Arizona Department of Agriculture

Quality... from the land to you

Agricultural Fumigation Guide

For the Arizona Private Pesticide Applicator Certification

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for the

Arizona Department of Agriculture

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Introduction

All fumigants are toxic to humans and other warm-blooded animals, as well as to insects and other pests. As a result, they are classified as **Restricted Use Pesticides**. Only individuals holding a valid Certification may purchase them. The Structural Pest Control Commission certifies commercial applicators in the non-agricultural environment. A trained, professional fumigator should be the only one doing the fumigation. Since professional fumigators are not always available to provide timely service, this guide is designed to help ranchers and farmers who decide to do the fumigation themselves. Although special training and certification are required before these fumigants can be purchased and used, this training alone is not adequate to qualify the person to conduct fumigation -- considerable study and planning will also be needed to complete a safe and effective fumigation. This guide provides general instructions for fumigating stored grain along with controlling rodent populations using fumigants. The information in this guide is not intended to replace label instructions or other material provided by manufacturers. Throughout this manual you will see RTL, this is to remind the user to refer to the fumigation label for specific requirements. Because labels change on a regular bases, please always refer to the current container label when fumigating.

Chapter 1: FUMIGANTS

Part 1: Registered Fumigants In Arizona

The three main chemical fumigants registered for use in the State of Arizona are:

1. Aluminum Phosphide,
2. Chloropicrin and
3. Magnesium Phosphide.

What Are Fumigants?

Fumigants are pesticides in the form of gases that are slightly heavier than air and have the ability to spread to all areas of a sealed structure. Because they are highly toxic and can seep into the smallest of cracks and crevices, they have become a popular solution to insect/rodent infestations in stored grain. But their ability to move quite easily throughout the grain mass also poses a problem of seepage from the bin or storage building. This seepage poses three major problems for the fumigator. 1) without enough fumigant inside the structure, the pest may not be killed; 2) loss of the fumigant to the outside of the structure means a loss of a fairly expensive pesticide; and 3) the ability of fumigants to move through the smallest of cracks, also means that they may move along electrical conduits, pipes, augers, and other passageways into adjacent buildings where they may harm and quite easily kill animals and people. Some of today's fumigants are similar to the infamous "mustard" gases used on the allies in World War I, so it is no surprise that they are considered Restricted Use Pesticides (RUPs). Arizona is now requiring that private pesticide applicators have a certificate in order to use fumigants. The Arizona Department of Agriculture (ADA) in cooperation with the agriculture sector developed the recommendations for fumigation training and an endorsement on the private pesticide applicator certificate. The goal of the ADA is to create common sense recommendations for pesticide education and training in Arizona. ADA, which is the state lead agency for agricultural pesticide licensing and regulatory compliance, worked in cooperation with the University of Arizona Cooperative Extension to develop this guide and the Private Fumigation Endorsement Exam. The main purpose of this guide is to increase awareness of the dangers and benefits inherent with the use of these hazardous chemicals. Remember always READ THE LABEL (**RTL**) before you begin.

The Need for Fumigants

The most important step that must be taken before fumigating stored grain is to be absolutely certain that the insects in the grain are harmful to the quality of the grain and your ability to sell the grain. Many insects that find their way into storage from the field are either not harmful to the grain and will leave on their own or are helpful insects that may eat or kill harmful insects. Since choosing to fumigate is not only expensive but also potentially dangerous, it is very important to be able to identify the insect and be sure that there is an infestation. It is important to correctly identify the insect or insects because insects differ in their behavior. These differences in insect behavior require different management strategies to effectively control the infestation. It is a difficult task even for experts to identify stored grain insects, primarily because these insects are very small (1/16 to 1 inch long) and look quite similar to each other.

FUMIGANT ADVANTAGES-

• toxic to insects, rodents, birds, and mammals
• some are toxic to weed seeds, nematodes, and fungi
• can be applied by several methods
• penetrate into cracks, crevices, burrows, partitions, soil, commodities, and equipment
• applied without disturbing the commodity, and
• usually available and economical to use.

FUMIGANT DISADVANTAGES-

• highly toxic to humans; apply with proper protective equipment
• require trained applicators
• area or commodity treated must be enclosed
• may injure seed germination
• may leave excessive residues that exceed tolerances
• may alter the taste or odor of the fumigated product
• will not prevent re-infestation after the fumigation.

Part 2: Aluminum Phosphide Use Patterns and Formulations

Aluminum Phosphide (Phostoxin)
Name of Chemical: Aluminum Phosphide
Generic Name: Aluminum Phosphide
Trade Names: Phostoxin,
Pesticide Type: Solid
Chemical Family: Inorganic Phosphides

Application Sites: Indoor fumigation of agricultural food commodities, animal feeds, processed food commodities and non-food commodities (tobacco). Can use outdoors as a fumigant for burrowing rodent and mole control.

Application Rates: See the label.

Formulations: Comes in tablets and pellets; powders in bags, envelopes and other types of containers.

Chemical Characteristics: Solid, dark gray material (granules, or powder); molecular weight 57.96; material must be protected from moisture in the atmosphere in air-tight containers; contact of the solid material with moisture in the air or with water, or acids releases phosphine, a highly toxic gas.

Toxicology Characteristics: Requirements for acute toxicity data have been waived because of the well-known extreme inhalation toxicity of phosphine gas, which it generates. Accordingly, aluminum phosphide has been placed in toxicity Category I, the highest toxicity category. Toxicology studies on phosphine gas are required to assess the margins of safety for exposed workers and applicators because the Agency does not have adequate data to determine whether phosphine may cause any long-term adverse effects to humans.

Environmental Characteristics: Aluminum phosphide reacts with moisture or water to release phosphine gas, which eventually dissipates into the atmosphere. The resulting material from the reaction is aluminum hydroxide, a relatively inert and innocuous material, which is a constituent of clay. Exposure (monitoring data) and related information are required to help assess the margins of safety for applicators and workers exposed to phosphine gas.

Ecological Characteristics: Phosphine is a highly toxic gas to a wide range of living organisms. Indoor uses pose no risk to non-target organisms outside of the site to be treated. Outdoor end use products (i.e., rodent and mole control) must bear special precautionary labeling to protect endangered species. Manufacturing use products must bear environmental hazard statements for wildlife.

Part 3: Magnesium Phosphide Use Patterns and Formulations

Magnesium Phosphide (Magtoxin)
Name of Chemical: Magnesium Phosphide
Generic Name: Magnesium Phosphide
Trade Name: Magtoxin
Pesticide Type: Solid fumigant
Chemical Family: Inorganic Phosphides
U.S. and Foreign Producers: Degesch America, Inc.; Research Products Company; PestCon Systems, Inc.; Bernardo Chemicals.

Application Sites: Indoor fumigation of agricultural commodities, animal feeds, processed food commodities, and non-food commodities (tobacco). Used in outdoor fumigation for burrowing rodent and mole control.

Application Rates: See the label.

Formulations: Comes in tablets and pellets; powders in bags, envelopes and other containers.

Chemical Characteristics- Solid, dark gray material (granules, or powder); molecular weight 134.70; material must be protected from moisture in the atmosphere in air-tight containers; contact of the solid material with moisture in the air, or with water, or acids releases phosphine, a highly toxic gas.

Toxicology Characteristics: Requirements for acute toxicity data have been waived because of the well-known extreme inhalation toxicity of phosphine gas, which it generates. Accordingly, magnesium phosphide has been placed in toxicity Category I, the highest toxicity category. Toxicology studies on phosphine gas are required to assess the margins of safety for exposed workers and applicators because EPA does not have adequate data to determine whether phosphine may cause any long-term adverse effects to humans.

Environmental Characteristics: Magnesium phosphide reacts with moisture or water to release phosphine gas, which eventually dissipates into the atmosphere. The resulting material from the reaction is magnesium hydroxide, a relatively inert and innocuous material, which is a constituent of clay. Exposure (monitoring data) and related information are required to help assess the margins of safety for applicators and workers exposed to phosphine gas.

Ecological Characteristics: Phosphine is a highly toxic gas to a wide range of living organisms. Indoor uses pose no risk to non-target organisms outside of the site to be treated. Outdoor end use products (i.e. rodent and mole control) must bear special precautionary labeling to protect endangered species. Manufacturing use products must bear environmental hazard statements for wildlife.
Summary Science Statement- EPA has determined that the registered uses of this chemical will not generally cause unreasonable adverse effects to humans or the environment if used in accordance with the approved use directions and revised precautionary statements prescribed by this document.

Part 4: Chloropicrin Use Patterns and Formulations

Chloropicrin
Name of the Chemical: Trichloronitromethane
Generic Name: chloropicrin
Common Product names: Acquinite®, Chlor-O-Pic®, and Larvacide®.
Pesticide classification: Fumigant
Registered Use Status: Restricted Use

Application Sites Registered forestry, rangeland, and right-of-way uses: Chloropicrin is registered for use as a preplant soil sterilant in seedbed and transplant nurseries**.**

Applications Rates: See the label.

Formulations: Commercial chloropicrin products generally contain one or more inert ingredients. An inert ingredient is anything added to the product other than an active ingredient. Chloropicrin also may be formulated with other active ingredients, such as methyl bromide. In the Brom-O-Gas® formulation, chloropicrin is added as a signal odor agent, because unlike the odorless methyl bromide, it has a sharp pungent odor and is irritating to the eyes, nose, and throat.

Target organisms: Soil fumigation with chloropicrin formulations is used to control or suppress plant disease-causing organisms including nematodes, bacteria (*Pseudomonas solanacearum*), fungi (*Cylindrocladium, Fusarium, Phytophthora, Pyrenochaeta, Pythium, Rhizoctonia, Sclerotinia, Sclerotium, and Veticillium*), the clubroot organism *Plasmodiophora,* the soil pox organism *Actinomyces ipomoea*, and certain soil-infesting insects such as cutworms, grubs and wireworms. Chloropicrin is also active against *Phellinus weirii* root rot in Douglas fir stumps, helping to control the fungus in stands of young fir trees; the same activity is seen with ponderosa pine stumps.

Mode of action: Chloropicrin applied to the soil comes in contact with soil fungi, microorganisms, insects, and bacteria. The specific mode of action is not understood, but chloropicrin is a strong irritant that is very toxic to all biological systems; affecting body surfaces and interfering with the respiratory system and the cellular transport of oxygen.

Timing of application: Soil fumigation should be performed at least 14 days prior to planting. Soil temperature should ideally be between 60°F and 85°F, and must be above 50°F. The treated area must be aerated for at least two weeks after treatment and before planting to ensure the safety of the workers planting the area.

Use Precautions: Always read all of the information on the product label before using any pesticide. Read the label (RTL) for application restrictions.

Re-entry: Consult the label as labels change regularly. For both indoor (greenhouse) and outdoor applications, trained protected handlers can reenter the area. However, if the air concentration of chloropicrin is above 0.1 ppm at any time, an air-purifying respirator must be worn. If the levels at any time are above 4 ppm, an approved air-supplying respirator or self-contained breathing apparatus (SCBA) must be worn. For outdoor soil fumigation, entry into the treated area by any person other than trained protected handlers is prohibited from the start of application until 48 hours after application. Non-handler entry is also prohibited during tarp removal.

Protective precautions for workers: RTL. Avoid contact with eyes, skin or clothing. Avoid breathing vapors. Do not rub eyes or mouth with hands. If you feel sick in any way, STOP work and get help right away. Do not wear jewelry, gloves, goggles, tight clothing, rubber protective clothing, or rubber boots when handling. Chloropicrin is heavier than air and can be trapped inside clothing and cause skin injury. Wear loose-fitting or well-ventilated long-sleeved shirt and long pants, and shoes and socks. Remove clothing immediately if chloropicrin gets inside, then wash body thoroughly and put on clean clothing.

DO NOT USE WATER TO WASH PROTECTIVE EQUIPMENT. The protective equipment should be flushed with kerosene or fuel oil and thoroughly cleaned according to the manufacturer’s instructions before reuse.

Do not use aluminum or magnesium handling equipment or containers for chloropicrin.

Always remember to RTL. It is a legal document.

Chapter 2: PESTS

<u>Part I: Rodent Management</u>

Pest Identification
It is important before any pesticide application that the pest is properly identified. In order for you to identify these pests an understanding of their biology is critical to their control. In many cases pest problems occur because of favorable habitat conditions. Good integrated approaches identify and manage the pest populations before they become problems. In this section information is presented for not only chemical control but management decisions as well. In general, you will encounter rodents, grain pests and the occasional pathogen when it comes to on-farm fumigation. A general overview of the pests you might encounter follows.

Disposing of Rodent Carcasses
Before initiating any rodent control program in Arizona, carefully read and follow the precautions and recommendations for handling and disposing of rodent carcasses under the descriptions of Hantavirus Pulmonary Syndrome and plague.

General Description
Rodents are mammals of which there are over 200 species of rodents in North America and over 70 species in Arizona. Due to their high reproductive rate, their ability to adapt to a wide variety of environments and food sources, and their capacity to avoid predators, rodents are considered the most successful mammals on earth. Rodents conflict with humans by destroying crops, stored grain, foodstuffs, landscape plants, and vast amounts of property. Rodents are also associated with the transmission of diseases to both humans and other animals.

Most rodents are nocturnal, however some, such as Arizona's ground squirrels, are active during daylight. Most of Arizona's rodent species are active year round, although some may hibernate during colder months and some estivate during the hottest part of summer. Rodents have commensal behavior. The word "commensal" is used to describe a relationship between different species of animals in which one obtains food from the other. These are the Norway rat (*Rattus norvegicus*), the roof rat or black rat (*Rattus rattus*), and the house mouse (*Mus musculus).* Roof rats are rarely encountered in Arizona and will not be included in this guide. In the United States, roof rats range throughout southeastern coastal and Gulf states and in the western portions of Pacific coastal states.

Although Norway rats have often been reported in Arizona, they have only been positively identified, to date, on two occasions. A Norway rat was identified taken from Tucson, in 1893 and one taken near the Grand Canyon in 1958. However, this is currently not a problem.

Distribution in Arizona
Rodents are found throughout Arizona primarily near human habitation. They are often found within human constructed structures but may be found in the wild usually in or near cultivated fields or other human modified habitat. Sources of free water or suitable moisture containing foods may be a limiting factor in some desert areas.

Chapter 2 Part 1, provided by Larry Sullivan Extension Wildlife Damage Specialist, University of Arizona

Legal Status in Arizona

It is important to realize that State laws do not protect most rodents and rodents may be controlled using any pesticide registered by federal and state authorities for this purpose, or by mechanical means such as traps. However, check with local authorities if you have any questions.

General Biology and Behavior

Rodents are active primarily at night, with some species having some daytime activities. Under normal conditions, most rodent's breed year round. Outdoors, most rodents may tend toward seasonal breeding, peaking in the spring and fall. Environmental conditions, such as the availability and quality of food, can influence frequency of pregnancies, litter sizes, and survival. Under ideal conditions, females may produce upward of 10 litters per year. The average life span of a rodent can vary from 1 to 2 years. In general they do not hibernate and live outdoors but may seek indoor shelter when weather is severe. Rodents have relatively poor vision, but very keen sense of smell, hearing, touch and taste. Their poor vision permits coloring poison baits for safety reasons as long as the dye used does not impart an objectionable taste or odor. Rodents prefer to travel along walls, repeatedly using the same runways and usually tend to travel to their territory regularly investigating each change or new object that may be placed there. Depending on the rodent, they can be aggressive showing no fear of new objects or not showing repellency toward strange objects. This behavior can be used to increase the effectiveness of control programs. Disturbing the environment, depending on the rodent can be effective at the beginning of a control program. Moving boxes, shelves, pallets, and other objects can improve the effectiveness of traps, glue boards, and bait.

Specific considerations related to rodents: Food Habits

Rodents feed on foods that humans eat, including grains, seeds and occasionally insects. In general, they seem to seek foods high in fat or sugar such as bacon, nutmeats, peanut butter, candies, and cookies. Depending on the rodent they meet their water requirement from foods with sufficient moisture content and need little or no free water. However, they will readily drink water if it is available. The lack of free water and appropriate food sources may be limiting factors for their presence in some desert areas of Arizona.

Damage and Identification

Whenever rodents are present in or around a structure they almost always cause some type of damage. This may include the consumption and contamination of food and feedstuffs, and structural damage caused by gnawing and nest building. The habit of gnawing wires and building nests in electrical boxes can cause shorts in electrical circuits and pose fire hazards. Due to their habit of nibbling on many foods and discarding partially eaten items, rodents can contaminate more food with hair, droppings and urine, than they consume. ***Visual Sightings*** most rodents are nocturnal in habitat and thus more difficult to observe in daylight. ***Sounds*** **(**can be heard in structures), such as squeaks, noises of clawing and scrambling in walls**,** or gnawing sounds when all is quiet. ***Estimating Population Numbers*** can be difficult, one can only get an estimate of the numbers present usually using either visual sightings which are not reliable, or comparing the number of tracks or patches with rodent tracks before and after a control program.

Prevention of Rodent Damage

Habitat Modification is probably the single most important thing a pesticide applicator can do. Habitat modification can often be as simple as the removal of attractants. As with any vertebrate pest, the particular situation should be looked at in terms asking what is attracting the animal to the area and what can be done to make the area less desirable. A common attractant is food. Denying the pest species access to sources of food by removing the food or containing the food so access is denied is a first step in making the area less desirable. Storing food in rodent proof containers, securing garbage, and all the aspects of general sanitation will help minimize infestations. Any food source available to these rodents will compete with and decrease the effectiveness of rodent baits used. General sanitation will make inspections for rodents easier, will increase the effectiveness of trapping and baits, and limit the potential population.

Reducing shelter and nesting sites, often referred to as harborage, can be accomplished by a variety of methods. Storing boxes and other items away from walls will expose potential runways. A common practice in warehouses and other areas where there is a considerable amount of storage is to paint a 12 inch white strip along the base of walls. This strip is kept clear of boxes, pallets and other items. This will expose potential runways and make signs of droppings and smudge marks easier to detect. In general, all potential shelter should be eliminated, made inaccessible, or exposed as much as possible.

Exclusion
Rodent-proofing a structure can be a challenging endeavor but can provide long term protection. All possible entry holes or spaces must be blocked with material that is resistant to rodent gnawing. These include galvanized sheet metal, aluminum of 22 gauge or heavier, brick, heavy gauge hardware cloth, concrete, and some commercial filling products made for this purpose. The most challenging species is the house mouse because of its physical abilities to get around and in structures.

Rodent Proofing Building Exterior:

* Seal all cracks and holes 1/4 inch or larger in building foundations and exterior walls.
* Block openings around water and sewer pipes, electric lines, air vents, and telephone wires where they enter walls.
* Screen air vents.
* Caulk and seal doors to ensure a tight fit, especially between door and floor threshold. The space between the bottom of the door and the threshold should not exceed 1/4 inch.
* Fit windows and screens tightly.
* Caulk and close openings on upper floors and the roof, inspect under siding, and repair damage SOFFITS.
* Smooth sheet metal guards can be used to keep rodents from climbing rough surface walls. These guards must be at least 12 inches high to exclude mice.
* Sheet metal cones or disks can be used to prevent rodents from climbing pipes, wires and ropes.

Rodent Proofing Building Interior:

* Seal spaces inside hollow block voids or behind wallboard. Repair broken blocks and holes around pipes.
* Repair gnawed holes or stuff them with copper wool.
* Equip floor drains with sturdy metal grates held firmly in place. Grate openings should not exceed 1/4 inch.

Part 2: Rodent Control

As a certified applicator, you will have several options in the control of rodents, some of which are physical/mechanical and others are chemical. Listed below are some general control options.

Trapping - Though the use of proper techniques, trapping can be an effective means in reducing rodent colonies. Trapping is the preferred method to try first within smaller structures because of limited access. Trapping is labor intensive, but has some advantages over the use of poisons. These include avoiding hazardous poisons and the odor problems that occur when poisoned rodents crawl into inaccessible places to die. Trapping also provides physical evidence of success.

Snap Traps - Common, wood base snap traps can be used and should be the type with expanded triggers. Not suitable for all rodents, traps must be set in the right places, in high numbers, and in the right position, or rodents will miss them entirely. Understanding of habitat requirements is critical to any trapping program. Some of the best sites for trap placement are those with large numbers of droppings, which means the rodents are spending a lot of time there. Other good sites are along walls, behind objects, and in dark corners, and particularly where runways narrow. Traps may be baited with pieces of hot dogs, bacon, chocolate candy, nutmeats, peanut butter, or anything the rodents are currently feeding on. The effectiveness of any bait will be decreased if there are other readily available food sources for them to feed on. Baits should be tied to the trigger, with string or dental floss, to prevent bait stealing. Since some rodents such as mice are breeding year around, they are constantly looking for nest materials. Trying several different types of baits can lead to the determination of baits favored by the particular colony of rodents. In addition to the common wood based snap traps, a variety of other snap traps designs are available constructed out of plastic or metal.

Multiple Catch Traps - Multiple catch traps are also available and can be very effective. These include the Ketch-All® which has a wind-up mechanism that mechanically entraps rodents such as mice as they enter a hole in the trap. The Tin Cat® is a similar trap but without the wind-up mechanism. This trap has a one-way entrance that prevents rodents such as mice from leaving once they enter the hole. Place the traps directly against a wall or object with the opening parallel to the runway, or point the tunnel hole towards the wall, leaving 1 or 2 inches of space between the trap and the wall. For maintenance trapping, place the traps in high-risk areas and also at potential entry points such as loading docks, near utility lines, and at doorways. These multiple-catch traps will catch upward of 15 small rodents and do not have to be reset each time one is caught.

Glue Boards - Glue boards are an alternative to snap or live traps. Glue boards are available commercially in several sizes and consist of a plastic base covered with very sticky glue. Glue boards should be placed in runways so the rodent will run over them.

Toxicants - Whenever toxicants are used to control pests, there is a risk to non-target species. The risk to non-targets will vary with the toxicants used and the non-target species. To protect against non-target exposure consult the label. Rodent toxicants (rodenticides) are generally classified into two groups, anticoagulants (also known as “chronic” rodenticides) and non-anticoagulants (also known as “acute” rodenticides). **Non-anticoagulant Rodenticides** are common non-anticoagulant toxicants used for house mouse control and include zinc phosphide. These rodenticides are formulated, with a variety of food grade, inert baits, to provide a lethal dose in a single feeding. With some non-anticoagulants, such as zinc phosphide, “bait shyness” may occur. Bait shyness occurs when the target animal experiences sickness or discomfort shortly after consuming a sub-lethal dose of the toxin and associates the discomfort with that particular bait. The animal will then avoid that bait in the future. If you use Zinc phosphide, do not let it go unattended for more than a few days, as bait-shyness is likely to occur within the target colony with continued exposure. **Pre-baiting** is the concept in which similar but non-toxic bait is offered to a rodent in order for them to get accustomed to feeding on it. Once the rodent is willing to feed on the non-toxic bait, it is switched for toxic bait. This helps to avoid bait-shyness. Zinc phosphide is often used as a tracking powder, which rodents lick from their fur during grooming. Extreme care should be used when handling zinc phosphide baits. Zinc phosphide should be applied in well-ventilated areas or with the use of an appropriate respirator. Zinc phosphide can be absorbed through the skin. **Zinc phosphide should never be mixed with bare hands nor applied without wearing gloves.**

Anticoagulant Rodenticides - act by disrupting the blood clotting ability and destroying small capillaries causing the animal to bleed to death internally. Because of the similarity of their mode of action, label directions for all anticoagulant toxicants are similar. They also instruct the user to maintain a continuous supply of bait for 15 days or until feeding ceases, thus ensuring that the entire population has ample opportunity over time to ingest a lethal dose of the bait. Regardless of the anticoagulant bait used, it may take 3 to 5 days for death to occur. Because of the lack of sickness associated with the slow action of an anticoagulant, rodents feeding on these baits do not associate any discomfort consuming the bait. Therefore, bait-shyness does not occur with anticoagulants.

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Bait Selection - Commercial, anticoagulant rodent baits are available in several forms and formulations. These include dry baits formulated with various grains or other seeds. Baits may be purchased in a variety of forms including loose meals, pellets, or paper or plastic “place packs”. Anticoagulant baits also are available in wax or extruded blocks to protect them from moisture and spoilage. Place packs contain a small amount of meal or pellet type bait and are convenient to drop into hard to reach places. Extruded block baits provide an attractive gnawing medium for rodents and some have a hole through them to facilitate securing the bait in a bait station to prevent them from being carried off. Anticoagulant baits are also available in liquid form.

Bait Boxes - A tamper-resistant bait box is designed so that a child or pet cannot get to the bait inside but the target rodent can. Tamper-resistant boxes vary in type and quality of construction, but they are usually metal or heavy plastic. Ensure that bait boxes are clearly labeled with a precautionary statement. In addition to a warning word such as “danger” or “poison”, this statement should include the type of rodenticides inside and the pest control person or company name with a phone number.

Dry Baits (Food Baits) - Dry baits may be anticoagulants or non-anticoagulants and in one of the several forms previously mentioned. Protect children, pets, wildlife, and domestic animals by putting the bait in inaccessible locations or inside tamper-proof bait boxes.

* Apply many small bait placements rather than a few large placements.
* Use baits labeled for rodent control.
* Place the baits in favorite feeding and resting sites, as revealed by large numbers of droppings.
* Place the baits between hiding places and food, up against a wall or other object to intercept the rodent.

* Make bait placements 10 feet apart or closer in infested areas.
* If bait is refused, try switching to a different type and replacing the baits often.
* Use appropriate size bait stations, for example, small bait stations are more attractive to mice than the larger rat-type stations.
* Practice strict sanitation so that other food is not out competing the baits.
* Place secure, tamper-proof bait boxes in safe locations near doors in late summer to intercept pests entering from the wild.

Liquid Baits - Rodenticides are also formulated as liquid baits. For example, liquid baits can be especially effective in sites that do not have a ready supply of water. Commercially available rodent liquid bait dispensers should always be used. These dispensers help to avoid spillage and contain the liquid to minimize evaporation. As with food baits and traps, many stations will be necessary to put the bait into the territory of all those infesting a building. These locations must be carefully selected keeping in mind that liquids can spill or splash and contaminate other surfaces, products and areas where they may be exposed to non-targets.

Tracking Powders -Powders or dusts containing a rodenticide can provide another means of getting rodents to ingest the toxicant. These powders can be placed where rodents will walk across them and pick up the toxic powder on their feet. The rodents will ingest the powder while grooming themselves. Tracking powders are especially effective against mice. Mice groom themselves more than rats, and they investigate enclosed areas that can be dusted with tracking powder. Tracking powders can be very useful in situations where bait acceptance is poor. Tracking powders should be placed in runways and areas where rodents are actively moving through. Tracking powders are not generally recommended in homes where the risk to non-targets would be greater or in food handling or storage areas. When tracking powders are used they should be cleaned up and removed when the control program is completed.

* Apply inside infested dry wall voids.
* Do not apply tracking powders to elevated surfaces where it may drift or fall into sensitive areas.
* Do not apply tracking powders near outside doors or near fans or anywhere they can be blown by drafts or air currents.
* Place tracking powder in a bait station, a PVC tube, a cardboard tube, or any small, dark shelter that a rodent such as a mouse could enter. Mice will explore such a shelter. Apply the tracking powder in a layer less than 1/16 inch deep.
* Do not allow tracking powders to drift into non-target areas.

Frightening - The use of devices that produce sounds out of the normal range of human hearing (ultrasonic) are of very limited value in rodent control. Some of these devices may frighten rodents and cause them to leave an area for a short time, but they will likely habituate to the ultra-sound and return.

Repellents There are repellents available commercially. Check with the Arizona Department of Agriculture for currently registered materials.

Part 3: Common Rodent Pests

HOUSE MICE

Photo: Jack Kelly Clark, UC Statewide IPM Project, University of California Davis, 2000.

Description -The house mouse (*Mus musculus,)* is the most common rodent pest in the U.S. Their close association with, and dependence upon, humans classifies house mice as "commensal" rodents. House mice are slender and small weighing less than one ounce and measuring from 2 ½ to 3 3/4 inches in length including the tail. Our native mice in the genus *Peromyscus* (white-footed mice, deer mice, and several other species) often invade buildings adjacent to fields and woodlands, are about the same size as or slightly larger than house mice, and are often misidentified as house mice.

NORWAY RATS


Photo: The Mammals of Texas, Drs. William B. Davis and David J. Schmidly

Description-Although **not** found in Arizona and several other interior, western states, the Norway rat (*Rattus norvegicus*) is the most common rodent pest in the United States. The Norway rat, also called the brown rat, sewer rat, barn rat or wharf rat, is a stocky, burrowing rodent about the same size as a wood rat see figure 4.2 for a comparison of the Norway rat to the cotton rat and wood rat. Adult Norway rats weigh about one pound. Their fur is coarse and usually brownish or reddish gray above and whitish gray on the belly.

WOOD RATS (Pack Rats)

C.D. Grondahl

Description-There is five species of wood rats (genus *Neotoma*) found in Arizona and two to six sub-species of each of these. The common names of the species found in Arizona are; the white -throated wood rat (*N. albigula*); the desert wood rat (*N. lepida*); the Stephens wood rat (*N. Stephensi*); the Mexican wood rat (*N. mexicana*); and the bushy-tailed wood rat (*N. Cinerea*).

Wood rats are large bodied rats (head to tail 12 -14 inches) with a relatively well-haired, long tail (about as long as the head and body together). The underside of the tail is lighter in color as is the underbelly with some white hairs. Wood rats are mostly nocturnal and are rarely seen during daylight. In Arizona, wood rats may breed year around, but breeding may slow down in mid-summer. Wood rats have a home range that is generally less than 100 feet in diameter and populations of 10 to 20 adults per acre have occurred.

COTTON RATS

hispid cotton rat (*Sigmodon hispidus*)
Photo: The Mammals of Texas, Drs. William B. Davis and David J. Schmidly

Description-There are four species of cotton rats in Arizona. These are: hispid cotton rat (*Sigmodon hispidus*), Arizona cotton rat (*Sigmodon arizonae*), tawny-bodied cotton rat (*Sigmodon fulviventer*), and yellow-nosed cotton rat (*Sigmodon ochrognatus*). Cotton rats are about the size of wood rats, thick bodied with coarse and grizzled appearing fur and a sparsely haired tail which is slightly shorter than the head and body combined. They are brownish in color with some buff colored or grayish hairs. Cotton rats are active throughout the year and although primarily nocturnal, they are often seen during daylight hours. Breeding year around, with a gestation period of about 34 days and an average litter size of six, cotton rats have a high reproductive rate. Cotton rats prefer dense cover. Their nests are built in shallow burrows or abandoned burrows of other animals.

POCKET GOPHERS

Adult pocket gopher.
Photo: Jack Kelly Clark, UC Statewide IPM Project, University of California Davis, 2000.

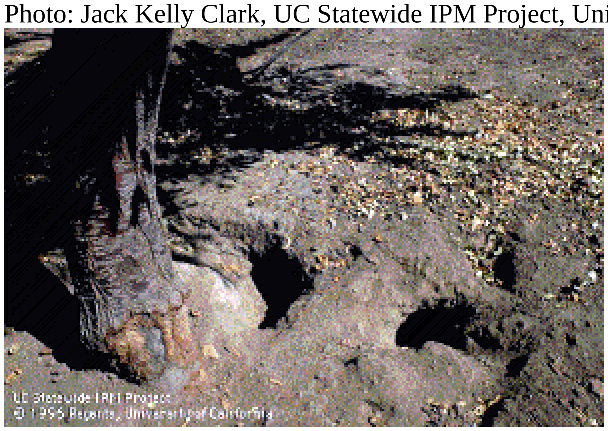
Crescent-shaped mound and plugged burrow opening of a pocket gopher.
Photo: Jack Kelly Clark, UC Statewide IPM Project, University of California Davis, 2000.

Description-Pocket gophers are thick bodied rodents five to seven inches long with a short sparsely haired tail, wide head, very small eyes and ears and strongly clawed front feet which are well suited for digging. They have external, fur-lined cheek pouches or "pockets" (hence the name pocket gopher) that they use to transport food.

There are three species of pocket gophers in Arizona. All three species belong to the genus *Thomomys*. The most common species is *Thomomys bottae* commonly known as the Botta's or valley pocket gopher. Pocket gophers are found throughout Arizona in any moist habitat in which sufficient amounts of tuberous roots and other plant material are available and the soil is suitable for digging tunnels. Pocket gophers live most of their lives in underground burrow systems or runways they have dug. They will occasionally venture out on the above ground surface to feed on plants close to the burrow entrance or to seek new territory. Pocket gopher burrow systems consist of a main tunnel or runway, which is commonly six to eight inches below the surface, but this depth, can vary greatly with the type of soil. Soil is excavated from short lateral runways leading off from the main runway. The soil is pushed to the surface forming a distinctive horseshoe or fan-shaped mound.

GROUND SQUIRRELS AND CHIPMUNKS

California ground squirrel.
Photo: Jack Kelly Clark, UC Statewide IPM Project, University of California Davis, 2000.



California ground squirrel burrows.
Photo: Jack Kelly Clark, UC Statewide IPM Project, University of California Davis, 2000.

Description-Two genera of ground squirrels are found in Arizona - *Ammospermophilus* and *Spermophilus*. There are two species of *Ammospermophilus*, commonly referred to as antelope ground squirrels, in Arizona. There are five species of *Spermophilus* found in Arizona in nearly all kinds of habitats. Two species are more commonly associated with human habitation. These are the rock squirrel (*S. Variegatus*) and the round-tailed ground squirrel (*S. tereticaudus*). The rock squirrel is the largest of the ground squirrels and is often confused with a tree squirrel. The rock squirrel has a long bushy tail, grayish or brownish or reddish in color and mottled with light gray or whitish specks or spots. The round-tailed ground squirrel is a small to medium, uniformly colored light buff to darker squirrel with small ears, a tail covered with short hairs giving it a rounded appearance. Both ground squirrels and chipmunks are active during the day and are easily seen when foraging. But they spend much of their time in their burrows. In winter, most ground squirrels and chipmunks go underground and stay inactive. In the hotter desert areas, ground squirrels will go into a period of aestivation (summer hibernation) when temperatures are high.

Rodent Summary
Worldwide rodents are responsible for more conflict with humans than any other order of mammals. The incredible ability of rodents to gnaw on almost any material is responsible for serious damage to property. In addition, rodents contaminate food and feedstuffs, consume crops and landscape plants, and pose a health risk to humans and other animals. Of all the rodent species, the commensal rodents are by far the most problematic and are generally not tolerated under any circumstances.

Part 4: Understanding Grain Pests

Grain Pest Insects

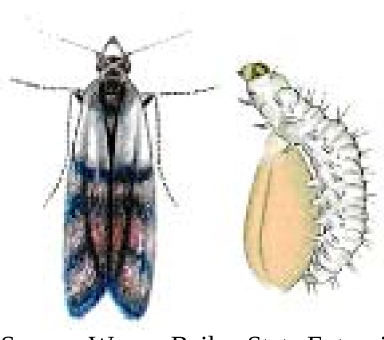
Arizona climate does not provide an ideal environment for most pest organisms. However, stored grain can provide a very hospitable environment for a wide range of pest organisms. The following section of this guide will introduce some of the more common stored grain pests including pathogens.

Insects are the major cause of stored grain deterioration. Some insects are well adapted to exploit the stored grain environment. Most stored grain insects are highly prolific, producing large numbers of offspring in a year. A pair of insects can produce enough young within a couple of months to severely infest several tons of grain. Most insects reproduce by sexual reproduction. They develop by either simple or complex metamorphosis (change). The more primitive insects undergo **simple** metamorphosis. A young nymph (immature) hatches from an egg and grows by a series of molts (shedding of skin); the fully formed adult emerges from the final molt. Examples include psocids, silverfish, and cockroaches. In complex metamorphosis, the insect molts on several occasions growing larger each time until it molts into a non-mobile form known as a **pupa**. The adult emerges from the pupal case and seeks out a mate. Temperature is a critical factor in insect development. Very cool conditions retard development, and warmer temperatures enhance development. The most important grain insect pests are moths and beetles. Adult moths have two pair of wings used for flight. The tube like mouthparts of the adult moth are for sucking nectar whereas; the mouthparts of larvae are for chewing.

Complex Metamorphosis (i.e. saw tooth grain beetle) Adult beetles and weevils also have two pair of wings, but the outer pair (elytra) serves as a hard, protective cover. The elytra protect the hind pair of wings, which are used for flight. Both adults and larvae have biting and chewing mouthparts. The type of damage they inflict often characterizes grain pests. They are primary pests if they actually attack and damage previously undamaged grain. If they can only attack grain that was previously damaged mechanically (handling practices, milling) or by other pests, they are secondary pests.

Listed below are some of the grain pests you may encounter with a brief description.

INDIAN MEAL MOTH *Plodia interpunctella* (Hubner)



Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri - Columbia

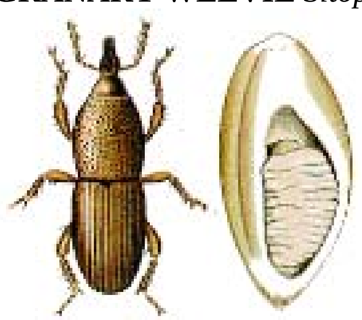
Indian-meal moth larvae spin webs on the surface of grain and feed on kernels enclosed within the webbing. The larvae will also spin webs on sacked grain in storage areas. The larvae or caterpillars are the feeding stage and may range from yellow-white to pink to light green with a light brown head. Full-grown larvae measure about 0.7inch long.

Biology-Female moths deposit from 60 to 300 eggs, singly or in groups on or within the upper surface of the grain mass. The female lays her eggs over a 3-week period. The larvae move about in the upper grain mass, feeding on fines and cracked kernels. They produce silken webbing as they feed. Full-grown caterpillars may leave their food source and climb up walls to pupate. The life cycle from egg to adult takes about 6 to 8 weeks during warm weather. Usually four to six generations hatch per year, depending on food supply and temperature conditions.

Damage-Indian meal moth larvae are secondary pests. They prefer to feed on grain fines or broken or damaged kernels. Infestations are most common in the upper 4 to 6 inches of grain in a bin. The larvae produce silken threads, which result in caking or crusting of the surface grain. Their frass (excrement), cast exoskeletons (exterior skinlike covering), and silk contaminate grain.

Description-Adult Indian meal moths at rest, having wings folded over their backs measures about 0.4 inches long. The wingspan is about 0.6 inch. The outer portion of the front pair of wings is bronzed to purple; however, this color is lost as the moth ages. The inner half of the wings near the body is light gray. The hind wings are gray and lack distinctive markings. Larvae are creamy white. The small dark head partially retracts into the widened thorax. The thorax has three pair of small legs. The abdomen, more slender than the thorax, may curve to give the larvae a C-shaped appearance.

GRANARY WEEVIL *Sitophilus granarius* (L.)



Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri - Columbia

Granary weevils cannot fly. Eggs are placed inside whole kernels. Damage is caused by the larvae feeding in whole grain and the adults feeding in and on whole or broken grain.

Damage-Granary weevils are extremely destructive grain pests. The larvae feed and develop within grain kernels. They can completely destroy grain in elevators or bins where conditions are favorable. Infested grain usually heats at the surface, and with proper moisture, sprouting can occur. Eaten out kernels containing small, white, legless larvae and small brown to black snout beetles are signs of infestation. Other storage insect pests may attack damaged kernels.

Description-Adult granary weevils measure about 0.2 inches long. The head is drawn out into a distinct snout; a pair of elbowed antennae comes off the snout near the head. The granary weevil is polished red-brown to black and has no wings under its hardened elytra (outer wing covers). Its thorax is well marked with oval pits.

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Biology-The female deposits her eggs in clusters of 2 to about 30 outside the kernels. Most of the newly hatched larvae chew their way into kernels and complete their entire development there. However, larvae are capable of feeding on fines and can develop as free-living insects in the grain. Larvae molt two to four times and can develop from egg to adult in about 60 days. Both larvae and adults produce large amounts of frass. Larvae push fecal pellets out of the kernel. Large amounts of fecal pellets may accumulate in the grain. The adults lack hind wings and cannot fly.

FLAT GRAIN BEETLE *Cryptolestes pusillus* (Schonherr)

Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri – Columbia

Flat Grain Beetle is one of the smallest common stored grain insects. It is usually found associated with moist, mold-damaged grain and considered a secondary pest because it typically will not infest grain that has not been damaged.

Biology Flat grain beetles are small, less than 0.1 inch in length, and red brown. Antennae are long, often nearly the length of the entire body. Adults are quite active and can both jump and fly. White, and legless larvae develop within the grain kernel. These hump-backed larvae have small dark heads. Under ideal conditions, it takes 5 to 9 weeks for complete development of a flat grain beetle from egg to adult. Larvae form the pupa using food particles that adhere to the sides, which helps, conceal them.

LESSER GRAIN BORER *Rhyzopertha dominica* (Fab.)

Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri – Columbia

The eggs of the lesser grain borer are placed on kernels and the larvae bore into the kernels. The adults can fly and also feed on grain.

Damage Lesser grain borers mainly attack various grains including wheat, corn, rice and millet. The larvae and adults are both **primary pests**. They bore irregularly shaped holes into whole, undamaged kernels and the larvae, immature stages, may develop inside the grain. Larval and adult feeding in and on grain kernels may leave only dust and thin brown shells. A sweet, musty odor is often associated with infestations of this insect.

Description Adults are 0.1 inch long, brown to black beetles with cylindrical bodies and numerous small pits on the wing covers. The head is directed downward and covered by the prothorax so that it is not visible when the insect is viewed from above. The creamy white larva is a c-shaped grub with a small dark head that is partly retracted into the thorax. The thorax has three pairs of small legs.

Biology Female deposits her eggs in clusters of 2 to up to 30 on kernels. Newly hatched larvae chew into kernels and complete their entire development there. Nevertheless, the larvae can feed on fines or can develop as free-living insects in the grain. There are four larval stages. Development under ideal conditions of 93° F and 12% moisture enables egg to adult maturity in about 25 days. Both the larvae and adults produce a large amount of frass or waste. Larval fecal pellets are pushed out of the kernel and large amounts can accumulate in the grain. The adults are winged and can fly to spread infestations
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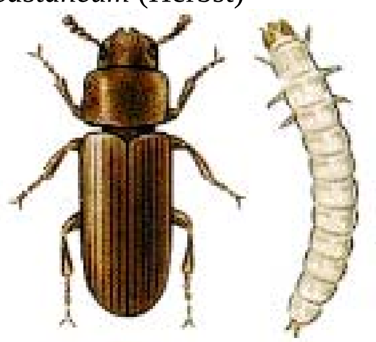
FLOUR BEETLES Confused Flour Beetle- *Tribolium confusum* (duVal) Red Flour Beetle- *Tribolium castaneum* (Herbst)



Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri – Columbia

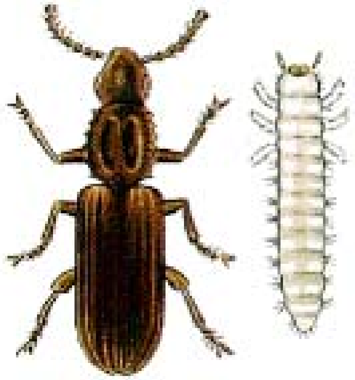
Larvae and adults of the red flour beetle and a closely related species, the confused flour beetle, feed on flour, grain dust, and broken grains.

Damage-Flour beetles cannot feed on whole undamaged grain; however, they often appear among dust, fines, and dockage. Both species cause damage by feeding but probably cause more problems because of contamination. Large numbers of dead bodies, cast skins, and fecal pellets, as well as liquids (quinones), can produce extremely pungent odors in the grain.

Description-Both beetles are slender, red-brown and about 0.1 inch long. While they are similar in appearance, you can, with some difficulty, distinguish them by the shape of the antennae. Of these species, the red flour beetle is more prevalent in this area. This species can fly and has been the most common pest insect of stored wheat in the Pacific Northwest. Full-grown larvae are less than 0.1 inch long and are yellow-white. The head and the pair of projections on the tip of the abdomen are dark.

Biology-Under favorable conditions, a female may lay 400 or more eggs at a rate of six to twelve eggs per day. A sticky fluid covers the eggs and collects particles of debris, resulting in almost perfect camouflage. Larvae undergo from five to twelve molts; the egg to adult life cycle takes about 30 days.

SAWTOOTHED GRAIN BEETLE *Oryzaephilus surinamensis* (L.)



Source: Wayne Bailey State Extension Entomologist, Stored Grain Insects. University of Missouri - Columbia

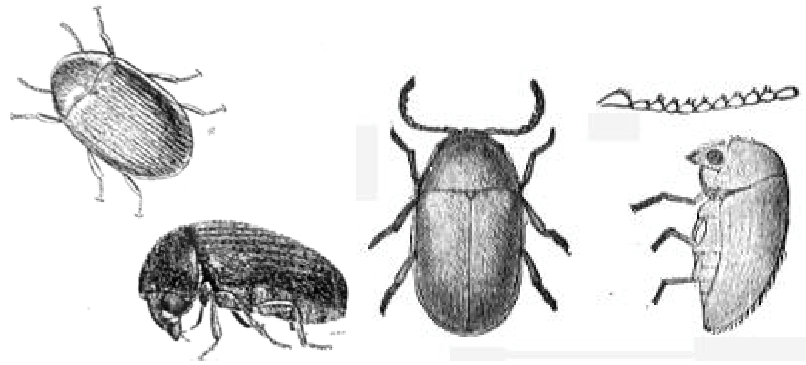
Saw-toothed grain beetles seldom fly but both the larvae and adults feed on cracked or broken grain, flour, meal, breakfast food, stock feed, candy, and dried fruit. The thorax, the body region behind the head, has saw- toothed points on both sides.

Damage-Sawtoothed grain beetles prefer to feed on damaged kernels but will sometimes penetrate and feed on or develop in sound kernels.

Description-Adult sawtoothed grain beetles are small, slender, dark brown, flat insects about 0.1 inches long. The most distinguishing characteristic is the six sawlike teeth found on either edge of the thorax. The flattened body is well adapted for crawling into cracks and crevices. The adults have well-developed wings but have never been observed to fly.

Biology-Female sawtoothed grain beetles may lay from 50 to 300 eggs in their 6- to 10-month lifetimes. Females lay eggs singly or in small batches in cracks or crevices in the food material. They also may lay eggs directly into finely ground materials such as flour or grain dust. At temperatures of over 80°F, sawtoothed grain beetle eggs hatch in 4 to 5 days, while at under 70°F it takes 8 to 17 days. Larvae molt two to four times depending on temperatures. The larval stage lasts about 40 days. When mature, larvae construct crude pupal cells from bits of food material held together with oral secretions. When pupating, the larva attaches its anal end to a solid object. The pupal stage lasts about 7 days. The entire life cycle from egg to egg takes from 27 to 375 days. The adult can live up to 3 years. Sawtoothed grain beetles feed on a wide variety of stored products. They appear in grain bins or grain handling facilities. Usually these beetles appear in grain dust, fines, and kernels that have been damaged during harvest or by other types of grain feeding insects.

CIGARETTE BEETLE *Lasioderma serricorne* (Fab.)



Source: Peggy K. Powell, Cigarette Beetle. West Virginia University Extension Service, Household Pest Management Publication 8003.

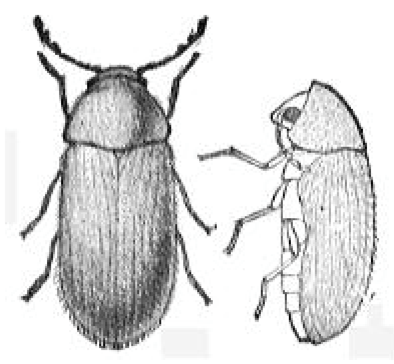
The cigarette beetle infests many stored products. It often is confused with a related species, the drugstore beetle, which is more elongate in proportion to its width and has distinctly striated wing covers.

Damage-Cigarette beetle adults and larvae are omnivorous pests of stored products. They occur in stored grain, where they feed on debris or dead insects as well as on damaged grain.

Description-Light brown adult cigarette beetles measure about 0.1 inches long. They appear humpbacked because the head and thorax are bent downward. These insects have distinct saw-like antennae and smooth elytra. The C-shaped larvae are 0.2 inch long when fully developed. They are creamy-white colored and covered with long hairs.

Biology-Adult females lay eggs singly on food materials. Eggs hatch in 6 to 10 days. Larvae develop over the next 5 to 10 weeks. Four to six larval instars develop, after which the beetles pupate in silken cocoons disguised by food debris. The entire life cycle takes from 40 to 50 days. Three to six generations may develop each year.

DRUGSTORE BEETLE *Stegobium paniceum* (L.)



Source: Peggy K. Powell, Drugstore Beetle. West Virginia University Extension Service, Household Pest Management Publication 8004.

The drugstore beetle is similar to the cigarette beetle in appearance but is slightly larger, more elongate, and has distinctly striated wing covers. The last three segments of the antennae are like a saw. Its food is even more varied than that of the cigarette beetle, and it is said to feed "upon almost anything except cast iron."

Damage-Drugstore beetles infest a wide variety of stored products, including some plant materials that are poisonous. They are often found in stored grain, usually in association with other insect infestations such as Indian meal moths.

Description-Adult drugstore beetles look almost identical to cigarette beetles. They are about 0.1 inch long, light brown to red-brown and cylindrically humpback shaped. Drugstore beetles have distinct grooves in their wing covers, while cigarette beetles have smooth wing covers. Drugstore beetle antennae end in three enlarged segments, while those on cigarette beetles are sawlike. Drugstore beetle larvae are C-shaped and are relatively hairless in contrast to the fuzzy appearance of cigarette beetle larvae.

Biology-Female drugstore beetles lay oval white eggs on food materials where they hatch in 6 to 10 days. Larvae have six to nine instars and are about 0.2 inch long when fully developed. The larvae form a small cell out of silk and food material in which they pupate. The entire life cycle takes from 40 to 50 days. One to four generations develop each year. Adult drugstore beetles are very active. They often appear in samples of infested grain. You can identify them by the rapid skittering movement in a grain sample pan.

PSOCIDS *Liposcelis* spp.

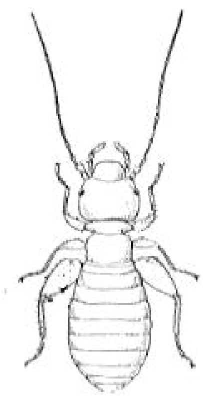
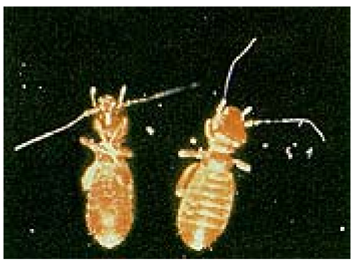



Photo: USDA, J. Brower

Description-Psocids are pale gray to yellow insects about 0.04 inches long. These soft bodied, louse like insects have relatively large heads, poorly developed eyes, and long, slender antennae. Their hind legs are long and well developed. The immature stage (nymphs) resemble adults in general appearance. They undergo simple metamorphosis.

Biology-Females lay as many as 100 eggs. Development from egg to adult requires about 3 to 4 weeks. Psocids feed on a great variety of organic matter of both plant and animal origin. Warm, moist, and dark undisturbed places provide favorable conditions for Psocid development and for microscopic molds on which they feed. Adults may live about a year.

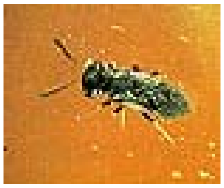
Example of Time Required for Insect Life Cycle

It is important to know the stored grain pests and inspect according to the length of time it takes to complete a life cycle.

Grain Pest	**Life Cycle**	**Observations**
granary weevil	5 weeks	Universal feeder on whole grains
rice weevil	26 days	Universal feeder on whole grains.
broad-nosed grain weevil	4 weeks	Usually attacks soft or damaged grain.
coffee bean weevil	4 weeks	Lays eggs in corn in field infestations, may continue for 3 months after storage.
lesser grain borer	4 weeks	Universal feeder on whole grains.
angoumois grain moth	5 weeks	Most important in stored corn.
rice moth	6 weeks	General feeders.
Indian-meal moth	6 - 8 weeks	Prefers coarse grades of processed grain.
Mediterranean flour moth	8 - 9 weeks	Prefers finer grades of processed grain.
sawtoothed grain beetle	4-53 weeks	Prefers grain products.
confused flour beetle	4 weeks	Attacks grain and grain products.
red flour beetle	4 weeks	Attacks grain and grain products.
Source: P. G. Koehler. Control of Stored Grain Pests. Entomology and Nematology Department, University of Florida Cooperative Extension Service. Document ENY-247, July 1997.		

3 Examples of Beneficial Bio-Control Grain Storage Insects

BRACON HEBETOR - Beneficial Grain Storage Insect



Minimum Life Cycle: Egg to adult 9 to 10 days (30°C). Longevity of an adult female is about 23 days.
Fecundity: approximately 100 eggs.
Distribution: Cosmopolitan associated with stored product moths. Not injurious to stored grain.
Biology:
Adults **-** Females paralyze and lay eggs in late instar moth larvae. Each female produces about 100 eggs. On the average, eight larvae develop in one host. (Host: Indianmeal moth and almond moth external to grain.)
Bracon hebetor, **a Parasitoid.** Bracon hebetor parasitizes several of the common grain moths such as the Indianmeal moth in the late larval stage. According to the results of laboratory tests, it promises to be a useful biological control agent.

ANSIOPTEROMALUS CALANDRAE - Beneficial Grain Storage Insect

Minimum Life Cycle: Egg to adult 12 days (30°C). Longevity of an adult female is about 70 days.

Fecundity: approximately 280 eggs.

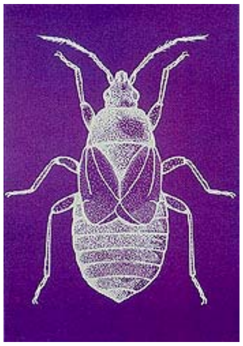
Distribution: Worldwide. Not injurious to stored grain.

Biology:

Most important natural enemy of *Sitophilus* weevils. Female adults locate weevils inside grain kernels. Female lays eggs inside grain kernel on weevil larvae. Can also attack larvae external to grain. (Host: *Sitophilus* weevils, bruchid bean weevil, cigarette beetle.)

***Anisopteromalus calandrae,* a Parasitoid.** This parasitoid has been demonstrated to reduce populations of the maize weevil in stored corn. This small pteromalid wasp is now produced commercially for release in grain bins.

WAREHOUSE PIRATE BUG - Beneficial Grain Storage Insect



Minimum Life Cycle: Egg to adult 16 days (30°C). Adult female longevity is five to six weeks.

Fecundity: approximately 150 eggs.

Distribution: Widespread and common in grain storage. Not injurious to stored grain.

Biology:

Most important predatory insect in grain storage. Nymphs and adults prey on eggs, larvae, and pupae of many species of grain insects.

Warehouse Pirate Bug *(Xylocoris flavipes).* This predator is an anthocorid bug that is commonly found with stored products. This insect shows considerable promise as a biological control agent since it preys on moths as well as several important beetle species, such as red and confused flour beetles and sawtoothed grain beetles. This predator also is produced commercially for release in grain bins.

Source: Vera Krischik, Wendell Burkholder, Stored-product Insects and Biological Control Agents. Oklahoma Cooperative Extension Service - Oklahoma State University, Publication E-912 (Photos and drawing courtesy of USDA, J. Brower.)

Part 5: Pest Pathogens

Grain Mold and Fungi

Storage rots or moldy grain may develop in grain storage bins if the moisture content of the kernels is excessive and the air temperature is high enough to permit fungus growth. Over 150 different species of fungi occur on cereal grains. Fungi are plantlike organisms that must obtain food from outside sources since they lack chlorophyll and cannot produce their own food. Stored grain fungi break down and digest grain tissue. They spread by sexual reproduction and by releasing spores. The tiny spores travel easily in the air but are also transferred by insects and other organisms. The spores can withstand dry conditions for extended periods of time. Major storage fungi are species of the common molds, Aspergillus and Penicillium. Some species of fungi, such as Alternaria sp. and Fusarium sp. can cause infection in the field and can cause advanced decay in high moisture grains. Some of the fungi grow in grains and other seeds before harvest or in storage produce toxins. One common storage fungus, *Aspergillus flavus* produces several toxins called **aflatoxins**, which cause health problems for animals that eat them.

Damage

These pests may be abundant in or around high moisture stored grain. Their nuisance value generally far outweighs the actual damage they cause. Depending on the commodity, toxin contamination is a field problem, a storage problem, or a combination of the two. Since fungi produce toxins, watch for them as a potential danger wherever fungi grow on materials used as food or feed. Fungal contamination is necessary for production of toxins, but toxicity is certainly not the inevitable result of all fungal invasions. Fungi are almost universally present on and in cereal grains and nearly all other plant materials, but toxicity seems to be the exception rather than the rule.

Potential Damage

Storage fungi cause loss of germination, dark germs (in wheat, designated germ damage or sick wheat), bin burning, mustiness and heating. These are the final results when storage fungi invade grain. Storage fungi are the cause, not the result, of spoilage.

Discoloration

Both field and storage fungi may cause discoloration of whole seeds or portions of them, including the germplasm. It is not uncommon to find seeds with germplasm ranging from tan to black. Sometimes the fungi that cause this discoloration will be producing spores. When the growth of the fungi is obvious to the naked eye, the grain will be graded as damaged. This condition in corn is known as blue-eye. Any discoloration due to molds will be graded as damaged according to the Official U.S. Standards For Grain. It is not uncommon to find grain, in hot spots, that is brown or totally black due to invasion of these microorganisms. **Heating** by microorganisms is common in many kinds of organic materials such as grain. Storage fungi begin to grow when grain reaches the minimum moisture level. Some grain is moist enough when stored to initiate fungal growth, or it becomes moist through moisture transfer resulting from temperature differences within the grain mass. The most obvious signs of microorganism infestation are heating and moisture movement. Fungi alone or together with insects are major causes of hot spots. Heat released during normal organism metabolism produces hot spots. The moisture produced also enhances organism growth. Usually the succession of fungi develops as the moisture content and temperature increase. The fungi involved can raise the temperature up to about 130°F and hold it there for weeks. Sometimes the heat of the hot spots dissipates the metabolic water produced by these fungi.

The moisture then accumulates in grain around the original hot spot. This is the factor that determines whether heating will gradually subside or pass into the next stage, where a variety of heat-loving fungi take over. These fungi may carry the temperatures up to 140° to 150°F when bacteria may follow. Bacteria can cause a temperature increase to over 150°F, the maximum temperature that can be obtained by microbiological heating. Under certain conditions, purely chemical processes take over and carry heating to the point of spontaneous combustion.

Germination Reduction

Under conditions that permit fungi to grow, fungi almost exclusively invade seed germplasm. If the moisture content of the seeds is at or slightly above the lower limit that permits fungal growth, fungi can invade the seed germplasm to the point of almost total decay. Frequently, no outward evidence of molding exists, even with microscopic examination, and little or no invasion is evident. The first effect of this invasion is weakening of the seed, followed by seed death. Usually, storage fungi cause weakening and death of the seed embryo before any discoloration develops. By the time discoloration becomes evident the seed germplasm is dead.

Fungi Cause:

- reduction in seed germination
- dark germs
- bin burning
- mustiness
- heating

It is not uncommon for grain to reach over 120°F to become a hot spot. Grain will be caked and black and will appear burned, even though it has not been exposed to temperatures required for ignition. Many times, heating begins in fines that accumulate in the spout line while grain is loaded into the bin. Some fines and accompanying weed seeds have high moisture content and, therefore, can furnish enough moisture to facilitate growth of storage fungi, thus initiating the heating process.

Mustiness, Caking, and Decay

Mustiness, Caking, and Decay are advanced stages of spoilage by fungi, which can be detected by eye or nose. However, considerable fungal growth occurs in grain before it becomes apparent to the naked eye. Mustiness may develop where grain is still relatively sound, but usually some mold is visible on the kernels. Clumping or caking of kernels results from fungal filaments that occur in damp grain. The amount of caking will range from a slight adhesion observable when unloading a bin of grain to solid masses that do not break apart during handling. Bins with uneven internal temperatures can cause moisture migration and accumulation in the top. These conditions may cause heavy mold growth and allow a crust to form over the grain mass. The crusted layer, usually only a few inches thick, may consist of rotted kernels and fungus tissue occupying all of the pore spaces between the kernels. Grain in this condition may be 30% to 35% moisture, while the grain immediately below can be as little as 13% moisture. Caked and decayed grain, whether in a surface crust or in an entire bin of grain, represents the final stages of mold growth. Mustiness, caking, and discoloration of kernels can cause severe losses. A small hot spot will plug up the unloading augers, causing time delays. At other times, caking and severe discoloration can reduce grain quality in a particular bin to salvage value.

Part 6: The Grain

Moisture Content

Moisture content is the most important factor affecting microorganism growth in stored grain. If you maintain moisture at a low enough level, other factors that influence storage will not greatly affect grain spoilage. Microorganisms respond to their environment in somewhat the same way that grain does. Microorganisms absorb water, which carries dissolved nutrients, for their growth and reproduction. Only dissolved nutrients can enter the microorganism cell. When the relative humidity is high enough, microorganisms can absorb nutrient rich moisture. If the relative humidity drops below a critical level, microorganisms cannot absorb water; and growth and reproduction cease. Moisture content of stored grain and relative humidity within the grain mass are very important.

A good rule of thumb to alleviate direct moisture problems is to check for leaks in the storage facility during or after the first heavy precipitation after binning. Roof or bin wall leaks often produce high moisture pockets in the grain mass, which serve as ideal sites for mold development and insect infestations.

Moisture Migration

Grain is a good insulator; heat loss from grain is relatively slow when compared with other materials. For this reason, when placed in a bin in the fall, grain near the center tends to maintain field temperature. Grain near the bin wall cools close to the average outside temperature. As the outside temperature decreases, the difference in temperature between grain at the center of the bin and that near the bin wall produces air currents inside the grain mass, which drive moisture migration. Cool air near the bin wall sinks since it is more dense, forcing the warmer air up through the center of the grain mass. As moist air passes through the center of the grain mass, it warms and picks up more moisture. As the air nears the top center surface of the grain, it cools and can no longer hold the moisture it has picked up. Moisture condenses on the surface of the grain, increasing grain moisture content and creating an environment that enhances mold and insect growth. A surface moisture change can occur even though the average grain moisture content is at or below recommended levels. The reverse situation occurs during the summer months. Then moisture condenses near the bottom center of the grain mass.

Aeration Systems

Most modern grain storage bins have either subfloor aeration ducts or perforated floors. Subfloor duct systems may be of several types, usually resembling an “X”, “Y”, or “I” system. Air flows along the path of least resistance; hence, dead space areas may occur through which very little air passes when using a duct type aeration system. Likewise, overfilling a bin may create dead space zones. When inspecting a bin for possible trouble spots, be sure to probe into dead space zones. Generally, you can minimize the problem of natural air currents developing within a bin by covering fan outlets when not in use and by keeping the grain temperature in the center of the bin within 10ºF of the average grain temperature near the bin wall. You can maintain temperatures in most structures by using aeration fans that pull or push air through the grain at airflow rates of at least 0.1 cfm (cubic feet per minute) for each bushel of grain in the bin until the temperature of the grain mass is within 10ºF of the average monthly temperature. Use a slightly lower airflow rate in very large structures. It is not necessary to lower the grain mass temperature below 40°F because fungi and most insects that attack stored grain cannot develop below this temperature. Do not allow grain to freeze, because it will require longer rewarming and may present unloading problems. Keep grain temperatures below 60ºF because mold and insect growth occur at a much faster rate above this temperature. It takes approximately 120 hours (5 days) for the entire grain mass to cool or warm when air is supplied at the rate of 0.1 cfm per bushel. You can reduce the time of aeration to 12 hours by increasing the airflow rate to 1 cfm per bushel.

The best method for distributing air evenly through the grain mass is to use a perforated floor. However, trouble areas could still show up if fine material and foreign matter accumulate in the top and bottom center of the bin. Likewise, overfilling may present the same problem for bins equipped with perforated floors as for those with duct systems.

Filling and Unloading Grain Bins

Storage problems may result from factors other than inadequate aeration. For example, when grain bins are filled, foreign and light material (trash, weed seeds, broken parts of kernels) accumulate in the center of the bin and may form a core of material from top to bottom. This core may be so tightly packed that little air can circulate through it. Consequently, this zone may not cool properly. It then provides an excellent environment for mold and insect problems. To avoid a packed core use a grain spreader to evenly distribute the fines. It is also possible to remove the center material by unloading the bin with a center draw unloading auger, and then uniformly spread this material over the top surface of the grain after leveling. Other options include feeding or selling the core material. One method of determining when the central core has been removed is to place tissue paper on the grain surface and observe when it passes through the unloading auger.

Core removal may involve risk to workers, so be extremely careful that no one is caught inside the bin when unloading. The preferred procedure is to clean the grain before placing it in the bin. Probe the center of the bin to indicate the extent of center core formation. Hot spots may be found in any part of the grain mass. These trouble zones usually occur around accumulations of trash or foreign material. However, if you place a load of relatively wet grain into a bin of dry grain, the wet grain may begin to spoil regardless of the average moisture content of the entire grain mass. When probing a bin, investigate points where the probe has relative difficulty in penetrating. Generally, wet grain or trash offers more resistance to probe penetration than does dry grain. Again, the safety aspects associated with entering a bin of grain are important. Another important factor when filling a grain bin is to leave adequate head space between the top of the grain and the bin roof. Leveling the grain a few inches below the top of the bin wall will reduce the potential for core moisture pockets characteristic of overfilled bins. Adequate headspace also makes it much easier to monitor pest activity and to fumigate when necessary. When unloading a typical grain bin, remove grain from the top portion of the bin first. The grain will continue to flow until it reaches a natural angle with the bin floor, called the angle of repose. The angle of repose usually ranges from 25° to 35º, depending, in part, on its moisture content. Workers may continue to fill or unload a bin without ever removing grain from the stagnant areas. Examine this stagnant grain carefully, because it may have higher moisture content or contain different levels of foreign materials than the rest of the grain. When constructing bin floors, place a layer of plastic under the concrete floor to serve as a vapor barrier. This barrier will prevent water from condensing on the floor and wetting the grain. Likewise, sealing the sidewall and roof and the bottom ring on the concrete slab will keep rain from wetting the grain. Spoilage generally appears near any point where wetting occurs. Clean the unloading auger before placing grain in a bin or after a partial unloading. Otherwise, when unloading the grain, the sample the inspectors take from the truck may indicate contamination by mold or insects at a level higher than is actually present inside the bin. Also, water may collect inside an auger and wet the grain left from a previous unloading. ***Remember To Level The Grain!***

Part 7: Insect Infestations

In Arizona primarily insects moving from nearby or adjacent sites infest stored grain. Infestations most likely develop from small populations of grain insects in or around improperly cleaned bins and grain handling machinery. Spilled grain, residues in machinery, or grain stored at animal feeding areas are other sources of insect pest problems. It is very important to detect and eliminate potential pest reservoirs if you want to prevent stored grain infestations.

Preventive Maintenance

Grain bins and other grain storage facilities have numerous cracks, crevices, and other harborage where insect pests can hide and develop. Thorough bin sanitation is necessary to clean up these areas, but the most permanent solution is to fill them with caulking material. Roof leaks or large holes in the walls or floor of the bin provide entry points for moisture as well as for rodent and insect pests. Repair this damage promptly to maintain a high quality grain storage environment. Prior to harvest, make sure all grain equipment (combine, trucks, augers, etc.) is clean and that no grain reservoir or insects are present to infest new grain. Success of a long-term grain storage program relates directly to care and maintenance of an appropriate grain storage environment.

Bin Preparation

Pre-binning sanitation and bin preparation are absolutely essential. The first principle of proper grain storage is never store new grain with old grain. Thorough pre-binning sanitation includes removal of grain and grain parts that may be infested with insects. Eliminate cracks, crevices and other potential insect harborage. Apply insecticides to bin walls, floors and to bin subfloor areas to control insects missed in bin cleanup. Several insecticide are available for this use, check labels for registered uses because pesticides are regularly withdrawn from the market.

Aeration subfloors or ducting in grain storage facilities often provide ideal harborage for insect populations. Such sites are often difficult, if not impossible, to clean or treat with pre-binning insecticides. Chloropicrin, a chemical formerly registered as a grain fumigant and now usable only for empty bin treatments, is highly effective in controlling insect infestations in hard to reach areas. Chloropicrin is particularly effective against immature stages of grain pests that develop within the grain kernel. Chloropicrin is a nonflammable liquid fumigant marketed in pressurized and non-pressurized containers. Use it as a soil or space fumigant, but do not apply it to grain. Chloropicrin, commonly known as “tear gas,” vaporizes to a highly toxic gas when exposed to air. Chloropicrin gas, nearly six times heavier than air, will concentrate in low areas and effectively control subfloor insect populations. Chloropicrin is a highly toxic pesticide that must be used with caution and protective equipment. Concentrations as low as 1 ppm may produce intense eye irritation. Continued exposure may cause serious lung injury. The irritating qualities of chloropicrin serve as a warning against accidental exposure.

It is extremely important that you apply all pesticides according to their label directions. Any grain that has been treated above the legal limits will be subject to seizure according to the directives of the U.S. Food and Drug Administration and the ADA.

Bin Monitoring
A bin inspection program is essential for effective management of grain in long-term storage. Regardless of the effectiveness of the rest of your storage program, nothing can guarantee that an insect infestation will not occur. Make regular inspections of stored grain to evaluate storage conditions and to detect pest infestations before they become severe. Vary sampling techniques and intervals by season, crop, suspected problem, and bin sites, but establish a consistent inspection and sampling program. Inspect stored grain once a month. Monitor grain by forcing the bare arm full length into the grain. Areas that are hot generally indicate an infestation. Watch especially for signs of crusting near the top center and outside edges. You may see live insects and damaged kernels on the surface, especially on the crown. Visually monitor area for rodents. Look for rodents and their runways, gnawing, fecal material, and urine.

Traps and Pheromones
Several types of traps are available to monitor insect populations in stored grain. You may use physical traps alone or with other attractants. Place traps down into the grain mass where insects can crawl or fall into them. Then retrieve them and check for infestation level. Examples of traps used alone include the traditional grain tier method and the more sensitive plastic grain probe. For attractant traps, add food or odor to draw insects.

Insect pheromone mimics are now available for use in traps. Pheromones are chemicals that insects produce and release to cause behavior changes in insects of the same species. Females emit sex pheromones to attract males of the species. Traps for Indian meal moths use sex pheromones. Some insects release aggregation pheromones to attract a large grouping of insects. Traps for lesser grain borer and red flour beetle use aggregation pheromones. To use these chemicals in traps, you need to understand the types of reproductive biology and communication of grain-infesting insects. Use pheromones and other attractants to detect low levels of insect infestations in grain. Continuous monitoring will provide important information pertaining to location of infestation and population levels. Pheromone monitoring programs may result in lower costs and less commodity damage when compared with older methods. You can improve efficiency by applying control measures when necessary and in specific areas.

Controlling Pest Infestations
In summary, when you detect major insect infestations or other damaging conditions, several courses of action are open to the applicator. If problems arise during the winter months, cooling the grain to a point where insects and fungi will not continue to grow may solve the problem. However, a large hot spot will inhibit airflow and make cooling the center of the hot spot difficult. If possible, move the grain from one bin to another. This will cool the grain and facilitate more thorough sampling of grain from all parts of the bin. As you move the grain, reapply grain insecticides or add certain fumigant formulations if necessary. When grain fumigation becomes necessary, you must consider many factors, especially the acute hazards associated with fumigants.

Chapter 3: THE LABEL

The single most important piece of information to remember is, always read and follow label directions, it’s the law. The information provided in this chapter is to give you an overview of what is on the label and what are the important aspects of the label. Remember the label is a legal document and should always be followed.

Aluminum and magnesium phosphide containers may flash on opening. Pay careful attention to the handling procedures on the labels.

Source: NIOSH Alert, Preventing Phosphine Poisoning and Explosions Durring Fumigation. DHHS (NIOSH) Publication No. 99-126 September 1999.

Part 1: Precautionary Statements

Hazards to Humans and Domestic Animals

Tablets and pellets of aluminum or magnesium phosphide and the dust that is rubbed off of them in transport and handling may be fatal if swallowed. This is true both for animals and humans. Most farmers are very good about how they handle and store pesticides and have quite a bit of experience in handling toxic chemicals so they are not ingested or swallowed by themselves or their animals. But the handling of phosphine is different from other chemicals on the farm and does not follow the common sense rules of pesticide use. Check the label for more detail about the protective clothing needed when handling phosphine. Only light cotton gloves and loose-fitting cotton clothing should be worn while fumigating with or handling phosphine so no residues will be trapped against the skin and cause burning. Since less protective gear is worn while handling phosphine than with other pesticides, there is more of a chance of having the residual dusts cling to hands, lips, hair, and clothing. As long as this dust does not become wet, it will take quite some time for the humidity in the air to cause the reaction that turns aluminum or magnesium phosphide into phosphine gas. Remember that even sweat or dampness in the clothing from sweat can begin this reaction. This residual dust can be inadvertently swallowed and may kill if the applicator does not follow these precautions:

- Do not eat or drink while fumigating or before completely washing up and changing clothing after fumigating. Even though this makes perfect sense, many applicators forget that after they have left the fumigating area (bin or building) and are out of the immediate inhalation danger, they may still contaminate themselves.

- Only light cotton gloves and loose-fitting cotton clothing should be worn while fumigating with or handling phosphine.

It is very easy on a hot day to want to have a quick drink of water, or over the lunch hour grab a bite to eat, or even share a cup of coffee with the neighbor who pulls up to see "what is going on", before fumigating that last bin. But remember that the lips or fingers almost always touch anything that goes in the mouth. Even if you are extremely careful, dust may waft down from the hair, eyebrows, eyelashes, or nose and contaminate what is going in the mouth. Remember All Clothing Must Be Removed Outside for everyone's protection and the applicator must completely wash every part of the body with soap and water before even thinking about having that sandwich or soda. Eat and drink before you start fumigating or after you clean up.

- Do not smoke or chew tobacco while fumigating. Every precaution might have been taken not to smoke or chew while fumigating or even until after cleaning up, but that pack or can that was in the pocket of the shirt or jeans may still be contaminated. If you must smoke or chew, do so before you start fumigating or after you clean up.

- Do not take bathroom breaks while fumigating. Pesticide poisoning most often occurs through the skin, and even though fumigants are more likely to severely burn the skin than to be absorbed into the body, absorption sometimes happens. Use the bathroom before you start fumigating or after you clean up.

- The entire fumigation should be completed in one session with no breaks.

- When conducting a large fumigation (several large bins or buildings), it may be a good idea to decontaminate and change to new clothing at the halfway point, so there can be time to rest and recover.

Part 2: Physical and Chemical Hazards

Aluminum and magnesium phosphide tablets and pellets produce phosphine gas when they come in contact with the moisture in the air. Usually this process takes between a half hour to an hour to produce measurable levels of phosphine gas, but this is not always the case. Phosphine gas can ignite spontaneously when the levels in the air exceed 18,000 ppm. When this "flash point" or burning point is reached, there is a very energetic burn. And if the concentration of phosphine gas is high enough around the burn, an explosion may occur that could cause severe personal injury or even death. When handled properly, it is very difficult to bring the levels of phosphine up to this flash point. But there are several situations in which this may happen:

- Phosphide pellets and tablets produce phosphine gas when they are exposed to moisture in the air. This process is speeded up when pellets and tablets are exposed to water, oil, acids, and many other liquids and phosphine gas may be produced in quantities high enough to produce an explosion in an isolated area. For example, pellets tossed into an aeration floor or duct where water or oil leaking from hydraulic hoses leading to a rotary motor has pooled and where the gas may be trapped.

- Phosphide pellets or tablets that are stacked or piled on top of each other may cause a temperature increase that in turn speeds up the release of phosphine gas. This gas may be confined to the pile, even a small pile, and quickly reach the flash point. Pellets and tablets must be spread out throughout the fumigation area, or when probed into the grain, they must be deposited at various depths. For example, pellets placed in a heap on top of the grain mass may heat up and explode.

- Phosphide tablets and pellets usually come in metal flasks with a screw top lid. Inside these flasks there is always some air, phosphide dust, and some phosphine gas. It is unusual for the phosphine concentrations inside the canister to reach 18,000 ppm, the flash point, but it can happen. ALWAYS open phosphide flasks outside, or next to a ventilation fan that will direct the fumes immediately outside, and ALWAYS point the flask opening away from your body while unscrewing the canister slowly! “18,000 ppm is phosphine “flash point” Pure phosphine gas is stable at room temperatures below concentrations of 18,000 ppm. But it may react with certain metals and cause corrosion. This corrosive ability increases with the temperature and even the slightest humidity.

These are the metals that phosphine gas corrodes:

- Copper
- Copper alloys
- Brass
- Silver
- Gold

While these metals aren’t often stored in their raw form inside a grain storage facility, keep in mind that elements of each of them are often found in the following:

- Small electric motors
- Smoke detectors
- Sprinkler heads
- Batteries
- Battery chargers
- Fork lifts
- Temperature monitoring equipment
- Switching gears
- Communications devices
- Computers
- Calculators
- Cell phones

It is a good idea not only to keep these and other electrical devices away from phosphine for the sake of the particular item, but also to make sure that any electrical circuits aren’t damaged and create a fire. Phosphine also will react with certain metallic salts, and any items that contain them, such as photographic film and inorganic pigments, should not be exposed. Remember to remove all jewelry, watches, rings, necklaces, bracelets, and keys from the body before fumigating. If they are worn during fumigation, they may be corroded. Also, if they are worn they may trap the gas or dust against the body and cause severe burning.

Part 3: Practical Treatment Statement (First Aid)

Symptoms of overexposure to phosphine are headaches, dizziness, and nausea, ringing in the ears, difficulty breathing, and diarrhea. If any of these symptoms occur to any person in or around a grain storage facility during fumigation or up to several days after fumigation, CALL 911 and SEEK MEDICAL ATTENTION IMMEDIATELY!

Do not wait to see how the symptoms will develop or if the affected person will recover; CALL 911 and go directly to the hospital. When dealing with fumigants, the old saying, "Better to be safe than sorry" changes to "Better to be safe than DEAD!" In every case of exposure where symptoms are noted, a hospital visit is in order. But to reduce the risk of further injury before a doctor can be reached; here are the recommended first aid tips:

If phosphine (gas, powder, dust, pellets, or tablets) is:

- Inhaled first move the exposed person to fresh air. Keep the person warm and make sure he or she can breathe freely. If the person has stopped breathing, give artificial respiration by mouth or other means. Do not give anything by mouth to an unconscious person.
- Swallowed drink or administer one or two glasses of water and induce vomiting by touching the back of the throat with a finger, or by drinking syrup of ipecac if available. But do not give anything by mouth to a victim who is unconscious or not alert.
- Gotten on the skin brush material off clothes and shoes in a well ventilated area. Allow clothes to aerate in a ventilated area prior to laundering. Wash contaminated bare skin thoroughly with soap and water. Medical attention is needed only if there is burning or severe irritation.
- Splashed in the eye(s) flush eyes with plenty of water.

Part 4: Note to Physician

Every pesticide label includes a section called "Note to Physician" This section is intended to assist the doctor in quickly diagnosing and treating exposure to a particular pesticide. On phosphine labels, the notes to the physician include symptoms normally associated with mild, moderate, and severe poisoning. Some labels may even include the recommended treatments for each of these exposures. But the most important piece of information in the "Note to Physician" section is what chemical the victim has come in contact with, so the doctor can contact Poison Control, whether on the state or national level, for information on the best way of treating the exposure.

It is a good idea for every applicator to carry a highlighted copy of the "Note to Physician" in his or her pocket when fumigating. If for some reason, one or both applicators should become unconscious or severely ill during fumigation, this gives emergency personnel information to pass on to the doctor that may limit injuries or even save lives.

Symptoms of Exposure

According to the NIOSH Alert, Preventing Phosphine Poisoning and Explosions During Fumigation, phosphine gas irritates mucous membranes—especially those of the deep lungs and upper airways. Because phosphine gas releases highly acidic forms of phosphorus when it contacts deep lung tissues, it tends to cause pulmonary edema (fluid in the lungs). Once absorbed into the body, phosphine can damage cell membranes and enzymes important for respiration and metabolism. Intermittent, low concentrations of phosphine gas (probably 0.08 to 0.3 ppm) have been associated with mild headaches and are an indication of mild pesticide poisoning. Higher intermittent concentrations (0.4 to 35 ppm) have been linked to the following symptoms:

- Diarrhea, nausea, abdominal pain, and vomiting
- Tightness of the chest, breathlessness, soreness or pain in the chest, and palpitations
- Headache, dizziness, and staggering
- Skin irritation or burns

Exposure to higher concentrations or the direct ingestion of tablets can cause death to humans and other mammals such as livestock and pets.

The following is an example of the material data safety sheet heath statements for an aluminum phosphide product:

MATERIAL SAFETY DATA SHEET: ALUMINUM PHOSPHIDE, *Brand X*

Signs and Symptoms of Exposure:
Aluminum phosphide tablets, pellets or bags react with moisture from the air, acids and many other liquids to release hydrogen phosphide (phosphine, PH3) gas. Mild exposure by inhalation causes malaise (indefinite feeling of sickness), ringing in the ears, fatigue, nausea and pressure in the chest, which is relieved by removal to fresh air. Moderate poisoning causes weakness, vomiting, pain just above the stomach, chest pain, diarrhea and dyspnea (difficulty in breathing). Symptoms of severe poisoning may occur within a few hours to several days resulting in pulmonary edema (fluid in lungs) and may lead to dizziness, cyanosis (blue or purple skin color), unconsciousness, and death.

Emergency and First Aid Procedures:
Symptoms of overexposure are headache, dizziness, nausea, difficult breathing, vomiting, and diarrhea. In all cases of overexposure get medical attention immediately. Take victim to a doctor or emergency treatment facility. If the gas or dust from aluminum phosphide is inhaled:
Get exposed person to fresh air. Keep warm and make sure person can breath freely. If breathing has stopped, give artificial respiration by mouth-to-mouth or other means of resuscitation. Do not give anything by mouth to an unconscious person.

If aluminum phosphide pellets, tablets or powder are swallowed:
Drink or administer one or two glasses of water and induce vomiting by touching back of the throat with finger, or, if available, syrup of ipecac. Do not give anything by mouth if the victim is unconscious or not alert.

If powder or granules of aluminum phosphide get on skin or clothing:

Brush or shake material off clothes in a well-ventilated area. Allow clothes to aerate in a ventilated area prior to laundering. Do not leave contaminated clothing in occupied and/or confined areas such as automobiles, vans, motel rooms, etc. Wash contaminated skin thoroughly with soap and water.

If dust from pellets or tablets gets in eyes:
Flush with plenty of water. Get medical attention.

It is a good idea for every applicator to carry a highlighted copy of the "Note to Physician" in his or her pocket when fumigating. If for some reason, one or both applicators should become unconscious or severely ill during fumigation, this gives emergency personnel information to pass on to the doctor that may limit injuries or even save lives.

Remember: The law says you are required to have a label on hand for every restricted use pesticide you are applying.

Equipment Needed:

1. Man-in-Bin sign placed near the control panel.
2. Tape measure to calculate volume to be treated.
3. 2-6 ml polyethylene film cut to the size of grain to be covered. A rope should be attached for easy removal after fumigation.
4. Cotton gloves for handling phosphine tablets / pellets.
5. Proper respiratory protection for two people. Check fumigant label for specific requirements.
6. Probes made from conduit or rigid PVC pipe for applying aluminum phosphide tablets.
7. Safety rope for anyone climbing into a bin.
8. Shovels to level grain mass.
9. Grain thermometer to measure grain temperature throughout the grain mass.
10. Warning signs for the fumigant being used.
11. Lock to keep unauthorized personnel from turning on power to bins and to keep them out of building being fumigated.
12. Monitoring equipment to check gas concentration.
13. 2 or 3-inch masking tape, spray glue, glue for polyethylene sheets.
14. Instruction manual and label.
15. Dosage chart.
16. Sufficient fumigant.
17. Grain sampling probe.

Chapter 4: APPLICATION AND CALIBRATION

Part 1: Pre-Application

Level the Grain

Remove the "cone" and break up any crusted areas that have formed. When grain is peaked, the action of fumigants is similar to rain on a hillside. The heavier-than-air gases simply slide around the peak, resulting in poor penetration of the grain mass and, therefore, greater survival of pests in the peaked portion of the grain. Moldy or crusted areas near the grain surface are generally caused by moisture condensation when warmer air in the grain rises to the surface and encounters cold air above the grain. These areas are sometimes hidden from view just below the grain surface. Failure to locate and break them up will result in uneven penetration of grain fumigants and may lead to further deterioration of the grain from mold development and invasion of the grain by insects that feed on grain molds.

Seal the Bin

Sealing the bin is the single most important step in fumigation. Attention to proper sealing of grain bins before fumigation will often make the difference between success and failure of the treatment. A high degree of air and gas tightness is essential to achieve the required combination of gas concentration and exposure time necessary to kill grain pests. Metal storage bins are not gas-tight. In fact, many are designed to hold and aerate grain. However, they can be used for fumigation with proper sealing. Bins will vary in tightness, depending upon how well they were built. If the corrugated sections were caulked when put together and bolted tightly, then they will be tighter. Loosely constructed wooden bins may have to be totally covered with a gas-tight tarpaulin to retain enough fumigant to be effective. Remember, the goal is to confine the gas long enough at the proper concentration to be lethal to the target pests. Sealing is extremely important and demands study and work, but there are a number of techniques that can make the job more effective. There are several places in a bin where gas can escape. The roof-wall junction may look tight from the outside, but examination from the inside may reveal a gap around the perimeter. This gap is difficult to seal because it is usually dusty and may be damp. Cracks wider than 1 inch are even harder to seal. Before trying to seal these cracks, clean the dust from the surfaces before applying tape or other sealing material. Professionals will clean the surface first and then spray it with an adhesive dispensed from a pressurized can. The gap is then sealed with duct or furnace-cloth tape (which are generally more effective than masking tape). Use at least 2-inch and preferably 3-inch tape when sealing these cracks. Tape primer is an expensive but useful tool. This comes in pressurized cans, and may be obtained from the fumigant distributor or sometimes from an auto paint store. These materials make the surface tacky and improve the holding quality of the tape. They also can be applied to the adhesive surface of a piece of tape to improve its sticking power. Polyurethane foams can be used to seal gaps but they are expensive and difficult to remove if the gap is needed for extra grain aeration. Unless insects burrow into the foam and destroy its effectiveness, the seal can last for several years. Another key area is the gap between the bottom of the wall and the floor. Some manufacturers design the wall base to accept a special sealant that can give a long-term seal. Various materials have been used, including one made with polyurethane impregnated with asphalt. Plain asphalt has also been used on the outside but does not have as much elasticity.

Example of Resistance and Unsealed Silos
As phosphine moves around, it leaks rapidly from silos that are not sealed to be gas-tight (Figure 1). Susceptible adult insects are killed quickly, usually within a day. However, immature insects in the egg and pupal stages are tolerant of phosphine and survive the short exposures to high concentrations of phosphine in unsealed silos (Figure 1). Strongly resistant adults can also survive fumigation in unsealed silos.

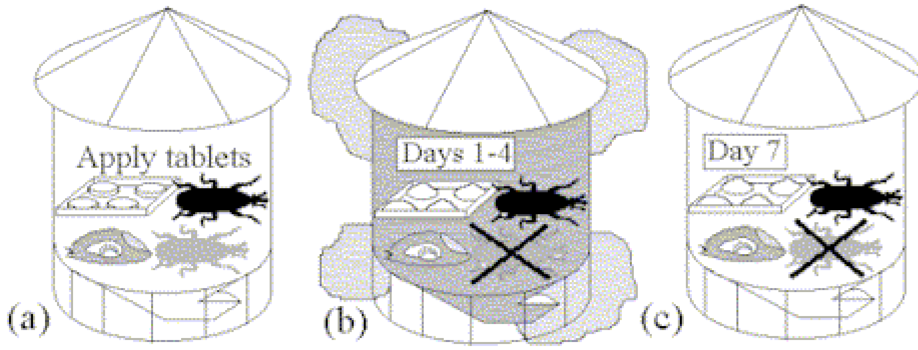


Figure 1. Phosphine fumigation in an unsealed silo: (a) Application of phosphine tablets in a silo with live weevils and immature weevils (eggs, larvae, pupae) inside the grains; (b) During the first few days, tablets react to release phosphine gas that kills susceptible adult weevils (gray) quickly, but not the eggs and pupae nor resistant adults (black), and the gas leaks out of the silo; (c) After 7 days little phosphine remains, and the eggs, pupae and resistant adult weevils survive.

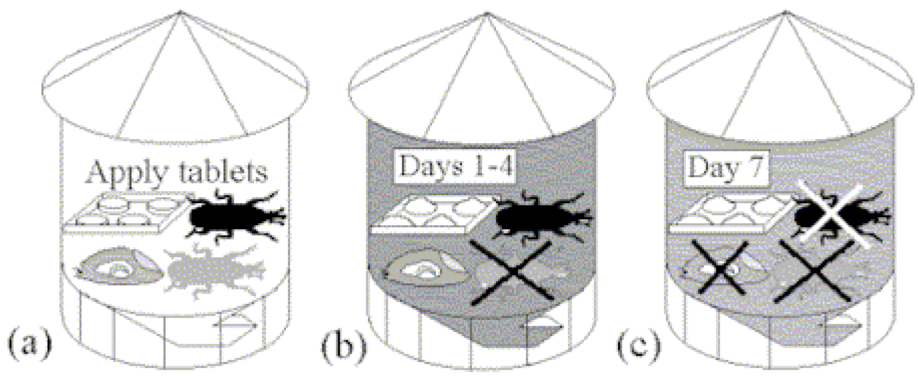


Figure 2. Phosphine fumigation in a sealed silo: (a) Application of phosphine tablets in a silo with live weevils and immature weevils (eggs, larvae, pupae) inside the grains; (b) During the first few days, tablets react to release phosphine gas that kills susceptible adult weevils (gray) quickly, but not the eggs and pupae nor resistant adults (black); (c) After 7 days phosphine remains in the silo at a high enough concentration to kill the eggs, pupae and resistant adults.
Phosphine fumigation in unsealed silos can give the appearance of success by killing susceptible adults. But when strongly resistant insects are present, phosphine fumigation in an unsealed silo will have virtually no effect on the insects.
Source: *Grain storage – resistance to phosphine fumigant* Graham White, Farming Systems Institute, October 2000.

Part 2: Calibrate the Dosage

Read the Label first before doing anything. Determine the number of tablets required to treat the volume enclosed by your sealing efforts. For example, hydrogen phosphide is a very mobile gas and will penetrate to all parts of the storage structure. The dosage must be based upon the total volume of the space you have enclosed by your sealing efforts, and not on just the amount of grain the bin contains. For example, this may include the area below a perforated floor or the volume of aeration ducts in a concrete floor or the headspace above the grain mass if you have sealed the entire bin instead of covering the top of the grain with a gas-tight cover.

The dosage listed on the aluminum phosphide label will be in a range. Use the higher rate if the bin cannot be adequately sealed and/or it contains grain in poor condition. Use the lower dosage if the bin is exceptionally gas-tight or contains clean, dry grain. Dosages recommended for the various phosphine-producing fumigant formulations are fairly similar. However, the actual amount of phosphine involved will vary depending on the type of structure to be treated. Because phosphine distribution is not materially affected by being taken up by the grain, application rates are based primarily on the gas-tightness of the structure and the method of application.

Follow label instructions for dosage increases or decreases. All fumigant labels provide information on the recommended dosages required to effectively treat stored grain. Using less fumigant than recommended can result in a concentration of gas too low to be effective. Using more fumigant than recommended is illegal, may leave an unwanted residue and adds unnecessary cost and risk.

Dosages for aluminum phosphide formulations are expressed in terms of tablets per 1,000 bushels storage capacity or 1,000 cubic feet of space. Use the following formula to calculate the number of bushels in a bin.

> 0.6283 x diameter (ft) x diameter (ft) x grain depth (ft) = the number of bushels in a round bin. (THIS DOES NOT INCLUDE THE AREA ABOVE THE GRAIN MASS)

Part 3: Application Requirements

Post Warning Signs

The applicator must post warning signs at all entrances to the fumigated area. Signs can only be removed after the commodity has been completely aerated. If incompletely aerated the commodity can be transferred to a new site. Always refer to the fumigant label for additional requirements.

Signs must contain:

- the words: "DANGER/PELIGRO"
- the SKULL AND CROSSBONES symbol in red, area and/or commodity under fumigation,
- "DO NOT ENTER/NO ENTRE"
- date and time fumigation begins and ends

- names of a fumigants used,
- name, address, and telephone number of the applicator

Using the Tablets
Divide the total number of tablets needed by four to place in each pie-shaped quarter of the bin. For example, if the total number of tablets required for the bin is 280, the number for each quarter is 280 divided by four, which equals 70. Typically, five tablets are applied at each probe site, thus the number of tablets needed for a quarter of the bin (70), should be divided by five to determine the number of probes needed. In this example, each section would be probed 14 times and with five tablets deposited in each probe.

When placing the tablets in the probe, place the first one when the probe is down 5 feet, then raise the tube one foot and drop the next tablet. Continue until five tablets are placed. The last tablet should be about 6 inches from the surface. As many as 20-50 tablets may be released at one probe site; however, releasing all the tablets at once may slow the release of gas and may cause an explosion. Arrange for enough applicators and other workers to complete the job quickly enough to avoid excessive exposure to hydrogen phosphide gas. Opening the flasks out-of-doors and conducting fumigation when temperature in the bin is lowest can reduce the production of gas during application. Be advised that if the temperatures are too low the product capacity to kill the pest can be limited. Check the label for details. REMEMBER APPLICATORS SHOULD WORK IN PAIRS AND BE PROPERLY FITTED WITH RESPIRATORY DEVICES.

Respiratory Protection
Gas-monitoring equipment must be used as required by the label. The permissible gas concentration ranges (based on eight hours, Time Weighed Average) for various types of respiratory protection devices are:

Gas Concentration	**Respiratory Protection**
Less than 0.3 ppm	**None required**
0.3 - 15 ppm (or escape from levels up to 1,500 PPM)	**NIOSH/MSHA approved full-face gas mask – hydrogen phosphide canister combination.**
More than 15 ppm	**NIOSH/MSHA approved self-contained breathing apparatus (SCBA).**

Note: Read the Label for details

Sealing the Bin Doors
After all sections of the bin have been probed, close the bin and seal the access point with masking tape or plastic glued into place. This seal prevents the fumigant vapors from venting to the outside and prevents the wind from drawing the fumigant out of the grain. Placing a polyethylene sheet cut to size over the grain before sealing the door can reduce gas loss. Fasten a rope to this sheet so it can be removed safely after the fumigation to prevent moisture condensation problems. Remove the plastic immediately after the fumigation is complete to prevent moisture condensation and avoid hindering aeration. Use proper respiratory protection when removing the plastic. The rest of the bin still needs to be well sealed for best results.

Other Considerations
If the grain temperature is considerably warmer than the outside air, or if the grain is more than 12-15 feet deep, the professional fumigator may place as many as 25 percent of the tablets in the aeration system. Tablets or pellets should never be stacked on top of each other. Never place aluminum phosphide on a wet surface or in standing water since it would evolve the gas too fast and could possibly ignite or explode. Once aluminum phosphide tablets or pellets have been exposed to air, they should not be resealed since they may ignite or explode spontaneously. Be sure to seal the fan opening.

Length of Fumigation
The amount of time for exposure of the gas to the grain must be long enough to provide for adequate control. Lengthen the time at lower temperatures because insects are more difficult to kill under these conditions.

Table 1. Guide to determine the minimum length of exposure period[1] for aluminum phosphide

Temperature to which fumigant and/or insects are exposed	**Pellets**	**Tablets**
Below 40 degrees F	**Do Not Fumigate**	**Do Not Fumigate**
40 - 53 degrees F	**8 days**	**10 days**
54 - 59 degrees F	**4 days**	**5 days**
60 - 68 degrees F	**3 days**	**4 days**
Above 68 degrees F	**2 days**	**3 days**

[1]As a rule-of-thumb a minimum of one day should be added to the exposure time listed above for each 10 feet the gas must penetrate downward. It is preferable to add two days for each 10 feet**.**

Note: Read the Label for details

Spray
To complete the treatment, spray the outside of the bin following fumigant application and after sealing is completed. Use a short residual insecticide, and spray to point of runoff. Follow instructions on the container label for mixing rates.

Aeration and Re-entry (RTL)
If the area is to be entered after fumigation, it must be aerated to a safe level of hydrogen phosphide gas of 0.3 ppm or less. Remove the plastic covering from the grain surface immediately after fumigation even if the bin is not to be aired out. The area or site must be monitored to insure that liberation of gas from the treated grain does not result in the development of unacceptable levels of hydrogen phosphide. Do not allow the re-entry into treated areas by any person before this time, unless an approved respirator protects them.

Fumigants do not provide any residual control. After the bin is aired out, you may wish to consider spraying the grain surface to reduce insect re-infestation and fogging the space above the grain to kill flying insects. At the end of the phosphide fumigation, the powdery residue of tablets or pellets will contain a small amount of non decomposed aluminum phosphide for several additional days. Under normal circumstances of grain handling, these residues do not present a hazard, but inhalation of the powder should be avoided. It is very important to monitor the fumigant concentration to determine any losses due to sorption or leakage so that adjustments can be made if necessary. It may be necessary to reseal an area, add more gas, or lengthen the exposure period to give the proper concentration of fumigant for the necessary time. After the fumigation is over, it is equally important to be able to know that the gas has been reduced to a level below the 8 hour Time Weighed Average (0.3 ppm) to insure worker safety upon reentry.

There is no single device that economically and efficiently measures all fumigants at all normal levels. Various devices can be used depending on the gas being measured and whether a high reading during the fumigation or a low-range reading for compliance with the Time Weighed Average after the fumigation is needed. Follow instructions for the particular device you use. Detection tubes are probably the most versatile tools available for measuring gas concentrations. They are available for many industrial gases, as well as almost all fumigants. The equipment used with the tubes is well built, durable, and manufactured by a number of suppliers. The initial cost of the equipment is moderate and can be amortized over hundreds of uses and many years. For most gases, they are sufficiently accurate.

The disadvantage to using these tubes is that they are designed for a single use on a single type of fumigant. Their cost of over $4 per tube can be burdensome when many readings are needed. They are not available for both high and low readings so separate tubes of different capacities must be used. The tubes have a limited shelf life and are not reliable after the expiration date. In addition, they have limited accuracy on some gases. Plastic tubing must be placed so that air within the bin may be sampled from outside the bin.

Part 4: Cautions!

- All fumigants are dangerous when improperly used. Follow the cautions listed on the container label and use only in strict accordance with label directions.
- Wear respiratory protection approved by NIOSH/MSHA for the level of hydrogen phosphide gas to which you will be exposed.
- The effective life of a gas mask canister is limited. Keep an accurate account of the time that a canister is used and replace it after each use, if you smell fumigant, or the canister is out-dated. Note that the 3 fumigants in this manual produce an odor, but not all fumigants do.
- Self-contained breathing apparatus requires a refilling source. Your local fire station or rescue squad may be a refill source.
- Never fumigate a bin by yourself. Have another person on site to help if you get into trouble. The helper must also be properly fitted with approved respiratory protective devices. Devise a code so that you can communicate with each other. Make sure gas and electrical connections are turned off. Have the telephone numbers of the police and fire departments, hospital, physician, and rescue squad available.

- Do not drink alcoholic beverages for a day before, during, or after exposure to grain fumigants. Do not think that because you might have gotten away with fumigation without these precautions before that you can always get away with disregard to safety. Fumigants demand respect if you want to avoid injury or death.

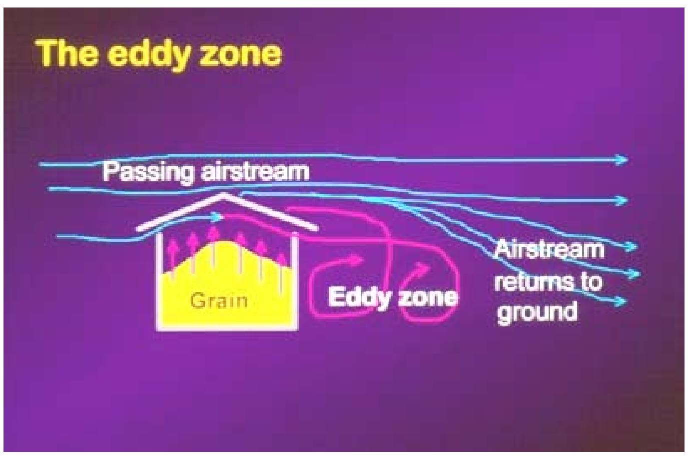
- If there are differences in statements in this guide and the aluminum phosphide label, follow the label instructions.

- Grain in flat-storage, machine-shed type buildings should be covered with a tarpaulin for maximum effectiveness.

- Avoid falling or coming in contact with electrical wires when doing fumigation.

Example of How Air Flow Can Trap Phosphine Gas Near the Bin

This diagram shows how phosphine gas can get trapped in an eddy zone at the leeward side of the grain storage bin. The wind flow around the bin can create pocket of abnormally high gas concentrations that should be avoided by applicators, non-target organisms, pets and livestock.



The smoke indicates high gas concentrations on the leeward side of the building.

Source: Stephen Pratt. 2000. Phosphine levels outside grain stores during Siroflo® fumigation. Stored Grain Research Laboratory, CSIRO Entomology.

Examples of Protective Equipment

1. Fumigator wears suitable gloves when handling phosphine pellets.

Photo: NIOSH Alert, Preventing Phosphine Poisoning and Explosions Durring Fumigation. DHHS (NIOSH) Publication No. 99-126 September 1999.

2. You must use a Gas mask and canister (A) or Self Contained Breathing Apparatus (B)

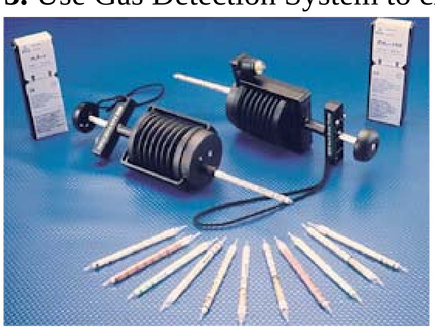
A. Gas Masks and Canisters

Photos: Degesch America®

B. Self Contained Breathing Apparatus

Photos: Degesch America®

3. Use Gas Detection System to check for harmful gas concentrations.



Pump System with detection tubes.

Photos: Degesch America®

Electronic System with detection chips.

Chapter 5: SOIL FUMIGATION

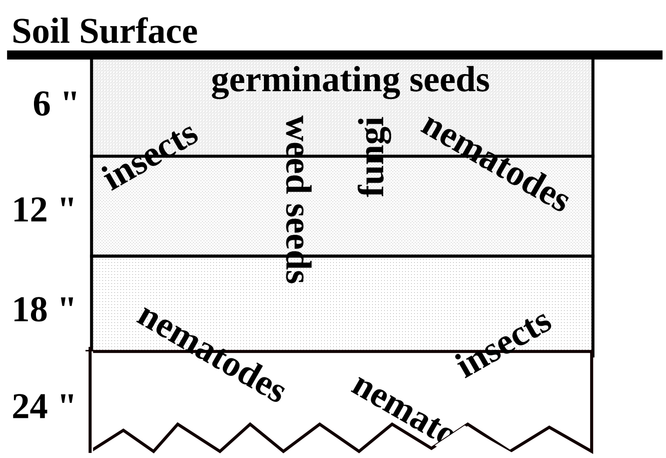
Part 1: Factors Affecting Soil Fumigation

Many factors affect soil fumigation and its effectiveness for pest control. The pest and its habits will affect fumigant selection, application rate, and time of application, fumigant placement, and necessary length of exposure. Soil factors also play a key role in fumigation. Soil texture, soil condition, debris, soil moisture, and soil temperature may affect the volatility, movement, and availability of the fumigant once applied. Fumigant dosage is both pest and soil dependent. The following section discusses some of these factors in greater detail. After fumigation, aeration is often important to make sure phytotoxicity does not occur.

Pest Habits

Proper identification of the pest(s) is crucial. Once you have properly identified the pest, you can find out about pest life cycles and habits. Understanding the pest's habits provides information for proper application timing to target the susceptible stage and for proper application depth to ensure adequate contact with the pest organisms. (Contact your local Cooperative Extension agent for assistance in pest identification.)

Know Where the Pests Live:



Soil texture - influences fumigant movement and availability due to its effects on the amount of soil pore space (air spaces) and the number of adsorption (binding) sites. Fine textured soils, such as clay, have many adsorption sites per unit area and many pore spaces. Coarse-textured soils have relatively few binding sites and few air spaces. For these reasons, soils high in clay content require more fumigant to attain a lethal dose. Generally, coarser-textured soils require less fumigant than fine-textured soils. Read the label for any statements regarding amount of clay content or organic matter in soils.

Soil condition - is a major factor in fumigant penetration and diffusion. Fumigants do not move uniformly through the soil. Compacted soil limits the amount of diffusion and penetration. Cultivation of soil prior to fumigation is essential. Cultivate the soil to the level where the fumigant needs to diffuse. Break up or remove soil lumps and clods. Pulverize and smooth the soil surface before fumigation to aid post application sealing, if required. Sealing prevents fumigant vapor from escaping too quickly.

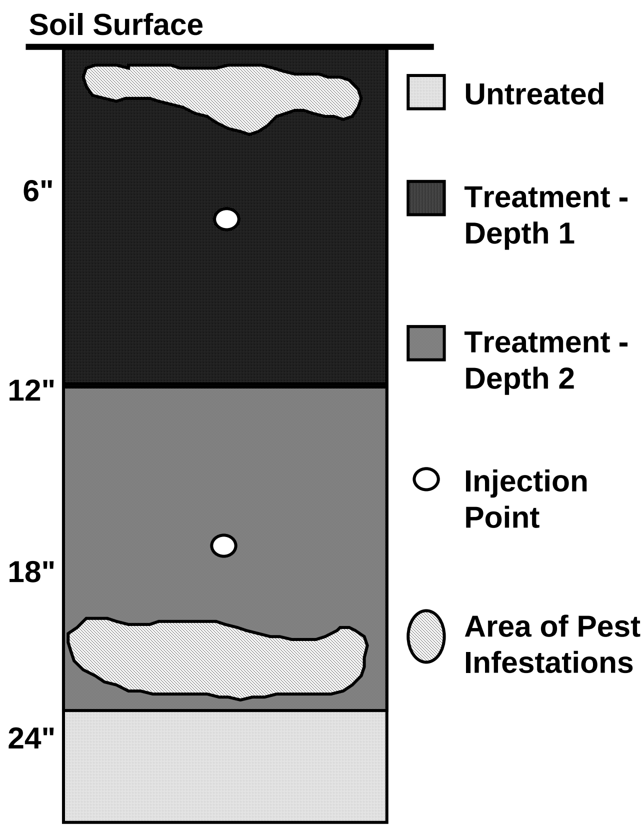
Improper soil preparation is the major reason for fumigation failures. Fumigate soils before applying manure, sawdust, or other organic matter.

Plant debris - can pose problems to shank type fumigation if excessive amounts of fresh or decaying plant material are present. Work all vegetation into the soil thoroughly. Allow vegetation plenty of time to decompose before fumigation. Do not fumigate soils that contain excessive amounts of organic matter.

Soil moisture - affects the diffusion of the fumigant. Most fumigation is conducted when the soil moisture reaches 50% - 75% of field capacity. (Consult your Natural Resources Conservation Service or Cooperative Extension Agent for assistance.) Fumigation requires a certain amount of soil moisture to ensure that the fumigant does not escape too quickly. Too much moisture may impede fumigant movement because soil pores filled with water do not allow the gas to move. Cold, wet soils retard diffusion and require a longer than normal exposure period. The soil moisture requirements necessary for effective fumigation differ among fumigants; read the product label directions carefully.

Soil temperature - correlates directly with fumigant volatility and movement. Soil temperature determines the fumigant state (solid, liquid or gas). As temperatures increase, fumigant volatility and diffusion increase. Generally, soil temperatures 45˚ to 80˚F at the depth of fumigant injection are best for volatilization. Temperatures below the label minimum reduce volatilization and penetration, and the fumigant persists longer in the soil profile. Above the maximum stated temperature, as can be found in Arizona, volatilization and penetration increase to the point of loss or breakdown. Again, this may differ among fumigants; some are active at 40˚F, while others remain in the nongaseous state at that temperature.

Application depth - is variable. Proper fumigant placement depends on a combination of factors, including where the pest organism lives, soil temperature, dosage, vapor pressure, and soil type. If the application is too deep, the rate too low, and the pest organisms are relatively shallow, fumigant may not diffuse far enough upward to contact the pest at a sufficient dose (concentration in ppm x time in hours) to obtain control. If the application is too shallow the fumigant may not diffuse far enough downward to reach the deeper pests. The fumigant may actually dissipate upward and out of the soil. Split depth applications may be necessary if soil condition is marginal and if broad depth control is required; for example, applying at 6 to 8 inches and 16 to 24 inches for even diffusion. Read the label for application depth directions and know the pest habits. For proper placement, you must know the pest habits and follow the product label instructions.



Time of Application - Late fall applications of soil fumigants are generally best because soil temperatures and moisture levels are more favorable. Fall applications after crop removal both allow the fumigant time to dissipate over the winter and allow growers to plant at the normal time in the spring. In the spring, soil factors are often variable so growers may need to delay planting to allow the fumigant time to diffuse and break down to a level that will not cause phytotoxicity.

Dosage - depends on several factors. Different soil types require varying rates, given the amount of pore space and amount of adsorption to clay and organic matter. Some pests, such as endoparasitic and cyst nematodes, require higher dosages than other pests. Rates also vary depending on what plants or crops will be planted. Follow label directions. Performance data indicate label rates are effective. Applications above label rates are illegal and may damage the crop. Applications below label rates may not provide adequate pest control.

Soil sealing - is especially important in soil fumigation. Seal the soil immediately following fumigation, the sooner the better. The seal caps the soil surface, minimizing the amount of fumigant that escapes into the atmosphere. For effective pest control, keep the seal in place long enough to maintain a lethal gas concentration for the exposure period. It may be necessary to cover the area with a plastic tarp when using highly volatile chemicals, such as chloropicrin, or when trying to control pests at or near the soil surface. Two other soil sealing methods are mechanical compaction (cultipacking, rolling, dragging) and light irrigation. If injection shank traces are present after treatment, disc them before sealing. For water seals, lightly water (to wet) the top inch or so of soil. Maintain that soil moisture throughout the exposure period. For optimum effectiveness, seal the soil as the fumigation progresses.

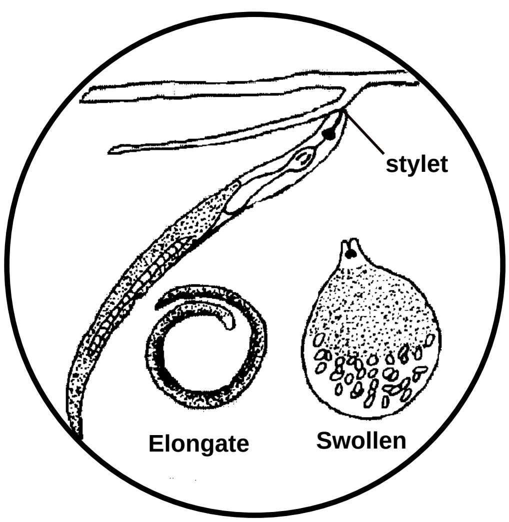
Exposure period - varies depending on the pest organisms, the fumigant type and rate, soil moisture, and soil temperature. After the application and soil sealing, leave the soil undisturbed for the specified amount of time listed on the product label.

Soil aeration - may be necessary at the end of the fumigation "exposure period" to let any fumigant in the soil dissipate. Once the soil is properly aerated, growers can plant the crops or plants without concern for phytotoxicity. Application rate and depth, soil moisture, soil temperature, and sealing methods govern aeration times. Cool, moist soils tend to retain fumigant longer, requiring longer aeration periods. Cultivating the soil to the depth of fumigant application often aids aeration. Refer to the label to determine exposure times and aeration recommendations. Planting a test sample of seeds may be warranted in certain situations to ensure that no phytotoxic effects occur on highly susceptible plants.

Phytotoxicity - plant injury, is a major concern when using soil fumigants. Apply most soil fumigants weeks or months prior to planting because of potential phytotoxic effects. Some plants or crops are very sensitive to small traces of soil fumigants, and phytotoxicity occurs when they are planted into soils where fumigant is still present. Read the fumigant label for certain precautions when planting certain plant varieties after fumigation. Another concern is off-target movement (drift, runoff). Fumigant may escape through the soil surface and drift onto nearby susceptible plants. Rain or over irrigation may cause runoff. Pay close attention to what is planted on or is inhabiting areas near the application site.

Part 2: Soil Pests

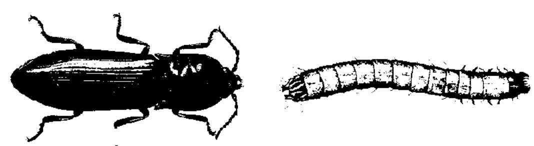
Nematodes are generally microscopic. They are small, non-segmented, threadlike roundworms that can attack and injure plants. Some develop into swollen adult females. Usually transparent, nematodes range in size from 1/64 to about 1/10 inch.



Nematodes in Two Forms: Elongate and Swollen

A key feature used to identify nematodes that feed on plants is the presence of a hard, piercing spear or stylet in the anterior portion of the body. Plant parasitic nematodes use a stylet to puncture and feed on plant cells. Nematodes reproduce by laying eggs. Nematodes live either in the water film in and around soil particles and plant tissue or within plant tissues. "Ectoparasitic" plant nematodes remain on the outside of the plant. Most ectoparasitic nematodes migrate freely over the root surface, while some more sedentary nematodes remain at one point to feed. "Endoparasitic" nematodes move into the plant tissue to feed. Endoparasitic nematodes either move in and out of roots or remain sedentary within the root. At certain life stages, nematodes are present in the soil.

Soil fungi also can be destructive to plants. Fungi (molds, mildews, *Pythium*) are plantlike organisms that lack chlorophyll, thus, they do not manufacture their own food. They must obtain nutrients from other sources, including plants. Most fungi reproduce by spores. Fungal spores germinate into threadlike filaments called **hyphae** that grow, secrete enzymes, absorb nutrients, and release chemicals that induce plant diseases. Most soil fumigants can effectively control soil fungi. A few species of soil *bacteria* cause plant diseases. Bacteria are very small, one-celled organisms that reproduce by simple fission. They obtain nutrients from plant cells and generally need an injury or natural opening to enter plants. Several *insects* and insect relatives that live in the soil are pests of plants. The insects are generally immature stages of beetles and flies. These two groups of insects undergo complete metamorphosis, developing from egg to larva to pupa to adult. The larval stage (maggot, grub, worm) usually causes damage, though some adults also will feed on underground plant parts.



Wireworm Adult and Larva

Symphylans (garden centipedes) are close relatives of insects. They occasionally cause problems by feeding on underground plant parts.

Weeds also compete with plants. Some fumigants control weed seeds and germinating plants.
In summary, as a certified applicator you have a large responsibility in protecting not only yourself but also the environment. We would advise you to utilize this guide in the form of a notebook that can be updated as needed on current fumigation information.

Example of Tarping a Field

The most commonly used tarping machine consists of two discs that open small furrows immediately outside the area to be treated. These discs are connected to a tarp layer containing rolled polyethylene, which is unrolled over the treated area. Small press-wheels insert the tarp into the open furrows and the tarp is sealed with soil thrown back into the furrow by closing discs. Rates of application depend on tractor speed and flow rate of the chemical.

To treat a field on a broadcast basis, one strip is applied as described above and then one set of discs removed and replaced with an adhesive dispenser. One side of the second tarp is sealed with the adhesive to the first tarp and the other side of the second tarp is sealed in the furrow made by the remaining discs. This is repeated and the entire field is fumigated and covered with polyethylene.

Notice the adhesive strip in the lower right of this photo, this strip of adhesive is mechanically applied to the polyethylene. The valve in this photo is the adhesive applicator.

Source: Virginia Tech Pesticide Programs, *How to Apply Liquefied Gas Formulations*, http://www.vtpp.ext.vt.edu/

GLOSSARY

Absorb -to drink up or take in.
Adsorb -to hold or bind to the surface.
Aflatoxin -toxin produced by fungi, which can be quite poisonous.
Bacteria - very small, one-celled organisms that reproduce by simple fission.
Cast Skins -skins that were shed during molting.
Caterpillars -larvae of moths and butterflies.
Complex Metamorphosis -develops from egg to larva to pupa to adult.
Diffuse -to move from an area of higher concentration to an area of lower concentration.
Egg -reproductive unit of nematodes, insects, and symphylans.
Elytra -hard and leathery outer wings of beetles that protect the hind wings.
Eradicant -chemical control to kill all pest organisms present.
Exoskeleton -the hard outer skeleton.
Fecal Pellets -frass, excrement.
Fines -grain flour and dust.
Frass -excrement.
Fungi -mold like plants with no chlorophyll, reproduce by spores.
Fungivores -organisms that eat fungi.
Germination -sprouting or developing of a seed, bud, or spore.
Germplasm -reproductive cells of an organism.
Hot Spots -areas where temperature is higher; more optimal locations for pest development.
Insect -an animal with an exoskeleton and jointed appendages that has three body regions, three pairs of legs, and sometimes wings.
Instars -larval stages between egg and pupa molts, also nymphal stages
Larva-the immature form of an insect that undergoes complete metamorphosis.
Life Cycle-time from egg laying to development of adult.
Mandibles -biting jaws.
Microorganism -any living thing that is very small in size; bacteria, fungi, virus, nematode, etc.
Molt -shed the outer skin.
Organism -any living thing; plant, animal, fungus, bacterium, insect, etc.
Omnivorous -eating any type of food, animal and vegetable.
Pheromone -chemical released by an organism that initiates response of another organism of the same species.
Phytotoxic -poisonous to plants.
Placard -a poster or notice giving information.
Pore Space -area between grain kernels that fills with air or water**.**
Primary Pest-attacks undamaged grain kernels.
Protectant -chemical placed on grain to guard against a possible infestation.
Pupa -a stage in insect development between the larva and adult**.**
Sanitation -maintaining an environment clean free spilled grain and hiding areas for pests.
Secondary Pest -can only attack previously damaged grain kernels.
Simple Metamorphosis -develops from egg to nymph (looks like adult with no wings) to adult**.**
Sorption -absorption or adsorption.
Spore -reproductive unit of fungi**.**
Symptom -an expression, a sign, an indication of something wrong.

Target Organism -plant or animal to which a control is directed.
Thorax -the middle portion of an insect to which the legs and wings are attached.
Toxic -injurious to plant and/or animal, poisonous.
Vesicant -causes blisters.
Volatile -will evaporate readily.
Volatilize -to evaporate (i.e., changes from liquid to a gas).
Weevils -beetles with mouth parts at the end of an extended snout.
Wingspan -distance between tips of wings.