked closely to determine if beetles are still active. If structural wood has been heavily attacked, it may have to be replaced. Probe the infested wood with an ice pick to assess damage. Remember, much of the attack is confined to sapwood so a beam consisting mostly of heartwood may not be susceptible to further attack. Chemical sprays such as Dursban TC can be used, or the building can be fumigated. For fumigation, methyl bromide is preferred because it kills all life stages of the beetle. The client should be informed, however, that fumigation alone cannot prevent further infestations.

The third family of beetles that can reinfest wood structures is the false powderpost beetles (family Bostricidae). This small group is most abundant in the tropics and is not an important pest group in Iowa. Most problems are associated with firewood or wood articles imported from the Orient. One species, *Donoderus minutus*, is common in bamboo. Bostricids rarely attack and reinfest seasoned wood.

Bostricids primarily attack individual pieces of trim or flooring and rarely cause significant damage in framing lumber. Replacement of structurally weakened wood is the most economical and effective control. Infested wicker and bamboo objects may need to be disposed of or fumigated. Care should be taken to prevent bringing infestations into a home.

Stored product beetles

All adult beetles have two pairs of wings, with the first pair being thickened and hardened to form wing covers. Beetles go through a complete metamorphosis. Larvae are wormlike with three pairs of legs. Adults and larvae can damage stored products because both developmental stages have chewing mouthparts. Adults also can attack natural fabrics.

Adults of the rice weevil (*Sitophilus oryzae*) and the granary weevil (*Sitophilus granarius*) are ⅛ inch in length and dark brown with elongated snouts. These insects develop only in whole-grain kernels of corn, wheat, and oats, and in large seeds and nuts. Infestations are often diagnosed by the presence of hollowed grain caused by larval feeding. Breeding takes place at temperatures above 50° F. Adults cannot fly.

Drugstore beetles and cigarette beetles are small, cylindrical, and reddish brown. Adults are less than ⅛ inch in length and have heads that are tucked down so that they cannot be seen from above. Adults and larvae feed on dried plant material, including cigars, spices, paprika, drugs, dried raisins, and cereal products. They can penetrate most paper packaging. Adults can fly and are attracted to windows or other sources of light.

The red flour beetle (*Tribolium castaneum*) is a serious pest in flour mills. Adults are reddish brown, ⅛ inch in length, and have heads and antennae that are easily seen from above. Larvae are yellowish brown and prefer milled cereal, flour, and other finely ground food. The sawtoothed grain beetle (*Oryzaelphilus surinamensis*) is ⅛ inchin length and dark brown, but it is thinner and more flattened than the red flour beetle. Adults have six sawtoothed projections on the thorax. Red flour beetles and sawtoothed grain beetles are common pests in kitchens, bakeries, and storage facilities and feed on almost any dry goods. These species, along with a number of other small, brown to black beetles, are often referred to as pantry pests or bran bugs. They are unable to attack sound whole grain, and they cannot penetrate sealed packaging. They can go through multiple generations per year at room temperature.

Control of red flour beetles and sawtoothed grain beetles often involves thorough sanitation. Sweeping or vacuuming spilled materials and dusts that accumulate on ledges, inside fuse boxes, in cabinets, and on filters helps deter infestations. Machinery or building designs that allow easy cleaning and that prevent dust and debris from accumulating lessen pest problems. When a problem is found, all infested goods may have to be disposed of or fumigated.

Carpet beetles (family Dermestidae) also infest stored products. Adults are small and oval and the body is covered with fine "hair" or scales. Larvae are tapered and brownish and have prominent bristles or hair tufts on their tail end. Some species can go without food for up to 2 years.

Carpet beetles also attack wool, leather, silk, animal skins, dead insects, feathers, and felt. Most fabric damage caused by insects is a result of carpet beetle activity. Infestations are common in old boxes of clothes, overstuffed furniture, and along baseboards of wool carpets. Small numbers of carpet beetles can be found in most buildings. In nature, carpet beetles are found in bird nests, wasp nests, and dried carrion. Residual treatments may be needed to reduce problems. Small items can be frozen or heated to correct some infestations.

Many other beetles may enter homes and buildings. Some are associated with products such as firewood or pallets, whereas others feed on shrubbery or plant material outdoors, or are attracted to outdoor lights. Most of these beetles are only a nuisance and do not reproduce indoors or damage household goods. They can, however, present a continual contamination problem.

Moths

Adult moths have two pairs of wings. Their wings have a dense covering of tiny scales that leave a powderlike residue on your fingers if you touch them. Adults have tubelike, sucking mouthparts, whereas the larvae have chewing mouthparts. Moths go through a complete metamorphosis. Only about five of the more than 2,000 moth species found in Iowa are important pests of stored products or households. Adults feed on the nectar of flowers and on other liquids and are not damaging. The larvae are wormlike and eat large amounts of food. Their contamination of food, making it unfit for human consumption, however, is considered the major problem.

The Indian meal moth (*Plodia interpunctella*) is the most common stored-product moth found in Iowa. Adults are ⅓ inch in length and have a tan-to-grey wing base with a coppery reddish tip. Larvae are white with a green or pink tinge. They are associated with dry goods such as nut meats, birdseed, chocolate, dried fruit, cereals, flour, and stored grain. Larvae spin large amounts of silk webbing in and over the stored product. Indian meal moths go through 5 or 6 generations per year. Adults are often seen flying weakly indoors or resting on walls. In stored grain, this moth has shown resistance to malathion treatments.

Other species of stored product moths found in Iowa include the Mediterranean flour moth (*Anagasta kuehniella*), which prefers milled products, and the almond moth (*Cadra cautella*), which is common in candy. Adults of both species are ⅓ inch in length and can produce multiple generations each year. To eliminate moth infestations in food and stored grain products, the infested material must be destroyed. Thorough cleaning followed by good housekeeping to prevent reinfestation is essential for control. Residual treatments or space sprays may be needed.

Cockroaches

There are five species of cockroaches commonly found in Iowa. All have chewing mouthparts, are dull or dark colored, and are fast moving. They have long, hairlike antennae and are most active at night. Cockroaches hide in cracks and crevices during the day and scurry for cover when disturbed at night. The eggs of cockroaches are enclosed in a capsule. These egg cases can be used to help identify specific cockroach species.

American cockroach (*Periplaneta americana*) adults are reddish brown, 1 to 1½ inches in length, and have wings covering the entire abdomen. They prefer warm, damp, dark areas and are most commonly found in sewers, bakeries, and restaurants. They do not fly.

German cockroach (*Blattella germanica*) adults and nymphs have two dark stripes running lengthwise behind the head on the thorax. They are tan and grow up to ⅝ inch in length. This species is the most common cockroach in Iowa. It is found near food and water sources (kitchens, bathrooms, etc.). These cockroaches hide in crevices during the day and emerge under dark conditions. German cockroaches are prolific breeders and can go through 3 to 4 generations per year. A single female can produce more than 240 offspring during her lifetime. Some German cockroach populations are resistant to some insecticides.

The brownbanded cockroach (*Supella longipalpa*) is similar in size and outline to the German cockroach but does not have the dark stripes behind the head. Brownbanded roaches have two tan to yellow stripes running across the body where the wings attach. Adult females have shorter wings and are broader than the males. Brownbanded cockroaches can live in fairly dry environments and can be found in television sets, toasters, and other appliances. Living in such hard-to-treat areas, along with their resistance to some insecticides, makes them considerably more difficult to control than other cockroach species. Adults are fairly good flyers.

Oriental cockroach (*Blatta orientalis*) adults are 1¼ inches in length, dark brown to black, and are often found in damp areas such as basements and sewers. They are commonly called "water bugs" and are rarely found above the first story of a building. Adult females have very small wings that expose most of the abdomen, whereas the wings of males cover three-fourths of the abdomen.

The wood cockroach (*Parcoblatta* sp.) is the only outdoor cockroach found in Iowa. It lives under the bark of dead trees and usually enters the home via firewood. It is slow to reproduce indoors and prefers very damp environments.

Cockroaches usually enter homes or buildings on infested food products, pallets, or used furniture. They contaminate food with their droppings, with their bodies, and with the bacteria that they carry. They often suggest poor sanitation and they must be controlled to protect the quality of products. Once cockroaches become established, sanitation alone cannot control them. Unsanitary conditions will make it impossible to control cockroaches solely with insecticide sprays.

Mites

Mites are minute, soft-bodied, eight-legged creatures that are related to ticks. They are under 1⁄50th of an inch in length and have no wings. Although there are both plant-feeding and animal-feeding species found in nature, the most common species found indoors are either parasitic mites or grain mites.

Many species of birds and rodents harbor parasitic mites. Bird mites have been known to move into buildings by the thousands when birds are nesting or roosting on a building. These mites are capable of biting people and pets. To control bird mites, the nests of the birds must be removed and residual or space sprays applied indoors to eliminate invading mites. Rarely is fumigation justified.

Several types of grain mites develop indoors or on food products if conditions are damp. These mites require relative humidities above 80 percent to survive. Drying out a room or building often controls the mite problem; however, drying may not be feasible when you have infestations in cheese, plants, or high-moisture animal feed. In these situations, fumigation may be the only practical solution for eliminating mites. It is important to remember, however, that animals may sometimes refuse to eat grain or feed that has been heavily infested with grain mites even after the mites have been eliminated. Thus, disposing of the grain may be the most cost-effective solution.

Occasional invaders

A number of other species of insects and mites may accidentally enter structures during warm weather. These species include strawberry root weevils, leaf beetles, ground beetles, crickets, sowbugs, millipedes, clover mites, and ants. Setting up a pesticide barrier around the perimeter of the home or building may temporarily stop their movement indoors.

A more permanent solution can be achieved by reducing nesting and breeding habitats. Landscape plants such as hackberry, boxelder, and elms are prone to insect problems and should not be planted close to buildings. Keep a 2-foot-wide vegetation-free barrier around the outside foundation to prevent organic matter from accumulating. A barrier can help eliminate breeding and hiding places for ground beetles and crickets. Proper drainage lessens problems from moisture-loving species such as sow bugs and millipedes.

The presence of spiders may indicate insect infestation problems. Spiders are considered beneficial because they feed only on insects. The presence of a large number of spiders, however, may constitute a nuisance problem. Spiders can be controlled by removing their webs and reducing the number of insects that they feed on. For example, security lights placed next to buildings can attract large numbers of nocturnal insects that , in turn, may result in increased spider populations. Thus, these lights should be moved or directed away from doors, windows, or other entry points into the building.

Toxicity of fumigants

The *Iowa Core Manual for Commercial Pesticide Applicators* (IC-445) and the *Private Pesticide Applicator Study Guide* (PAT-1) provide a general review of pesticide toxicity. You also should review the following information carefully because fumigants are the most toxic pesticides. When handling fumigants the risk of respiratory exposure is the greatest hazard. When handling nonfumigants, absorption through the skin is the most common route of exposure.

Fumigants should always be used with extreme caution. As standard practice, no alcoholic beverages should be consumed for 24 hours before and after a fumigation treatment. Alcohol tends to increase sensitivity to fumigants and also can interfere with proper diagnosis of fumigant poisoning.

Methyl bromide

Methyl bromide is perhaps the most widely used fumigant. It is particularly dangerous because it is both highly toxic and odorless. It is nonirritating to skin and eyes during exposure but later can cause serious skin or eye injury. Inhalation of toxic levels may occur without warning or detection by the user. The established threshold limit (maximum permitted daily exposure) for methyl bromide is 5 parts per million (ppm). Workers should not reenter a treated area without wearing appropriate respiratory protection until the concentration of methyl bromide has dropped below this level.

General symptoms of poisoning are severe chemical burns of the skin, respiratory tract, and other exposed tissue; delayed chemical pneumonia, which produces water in the lungs; and severe kidney damage. Victims also may experience extreme nervousness. Severe exposure to methyl bromide can be fatal. If smaller amounts of methyl bromide are inhaled, symptoms are similar to alcohol inebriation. The effects of methyl bromide are cumulative, which means that repeated exposures to low doses result in an accumulation of methyl bromide in body tissues. Such exposure may produce skin rashes, sometimes followed by mental confusion, double vision, tremors, slurred speech, and a lack of coordination.

In acute exposures, methyl bromide can effect both the respiratory and central nervous systems of animals. These effects may be somewhat delayed, but rarely for longer than 24 hours in the case of respiratory symptoms and seldom over 48 hours for central nervous system effects. Methyl bromide may act as a lung irritant, causing problems ranging from mild bronchitis to pulmonary edema and respiratory failure. Symptoms may include cough, chest pain, dyspnea (labored respiration), and eventually wet breathing, often complicated by bronchopneumonia.

Central nervous system effects of methyl bromide exposure usually are accompanied by or are followed several hours later by respiratory effects. Symptoms include intense nausea and vomiting, dizziness, double or blurred vision, unusual fatigue, headache, loss of appetite, abdominal pain, staggering gait, and slurred speech. Convulsions may occur. Following excitation, central nervous system depression may intervene. Muscle weakness and respiratory paralysis may occur. Methyl bromide may produce cutaneous blisters and cause death via dermal exposure.

Methyl bromide is retained, at least for the short term, in body tissues. Repeated exposure may result in the presence of sufficient methyl bromide in tissues to cause illness.

Chloropicrin

Another commonly used fumigant is chloropicrin. Like methyl bromide, it is highly toxic. Unlike methyl bromide, it has a strong odor and is very irritating to the eyes at concentrations as low as 1 ppm. Thus, chloropicrin also is used as a tear gas. Although chloropicrin produces a strong odor, this odor should not be relied upon as a warning sign of exposure because individuals vary in their ability to detect odors and levels of odors. In addition, odors cannot be used to determine the concentration of fumigant present. If the concentration of chloropicrin in the work area is unknown or exceeds 0.1 ppm, all persons in the exposed area must wear appropriate respiratory protection.

If taken orally, chloropicrin can cause nausea, vomiting, colic, and diarrhea. Severe skin injury can result from dermal exposure. Inhalation of chloropicrin also may lead to vomiting. Prolonged respiratory exposure may result in severe lung injury.

Phosphine

Aluminum phosphide is the most widely used grain fumigant in Iowa. In the presence of moisture, aluminum phosphide breaks down and releases hydrogen phosphide gas (phosphine). Symptoms of phosphine exposure can be severe, but they are clearly recognizable and may be reversible if exposure is stopped as soon as symptoms begin to appear. Exposure is primarily respiratory because phosphine is not absorbed through the skin. The established threshold for phosphine is 0.3 ppm. Workers should not reenter a treated area without wearing appropriate respiratory protection until the concentration of phosphine has dropped below this level.

Slight or mild poisoning symptoms of phosphine include fatigue, buzzing in the ears, nausea, pressure in the chest, and uneasiness. Moderate poisoning symptoms include general fatigue, nausea, vomiting, diarrhea, disturbance of equilibrium, strong chest pains, back pains, a feeling of coldness, and dyspnea. Severe poisoning rapidly results in strong dyspnea, cyanosis (blue or purple skin color), agitation, unconsciousness, and death. Death may be immediate or can follow several days of edema (fluid) of the lungs, paralysis of the central respiratory system, or edema of the brain. Breath and vomit have a distinct odor of garlic or carbide.

Unlike methyl bromide, phosphine does not accumulate in body tissues. Any phosphine entering the body is eliminated within 48 hours.

Protecting human health

Label statements

Several new regulations have been enacted concerning the use and application of fumigants and worker safety. These regulations require that two applicators be present for most fumigant applications and mandate important changes in gas-monitoring practices, respiratory protection equipment, placard requirements, and notification and denotification of local police and fire departments. These regulations are presented as part of the use directions on fumigant labels and supplementary instructional material. Label instructions are considered law. Violation of the label instructions makes the applicator liable to criminal and civil proceedings.

Label statements that legally require the presence of two trained applicators during hazardous stages of fumigation reinforce long-standing recommendations that fumigators always work in pairs. New labels require that two applicators work together whenever fumigant application or gas monitoring requires entry into, or work within the confined space where a fumigant is applied. Aluminum phosphide and methyl bromide labels do allow an applicator to work alone if the fumigant is applied outdoors to a moving grain stream (aluminum phosphide) or in recirculation systems where methyl bromide concentrations do not exceed 5 ppm or phosphine concentrations do not exceed 0.3 ppm in the work area. Even so, the presence of two trained applicators is always a wise investment for safety in the event of accident or emergency.

Protective clothing and equipment

There is always a danger of exposure whenever fumigants are handled. Wearing protective clothing and other equipment offers some protection against dermal, inhalation, and eye exposure, but it does not eliminate the need for other essential precautions. When the label recommends the use of specific protective clothing or equipment, follow the recommendations explicitly.

The minimum protective clothing recommended when handling fumigants includes a long-sleeved shirt, long trousers, socks, and shoes. All items should be clean, dry, and free of holes and tears. Shirts and trousers should be loosely woven because tight-fitting garments can trap fumigants next to your skin. Coveralls worn over normal work clothes also are suggested, provided they fit loosely over the body.

Unlike other pesticides, it is not always recommended to wear gloves when handling fumigants. For example, when handling aluminum phosphide prepacs, no gloves are needed. But when handling aluminum phosphide tablets or pellets, dry cotton gloves should be worn. Do not wear gloves when working with methyl bromide because doing so can trap the fumigant between the glove and your skin and cause severe skin burns. Likewise, do not wear rubber boots because rubber absorbs methyl bromide and can cause severe chemical burns to your feet. When handling chloropicrin, use heavy neoprene gloves that are resistant to chloropicrin.

Respiratory protection

Cartridge respirators

Chemical cartridge respirators are usually designed as half-face masks that cover the nose and mouth but not the eyes. They have one or two cartridges attached to the face piece. The cartridges contain a filter pad that removes dust and spray particles and an absorbing material such as activated charcoal that removes most harmful vapors and gases. **Cartridge-type respirators are not suitable for protection against fumigants because the cartridges are too small and they tend to leak around the face piece.**

Canister respirators (gas masks)

Gas masks are normally designed to cover the eyes as well as the nose and mouth, and to fit more tightly than cartridge respirators. The canister is either attached directly to the face piece or worn on a belt and connected to the face piece by a flexible hose. Gas masks do not protect against deficient oxygen levels.

There are different types of canisters available for use. Always be certain you have the appropriate canister designed for the fumigant you are using. Like cartridges, canisters also contain filter pads and absorbing material but normally have longer effective lives. The effective life of an individual canister varies according to the fumigant concentration, humidity, and respiratory rate of the applicator. Maximum limits are stated on each canister or on the instructional information that accompanies each canister. The expiration date of the canister is the date the canister can no longer be used, regardless of whether or not it was ever unsealed.

Under NIOSH / MSHA regulations, canisters are color coded according to fumigant absorbency. Canisters approved to provide protection from hydrogen phosphide are coded yellow with an orange stripe. Canisters approved to provide protection from chloropicrin are coded black. No canisters are currently approved for protection against methyl bromide. No canisters are currently available for use in oxygen-deficient environments such as those produced during fumigation with carbon dioxide (CO_2). In addition to checking the color coding, applicators must be certain that written specifications indicate that the canister is effective against the fumigant to be used.

Canisters become relatively hot when they approach the end of their effectiveness. Some canisters have a color gauge or “window” that shows when they are about to become ineffective. Breathing hot air or encountering high resistance to breathing are also warnings that the canister is about to become ineffective. When this occurs, or when an applicator smells or tastes the fumigant or becomes nauseous or dizzy, the applicator should immediately exit the fumigated area. An expired canister should be crushed before it is discarded so that no one will mistakenly use it in the future. Additionally, a canister should not be used if the expiration date on the canister label has been exceeded.

Supplied-air respirators

Whereas cartridge and canister respirators filter contaminated air, supplied-air respirators provide a source of clean air either by pumping fresh air through a hose from outside the work area or from a cylinder of compressed air that is usually carried on the applicator's back. The latter is frequently referred to as a self-contained breathing apparatus (SCBA) and typically has a 20- to 30-minute supply of air. With either respirator, the hose is connected to a full-face mask.

Safe respirator use

No matter what type of respiratory protection will be worn, certain precautions should be followed. First, before any person wears a respirator, he or she should be examined by a physician to ensure proper physical health or respiratory fitness. Next, make sure that the gas mask, cartridge, canister, and air line are in good working condition. Next, check the mask for fit. An informal fit test can be accomplished by putting on the gas mask, blocking all air passages into the mask, and then inhaling. If the mask does not allow movement of air into the mask, the seal around the face is secure. An official fit test requires an irritant type of smoke to be used. Facial hair, such as a beard, side burns, or moustache can prohibit the gas mask from sealing tightly around the face, allowing gases to leak into the gas mask. New Occupational Safety and Health Administration (OSHA) standards require a written respiratory program. A complete listing of the requirements for respiratory fit testing can be obtained from an OSHA office.

Fumigant labels require the use of specific respiratory protection equipment during most fumigant applications. Labels also state maximum fumigant concentrations in which applicators can work without respiratory protection. Gas concentrations greater than specified levels indicate that exposed workers must use respiratory protection equipment.

Fumigant exposure limits

Phosphine

If the concentration of phosphine gas exceeds 0.3 ppm time weighted average (TWA) during the application of phosphine-producing fumigants, a canister-type gas mask, SCBA, or supplied air-line respirator (SALR) and SCBA combination must be worn (Table 1). At concentrations exceeding 15 ppm or when gas concentrations are not measured or are unknown, workers must wear either a SCBA or a SALR-SCBA combination.

After application of the phosphine-producing fumigant and reentry into the fumigated site, a SCBA or a SALR-SCBA combination must be worn if the concentration within the fumigated site is not known or exceeds 0.3 ppm. The TWA applies only during an application. A fumigant application is defined as the time period covering the opening of the first container, applying the appropriate dosage of the fumigant, and closing up the site to be fumigated.

Calculating exposure limits for phosphine

OSHA and the Environmental Protection Agency (EPA) have established certain TWA exposure limits for phosphine gas. A TWA exposure limit defines the maximum allowable concentration a worker may be exposed to during a specific period of time. OSHA has set two types of TWAs for phosphine: a short-term exposure limit (STEL) and an 8-hour TWA.

Table 1. Respiratory protection requirements for phosphine gas.

Gas Conc. (ppm)	Respiratory protection
0 to 0.3	none
0.3 to 15	full-face canister gas mask with approved canister for phosphine or SCBA or SALR-SCBA
>15 ppm	SCBA or SALR-SCBA
up to 1,500	Full-face canister gas mask with approved canister for phosphine **to escape** from concentrations of 15 to 1,500 ppm

A STEL is a 15-minute TWA that may be reached only four times per day. Each exposure to this limit must be at least 1 hour apart. The STEL for phosphine is 1.0 ppm and the 8-hour TWA is 0.3 ppm. The 8-hour TWA is calculated as follows:

TWA = $(C_aT_a + C_bT_b + \ldots C_nT_n) / 8$ h, where

C is the concentration during any period of time T,
T is the duration in hours of the exposure at the concentration C, and
"a" is the first exposure, "b" the second exposure, and so on for all exposures, "n."

Example: Calculate a TWA for a phosphine exposure of 0.5 ppm for the first ¾ hour, 0.2 ppm for the next ½ hour, and 0 ppm for the rest of the 8-hour period.

The calculated TWA would be as follows:

TWA = (0.5 ppm x ¾ h) + (0.2 ppm x ½ h) + (0 x 6 ¾ h) / 8 h
TWA = (0.375 + 0.1 + 0) / 8 = 0.059 ppm

In the example, the OSHA 8-hour TWA of 0.3 ppm was not exceeded, but the EPA ceiling concentration of 0.3 ppm was exceeded. The EPA allows the use of the 8-hour TWA of 0.3 ppm for applicators or nearby workers while the fumigant is being applied. Furthermore, EPA has not adopted a STEL, so the OSHA 1.0 ppm STEL must be followed.

Note: The use of a TWA to determine the need for respiratory protection does not apply to any of the other fumigants discussed in this manual.

Exposure limits of other fumigants

Workers exposed to methyl bromide levels greater than 5 ppm must wear a SCBA or SALR-SCBA combination. Workers exposed to chloropicrin levels greater than 0.1 ppm must wear a gas mask or SCBA. Workers exposed to CO_2 concentrations greater than 1.0 percent must wear a SCBA or a SALR-SCBA combination.

Detecting fumigants

Direct reading short-term detector equipment

Direct reading short-term detector equipment involves the use of a small manual pump that draws a prescribed amount of air through the detector tube. The detector tube consists of a small tube that contains chemicals that change color in the presence of the gas in question. These tubes are calibrated in parts per million so a direct, immediate reading can be taken.

There are several types of manual pumps available. Bellows pumps are sold by

MSA and Draeger. Piston-style pumps are sold by MSA, Matheson / Kitagawa, and Sensidyne. A rubber bulb style pump is sold by MSA. The number of pump strokes per reading varies between types of tubes and manufacturers. Thus, the length of time required to take a reading is influenced by this factor and should be considered when purchasing equipment. Pump kits can be used with a multitude of different tubes, with a list of the different tubes available and the gases they detect supplied by each manufacturer. All of the manufacturers listed previously provide low- and high-range phosphine tubes as well as low- and extra-low-range methyl bromide tubes. The low-range tubes can be used for concentration ranges that include the permitted exposure limits. These detector tubes are well suited for use with TLV, but because it takes only a few minutes to take a reading, they are not well suited to a 8-hour TWA.

Before using any pump, whether it is a piston, bellows, or bulb-type system, the pump should be checked for leaks. A leaking pump gives lower-than-actual concentration readings.

An example of how to use a Draeger type bellows pump system is described below. Many of the same principles apply to the piston or rubber bulb system, with minor modifications. To check for leaks in a bellows pump, insert a colormetric glass tube (unopened) into the tube receptacle and fully compress the bellows. If the pump is leaktight there should be no movement of the bellows for 1 minute. To use the pump with a colormetric tube for the detection of a gas concentration, break off both tips of the glass tube. On the Draeger bellows pump, an eyelet is provided to facilitate the breaking of the tip from the glass tube. A special tube breaker also can be purchased. After the ends of the glass tube have been broken off, tightly insert the opened tube into the pump head with the arrow on the glass tube pointing towards the pump. After the tube is tightly seated, hold the pump in an upright position at breathing-zone height and fully compress the bellows. After the bellows has been compressed, release the bellows by straightening the fingers. A suction process takes place automatically and is completed when the limit chain is taut. Repeat compression and suction steps as often as is specified in the tube operating instructions for that particular tube. To determine the gas concentration present, evaluate the color indication as described in the tube operating instructions for that particular tube.

High-range phosphine tubes work well in determining whether concentrations in fumigated areas are sufficient to control insects. Because it is not safe to enter an area under fumigation, these readings must be taken remotely using narrow-gauge concentration lines (i.e., ¼-inch polyethylene). Some of the low-range phosphine tubes detect concentrations as low as 0.01 ppm, whereas the high-range tubes measure from 700 to 3,000 ppm. For a successful fumigation, applicators need to achieve a phosphine concentration from 200 to 500 ppm over a 3- to 4-day period.

Low-range methyl bromide tubes detect concentrations as low as 2 or 3 ppm. Draeger is presently developing an extra-low-range methyl bromide tube that will detect methyl bromide concentrations down to 0.5 ppm.

The detector pump units are easy to use. Difficulty is often encountered, however, if the operator does not read the tube directions carefully. Although this equipment is relatively inexpensive, costs can multiply when many readings must be taken because the detector tubes are designed for a single use.

It is also important to stress that tubes from one manufacturer cannot be used with another manufacturer's pump.

Phosphine badges

Draeger has developed a passive, direct reading phosphine badge. This badge is a personal dosimeter that measures a TWA of phosphine exposure for periods up to 8 hours. The badge is a small card that is inserted into a diffusion holder that is clipped onto a person's pocket or lapel. Phosphine evenly diffuses through the permeable membrane of the holder onto the indicating layer of the badge, causing a uniform color change from white to gray. Exposure levels are easily evaluated by comparing the color change with the color-code scale printed on either side of the indicating layer. By dividing the corresponding value by the number of hours worn, the TWA is obtained. An additional feature of the badge is a short-term exposure window. If a dark gray color appears in this window, which can indicate an exposure concentration of 0.1 ppm within 1 to 2 minutes, the worker is alerted to either leave the contaminated area immediately or begin wearing the appropriate respiratory protection.

Halide leak detectors

Various forms of halide leak detectors are available. These are designed to detect refrigerant leaks. They also can be used to detect the presence and, in some cases, the level of methyl bromide because the bromine atom in methyl bromide is a halide. Many of these detectors are electronic devices. The primary use for such devices is for leak detection and not for determining exact levels of methyl bromide. The traditional detector that historically has been used for methyl bromide aeration and leak detection is one that uses a flame that is passed over a copper ring. The general concentration range of methyl bromide can be determined by the flame color coming off the copper ring. A very light green indicates a low gas concentration, whereas a royal blue indicates a high gas concentration. This device does not indicate methyl bromide concentrations below 25 ppm, so it is not adequate for determining worker safety. It can be used as an initial device to be followed by the use of more sensitive detection equipment. It cannot be used in an area where ignition sources are prohibited. It is very useful as a leak detector and can be purchased at most local air-conditioning supply stores.

Direct reading long-term detector equipment

A direct reading long-term phosphine detector tube is made by Draeger. It is designed for sampling from 1 to 4 hours. Air is drawn through this tube at a rate of approximately 20 ml / minute. Any air pump that can be adjusted to this rate may be used. Many manufacturers can provide this type of pump. Draeger provides a small battery-operated pump that is designed to be placed at a specific location, although it could be hand carried. SKC advertises a small battery-operated pump designed for use with this tube that is clipped to the worker's belt so that the tube can be placed in the worker's breathing zone and travel with the worker. If sampling for 4 hours, this tube measures concentrations from 0.025 to 0.375 ppm. If the sampling time is 1 hour, the concentration range is 0.1 to 1.5 ppm. This tube is used for TWAs but not for ceiling limits.

Electronic devices

Gas Tech makes two battery-operated electronic devices for phosphine detection: Model SC-7 and Model SC-87. Both devices provide a continuous LED readout of phosphine concentration and are set to read concentrations between 0.01 and 1 ppm. This range can be expanded to indicate concentrations up to 20 ppm, but readings may be inaccurate at lower concentrations; thus, it is not recommended that the range be expanded above 5 ppm. The SC-7 can be set to indicate the TWA over the sampling period. The SC-7 weighs 5 pounds but can be carried by using a shoulder strap. The SC-87 is much smaller and is designed to be attached directly to the worker as he or she performs normal work duties. The SC-87 does not calculate the average concentration. Both devices use an electrochemical cell for detecting phosphine.

The main disadvantage of the electronic devices is they need to be recalibrated several times per year. Also, when a substantial concentration is measured it takes approximately 5 minutes for the cell to clear itself. This delay causes the TWA displayed to be higher than the actual TWA. A data logger can be attached to the SC-7, thus allowing the storage and transfer of data to a computer.

International Sensor Technology has an electronic detector device, Model AG5000, that can be purchased for either low-range or high-range methyl bromide detection. It is calibrated in ranges from 0 to 50 ppm or from 0 to 40,000 ppm. Model AG5100 is a similar unit that can be clipped to a fumigator's belt.

The Fumiscope is an inexpensive electronic device used for methyl bromide detection. It can detect up to 1,000 ounces per 1,000 cubic feet but is not sensitive enough for worker exposure readings. It is a 9-pound battery-operated thermal conductivity unit that, when attached to remote sampling lines, is very useful for determining the concentration in an area under fumigation. The GOW-MAC Thermal Conductivity device is similar to the Fumiscope. By using these high-range devices an applicator knows when, or if, additional methyl bromide must be added.

Long-term gas absorption tubes

These devices are similar to the long-term direct reading tubes for phosphine, except the tubes are not calibrated and no color change occurs. Instead, the gas is absorbed during a sampling period. The tube is then sealed and sent to a laboratory for analysis. The turnaround time for analyses is typically from 1 to 4 months. Small, portable, battery-operated pumps are attached to the worker to draw air through the tube during the sampling period. The length of sampling, rate of sampling, and temperature also must be provided to the laboratory. These methods are used for determining long-term TWAs.

There are two validated methods for phosphine detection. They are NIOSH Method S-332 and OSHA Method ID-180. Method S-332 uses a small glass tube filled with silica gel that has been coated with mercuric cyanide. Colorimetry is used in the laboratory to analyze the results. This method was designed to be used at concentrations between 0.15 and 0.67 ppm. Method ID-180 uses a small glass tube containing beaded carbon coated with potassium hydroxide. This method uses ion chromatography to analyze the results.

NIOSH Method S-372 is designed for detection of methyl bromide. It uses activated charcoal in the glass tube. The laboratory analyzes the methyl bromide by using a gas chromatograph with a flame ionization detector.

Before purchasing detection equipment the buyer should carefully consider what detection range is needed and whether he or she wishes to determine ceiling concentrations, STELs, or 8-hour TWAs. The buyer also should consider the cost, accuracy, versatility, and convenience of use.

The technical expertise and conscientiousness of the person taking the readings are very important considerations. Although some of the monitoring equipment requires little expertise, it does require careful reading and strict adherence to the instructions.

Fumigants

Fumigants are pesticides or mixtures of pesticides that produce vapors (gases) that are toxic when absorbed or inhaled. Fumigants are formulated and sold as solids, liquids, or gases. All formulations volatilize when applied.

This definition of fumigants excludes aerosols, which are particulate suspensions of liquids or solids dispersed in air, and which are popularly referred to as smokes, fogs, or mists. It is important to make this distinction because it emphasizes one of the most useful properties of fumigants: as gases, they diffuse as separate molecules. This property enables them to penetrate into the material being fumigated and to diffuse away afterwards. Aerosols, by contrast, are unable to penetrate even a short distance into materials because their particles are deposited on the outer surfaces of structures.

It is important to remember that states may vary in their interpretation of labeling information regarding fumigants. Therefore, before using any fumigant, you should consider visiting with your state extension specialist or State Department of Agriculture to find out if there are any additional guidelines that must be followed for the legal use of fumigants in your state.

Methyl bromide

Methyl bromide is a colorless, odorless (under most conditions), and tasteless gas. It is heavier than air, so it usually settles out in low places when first released and can stratify during a fumigation. Fans should be used to speed up and maintain uniform gas distribution. Methyl bromide penetrates most commodities and is effective against all insect life stages. There is no fire hazard at normal rates of application. Even so, you must ensure that all pilot lights and other open flames are turned off when you apply methyl bromide because corrosion can occur from hydrobromic acid produced near high heat and moisture.

Methyl bromide is a fumigant that has many registered uses. It can be used to control drywood termites, powderpost beetles, and old house borers in structures. It can be used to control insect pests in soil, feed, and food grains, and in fruits and vegetables. Before using methyl bromide it is important to read the label to be sure that your specific application site is included on the label.

Methyl bromide is supplied in small cans containing 1 to 1.5 pounds of methyl bromide. These cans are ideal for small-scale fumigations. A special application device is recommended for puncturing the can. Polyethylene tubing can then transfer the methyl bromide into the fumigation enclosure. Heating the cans is usually not necessary. Methyl bromide also is supplied in steel cylinders of several sizes. In these pressurized containers, methyl bromide is a liquid. Once the pressure is released, the liquid vaporizes to a gas.

Methyl bromide supplied in cylinders is usually used for larger fumigation jobs. One-quarter-inch copper tubing is attached to the cylinder by a gastight fitting. This tubing is then formed into a 25-foot coil that should be immersed in a container of water heated to 150° F. The tubing from the heater to the fumigation chamber may be either copper or polyethylene. The fewer fittings the better because it is difficult to keep methyl bromide from leaking at the fittings. Because methyl bromide is heavier than air, fans must be used to provide equal distribution of the gas. When methyl bromide changes from a liquid to a gas it becomes very cold, and even though the gas has been heated, there is a chance that the low temperature created will change a part of the gas within the tubing back to the liquid state. Thus, a pan or poly-film sheet should be placed directly beneath the outlet end of the tubing to protect the commodity or structure from damage by the liquid.

After calculating the amount of methyl bromide required, the cylinder is placed on scales and weighed. From the total weight, subtract the weight of the fumigant required and set the new weight on the scales. When the scale beam balances, you have introduced the correct amount of methyl bromide and can close the discharge valve on the cylinder. Fumigation with methyl bromide is relatively quick and an exposure of 24 hours or less may be adequate for pest control.

Once the gas has been introduced, check for leaks by using either colormetric tubes or a halide gas detector (flame or electronic). The gas concentration within the fumigation enclosure also must be measured to ensure that there is an adequate concentration for a long enough period to obtain the desired pest control. There are several methyl bromide monitoring devices on the market that work well, including the Fumiscope manufactured by Robert K. Hassler Company, Altadena, California, and the GOW-MAC unit manufactured by the GOW-MAC Instrument Company, Madison, New Jersey.

There are a number of items that should not be exposed to methyl bromide. Some react with the gas and create long-lasting odor problems, whereas other items may actually be damaged by the gas. As a result, the following items should not be fumigated with methyl bromide:

- iodized salt
- full-fat soya flour
- materials that may contain reactive sulfur compounds such as some soap powders
- some baking sodas
- some salt blocks used for cattle licks
- sponged rubber; foam rubber as in rug padding, pillows, cushions, and mattresses; rubber stamps and other forms of reclaimed rubber
- furs, horsehair, pillows (especially feather pillows)
- leather goods (particularly white kid or any other leather goods tanned with sulfur processes)

- woolens (extreme caution should be used in the fumigation of woolen suits, coats, blankets, and hand-knit woolen socks, sweaters, shawls, and woolen yarn)
- viscose rayons (those rayons produced or manufactured by a process in which carbon bisulfide was used)
- paper (silver polishing paper and most of the inexpensive writing paper cured by the sulfide process)
- photographic materials used in dark rooms, cinder block, and any materials that may contain reactive sulfur compounds.

Seeds and bulbs that are to be used for planting, living plants or nursery stock, and fresh fruits and vegetables also may be injured. If seed grain is to be fumigated, it should be fumigated with phosphine or carbon dioxide. Pets, fish, and birds may be killed if exposed to methyl bromide.

Proper respiratory equipment must be worn when handling methyl bromide. Applicators should avoid wearing tight clothing, jewelry, gloves, and boots when applying methyl bromide. Any contaminated clothing or boots must be removed and not reused until they have been thoroughly cleaned and aerated. Whenever full-faced respiratory protection is not required, applicators should wear goggles or a full-face shield for eye protection when handling methyl bromide liquid.

Special considerations

In response to EPA's health concerns about methyl bromide, the methyl bromide label directions for the fumigation of residential or commercial structures have been modified. The new directions primarily concern the aeration of fumigated structures. Check the label carefully for these new directions. In addition, applicators must provide a structural fumigation fact sheet to the following persons:

- An adult occupant of a single family dwelling prior to the parties entering into a fumigation agreement; or
- the owner, manager or designated agent of the building for multiple-family dwellings, provided he or she acknowledges in writing to the applicator that a copy of the Structural Fumigation Fact Sheet has been provided to an adult occupant of each unit prior to the parties entering into a fumigation agreement; or
- an adult occupant of each unit in a multiple-family dwelling prior to the parties entering into a fumigation agreement; or
- the owner, manager, or designated agent for all structures or businesses other than family dwellings.

Phosphine fumigants

Aluminum phosphide

Aluminum phosphide is supplied as solid formulations. In the presence of atmospheric moisture, aluminum phosphide breaks down and liberates the gas hydrogen phosphide (phosphine). This gas is colorless but has a penetrating carbide or garlic odor due to impurities. Most people notice this odor at very low concentrations. It is important, however, to realize that the odor disappears before the fumigant has had a chance to completely dissipate.

Although hydrogen phosphide is slightly heavier than air, it has high molecular activity and does not tend to stratify. Fans are not normally needed to ensure even gas distribution, except in bulk commodity fumigations. Hydrogen phosphide in high concentrations (18,000 ppm) can explode. Therefore, manufacturers have found methods of controlling the rate of release of hydrogen phosphide. Some formulate aluminum phosphide with ammonium carbamate, whereas others use aluminum stearate, ammonium carbonate, urea, or calcium oxide. These controlled-release formulations prevent most explosion risks when used at proper application rates and methods.

Due to the manner in which hydrogen phosphide is liberated, the ease with which the gas is contained by fumigation films or barriers, and the carbide odor, hydrogen phosphide is safer to handle than methyl bromide. Hydrogen phosphide is a prime example of a highly toxic material with relatively low user hazard. Because the formulated aluminum phosphide does not break down immediately to liberate hydrogen phosphide, respiratory protection may not be needed during application of the fumigant. If the fumigated commodity has sufficient moisture, however, hydrogen phosphide can be released with 30 minutes. Thus, appropriate respiratory protection should be carried by each applicator and readied for use if needed. If gas masks are used, they should be equipped with canisters approved for phosphine.

Aluminum phosphide is formulated as pellets or tablets, or as a granulated form contained in bags or sachets. Each pellet liberates 0.2 grams of hydrogen phosphide, whereas each tablet releases 1 gram of gas. Individual tablets and pellets are packaged in resealable flasks so that the entire contents need not be used at one time. Aluminum phosphide also is supplied in gas-permeable, blister strips referred to as "prepacs." Each prepac strip contains 165 pellets and releases 33 grams of hydrogen phosphide. The prepac strips are generally packed in airtight, tearstrip tins with four prepacs in each tin. Once the tin has been opened, all four of the prepacs must be used. Aluminum phosphide comes in other types of packaging as well. Special gas-permeable paper bags containing 34 grams of 57 percent aluminum phosphide are available. Each bag releases 11 grams of hydrogen phosphide. Ropes made of tough, durable, gas-permeable gauze are manufactured with 528 tablets per rope. Each rope contains 16 sections, with 33 tablets per section. The ropes are packaged in a metal pail containing 1,056 tablets, or two ropes, per pail. A variation of this is the mini-rope. Each mini-rope pail contains 2,376 tablets, but a mini-rope differs from a normal rope in having only six sections per rope, with each metal pail containing 12 ropes.

Hydrogen phosphide, especially in high concentrations at high relative humidity, corrodes copper, brass, gold, and other metals. Switches, communication devices, computers, calculators, and electric motors contain sensitive components that can be destroyed if exposed to hydrogen phosphide. Corrodible materials should be removed from the area to be fumigated or partially protected by tightly sealing them in polyethylene.

Aluminum phosphide, or its residue, is not permitted to come in direct contact with most processed food. Pellets and tablets (or their reacted products) must not contact any processed food except processed brewers' rice, malt, or corn grits. This restriction means that aluminum phosphide pellets or tablets cannot be probed into other processed commodities but must be applied on trays or similar containers, or as prepackaged application devices such as "strips" or "blankets." Aluminum phosphide is also the only fumigant registered for the in-transit fumigation of insect pests in ships and railcars.

Proper respiratory equipment must be worn when handling aluminum phosphide. In addition, cotton gloves should be worn when handling aluminum phosphide pellets, tablets, or the residue that remains following fumigation.

Magnesium phosphide

Magnesium phosphide is similar to aluminum phosphide in that it also releases hydrogen phosphide when exposed to atmospheric moisture. It is produced in solid formulations of pellets or tablets, or impregnated onto polyethylene plates and strips. As with aluminum phosphide, magnesium phosphide pellets release 0.2 grams of hydrogen phosphide, whereas the tablets release 1 gram of the gas. Impregnated plates measure about 6 ¾ by 11 inches and are 5⁄32 inches in thickness. Each plate releases 33 grams of hydrogen phosphide. A strip is formed by attaching 20 plates together, end to end. Each strip or plate is sealed individually in gastight foil pouches. These pouches are not resealable. Pouches are in turn packed in tins, 40 plates or two strips per tin. The tins are packed three tins per case. Each case contains 120 plates or six strips and releases 3,960 grams of hydrogen phosphide. Magnesium phosphide also is packaged in small, gas-permeable blister packs used to fumigate equipment or small areas.

With aluminum phosphide, the release of hydrogen phosphide is slow, but with magnesium phosphide, the release of hydrogen phosphide begins minutes after exposure to atmospheric moisture. Therefore, concentrations of hydrogen phosphide that develop during normal application procedures would require the use of respiratory protection. Many of the same safety procedures and requirements for respiratory protection that apply to the use of aluminum phosphide also apply to the use of magnesium phosphide. Read and follow the label and application guidelines in the training manual before applying either aluminum or magnesium phosphide.

Special considerations

One advantage of aluminum and magnesium phosphide is that they are relatively easy to use for fumigation. The volume of the space to be fumigated is calculated, and the appropriate number of pellets or tablets is applied to that space. Another method is to place the appropriate number of bags, blister packs, or ropes in the fumigation area and either attach them to a cardboard tray or gauze belt, or place them directly in or on the commodity to be fumigated. The fumigated area is then sealed. Aluminum phosphide does not start to liberate hydrogen phosphide immediately; thus, an application may be conducted without respiratory protection. You must monitor the gas concentration, however, to determine if respiratory protection is required. Fumigation with aluminum phosphide does take time. Normal exposure periods are for 72 hours at 68° F and 45 to 55 percent relative humidity. Buildup of the fumigant concentration is slow. It may take from 12 to 48 hours before the desired concentration of phosphine gas is reached. The exposure period for magnesium phosphide may be as short as 36 hours. Concentrations of hydrogen phosphide released from magnesium phosphide build up faster than with aluminum phosphide. **Under no circumstances should water be permitted to contact aluminum or magnesium phosphide.** If water contacts aluminum or magnesium phosphide an explosion could result.

Decontamination of containers

Empty aluminum and magnesium phosphide containers can be decontaminated by triple rinsing them with water. Containers, stoppers, and absorbent pads should then be disposed of as prescribed on the label. States may vary in their disposal regulations. Contact your State Pesticide or Environmental Control Agency or hazardous waste specialist for more information on decontamination of fumigant containers.

Deactivation of spent dusts

Fumigations with aluminum or magnesium phosphide may leave partially spent dusts (green dust) that must be deactivated. Deactivation can be accomplished using either of two methods. The first method is referred to as the wet method. It involves immersing the partially spent dust in a well-mixed 2 percent detergent-water solution. Detergent should not be used for magnesium phosphide. Collect the partially spent dust from pellets or tablets in a bucket or container. Do not collect more than 2 to 3 pounds of partially spent dust per 1-gallon container. Pour the dust slowly into the container with the detergent solution and stir until the dust becomes thoroughly saturated and sinks to the bottom. Dusts from pellets or tablets should be mixed in no less than 10 gallons of water for each case of material used. Deactivating dusts within blister packs, prepacs, or paper bags involves much the same process as the loose dusts, except that the packages have a tendency to float to the surface. Use a wire basket that can be submerged or a suitable weight, if necessary, to hold the packages under water. It is important to remember that partially spent packages may ignite if they are allowed to float to the surface of the water. The suggested time that dusts or packages should be kept under water can be found in the fumigant's labeling or training manual. Different packages require different durations of emersion.

Magnesium phosphide plates and strips also can be deactivated by using the wet method. Strips should be cut into plates rather than attempting to deactivate an entire strip. Magnesium phosphide reacts very vigorously with water. Therefore, only one or two plates should be put into the water at one time. Reaction of magnesium phosphide should be complete within 15 to 30 minutes. The plates should be totally immersed, however, for at least 6 hours to ensure total hydrolysis.

Respiratory protection is required during wet deactivation of partially spent material. **Do not** cover the container at any time. Once the deactivation is completed, the water can be disposed of by pouring it onto the ground. State or local regulations may affect the manner in which you can dispose of the water-dust mixture. Contact your state extension specialist, State Department of Agriculture, or State Environmental Control Agency for further information.

The second method of deactivating partially spent dusts of magnesium or aluminum phosphide is called the dry method. Small amounts (not more than five flasks) of partially spent dust may be spread in an open area away from inhabited buildings that are restricted from access to humans or animals. Aluminum or magnesium phosphide is then further deactivated by atmospheric exposure. Putting partially spent dusts into buckets or other containers may lead to a flammable concentration of hydrogen phosphide. Blister packs, paper bags, and ropes containing partially spent dusts can be deactivated by spreading them out on the ground, but the preferred method is to put the packages into a wire basket or similar ventilated container, securely locking it, and then placing it in a well-ventilated area that is protected from rain.

Chloropicrin

Chloropicrin is a nonflammable liquid fumigant marketed in pressurized and nonpressurized containers. It is used as a soil and space fumigant but is no longer labeled for direct use on grain. Chloropicrin, however, remains an effective fumigant for the control of insects in aeration ducts and in the plenum area of bins with false floor aeration systems. Because chloropicrin is heavier than air, it can be applied to the bin floor and then move downward into the plenum area without the need for fans. This type of application would be made before filling the bin with grain. Chloropicrin is particularly effective against immature stages of grain insects that are developing within the grain kernel, and also is effective in the plenum area where grain or grain fragments that fall below the bin floor may be found.

Before using chloropicrin be sure to read and follow the label. Proper respiratory equipment must be worn when handling chloropicrin. If full-face respiratory protection is not required, applicators should wear goggles or a full-face shield for eye protection. Applicators also should wear full-body clothing that is washed after each use (or disposable protective clothing), heavy neoprene gloves, and a neoprene apron that is resistant to chloropicrin.

Carbon dioxide

Although phosphine and methyl bromide have been widely used as grain fumigants for many years, their future appears questionable because of insect resistance, concern for applicator safety, and chemical residues in food. Consequently, there is increased interest in the future use of modified atmospheres as alternatives for conventional fumigants. Fortunately, there is adequate information currently available to consider the use of inert gases for insect control in grain handling or storage facilities.

Controlled atmospheric storage is usually identified as a rapid change of atmospheric gas composition produced by inert gases. Modifying the concentrations of nitrogen (N_2), oxygen (O_2), and carbon dioxide (CO_2) in the atmosphere and maintaining such concentrations for specific periods of time and temperature are lethal to many species of storage insect pests.

Although CO_2 fumigations leave no toxic residues in treated commodities, applicators must realize that CO_2 gas is poisonous at high concentrations in enclosed spaces. The concentration of CO_2 in the atmosphere is about 0.03 percent. The TLV for CO_2 exposure is 1 percent. It is essential that CO_2 concentrations be monitored when applicators enter the fumigated structure and in enclosed work areas adjacent to the structure. Canister respirators and other equipment that filter a poisoned atmosphere do not provide protection in high-CO_2 and low-O_2 atmospheres. Only a SCBA provides adequate protection.

Methods of fumigation

Atmospheric vaults

Atmospheric vaults are usually small, well-sealed structures located far apart from other structures. Some are specially built for fumigation, whereas others are modified rooms or buildings. Atmospheric vaults have several advantages. For example, once an atmospheric vault has been built or modified for fumigation it can be repeatedly used. Gas concentrations can be monitored through a permanent arrangement. Commodities are easily moved in and out of the vault without special preparation. The applicator does not have to compute the volume of the structure each time the fumigation takes place. Special preparation of the commodity, such as padding corners, is not necessary. Although safety precautions must be observed, fewer considerations are necessary than in other methods of fumigation.

The disadvantages of vault fumigation include the initial cost of setting up a fumigation vault, the cost of moving the commodity to and from the chamber, the limited quantity of items that most vaults will hold, and the economical use of the facility.

Railcars and trucks

The fumigation of commodities in railcars or trucks is similar to vault fumigation. These vehicles should be well constructed and in good repair. If they are not, they must be made airtight, or the entire vehicle tarped so that the fumigant can be retained for the required fumigation period. Movement of the railcar during fumigation usually results in some loss of fumigant. When using aluminum or magnesium phosphide, however, hydrogen phosphide is generated over a period of time; thus, a low gas concentration is maintained. This concentration may not be enough to kill all stages of insects. It is also important to remember that trucks cannot be moved on any public road while under fumigation.

Building fumigation

Building fumigation is a modification of vault fumigation because the entire structure essentially becomes a fumigation vault. When using this method, only building contents that could be damaged by the fumigant need to be removed. Incidental control of nontarget pests is usually obtained. Less material is usually needed to make the structure airtight. This advantage, however, is usually offset by the labor required to find and seal gas leaks. The building is usually easily aerated. In general, exterior shrubbery does not need to be moved.

There are many disadvantages associated with building fumigation. The occupants of the building must be moved from the structure and, sometimes, from nearby areas. Because the fumigant can diffuse through walls, it may be difficult to maintain required gas concentrations. Additionally, insects in the exterior walls may not be killed because the gas concentration in these areas may be too low to be effective. Gas concentration test lines must be run throughout the structure. To determine the amount of fumigant needed, the volume of the building must be calculated. The fumigant must remain in the treated area for a period of time long enough to control the infestation. This may, in itself, be a problem because it is easy to overlook vents, cracks, conduits, etc., that may permit the escape of gas.

Premises inspection

If fumigation is required to control a pest problem, an on-site inspection must be completed. Frequently, the success or failure of the fumigation operation depends on what you learn, what you decide, and how you plan. You must ask yourself a number of questions and make a number of decisions. Some of these questions are as follows:

- If the structure itself is not infested, could the infested commodity be moved from the building and fumigated elsewhere? Assuming that removal of the infested commodity from the building is not practical, can you fumigate the commodity in place? Is there enough room between the commodity and walls or partitions so that you can seal the tarp to the floor? What is the volume of the commodity? What is the volume of the building? Can the structure itself be made reasonably airtight, or will it be necessary to tarp the entire building?
- From what construction materials is the structure built? Can the building materials be adversely affected by the fumigant? Are there broken windows that must be replaced? Are there cracks in the ceiling, walls, or floors that must be sealed? Are there floor drains or cable conduits that will require sealing?
- Are there any floor drains under stacked commodities? How are you going to handle air-conditioning ducts and ventilation fans? Will interior partitions interfere with fumigant circulation? Are the interior partitions gastight so that they can be relied upon to keep the fumigant from entering other parts of the structure?
- Are there parts of the building not under the control of your customer? Can these other operations be shut down during the fumigation? What are the building contents? Can any of them be damaged by the fumigant? Where are the gas cutoffs? Where are the pilot lights? Where are the electrical outlets? Of what voltage are they? Will the circuits be live during fumigation? Can the outlets be used to operate your fumigant circulating fans? Can circuits with fans be controlled outside?

Metals such as copper, brass, gold, and silver corrode when exposed to hydrogen phosphide, especially at high temperature and humidity. Therefore, items such as electric motors, smoke detectors, brass sprinkler heads, batteries and battery chargers, forklifts, temperature monitoring systems, electrical switch gear, telephones, computers, calculators, watches, and other electronic equipment should be protected or removed before fumigation. Hydrogen phosphide also reacts with certain metallic salts; therefore, sensitive items such as photographic film and copying paper should be protected. Depending on the fumigant, there are other materials that can be harmed. See the fumigant labeling or applicator training manual for further information.
An inspection of the exterior of the building also should be conducted. If you tarp the entire structure, can you make a good, tight ground seal? Is there shrubbery next to the building that might be damaged either by the fumigant or by your digging to make an airtight fumigation seal? Can this shrubbery be moved? How far is it to the nearest building? Does that building have air-conditioning? Does it have air intakes that could draw the fumigant inside, particularly during

aeration? How are you going to aerate your structure after fumigation? Are there exhaust fans, and where are the fan switches? Are there windows and doors that can be opened for cross-ventilation? Does the building contain any high-priority items that may have to be shipped within a few hours notice? If so, can you make provisions for interrupting the fumigation and aerating the building within a certain time requirement? Is the structure to be fumigataed located so that your operations may attract bystanders? If so, consider asking for police assistance to augment your own guards. Where is the nearest medical facility? What is the telephone number of the nearest Poison Control Center? Do you have the material safety data sheet (MSDS) or the label with you to provide information to the Poison Control Center or physician?

Once you are convinced that you have taken everything into consideration, prepare a checklist (see pages 39–42) of things to do and of materials needed. Don’t rely upon your memory. Finally, ask yourself the following two questions: What have I overlooked? Is fumigation still the best method of controlling the pest?

Vacuum fumigation

Vacuum fumigation is another modification of vault fumigation. The difference however, is that vacuum fumigation is conducted under vacuum rather than at atmospheric pressure.Vacuum chambers are large steel structures. By using a vacuum, the fumigation time can be reduced from 24 hours to about 4 hours. The vacuum both denies the insect oxygen and facilitates rapid penetration of the commodity by the fumigant. By adding an air-wash cycle (breaking the vacuum and drawing a second vacuum), aeration is also rapid. Vacuum fumigation chambers are usually found at port facilities and near large warehousing operations. The disadvantages of vacuum fumigation include a very expensive initial investment and the need to move the commodities into and out of the chambers. The fumigant usually used in vacuum fumigation chambers is methyl bromide. **Do not** use phosphine in vacuum fumigation chambers because phosphine may be explosive under vacuum conditions.

Tarpaulin fumigation

Tarpaulin fumigation involves the placement of a gastight material over the commodity or structure to be fumigated. The tarps may be specially made for fumigation, such as impregnated nylon, or they may be sheet polyethylene. Impregnated nylon tarps may be reused because they are very strong and resist ripping. Many sections of impregnated nylon tarps can be clamped together, so there is virtually no limit to the size of the stack or structure that may be covered. Polyethylene tarps can be used in thicknesses from 1 ½ mil up to 6 mil or more. The thinner material can be used only once, and only for indoor work. Thicker polyethylene tarps, such as 4-mil and 6-mil material, can be used outdoors and may be reused. Clear polyethylene eventually breaks down in sunlight. Therefore, black polyethylene films are preferred outdoors. It is normal to use gas-resistant tape and adhesives instead of clamps to join various sections of polyethylene sheets together. Moisture can develop on the underside of the polyethylene sheeting or tarp when fumigating commodities warmer than the surrounding air temperature. As a result, the poly sheeting or tarp should not be allowed to rest on phosphine-producing fumigants. Additionally, any moisture that may drip down the inside of the poly sheeting or tarp should not be allowed to come into contact with phosphine fumigants because it can result in an explosion. In addition to considering the material to use for tarpaulin fumigation, consideration must be given to the method of obtaining a ground seal. If they are smooth, concrete and asphalt surfaces can be satisfactorily sealed. Wood surfaces are not easily sealed. With wood, and frequently with soil surfaces, it may be necessary to place a section of the tarp material beneath the stack, as well as over it.

Several methods are available for obtaining an adequate ground seal. Of course, you must allow enough tarp material to skirt out from the stack. Then loose sand, sand snakes, or water snakes are used to hold the skirt to the ground surface. Snakes are merely tubes of cloth or plastic filled about three-forths full with sand or water. Do not fill them too full or there may not be enough ground contact to make a good seal. A word of caution about using water snakes: if the floor is not level, the water will run to one end and the seal will be poor. The snakes should overlap each other by about 1½ feet. Sometimes it is easier to use adhesive tape and make a direct seal to the floor so snakes are not needed. Occasionally, you may find a stack placed too close to a wall to obtain a good ground seal. One way out of this problem (if the wall is reasonably gas resistant), is to seal the tarp directly to the wall.

Indoors

If a stack of items is infested and requires fumigation, it is best to conduct the operation indoors so the stack is protected from wind and rain. If for safety, or other reasons, the storage area is not suited for fumigation, it is still better to move the commodity to another indoor location rather than to fumigate outdoors. This decision must be determined when you first inspect the structure. The commodity to be fumigated should be on pallets and not in direct contact with the floor. It is usually necessary to keep all persons not connected with the fumigation operation out of the area where the fumigation will be conducted. If partition walls are not impervious to the fumigant, the entire building needs to be evacuated.

If you are using methyl bromide, you must erect tarp supports that are 1 to 2 feet higher than the stacked commodity. The supports ensure that there will be adequate circulation of the gas during the initial stages of the fumigation. The gas introduction tubes should then be secured to the top of one of the supports. A pan or sheets of paper should then be placed beneath the gas introduction tube outlet to protect the commodity from any liquid methyl bromide. Next, all of the corners must be well padded to prevent the tarp from tearing. The lighter the polyethylene tarp, the more chance there is for tears. If the stack is large, nonsparking fans must be placed so that gas circulation is ensured. These fans should be run until gas concentrations are uniform throughout the fumigation area and again if unequal concentrations develop. You also must run tubing from various positions in the stack (one located high in the stack, one intermediate, and one at a low location) to the position where you will be sampling the gas concentration. The tarp can then be placed and sealed to the floor. You must know the volume of space beneath the tarp so that you can calculate the amount of fumigant needed. Because of the molecular activity of hydrogen phosphide, the air dome, tubing, and fans are not necessary; however, fans may improve the effectiveness of the fumigation.

Outdoors

The same principles as stated for indoor fumigation apply to outdoor fumigation. The difference is that the tarpaulin must be of a stronger material for outdoor fumigation. If polyethylene film is used, it must be at least 4 mil in thickness; 6-mil material is better. Black polyethylene is preferred over clear polyethylene because it is more resistant to the effects of sunlight. Black polyethylene, however, may conceal gaps between stacks, or other voids, and personnel working on top of the tarp may fall through. Such a fall could be fatal, especially if the fumigation has started.

A layer of loose sand placed on the skirt of the tarp is necessary to obtain a good seal. Additionally, steps should be taken to protect against unanticipated bad weather. If storms are expected, the fumigation should be delayed. Place braces over the stack (but under the tarp) so that rain will not accumulate in any low spots. Also, place weighted ropes (sandbags make good weights) over the tarp for protection against wind.

Entire structure

This type of tarpaulin fumigation is normally reserved for controlling drywood termites or wood-boring beetles. The fumigants normally used are sulfuryl fluoride (Vikane) or methyl bromide. Items that could be damaged by the fumigants or that retain gas must be removed. Building occupants have to be evacuated for the entire fumigation and aeration period. All pilot lights, flames, and electrical appliances have to be turned off. Tubing for drawing air samples has to be located at several places within the structure. It is best to introduce the fumigant into the structure at several locations. Nonsparking fans should be placed so the fumigant can be circulated throughout the structure for ½ to 1 hour after the introduction of the fumigant. If ornamental vegetation is too close to the structure to permit the tarpaulin to be sealed to the ground, the vegetation must be removed. All edges of the structure that could puncture or tear the tarpaulin must be well padded. Workers should wear shoes with nonskid surfaces, and all ladders should be strong and braced. Tarp sections then may be carried to the rooftop for further assembly. If impregnated nylon is used as the tarp material, the adjacent sections are usually connected with special clamps. Clamps can be used with polyethylene, but adhesive polyethylene tape may be better. Once enough sections have been joined, the completed tarp can be dropped over the sides of the structure and any additional clamping or taping completed. If the building top is flat, sand snakes should be used to hold down the tarp. If the roof is peaked, weighted ropes should be thrown over the tarp to prevent it from billowing. Excessive billowing of the tarp can ruin a fumigation job, and all possible measures should be taken to prevent this from occurring. The tarp should be drawn as close to the building as possible. If a high-capacity fan is placed in one doorway and directed outward, a partial vacuum is created and draws the tarp against the structure. The excess tarp material at the corners of the structure can then be drawn together and taped down. As in any fumigation, the ground seal is very important. The ground at this point should be level and devoid of vegetation. If the soil is porous, the soil around the perimeter of the building should be soaked with water to reduce the loss of the fumigant through the soil. Before using water to soak down any area, read the fumigant label. The tarp skirt must be at least 24 inches wide and weighted down by an ample amount of loose sand to withstand any unexpected wind. If sand snakes are used, they should be doubled or tripled.

Shipboard fumigation

The fumigation of products or commodities on board a vessel depends on the type of infestation present as well as the structure of the vessel. The volume of the area to be treated must be calculated to determine the amount of fumigant needed. Additionally, all cargo that may be exposed to the fumigant should be checked to make sure that it will not be adversely affected. All access to the fumigated area such as piping, bilge openings, ventilator openings, and hatches must be sealed. The use of heating and ventilation systems, however, may be helpful in temperature control, recirculation of the fumigant, and aeration of the treated area.

Because of the specialized nature and problems of ship fumigation, you should be thoroughly familiar with technical release No. 18-72 from the National Pest Control Association, *Good Practices in Ship Fumigation*, before undertaking any ship fumigation. In many instances firms or government agencies specializing in ship fumigation should be consulted.

Close cooperation with the responsible ship's officer, ship's agent and government inspector is essential. The Port Authority, Coast Guard, and fire and police departments should be notified, and guards obtained if necessary. If most of the cargo space is fumigated while the ship is docked, the entire crew not involved in the fumigation should be on shore. No one should be allowed to return until the ship is clear of fumigant and given a "Gas Free" certificate.

Application procedures

Railcar fumigation

There are several methods of phosphine fumigation that have been developed for railcars because of the high rate of insect contamination of commodities in this type of conveyance. Before fumigating any railcar, the car should go through a preloading inspection and cleaning. The inspection should determine the insects present and locate small holes or cracks that would allow the fumigant to escape. For boxcars, the door that will not be used for loading should be sealed from the inside. The door can be taped, but the most effective method of sealing involves using a liquid adhesive painted around the interior door frame. A precut 2-mil-polyethylene sheet is then secured over the entire door. The next step is to check the volume of the boxcar to determine the dosage. If the required dosage is used and other required conditions are met, the entire contents of the car should be thoroughly penetrated by the gas. This means egg, larval, pupal, and adult stages of the insects present will be killed.

One method of fumigation uses gas-permeable plastic fiber blister packs or wax-coated paper bags containing aluminum phosphide. The dosage rate may vary for different commodities (i.e., dried fruits or nuts versus packaged flour or grains). Check the fumigant application manual for recommended application dosages. The prepacs or paper bags are taped to cardboard discs or sheets in rows and then fastened to the top of the load, to the wall at each end, or on the wall on either side of the door used for loading. When using the gas-permeable ropes or mini-ropes it may not be necessary to tape them to cardboard disks or sheets. If tape is used, make sure that it does not cover any of the fumigant.

Magnesium phosphide tablets or pellets packaged as permeable blister packs or prepacs can be used in much the same manner as aluminum phosphide. Magnesium phosphide plates are placed in gas-permeable cotton bags that are then suspended from a nail on the wall or from the bulkhead. The bags also can be attached in rows on cardboard disks or sheets and placed on top of the load, on the wall at each end, or on the wall on either side of the door used for loading.

Once the fumigant has been applied, the remaining door should be covered in polyethylene, sealed with liquid adhesive, and taped before closing. As required by law, a warning sign or placard must then be placed on each door. The date and time of fumigation; the applicator's name, address, and telephone number; and the date and time the car can be opened must be on both placards.

Fumigating hopper cars with aluminum or magnesium phosphide is done nearly the same as with boxcars. The main difference is that with raw commodities such as corn, wheat, oats, and rice, the fumigant can be added to the commodity as it enters the hopper car. Additionally, the fumigant can be probed into the grain once the car is loaded. A popular method used by many applicators using the blister packs or paper bags is to attach them to cardboard trays that are then placed over the hatch openings. When using any of the aluminum or magnesium phosphide blister packs or paper bags mentioned previously, the procedure is changed only to the extent that the cardboard is precut to fit either the round or slot-type car. Tape is stretched across the opening to lend additional support to the cardboard. Magnesium phosphide plates can be put into gas-permeable cotton bags and suspended into the commodity. Hatch openings are then covered with polyethylene and sealed with tape and liquid adhesive. Allow for a 2 to 3 inch airspace between the fumigant and the plastic covering. If the gasket on the hatch cover is in good condition, no additional seal is required. A damaged hatch cover should be taped, as well as the hopper car end vents. If tape fails to properly seal the end vents, an asphalt-type compound may be needed to do the job.

After the fumigant and polyethylene are in place, the hatch is closed and warning signs are affixed on each hatch cover, and on each side of the car near the ladder. The warning signs state the fumigant and the applicator's name, address, and telephone number, and the date and time of the fumigation. Even though the car is now ready to move, the applicator's job is not finished. Any unused fumigant must be returned to a locked chemical storage area. If the railcar is to be shipped under fumigation, the person or company that will receive the railcar must be notified. In Iowa, the applicator or fumigation company is responsible for monitoring gas concentrations within a railcar to determine when aeration is completed, even if the railcar is moved to another location. This responsibility can be transferred to the receiving company or shipper only if the receiving company or shipper agree to **receive and monitor** the fumigated railcar. This agreement must be established, preferably in writing, prior to transport.

Space or tarp fumigation

Use of plastic (polyethylene) sheeting or tarpaulins to cover commodities is one of the easiest and least expensive means for providing relatively gastight enclosures that are well suited for fumigation. Poly tarps are penetrated very slowly by hydrogen phosphide gas and tight coverings are readily formed from the sheets. The volume of these enclosures may vary from a few cubic feet (a fumigation tarpaulin placed over a small stack of bagged commodity) to a plastic-covered storage capable of holding 60,000 bushels of grain or more.

An enclosure suitable for fumigation may be formed by covering bulk or packaged commodity with plastic sheeting. The sheets may be taped together to provide a sufficient width of material to ensure that proper sealing is obtained. If the commodity rests upon flooring made of wood or other porous material, it should be moved onto plastic sheets before fumigating. The plastic covering the pile may be sealed to the floor by using sand or water snakes, by shoveling soil or sand onto the ends of the plastic covering, or by other suitable procedures. The plastic covering should be reinforced by tape or other means around any sharp corners or edges in the stack so as to reduce the risk of tearing. Thinner plastic, about 2 mil in thickness, is suitable for most indoor tarp fumigations and for sealing windows, doors, and other openings in structures. Four-mil plastic or thicker, however, is more suitable for outdoor applications where wind or other mechanical stresses are likely to be encountered.

Blister packs, prepacs, or paper bags can be attached to cardboard or other ridged material and then applied to the tarped stack or bunker storage of bulk commodity through slits in the plastic covering. Use spacers or other methods to ensure that the plastic does not cover or rest on the fumigant or its packaging. The slits in the covering should be carefully taped to prevent loss of gas once the fumigant has been applied. Any moisture that forms on the underside of the plastic covering must not come into contact with the fumigant, or an explosion may occur.

Distribution of hydrogen phosphide gas is generally not a problem in the treatment of bagged commodities and processed foods. Fumigation of larger bunker storages containing bulk commodity, however, requires proper application procedures to obtain adequate results.

Warning placards must be placed on all sides of the fumigated stack with the required information. When gas readings are to be taken, test lines, which were placed in the fumigated area, are first purged to draw gas into the line. The concentration can then be read from detector tubes or an electronic direct-reading device. Several reliable detector devices are available, including Kitagawa, MSA, the Auer, and the Draeger. The scale is read in parts per million of hydrogen phosphide. A low-range detection tube also is available to monitor the surrounding area for worker safety.

If proper cross-ventilation is maintained in the area and the fumigant is less than that required for respiratory protection, work may continue in the warehouse. Large-space fumigations, such as mills, require special experience and should always be conducted by an experienced applicator. Among the applicator's duties are the notification and denotification of police and fire officials and, where required, the posting of guards.

The many intricacies of large-space fumigations, sealing vents, windows, and doors dictate that an experienced applicator be in charge. Following space fumigations, the residual dust of the fumigant material must be disposed of as described previously.

Fumigation safety checklist

The following fumigation safety checklist was produced by the National Pest Control Association. This checklist points out the major considerations for conducting a fumigation application. It emphasizes safety steps to protect lives and to prevent fires.The checklist is general and cannot be expected to apply to all fumigants in all types of situations. It is to be used only as a guide.

Preliminary planning and preparation

1. Become fully acquainted with the site and commodity to be fumigated, including:
   - A. The general layout of the structure, connecting structures, and escape routes, above and below ground.
     - Check equipment to ensure that product flow has ceased and that equipment has been made as tight as possible to prevent drafts or leaks.
     - Check all spouts, conveyors, conduits, heat pipes, or other possible openings leading from the areas to be fumigated.
   - B. The number and identification of persons who routinely enter the area to be fumigated, and the proximity of other persons and animals.
   - C. The specific commodity, its mode of storage, and its condition.
   - D. The previous treatment history of the commodity, if available.
   - E. Accessibility of utility service connections.
   - F. Nearest telephone or other communication facility.
   - G. Emergency shut-off stations for electricity, water, and gas.
   - H. Emergency telephone numbers of the local fire and police departments, hospital, and your personal physician.

2. Select a fumigant or combination of fumigants registered by the EPA for the required work.
   - A. Make certain the chemical or chemicals selected will not result in residues that may be illegal under Sections 408 and 409 of the Federal Food, Drug, and Cosmetic Act.
   - B. Check, mark, and prepare the points of application if the job involves spot fumigation.

3. Study directions, precautions, and antidotes on the label and in the manufacturer's instruction manual.

4. Notify local fire and police and other security personnel about the proposed location, chemicals, date, and time of application; the type of respiratory protection required; and the fire-hazard rating.

5. Inform local medical personnel of your fumigation practices and specific materials you will use.

6. Provide authorities with literature about safety measures for the materials to be used.

7. Arrange for standby equipment and replacement parts, and outline an alternate plan of action.

8. Inform all employees of the operational schedule, potential hazards to life and property, required safety measures, and emergency procedures.

9. Prepare warning signs for posting near treated areas, provide for security of buildings, and arrange for any necessary guards.

10. Have first aid equipment available.

11. If possible, plan for application from outside structure.

12. Plan to ventilate the treated space and commodities after the required exposure time is reached. Make this plan before you begin the treatment.

13. Identify the areas to be used for fumigant storage and provide conditions required by manufacturer's directions.

14. Make sure that no open fires, motors, or hot surfaces such as pipes or electric fixtures are within the space to be fumigated.

15. When necessary, provide fans for even distribution of the fumigant.

16. Provide gas sampling or detection devices.

17. Make a final check to clear all personnel and animals from the space to be fumigated.

Personnel

1. Assign at least two persons to each fumigation.

2. In circumstances where entry into a fumigated area is essential, use a "buddy" system—two workers, or groups of two.

3. Make certain that all employees actively taking part in a fumigation are in good physical condition, and that they:
   A. Have had physical examinations at least annually. Employee health records should be current.
   B. Have abstained from alcoholic beverages 24 hours before, and will abstain 24 hours after, a fumigation job.
   C. Have no colds or other conditions that impair breathing.
   D. Are not undergoing medical or dental treatment, unless a physician certifies they may work with fumigant chemicals.

4. Instruct all operating personnel about first aid, emergency procedures, antidotes, and decontamination.

5. Report any accidents to employer or supervisor. Personnel handling fumigants should be cautioned to report all indications of illness or physical discomfort, regardless of how minor it may seem. Some examples are dizziness, diarrhea, nausea, headaches, and lack of coordination.

6. Instruct all operating personnel about the hazards that may be encountered if selected chemicals are misused, and about the selection, operation, and maintenance of protection devices.

Protective equipment

The equipment recommended in this section is for prevention of injury or death. Follow the recommendations of the fumigant manufacturer about specific protective equipment and clothing. The limitations on operating conditions and performance of protective devices should be understood and observed.

1. When possible, arrange for two-way radio communication between employees applying fumigants within the treatment area.

2. Store all protective equipment to ensure maximum life of the device and accessibility to employees at all times.

3. Supply oxygen-breathing apparatus. Remember, however, that it does not prevent absorption through the skin.

4. Provide canister-type gas masks with super-size canisters that can be carried on the employees' backs. Note that canister-type gas masks:
   A. Are ineffective when breathable oxygen is too low.
   B. Do not prevent absorption through the skin.
   C. Will not remove toxic gases if the concentration is above the level stated on the label.
   D. Operate according to given conditions only if canisters are fresh.
   E. Require different types of canisters for different toxic gases.
   F. Should be mutilated after use.

5. Instruct personnel using canister-type gas masks that they must:
   A. Receive instruction in the proper care and use of gas masks and understand their limitations.
   B. Use the proper type of canister. (The label will provide information.)
   C. Check for airtight face pieces, hoses, and connections.
   D. Specify if special glasses are necessary.
   E. Be certain that the canister is unused or safe within the manufacturer's recommendations.
   F. Practice using an actual gas mask and become acquainted with it.
   G. Successfully pass a quantitative respirator "fit test" as outlined by OSHA regulations.

6. Recommend rescue belts for personnel required to enter fumigated tanks and similar enclosures.

Application procedures and fumigation period

1. Apply all fumigants in accordance with the label and labelling.

2. Post areas to be treated immediately before application.

3. Apply fumigant from outside where appropriate.

4. Caution personnel applying fumigants not to enter the area where fumigant gas or vapor is being discharged, except in extreme emergencies.

5. Take into consideration prevailing wind and other weather factors.

6. Provide guards where required.

Post-application operations

1. Provide guards where necessary.

2. Ventilate and aerate in accordance with structural limitations.

3. Turn on all ventilating or aerating fans where appropriate.

4. Use a suitable gas detector before reentry to determine fumigant concentration. Some fumigants do not provide adequate odor warning, and some areas aerate slowly.

5. Remove warning signs when aeration is complete.

6. Dispose of empty containers properly.

7. Return unused chemicals to their container. Make sure that the containers are properly and clearly labeled and then store them properly.

Structural insect management and fumigation

Fumigation of structures (residential and commercial structures other than food processing plants) is very rarely done in Iowa. Many other control options exist that are simpler and less dangerous to the operator, building occupants, and the public.

Structural fumigation should be used only when no other pesticide or non-chemical control method can reach the pest infestation. Alternatives to fumigation for structural pests include sanitation, habitat modification, disposal or replacement of infested materials and items, residual pesticides, and spot treatments.

Structural fumigation may be considered for elimination of the following pests:

- wood-destroying insects;
- drywood termites (uncommon; found in imported furniture);
- old house borer (does not occur in Iowa);
- powderpost beetles (active structural infestations are rare);
- carpenter ants;
- stored product pests;
- cockroaches, silverfish, carpet beetles; and
- rats and mice.

Fumigation of structural commodities can take several forms: whole- building fumigation, tarpaulin fumigation, and vault or chamber fumigation. Before deciding to fumigate an entire structure, you should determine whether or not the structure is infested. It may be easier, simpler, and less hazardous to remove infested items and fumigate them elsewhere (e.g., in a fumigation chamber). It is also possible under certain circumstances to fumigate infested items under a tarp rather than to treat the whole structure. Throughout the inspection and planning process continue to consider whether fumigation is indeed the best control method for a particular pest problem.

The precautionary statements previously given in this manual and on the product label must be followed during structural fumigation. Many additional limitations, precautions, and procedures unique to structures also must be followed. These include, but are not limited to, the following:

- Check with municipal and county authorities to become familiar with any local regulations such as required locks, guards, or notification of fire and police officials.
- Determine all possible air leaks that must be sealed (vents, cracks, broken windows, floor drains, sewer pipes, cable conduits, ventilation fans, fireplaces, and other openings).
- Decide if the structure can be adequately sealed or if it is necessary to enclose the entire building in an impervious tarpaulin.

- Determine if there are portions of the building not under your control. Can these be shut down and evacuated during the fumigation?
- Communicate to all involved occupants the details of the fumigation. For some products a structural fumigation fact sheet must be provided to and signed by an adult occupant, owner, manager, or designated agent.
- Remove or otherwise protect any items that could be damaged by the fumigant. These items include all food, animal feed, and medicines not sealed in metal or glass containers; seeds, bulbs, and live plants; pets, including fish and birds; furs, taxidermy specimens, and horsehair articles; rubber goods (natural latex); carbonless carbon forms and blueprints; automobiles; and articles containing sulfur.
- Locate all gas cutoffs and extinguish or turn off all open flames (pilot lights and electric heating elements).
- Open any interior doors (especially attics and crawl spaces). Open cabinet doors and drawers.
- Determine before the fumigation how to aerate the building. Locate exhaust fans, doors, and widows. Determine that they are operational and know which openings to use to provide the best and safest cross-ventilation.
- Release the fumigant from outside the structure. Position the shooting hose over an evaporating pan in a noncarpeted area. Very large structures will require release of fumigant at two or more locations to achieve even distribution of the gas. Circulating fans are essential.
- Maintain security and placarding throughout the fumigations and aeration.

Aeration and reentry

Know local requirements before beginning aeration. After tarpaulins and seals are removed from outside the building, open doors, windows, and vents. Until the building is completely aerated, entry is prohibited unless protective clothing and an approved self-contained breathing apparatus or air-supplied respirator is worn.

Natural (nonmechanical) ventilation may require a minimum of 7 days for structure aeration. Mechanical aeration by using fans inserted in windows or other exterior openings may require a minimum of 72 hours. After the aeration is complete the level of fumigant in the structure must be measured using a gas detector device. Only when it has been determined that the level of fumigant is below permitted levels can the building be returned to normal operation.

Stored grain insect management and fumigation

Because of geographic location, Iowa has particular advantages and disadvantages with regard to grain storage. The major advantage is prolonged periods of low temperatures because stored product insects and fungi generally remain inactive below 50° F. In contrast, rapid temperature changes, especially in the spring, combined with high humidity can cause moisture condensation on cold grain and may intensify some insect and mold problems.

Insect pests

Many different insects inhabit stored grain. The small size and overall similar-ity of many stored grain insects make their precise identification difficult. Although it is always wise to obtain a specific identification of any insects collected in stored grain, a general knowledge of the types of insects that occur in storage often provides a start towards understanding the role of an unidentified insect. A useful way to categorize stored-grain insects is to identify three major groups: true weevils (and other primary or internal insects), bran bugs, and surface-feeding caterpillars. The following paragraphs provide general information about these insect categories.

Primary (internal) insects

The most damaging insects of stored grain are those that develop within grain kernels. These insects are referred to as primary or internal insects. Females deposit eggs on or in whole kernels, and larvae develop within kernels. Damage caused by internal insects makes grain more suitable for infestation by insects that feed externally on grain or grain debris. The common primary insects of grain in Iowa are the rice weevil, maize weevil, and granary weevil. Other primary insects, such as the lesser grain borer and the Angoumois grain moth, are rare in Iowa.

Bran bugs

A second group of stored grain insects includes the beetles that develop and feed outside grain kernels or within cracked or damaged kernels. Most beetles commonly collected in stored grain in Iowa range in size from 1⁄16 to ½ inch in length. Adults of most species are reddish brown to black and have forewings that are hardened to form a shell-like covering over the body. Larvae of the most common species are cream colored and cylindrical. Species often collected in Iowa include the sawtoothed grain beetle, flat grain beetle, rusty grain beetle, foreign grain beetle, hairy fungus beetle, larger black flour beetle, and red flour beetle. Like the weevils, these beetles are not limited in distribution to the grain surface, but instead inhabit any portion of the grain mass. They are capable of feeding on several different grains, but their buildup in any grain depends on broken kernels (or other fine material) or on fungal growth on moist grain. This dependence explains the description of these insects as secondary pests, bran bugs, or fungus feeders. Concentrations of stored grain beetles can produce an increase in grain temperature and moisture, which may favor continued population growth.

Surface-feeding caterpillars

The third major group of stored grain insects is represented in Iowa by the surface-feeding Indian meal moth. This insect primarily inhabits the outer portions (i.e., the surface) of a grain mass, but it also can be found on the bottom of the grain mass just above perforated drying floors or aeration ducts.

Miscellaneous insects

Additional pests that sometimes infest stored grains in Iowa include psocids (booklice) and grain mites. These soft-bodied pests feed on grain-rotting fungi. An abundance of psocids or grain mites often indicates a more important problem of mold-related deterioration of the grain.

Beneficial insects

Not all insects found in stored grain are pests. Parasitic wasps, predacious fly larvae, and predacious Hemiptera (true bugs) attack certain grain pests. In addition, many field insects are inadvertently transported to grain bins where they cause no damage.

Characteristics of insect infestations and insect biology

It is important to realize that the behavioral and biological characteristics of the groups of stored grain insects discussed previously are important to management decisions. For example, an insecticide treatment incorporated in the surface portion of a grain mass may provide adequate control of Indian meal moth, but such an application cannot control a bran bug or weevil problem that already exists in the core of the grain mass. Likewise, cleaning grain to remove fine material contributes greatly to controlling at least some bran bug problems, but is of only limited value for reducing weevil infestations.

Although some stored grain insects may infest maturing grain crops in the field, field-originated storage problems are very rare in Iowa. Infestations more commonly develop from carryover grain, from small amounts of grain not cleaned from empty bins, from feed supply buildings, and from grain debris beneath the perforated floors of bins. Most insect species can fly at least short distances to reach new grain. Insect movement to, and development within, stored grain depends upon suitable air and grain temperatures. Common drying and aeration practices usually produce moisture and temperature conditions that allow a fall-harvested crop, such as corn, to remain nearly insect-free during the first winter of storage. As air and grain temperatures increase during spring and summer, insects can move into the stored corn and reproduce rapidly. Where corn remains in storage through additional seasons, normal winter cooling causes some insect mortality, but many individuals, although inactive, do survive. Each year of storage usually results in an increase in insect density compared with the previous year. The level of insect buildup at any particular storage duration varies among bins according to grain conditions (moisture, temperature, amount of fine material, and mold), proximity of insect sources, and the use of insecticides.

Some generalizations help to provide an overall understanding of insect population dynamics. First, insect reproductive potential is high, with females of the various species producing between 50 and 500 eggs. Under optimum conditions, individuals of several major species can develop from egg to adult in approximately 4 to 6 weeks. A few species, however, are characterized by the development of only 1 generation per year.

Although optimum developmental temperatures differ among species, the majority of insects develop most rapidly and successfully at temperatures ranging from 75° F to 90° F. At temperatures below 50° F, stored grain insects exhibit little or no activity. Cooling grain to temperatures below 50° F causes some insect mortality. It is important to note, however, that some species can survive extended exposure at temperatures at, or below, freezing.

Grain moisture also influences insect species composition and population densities. Several insects, including the foreign grain beetle, hairy fungus beetle, and mealworms, feed on fungi that develop in grain where the moisture content is too high for safe storage. Others, such as the weevils and the larger black flour beetle, are better able to feed directly on grain that is high in moisture content. Storage at moisture levels of 12 or 13 percent limits insect infestations, although some insect species can invade dry grain.

Insect damage

Insects damage stored grain directly by consuming kernels and reducing the weight and feed value of the infested commodity. Additionally, insects infesting stored grain produce heat and moisture that contribute to mold growth and spoilage. Owners of infested grain suffer the losses that occur before sale and the discounts or quarantines that may be imposed if live insects are detected upon attempts to deliver grain.

When discounts are assigned for an insect infestation, insect numbers and type of grain are important factors. Federal Grain Inspection Service (FGIS) standards for grain insect infestation are presented in Table 2. Local elevators, however, may levy discounts on the basis of more stringent standards.

Table 2. Number of live insects (per kilogram of grain) required for FGIS designation as infested.

Type of grain	Insect density for designation as infested
Wheat, rye, Triticale	2 or more live insects injurious to grain
Corn, soybeans, barley, oats, sorghum, sunflower, mixed grains	2 or more weevils, or 1 weevil and 5 or more other live insects injurious to grain, or 10 or more live insects injurious to grain

Preventing insect infestations in stored grain

Controlling established infestations of stored grain insects is often difficult. In all instances, preventing infestations is more profitable and successful than eliminating problems that have already developed. Preventative steps include thorough sanitation, application of an insecticide to empty storage, proper cleaning and drying of grain, application of protectant insecticides where extended storage is planned, and adequate aeration for temperature and moisture management.

Sanitation

An important rule for successful grain storage is that new grain should not be stored atop old, carryover grain. When this rule is ignored, insects that infest old grain readily move into the new grain placed in the same storage. Preventing insect carryover within a bin is also the reason for thoroughly cleaning bins before adding new grain. Cleanup should include removal of all grain that may be caked or webbed on the bin walls and all grain and debris on, and under, the bin floor. Persons working inside a dirty storage facility doing this cleanup job should always wear a filtering mask to remove both dust and mold spores. Although removing the perforated floor is impractical in most bins, cleanup practices that include the subfloor plenum are recommended where possible. Grain and grain debris should be removed from combines, wagons, and augers. Piles of spilled grain near bins serve as sources for insect infestations and should be removed before new grain is moved into storage.

Bin sprays and empty-bin fumigation

Applying a registered insecticide to the walls and floor of empty bins supplements but does not replace cleanup efforts. Insecticide residues provide control of insects that may have remained in hard-to-clean cracks and crevices or beneath the perforated floor. Sprays should be applied to the point of runoff, and applicators should be sure to thoroughly treat all cracks, crevices, and round doors. Directing extra spray to and through perforated flooring provides some control of insects in the subfloor plenum, but maximum control of insects in this space requires fumigation or the removal of the perforated floor and thorough cleanup.

Control of insects beneath perforated flooring is necessary when cleaning a bin in which grain will be stored during warm weather. Either chloropicrin or aluminum phosphide can be used to fumigate the subfloor plenum. Both of these fumigants are extremely toxic and hazardous. Closely follow the instructions provided in the following pages. Failure to comply with all label directions is unsafe and illegal.

Aluminum phosphide empty-bin fumigation

Use aluminum phosphide only on calm days. Make sure the temperature within the subfloor plenum is at least 60° F. Refer to the label to determine the correct appliction rate. Before applying the aluminum phosphide, seal the fan and all other bin openings below floor level. Scatter the appropriate rate of aluminum phosphide pellets or tablets over the floor surface and cover with a sheet of 4- to 6- mil plastic. This plastic should be at least 1 foot larger than the diameter of the bin and should fit up against the bin wall. Attach a length of rope to the plastic that is long enough so that it can be extended through the bin door. Shut the door with the rope draped across the threshold so that the loose end of the rope is on the outside, thus allowing you to remove the plastic without entering the bin. Placard the bin just as you would any structure under fumigation. After 72 hours remove the plastic and fan cover and run the fan for a few minutes to purge all fumigant from the plenum.

Chloropicrin empty-bin fumigation

Use chloropicrin only on calm days. Make sure the temperature in the subfloor plenum is at least 60° F. Before applying chloropicrin, seal the side door and all bin openings below the level of the side door. Be sure to seal fan openings and the unloading auger shaft. Post placards according to label directions. Always have a partner present when applying this, or any other, fumigant.

Chloropicrin can typically be used as an empty-bin fumigant at rates less than those required to fumigate the entire bin volume. Refer to the label to determine the correct application rate. To fumigate the subfloor plenum of empty bins, chloropicrin can be applied from a hatch on the bin roof. Chloropicrin forms a dense gas that settles in the lower portion of the bin, and does not spread to the upper portions of the bin to kill insects that may be hiding in grain debris remaining on the bin wall. The empty bin should remain sealed for at least 24 hours before aerating.

Moisture and fine material

Whenever management plans include keeping grain in storage during the summer, drying to moisture levels of 12 or 13 percent is recommended. This moisture range is less than the optimum for stored grain insects and helps to slow their buildup. In addition, insecticides applied directly to grain persist for a longer period on dry grain than on moist grain

Fine material (in corn, this is BCFM, or broken corn and foreign material) in stored grain is detrimental for several reasons. Broken kernels, weed seeds, and other crop debris often spoil at moisture levels generally considered safe for whole-kernel storage. Concentrations of fine material reduce airflow and prevent uniform aeration of a grain mass. Extremely fine particles form aerosol dusts that can explode. Fine material also contributes directly or indirectly to most insect problems in stored grain. Several bran bugs, including the red flour beetle and the flat grain beetle, depend on the availability of fine material to survive and reproduce. These insects release metabolic heat and moisture that contributes to the success of other bran bugs and weevils. Cleaning grain to remove fine material reduces the success of the most common insects found in grain in Iowa. As a general rule, rotary cleaners and aspirators are more effective in cleaning grain than perforated or screened sections of augers.

Protectant insecticides

Application of insecticides directly to grain to prevent infestation by stored grain insects is widely recommended if grain is to be stored for more than 1 year. These protectant insecticides are contact poisons that kill insects as they crawl about or feed on the treated grain and are generally applied to grain as it is being augered, loaded, turned, or transferred. Protectant insecticides do not readily form a gas and thus do not kill insects present in untreated portions of the grain mass. Therefore, a consistent rate of application is important when applying grain protectants to ensure an even distribution throughout the grain mass.

The stability of protectant insecticides and the duration of their effectiveness are determined by grain temperature and moisture. For example, protectants should not be applied before high-temperature drying or when temperatures drop below 40° F because these temperatures inhibit or limit the residual effectiveness of the protectant. Likewise, protectants applied to 13 percent moisture grain have a greater residual life than protectants applied to 15 percent or greater moisture grain.

Incorporating a top-dress or cap-off treatment is adequate for short-term protection against surface-feeding insects such as the Indian meal moth. Uniform application to the entire grain mass, however, is necessary for long-term protection against other stored-grain insects.

Controlling existing infestations

Management without fumigation

During cool weather, the use of aeration to cool the grain to 50° F or lower can prevent insect activity and allow an extended period of safe storage. Further cooling may provide some degree of control. Some stages of most insects, however, do survive the cooling procedures usually applied to stored grain. Once grain has been cooled, fumigation may be ineffective or prohibited until the grain has been rewarmed.

At times insect infestations are primarily limited to the surface or central core of a grain mass. If surface-feeding Indian meal moths are the only problem, a light infestation can be controlled by applying a registered insecticide as a top-dress or cap-off treatment. These treatments must be incorporated into the top few inches of the grain mass to be effective. The presence of abundant webbing on the grain surface may indicate a more severe infestation of Indian meal moth. The webbing should be raked from the surface of the grain before application and incorporation of the top-dress treatment. Fumigation also may be necessary in this situation.

Where bran bugs and other secondary insects are mainly confined to a central core that contains concentrations of fine material, removal of the core can reduce the risk of severe damage in the remaining grain. The grain removed from the core can be cleaned, treated with a registered insecticide, and returned to the same bin. Remaining grain that contains less fine material is not likely to be insect-free, but additional management and successful storage of this grain is easier once the excess fine material in the center of the storage has been removed.

Where primary insects such as the rice weevil are present, fumigation is necessary to kill the egg, larval, and pupal stages that occur within the infested kernel.

Stored grain fumigation

The leading cause of fumigation failure in stored grain is the inability to hold the fumigant at levels sufficient enough to kill insects in the fumigation area. Effective grain fumigation is dependent on a number of factors. The primary concern is that the bin or silo has been properly sealed.

Prior to introducing the fumigant, all bin surfaces should be inspected for holes or loose seams. One method of finding holes or leaks is to use smoke. Prior to filling the bin or silo a smoke canister is released within the bin. Points where smoke escapes can be marked with dye, paint, or other marking substances and later sealed with a caulking compound or sealant (Table 3). Only caulking compounds or sealants approved by the Food and Drug Administration (FDA) can be used inside the bin or silo or in other areas in which grain will come into contact.

If the bin or silo already contains grain, the inspection and location of leaks must be done without the use of smoke. Just prior to fumigation roof ventilators and aeration ducts should be covered with plastic bags that are gathered at the base and taped into place. Doors should be closed and sealed with a foam sealant or tape. Make sure that the roof–wall junction is tight.

Table 3. Chalking compounds and sealants.

Surface	Sealant
Access door and fill-hole seams	Urethane sealant Chemseco, Sikaflex #201
Roof seams	Urethane sealant Chemseco, Sikaflex #201
Sidewall and roof juncture	Vinyl sealer SM-904 sprayable vinyl sealer
Sidewall and floor juncture	Asphalt sealant Chemseco SM-570

*Other sealants are also commercially available.

Before applying phosphine, level the grain surface and break up any encrusted areas. These areas are sometimes hidden from view, usually just below the grain surface. Failure to locate and break up encrusted grain results in uneven penetration of fumigants and may lead to further deterioration of the grain from mold development and from invasion by insects.

Determine the amount of phosphine required to treat the volume of grain in the bin and in the headspace. If you use the tablet formulation, apply 90 tablets per 1,000 bushels. Allow extra tablets for the headspace unless the grain is going to be covered with a plastic sheet immediately following application of the fumigant. Increase this rate up to 180 tablets per 1,000 bushels if the grain bin cannot be adequately sealed or if the temperature of the grain is below 68° F. Decrease the dosage to as few as 60 tablets per 1,000 bushels if the bin is exceptionally gastight, contains clean, dry grain, or if the grain temperature is above 80° F. Read the label for exact dose recommendations. There are certain variations depending on whether you use aluminum or magnesium phosphide.

Before application divide the bin into quarters and place 25 percent of the required number of tablets in each pie-shaped section. Divide the total number of tablets per quarter by five to determine the number of probe applications needed per quarter. For example, if the total number of tablets needed for fumigation is 280, the number for each quarter is 70. Thus, each quarter of the bin would be probed 14 times with five tablets each. When inserting the tablets with a probe, place the first tablet in the probe when the bottom of the probe is 5 feet into the grain. Next, raise the probe 1 foot and place the next tablet in the probe. Continue until all tablets are used. The last tablet should be about 6 inches below the grain surface. After all sections of the bin have been probed, close the bin and seal and placard the access point as previously described.

Large bins or storage tanks taller than 30 feet are not easily fumigated with aluminum phosphide, except where the bin can be "cored." Hydrogen phosphide gas does not readily settle to reach lower portions of tall bins. Therefore, phosphine tablets or pellets inserted by surface probes are not deep enough to allow for uniform distribution of the gas. This problem can be overcome, at least partially, by unloading grain to extract the bin's central core and returning that grain into the top of the same bin with a metered application of aluminum phosphide. Continuous unloading and refilling of the core causes aluminum-phosphide-treated grain to be reintroduced to the top of the bin and drawn down to the bottom of the bin. Such cycling allows application of aluminum phosphide to a moving grain stream without transfer to an empty bin.

Application of aluminum phosphide while grain is cycled within a single large bin requires prior calculation of the number and rate of tablets or pellets to administer. The goal is to have almost all of the correct total dosage applied by the time the first tablets or pellets reach the bottom of the bin. Applicators must know the grain transfer rate and have an accurate estimate of the number of bushels that must be cycled before the first tablets or pellets reach the bottom of the bin. Although this method can effectively fumigate large bins, it requires thorough knowledge of the grain-handling system in use. Other approaches, such as recirculation of hydrogen phosphide, also may be practical.

During fumigant application gas concentrations must be monitored. Monitoring can be done using colormetric (Dreager type) tubes. If the concentration of the phosphine gas exceeds 0.3 ppm on an 8-hour TWA, or you do not wish to monitor the gas concentration during the application, the people within the bin must wear a NIOSH / OSHA approved full-face canister gas mask with appropriate gas canister or a positive pressure respirator (SCBA or supplied-air respirator). Gas loss can be reduced by placing a polyethylene sheet, cut to the appropriate (surface of the grain) size, over the grain before sealing the door. Post placards by attaching them to the door and ladder. Leave the bin sealed for at least 5 days after application. Never leave plastic on the grain surface more than 7 days. Following fumigation, the grain should be ventilated so that phosphine gas concentrations are below 0.3 ppm before reentry into the bin. If for any reason you have to reenter the bin during the fumigation or before ventilation is complete and do not know the gas concentration remaining within the bin, you must be accompanied by at least one other person and both must wear appropriate respiratory protection. The respiratory protection required for different gas concentrations of hydrogen phosphide is listed on page 20. Placards cannot be removed until the phosphine gas concentration is less than 0.3 ppm. If the grain is moved before this time, the placards must be transferred to the new storage site and remain until the gas concentration is less than 0.3 ppm. Monitoring of phosphine gas concentrations along the transfer route should be done to ensure that workers are not exposed to gas concentrations of 0.3 ppm or greater unless they wear the proper respiratory protection.

Another method of fumigating grain involves recirculation of the gas within the bin. The bin is sealed as previously described, except that polyethylene tubing or sleeves (12 inches in diameter) are placed around one of the top ventilators and a bottom aeration fan. Phosphine is then placed either in the top (as specified previously) or in the aeration duct. If the tablets or pellets are placed in the aeration duct make sure that the ducts do not contain any water. Blister packs or bags may be easier to handle or use. When recirculating phosphine be careful to not approach the flash point (18,000 ppm) of phosphine. The polyethylene sleeves should be secured in place to avoid cutting or wear. Where the sleeve goes over or around a sharp corner, like at the roof edge, you may wish to attach the sleeve to a polycanvas or metal elbow. When the sleeves are in place and the phosphine has been applied, the aeration fan recirculates the phosphine throughout the bin, usually from the bottom up.

If you use methyl bromide you can follow the same procedure as described in the previous paragraph, except that the methyl bromide is applied to the top of the grain bin and pulled down through the grain. Methyl bromide is applied using pressurized cylinders with the dosage calculated by pounds of fumigant per volume of grain. Read and follow label directions.

Factors affecting fumigant use in stored grain

Many factors affect the use and effectiveness of fumigants. The state of development and activity of the target insect are important. Active adult insects, for example, are easier to kill than inactive or hibernating adults. Immature insects generally require higher dosages or longer exposure times than adults. Eggs and pupae are the most difficult life stages to kill. The amount of free or open space in the area to be fumigated, the temperature, the porosity of product, the kind of product, the location of the insect within the product, and the structure to be fumigated all affect dosage and exposure period.

Temperature

The most important factor influencing the action of a fumigant is temperature. As temperature increases, the volatility of the fumigant increases so that it is released more rapidly, disperses and penetrates more quickly, and adsorption and absorption by the material being treated is reduced. In addition, the insect's rate of metabolism is higher and it is respiring more rapidly so that less fumigant is required to kill the insect. As a result of these effects, the dosages needed decrease as the temperature increases. Fumigants may not kill the insects if temperatures of the space are below 50° F or above 115° F.

Air movement or diffusion

It is necessary for a fumigant gas to be spread evenly and quickly throughout the space being treated. The gas must move, or be moved, into small crevices, cracks, or spaces within finely ground materials so that the gas will quickly come in contact with all of the commodity and insects within the confined area. The ability to spread varies among gases depending upon their weight and penetrating characteristics. Methyl bromide may require air circulation to avoid settling or stratification, resulting in poor control in part of the area and excessive residues or phytotoxicity in other parts of the treated area. Circulation with aluminum phosphide is usually unnecessary. Upright silos deeper than 40 feet are the only common exception. Diffusion or movement of the gas is favored by higher temperatures, lower air pressure, shorter distances to be penetrated, and higher initial concentration. The rate of evaporation of a fumigant into the treatment area is increased by stirring or moving the vapors rapidly from the evaporating surface. Air movement equipment is often used, and in some instances is necessary, for satisfactory fumigation. The type of equipment selected should fit the job. Fans are sufficient to stir up the air in relatively open areas. Confined areas with tightly packed commodities require the use of blowers or ducts and pipes to move the air from one place to another. Once the proper mixture with air has been obtained the problem of stratification of heavier-than-air fumigants is greatly reduced. Air movement resulting from poor seals results in loss of gas, with resulting lower concentrations and poor control, unless overdosed or recharged to offset the loss from leakage.

The use of fans to redistribute gas in a farm bin under fumigation is not advised. Introducing a single fumigant application, or other insecticides, through aeration or drying fans is ineffective. Repeated applications, introduced through the fans, may be effective if properly timed.

Absorption and adsorption

The extent to which a fumigant is absorbed (soaked up) by the commodity and the extent to which the fumigant adsorbs (binds or sticks) to the surfaces of the commodity affect both the performance of the fumigant and the amount of fumigant used. Sorption is a collective term referring to both absorption and adsorption. Several factors can influence the extent to which absorption and adsorption occur. For example, finely ground products such as flour or spices usually have greater absorbing and adsorbing characteristics and thus require more fumigant than grain or metal objects such as machinery. Likewise, clean grain requires less fumigant than grain that is damaged or contains excessive foreign material. In addition, commodities with high potential for adsorption or absorption usually require longer treatment periods for the fumigant to thoroughly penetrate the commodity. Commodities with high adsorption or absorption rates also take longer to aerate once the fumigation is over. This slower release of fumigant may cause problems with an off-flavor, persistent odor, or toxic residues above legal tolerance limits.

Moisture

As the moisture content of a commodity increases, penetration of the fumigant becomes more difficult. High moisture also increases the potential for residues to exceed legal tolerances. Adequate moisture, in contrast, is required for the generation of some fumigants, and with living plants may be necessary to avoid phytotoxicity. The moisture in the air is important for some fumigants to work. Aluminum phosphide in its solid state is not a fumigant; it must react with the humidity in the air to generate poisonous hydrogen phosphide gas.

Structures

The type of structure, what it is made of, and how tight it is influence the amount of fumigant needed and, to a large extent, dictate the success of a fumigation. Wooden structures, even when tightly constructed and well sealed, do not retain fumigant as well as steel, masonry, or concrete structures. Concrete silos usually retain fumigant better than other types of structures. Even new steel bins or buildings allow fumigant to escape rapidly unless care is taken to seal them properly. In general, round steel bins retain fumigant better than flat grain storage.

Plastic is frequently used to drape over commodities, cover the surface of grain, or close off large doors or openings. Although fumigants can penetrate through plastic, this penetration is slow. Plastic offers a good means of restricting air movement and concentrating fumigant in the commodity that you are attempting to fumigate.

Solubility

Each fumigant has its own solubility properties. Solubility is a measure of how the fumigant mixes with, or becomes incorporated into, materials exposed to it. Consequently, fumigants may react with some components of a commodity under fumigation. For example, methyl bromide is soluble in some oils and cannot be used on some high-oil-content commodities because of potential residue problems. Methyl bromide also reacts with, and may ruin, products made of rubber, including sponge and foam rubber, rubber insulation, and rubberized clothing or gloves. Aluminum phosphide is not soluble in oil and can be used to fumigate most commodities that are high in oil content.

Flammability

Fumigants have different flash points and vary in their potential to burn or explode. In some instances flammable fumigants are formulated with a safener to reduce this danger. Among the fumigants normally used in Iowa, chloropicrin is nonflammable and methyl bromide has a high flash point and a corresponding low potential for flammability or explosion. Aluminum phosphide, in contrast, generates hydrogen phosphide gas that has a very low flash point and ignites if high concentrations of 18,000 ppm are suddenly exposed to air. Aluminum phosphide also reacts with water and may explode if it comes in contact with water.

Some characteristics of three common grain fumigants can be summarized as follows:

Chloropicrin
Heavier than air: yes
Grain penetration: poor
Flammability: none
Warning odor: tear-gas
Germination effect: depresses

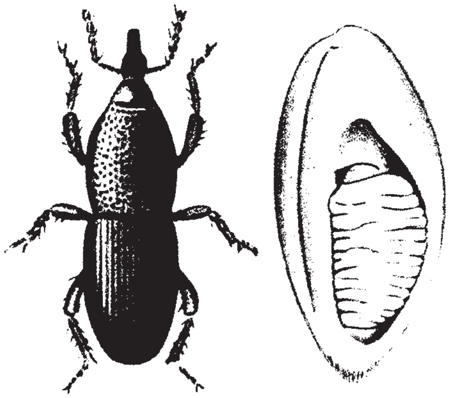
Methyl bromide
Heavier than air: yes
Grain penetration: excellent
Flammability: none
Warning odor: none
Germination effect: depresses

Aluminum phosphide
Heavier than air: slightly
Grain penetration: excellent
Flammability: self-combustible above 18,000 ppm
Warning odor: garlic or carbide
Germination effect: none

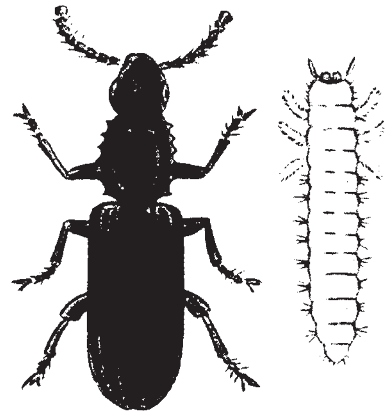
Picture sheet No. 1

PRINCIPAL STORED GRAIN INSECTS

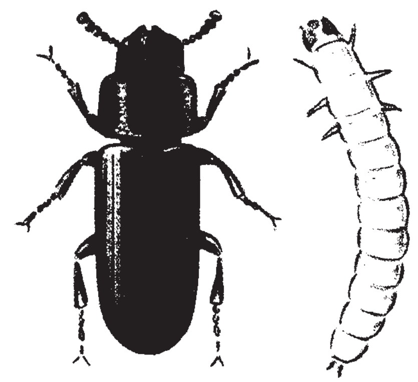
For safe and effective use of insecticides, always identify the problem correctly.



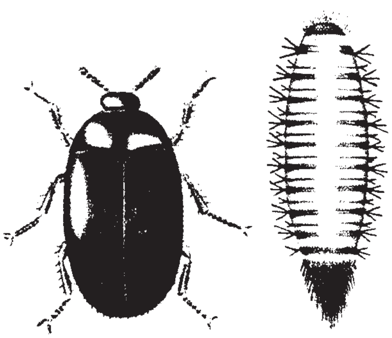
1. Granary weevil



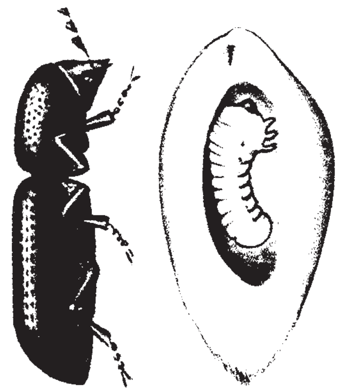
2. Saw-toothed grain beetle



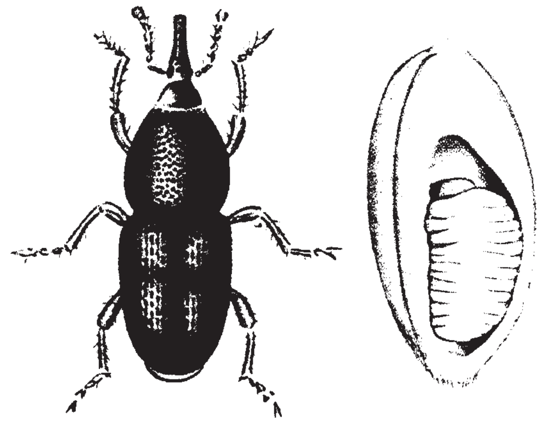
3. Red flour beetle



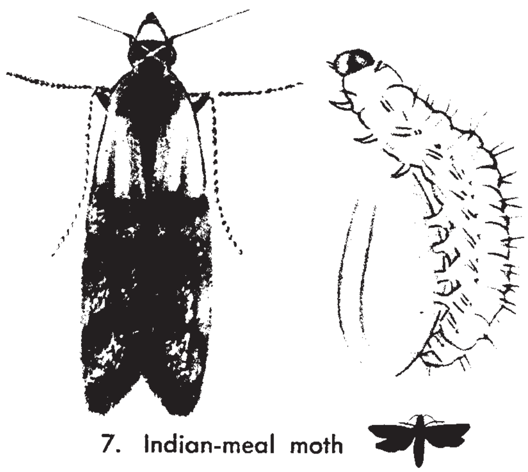
4. Larger cabinet beetle



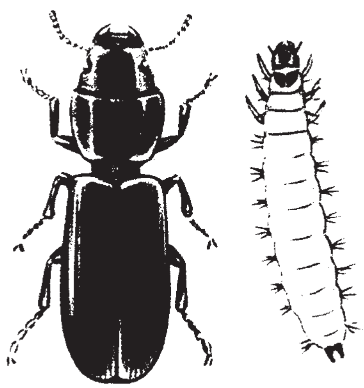
5. Lesser grain borer



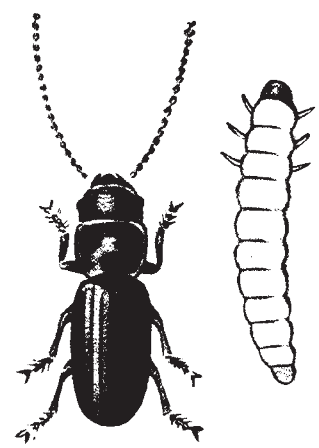
6. Rice weevil



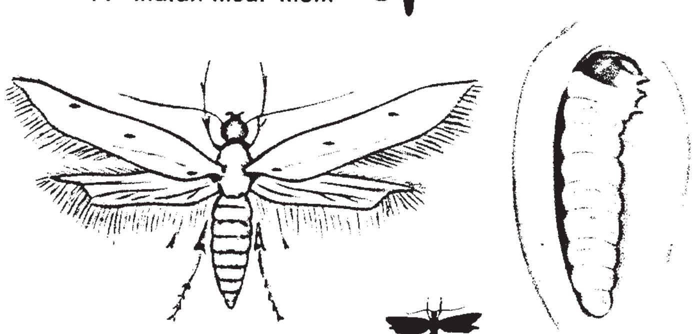
7. Indian-meal moth



8. Cadelle



9. Flat grain beetle



10. Angoumois grain moth

Some of these stored grain insects are also KITCHEN PESTS.

The sawtoothed grain beetle, red flour beetle, larger cabinet beetle, and Indian meal moth develop in flour, cake mixes, corn meal, breakfast foods, and similar products. The Angoumois grain moth infests popcorn.

Prepared by Extension Entomologists of the North Central States in cooperation with the Federal Extension Service, U. S. Department of Agriculture

PRINCIPAL STORED GRAIN INSECTS

1. **Granary weevil** is never found breeding in the field. It occurs only in places where grain is stored. A polished, chestnut-brown or blackish beetle, it is very similar in size and appearance to the rice weevil. However, it has no yellow markings on the back and has no hind wings, distinguishing it from the rice weevil. Adult beetles live about 7 to 8 months. The life history is like that of the rice weevil.

2. **Sawtoothed grain beetle** has a thorax with 6 saw-tooth projections on each side. It is often found in flour mills and warehouses. This species, together with the red flour beetle, causes major damage to stored grains and processed cereals in Iowa. Adult beetles may live for more than 3 years, though the average is 8 months. Females lay from 45 to 285 eggs, dropping them loosely in grain or in a crack in the kernel itself. The small, white eggs hatch in 3 to 5 days, and the larvae move about and feed freely. Larvae mature in about 2 weeks in the summer and construct "nests" of small grains and fragments stuck together with a sticky secretion. In this cell the larva changes to the pupal stage for about a week, emerging in the adult form.

3. **Red flour beetle** is an important pest of ground cereal products. The last few segments of the antennae are abruptly larger than the preceding ones. Unlike the confused flour beetle, this insect is a strong flier. Feeding and breeding habits of the two are alike and the larvae are very similar. Femlaes may live a year or more and lay about 400 to 500 eggs, dropping them in raw and processed cereals and grains. Larvae are wiry in appearance, about 3/16 inches in lenght, and whitish, tinged with yellow. Development from egg to adult is about 4 weeks.

4. **Cabinet beetles** belong to a large family that includes insects that attack animal products such as hides and wool rugs. Those we are concerned with feed mostly on grain products. A generation can be completed in 5 weeks. Larvae are hairy.

5. **Lesser grain borer** is found in flour as well as in stored grain. The beetle is a strong flier, and both adults and larvae cause serious damage, attacking a variety of grains. This species is uncommon in Iowa.

6. **Rice weevil** is the most destructive pest of stored grain in the world. It is a small reddish-brown beetle, about 1/8 inches in length, with four light-yellowish spots on the back. Adults fly. Adults live 4 to 5 months, and females lay about 300 to 400 eggs in holes bored in kernels of grain. Larvae hatch inside the kernel and mature there. The period from egg to adult may be as short as 26 days.

7. **Indian meal moth** breeds freely in ear corn and other feeds of all kinds around the farm and flies to bins of shelled corn or other grains where larvae may completely web over the surface. Female moths lay about 200 eggs singly or in groups on foodstuff. Caterpillars are dirty white with sometimes a greenish or pinkish tint. Moths are about 1/2 inches in length. The period from egg to adult is about 4 weeks.

8. **Cadelle** sometimes burrows into the woodwork or empty bins as larvae and remain dormant until fresh grain is stored. A seemingly clean bin may hold thousands of the insects. The cadelle is one of the longest-lived of the insects that attack stored grain; many adults live for more than a year and some for 2 years. Females lay about 1,000 eggs which hatch in 7 to 10 days into white larvae with black heads and two black points at the end of their bodies. Period of development from egg to adult is at least 70 days.

9. **Flat grain beetle** prefers grain that has been damaged and cannot survive in sound grain. Small white eggs are placed in crevices of the grain or dropped loosely. When fully grown, larvae may form cocoons to which food particles stick. Development from egg to adult may be as short as 5 weeks but is usually about 9 weeks.

10. **Angoumois grain moth** flies to fields of ripening corn and wheat as they are nearing maturity and females lay eggs on the wheat heads or corn kernels. Between crops the adults breed in grain in storage. Females lay about 40 eggs, one egg per kernel. Larvae hatching from the eggs bore into the kernels, where they develop.

Descriptive information prepared by entomologists at Iowa State University.

Pm 463-1 | October 1975

IOWA STATE UNIVERSITY
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Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Stanley R. Johnson, director, Cooperative Extension Service, Iowa State University of Science and Technology, Ames, Iowa.

Before Using Any Pesticide

STOP

READ THE LABEL

All pesticides can be harmful to
health and environment if misused.

Read the label carefully
and use only as directed.