FUMIGATION OF FARM STORED GRAIN AND STRUCTURES

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INSECT PEST MANAGEMENT FOR FARM STORED GRAIN

INTRODUCTION

Direct feeding damage by insects reduces grain weight, nutritional value and germination. Insect infestation also causes contamination, odors, molds, and heat damage that reduces the market value of the grain and can make it unfit for processing into food for humans or livestock. Federal and state laws specifically prohibit the use of insect or rodent contaminated grain for human food.

Commercial grain buyers may refuse to accept delivery of contaminated grain. Elevators will discount grain 1 to 20 cents per bushel if there are insects in the grain received, but the methods used to determine discounts are not uniform in the grain trade. An elevator that simply will not accept "weevily" grain at one time may make only a minimal discount for it at other times. The threat of the discounts, however, is always present as an economic incentive for protecting stored grain from insects.

TYPES OF STORED GRAIN INSECTS

The stored grain insects are a diverse group. They can be divided into three general types based on their location in the bin and the damage they cause: surface-feeding caterpillars, external feeders (insects that feed on the outside of kernels or on broken kernels in the grain mass) and internal feeders (insects whose larval stage develops inside grain kernels).

Following are examples of each of these insect types found in stored grain:

Surface feeders

One of the most common surface infesting caterpillar is the Indian meal moth (Fig. 1). The adult moth is about 3/8 inch long and dark in color except for a conspicuous light band across the base of the wings. When at rest, a conspicuous dark-light-dark pattern is visible.

Indian meal moth larvae are dirty-white caterpillars up to ½ inch long which web food particles together with silk and often wander out of the food material in search of pupation sites.

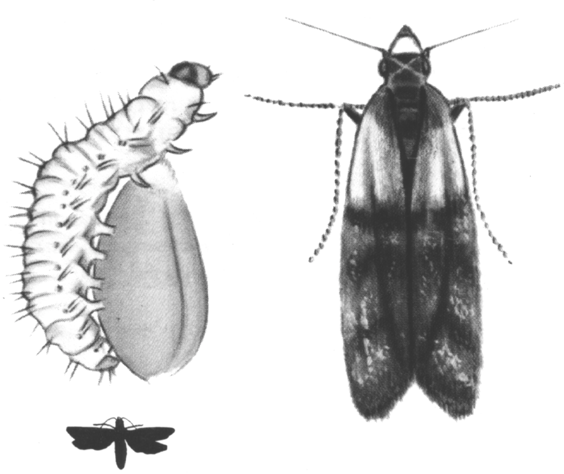

Figure 2. Indian Meal Moth larva and adult.

This insect will infest any commodity in storage including small grains, corn, beans and sunflower. They are also known to infest processed foods such as nuts, dried fruit, candy and baking products.

Indian meal moth larvae prefer to feed on fines, 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 skins (exterior body covering) and silk contaminate the grain.

Female moths deposit 100 to 300 eggs over a three week period. Fully grown caterpillars may leave their food source and climb up walls to pupate. The life cycle from egg to adult takes about six to eight weeks during warm weather. There can be several generations per year depending upon food supply and temperature conditions.

Internal feeders

Included in this group are the weevils (granary and rice), lesser grain borer and Angoumois grain moth.

These insects deposit their eggs on or in the kernels. The larvae that hatch from the eggs feed and pupate inside the kernels where they cannot be seen. The adults chew small, round holes as they emerge from the kernels. The holes in the kernels and the adults crawling on the grain are the only indications of their presence.

The Angoumois grain moth and the lesser grain borer are rarely found in Wyoming stored grain. The granary weevil and rice weevil will occasionally be found in the state, although these species are not as commonly encountered as the external feeders such as flour beetles (red and confused) and the sawtoothed grain beetle.

The granary weevil is a small, moderately polished, blackish or dark-brown beetle (Fig. 2). The head extends into a long slender snout with a pair of stout mandibles or jaws at the end. This insect is not more than 3/16 of an inch long and often is smaller. There are no wings under the elytra (wing covers), and the thorax is well marked with longitudinal punctures, two characteristics that distinguish it from the closely related rice weevil, which has fully developed wings and irregularly shaped punctures on the thorax.

Both the adults and larvae feed occasionally on a great variety of grains. The adult weevil lives an average of seven to eight months, and each female produces 50 to 250 eggs during this period. Before depositing an egg, the female uses her mandibles to bore a small hole in a grain kernel. She then deposits an egg in the hole and covers it with a gelatinous fluid that seals the hole. The small, white, fleshy, legless grub or larva feeds on the inside of the kernel (Fig. 2). When fully grown, the larva transforms into a pupa and then into an adult.

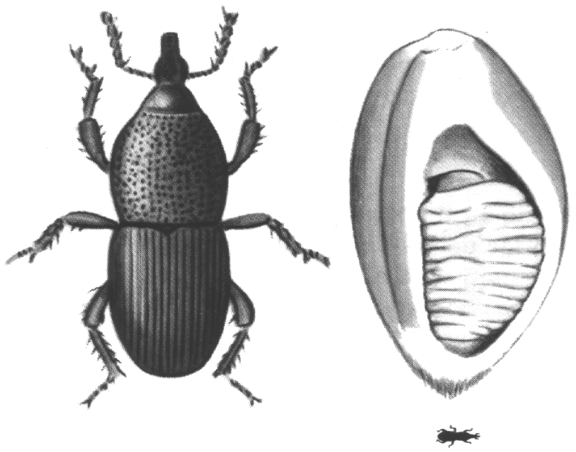

Figure 3. Granary Weevil adult and larva (in kernel).

In warm weather, the granary weevil develops from the egg to the adult stage in about four weeks. Cold weather greatly prolongs the developmental period.

External feeders

This group contains the insects most commonly found in stored grain, especially the flour beetles (red and confused) and the sawtoothed grain beetle. These beetles are sometimes referred to as "bran bugs."

Other external feeders include the flat grain beetle, foreign grain beetle, rusty grain beetle and the dermestids.

The red flour beetle (Fig. 3) and confused flour beetle are almost identical in appearance. However, the red flour beetle can be distinguished from the confused flour beetle by its antennae. In the confused flour beetle the segments of the antennae gradually increase in size from the bases to the tips whereas the last few segments of the red flour beetle antennae are abruptly much larger than the other segments, forming enlarged tips.

The average life of the flour beetles is about one year, but some have been known to live as long as three years. The female lays an average of about 450 eggs, which are small and white. They are covered with a sticky secretion, becoming covered with grain dust, flour or meal, depending upon what the beetles are infesting.

The eggs hatch in five to 12 days and small, wiry, slender, cylindrical worm-like larvae emerge. When fully grown, they are about 3/16 of an inch long and are white tinged with yellow. The larvae feed on grain dust, broken grain kernels and flour.

When fully grown, the larvae transform into small naked pupae which are at first white in color. Later changing to yellow and then to brown. In summer, the period from egg to adult averages about six weeks under favorable weather conditions, but the life cycle is greatly prolonged by cold weather.

The sawtoothed grain beetle is a slender, flat, brown beetle about 1/10 of an inch long. It derives its name from the peculiar structure of the thorax (area between head and abdomen), which bears six sawtooth like projections on each side (Fig. 4). It feeds on grain and grain products in both the larval and adult stage.

The adults live, on an average, six to 10 months, but some adults may live as long as three years. The female beetle lays 43 to 285 eggs. She deposits them loosely among the grain kernels or tucks them into a crevice in a kernel of grain. The small, slender, white eggs hatch in three to five days.

The emerging larvae crawl about actively and feed. During summer, they become fully grown in about two weeks. The mature larvae then construct delicate cocoon like coverings by joining together small grains with a sticky secretion. Within these cells, the larvae change to the pupal stage, which lasts about one week. In summer, the developmental period from egg to adult is four weeks.

CONDITIONS THAT ENCOURAGE STORED GRAIN INSECTS

Temperature, moisture, and grain dockage or dust interact to provide conditions necessary for the reproduction and survival of stored grain insects. The most favorable temperature for them is about 80 degrees F. At temperatures above 95 degrees F. or below 70 degrees F., reproduction is nil and survival is reduced.

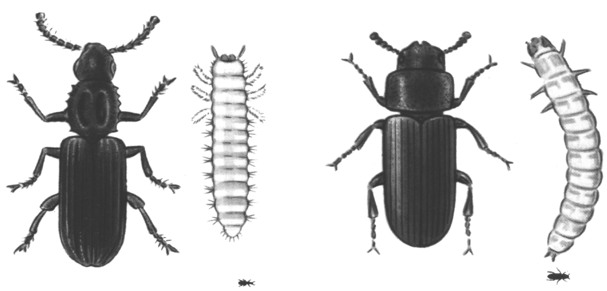

Figure 4. Sawtoothed Grain Beetle adult & larva (left); Red Flour Beetle adult & larva (right).

The most favorable moisture range for stored grain insects is 12 to 15 percent. The lowest limit required for their reproduction and survival in clean grain is about 9 percent moisture. However, as temperatures increase insects can reproduce in grain with a low moisture content, and when moisture increases they can reproduce at low temperatures.

Insect infestations are different in clean and dirty grain. Dockage content may directly influence the preference and subsequent infestation of grain by insects. Even the presence of grain dust or dockage permits some grain beetles to survive and reproduce at extremely low moisture levels.

SOURCES OF INFESTATION

Some of the stored grain insects can fly and begin their infestation in maturing grain in the field. While field infestation may occasionally occur in Wyoming, it is a negligible source of infestation. The insects can be virtually everywhere and may easily be carried onto the farm in infested lots of grain or feed or they may fly in from infested grains or bins on adjacent farms.

Without question, the greatest source of infestation is old grain, seed, feed, spills, debris and accumulated grain dust in and around storage areas.

MONITORING BINS FOR INSECTS

Stored grain insects are widespread, numerous, very small and they can show up even in the cleanest, best managed bins. You must check bins regularly to be sure of detecting pests before they cause damage. Bins should be inspected twice a month from May through October and at least on a monthly basis from November through April.

It's easy to check the surface of the grain. A grain sieve that will hold the grain while dropping the fines and any insects into a pan under a sieve is very helpful for examining grains. A grain probe for taking a core of grain from deeper in the grain mass is also very helpful. If a probe and sieve are not available, you can use a grain scoop or similar tool to take the sample and a pan or piece of plastic to spread it on for examination.

Grain deterioration symptoms:

! Be alert for heat, moisture or off-odors that indicate a problem as you enter the bin.

! Look for living or dead insects on the roof or sides of the bin or on the grain surface.

! Examine the grain surface for signs of mold, webbing, cast skins, droppings or kernels showing insect damage.

! Take several samples of grain with a probe or scoop. It is suggested that you take samples of 1 pint quantity from each of six or more areas of the surface. Examine the samples carefully for any signs of insects or their damage. Samples taken during cold weather can be taken indoors and allowed to warm up. Insects in the sample will soon become active due to the warm temperatures and can be easily detected. Be especially alert for round holes in the kernels that may indicate the presence of internal insect feeders.

! If you find insects, save them for identification, then dig into the grain (a probe is advisable) to determine how deep the insects are in the grain mass, and try to get an idea of their abundance.

Deep checking down in the grain mass is difficult. Try to check the space under the perforated aeration floor, if there is one, for any evidence of water, mold or signs of insects. You will have to use a flashlight and look through the fan or auger port for this.

USE OF INSECT TRAPS

In recent years a variety of insect traps have become available to help producers detect insects in stored grain. One such trap involves a pheromone placed inside a cardboard structure coated with a sticky material on the inside. Insects in grain are attracted to the pheromone emitted from the trap and once inside the trap they become entangled in the sticky material.

Pheromone sticky traps have openings to allow entry of insects and they are available in a variety of designs (Fig. 4). Also, different pheromones are available for attracting

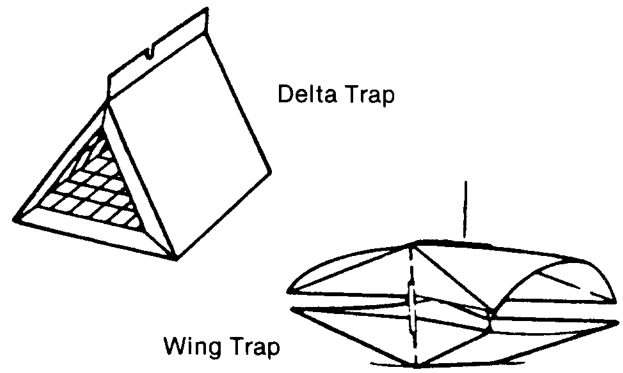

Figure 5. Pheromone baited sticky traps.

specific insects such as Indian meal moth, flour beetles. sawtoothed grain beetles, etc.

Another type of trap, known as the grain probe trap, functions as a pit-fall trap. The trap is made of plastic and is about 17 inches long with small holes in the upper section (Fig. 5).

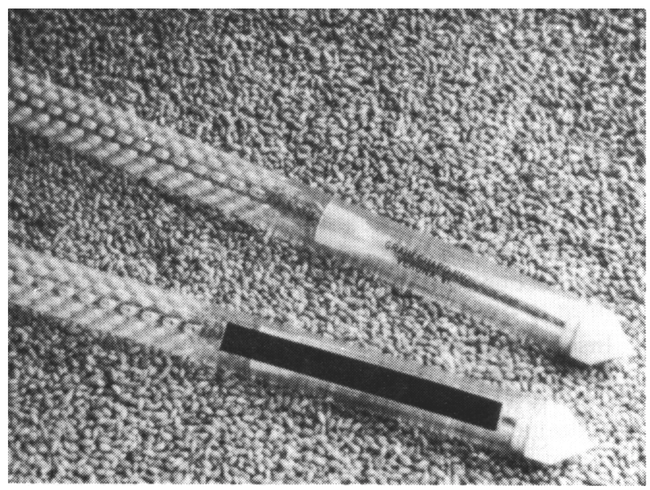

Figure 6. Grain probe trap.

Grain probe traps can be used with or without attractants and they should be shoved vertically into the grain and retrieved with a cord attached to the top of each trap.

For best results five traps are suggested for round bins up to 20 feet in diameter with one trap in the center and one trap in each quadrant of the bin.

The grain probe traps have a removable tip so that insects can be removed, counted and identified.
Traps should be checked once a week during periods when insects are most active and once a month during less active periods

PREVENTION OF STORED GRAIN INSECTS

Bin sanitation and maintenance

The most important and cost effective step in preventing insects from infesting stored grains is cleaning them out of the storage area before bringing in new grain. The insects are small and can live in the tiniest cracks, so assume that insects are present even if you don't see them.

The best time for bin cleaning is two to three weeks before new grain is brought in. Bin walls and floors should be swept thoroughly. Use a shop vacuum cleaner to remove grain dust, insects, eggs etc. from hard to clean cracks and crevices such as around the floor edges next to the bin walls, floor ducts, space under perforated floors etc. If you can tell what was previously stored in the bin, it isn't clean enough.

Be sure to remove all old grain from the bins and give special attention to cleaning in and around all grain handling machinery as well as around the outside of the bin.

Bin spraying

Regardless of how thorough the bin cleaning operation, some insects will no doubt be left in the bin. It is important to apply an interior bin spray to control the insects that were not removed during bin cleaning.

A hand pump garden sprayer can be used to apply the bin spray. Take special care to treat all cracks, crevices, and areas around doorways and other places where insects could enter from outside. Don't neglect spraying around the outside of the bin, especially around bin doors, seams, aeration vents and other possible sites of insect entry.

Insecticides and rates approved for bin spraying are given below:

- Malathion 50 to 57% (premium grade) emulsifiable concentrate at 1 pint in 3 gallons of water. Use 1 gallon of spray for approximately 500 square feet of bin surface.
- Methoxychlor 25% emulsifiable concentrate at 1 quart in 2 ½ gallons of water. Use 1 gallon of spray for approximately 500 square feet of bin surface.
- Methoxychlor 50% wettable powder at 1 lb. in 2 ½ gallons of water. Use 1 gallon of spray for approximately 500 square feet of bin surface.
- Reldan 43.2% emulsifiable concentrate at ½ pint in 3 gallons of water. Use 1 gallon of spray for approximately 650 to 1250 square feet of bin surface.
- Tempo 24.3% emulsifiable concentrate at 8 milliliters per 1,000 square feet in sufficient water to provide adequate coverage.
- Tempo 20% wettable powder at 9.5 grams per 1,000 square feet in sufficient water to provide adequate coverage.

NOTE: Insecticides, formulas, and rates of application approved for this and other uses are subject to change. You should always purchase material that has a label stating that it may be used for the purpose, then use strictly as directed on the label.

Grain protectants

Grain that will be held in storage for more than one year should be treated with a grain protectant. Grain protectants are insecticides that are mixed with the grain as it is being loaded into the bin. Protectants will continue to control insects in the grain, or those that enter the bin up to one year after application. When the protectants are used at recommended rates they will protect the grain effectively without leaving an objectionable or hazardous residue in the grain. The protectants are much less hazardous, easier to apply and less expensive than fumigants and protect the grain for a much longer period of time than fumigants will.

High temperatures or high grain moisture content will reduce the residual effectiveness of any insecticide protectant. When high moisture grain must be dried using a commercial grain dryer, the protectant should be applied after the grain has been through the dryer and has cooled to 90°F or less.

Liquid protectants

Liquid or emulsifiable concentrates (EC) currently registered for application to grain going into storage are malathion 5 lb. EC, Pyrenone and Reldan 4 lb. EC. Pyrenone is not readily available. Indian meal moths have developed a high degree of resistance to malathion and there is some evidence that insects in the bran bug group may also be developing resistance to malathion.

Dust and wettable powder protectants

Malathion is available as a 2, 4 or 6% dust. Reldan is available in a 3% dust formulation. Bacillus thuringiensis, a bacterial insecticide, is available as a dust or wettable powder and marketed under the product name of Dipel. Dipel may be used as a surface applied protectant for the control of Indian meal moth larvae. It should be noted that Dipel does not control grain infesting beetles, weevils or Indian meal moth adults.

Pest strips

Vapona (dichlorvos) insecticide strips can be used to protect against insects (such as Indian meal moth) invading the surface of the grain mass in bins. The strips are effective only in enclosed areas with limited air movement. They should be placed after the bin is filled using one strip per 1,000 cubic feet of space above the grain and changed at intervals indicated on the label. These strips are only effective during warm weather. Stored product pests are most active above and on the grain surface from May through September, and this is when insecticide strips are most effective

Application of grain protectants

Dosage rate:

- Malathion 5 lb. EC at 1 pint in 2-5 gals. of water per 1,000 bu. of grain. - Malathion 2% dust at 30 lbs. per 1,000 bu. of grain.
- Malathion 4% dust at 15.5 lbs. per 1,000 bu. of grain.
- Malathion 6% dust at 10 lbs. per 1,000 bu. of grain.

- Bacillus thuringiensis (BT) is available in several formulations of varying concentrations. This material should be mixed with the upper 4-6 inches of grain either by adding to the last grain being augered into the bin or by applying it to the grain surface after the grain has been binned. With the latter application, the BT must be thoroughly incorporated into the upper few inches with a rake or similar tool.
- Reldan 4E at varying dosage rates (see label) depending upon the commodity to be treated.
- Reldan 3% dust at 10 lbs. per 1,000 bu. of grain.

Application equipment

Dust formulations of grain protectants are applied to the grain using an auger-mounted dust applicator (Fig. 6). Applicators of this type are basically gravity flow devices with a trigger dispenser powered by the screw inside the auger. Be sure to calibrate the applicator in order to meter the correct amount of dust material onto the grain in accordance with the capacity of the auger in bushels of grain per hour.

Drip-on applicators work well for metering liquid (EC) formulations of grain protectants onto grain being augered into storage. A simple homemade drip-on applicator can be built by fitting two brass valves and a length of polyethylene tubing to an opening in the bottom of a plastic jug (Fig. 7). The upper shut-off cock serves as the on-off valve, while the lower needle valve regulates the amount of insecticide flowing through the plastic tubing. First calibrate the needle valve to the desired flow rate for the amount of grain being delivered.

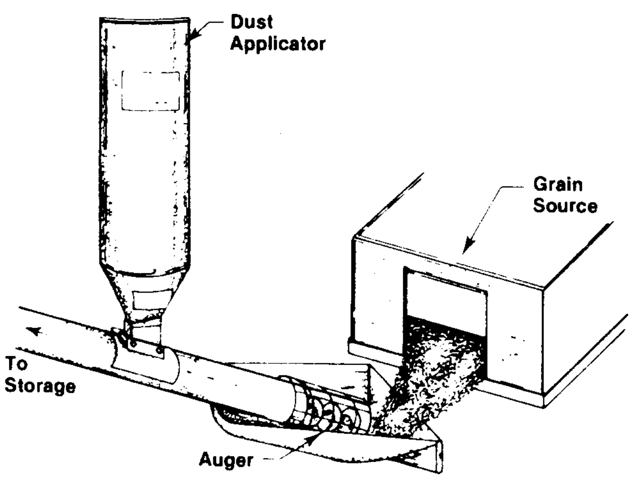

Figure 7. Auger-type dust applicator.

Use the shut-off valve to start and stop flow, eliminating the need to recalibrate each time the flow is turned on. Place the end of the plastic tubing about 1/4 inch beyond the end of the auger sleeve so the insecticide drips directly into the grain picked up by the auger. Grain movement through the auger and into the bin will distribute the insecticide

The flow rate of the liquid will vary with the depth of the liquid in the container. A more uniform flow can be obtained by using a float valve in a second container to

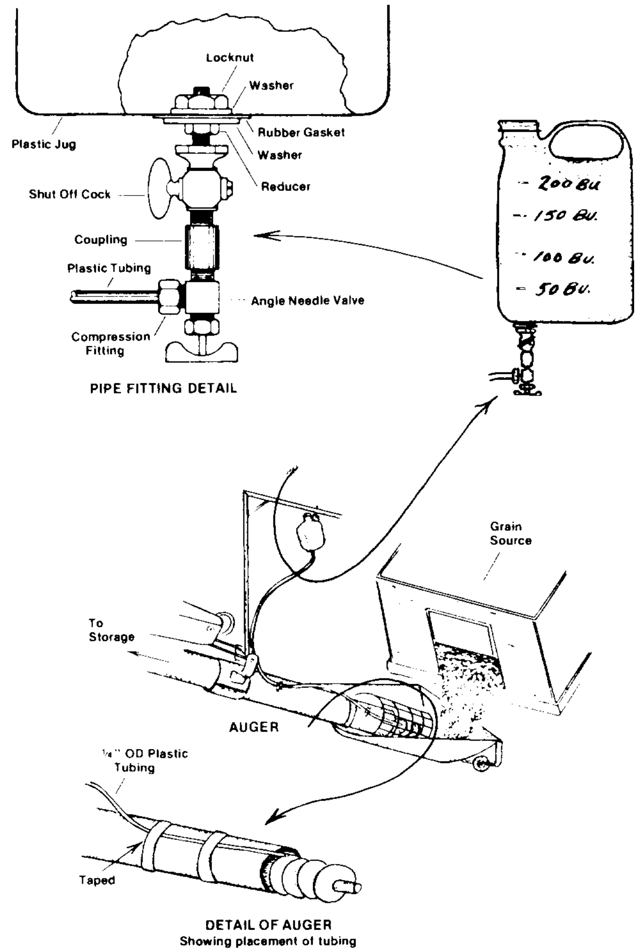

Figure 8. Drip on system for applying liquid grain protectants.

keep the liquid level constant above the needle valve (Fig. 8).

Commercial drip on applicators are available from the

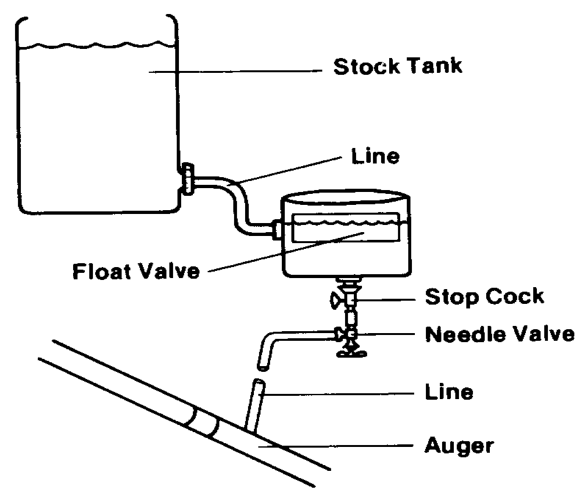

Figure 9. A diagram of a simple drip applicator for grain protectants. The needle valve is used to meter the protectant into the grain stream. The float valve is used to keep a constant level of liquid over the needle valve (developed by A.P. Love, MSU).

following companies:
"Auger Jet Applicator" from Acme Brass and Machine Works, 609 E. 17th St., Kansas City, MO 64108
"Gustafson Dripper' from Gustafson Inc., 6600 Washington Ave. So., Eden Prairie, MN 55344
"Reddick Flo Meter" from Reddick Fumigation, P.O. Box 71, Williamston, NC 27892

SURFACE TREATMENT

Insect infestation on the surface or upper few inches of grain, especially by Indian meal moth larvae, has been one of our most common insect problems in North Dakota stored grain. These infestations are aided by moisture condensation due to moisture migration and the lack of aeration or by roof leaks. Moisture problems and surface insect infestations often result in surface crusting of the grain mass. Be sure to remove the crust before treating, and correct the moisture problem as soon as possible. Apply a surface treatment of BT if only moth larvae are found or malathion if insects other than moth larvae are present.

Hanging "pest strips" over the grain (as noted in the section on grain protectants) will help control surface infestations.

Control grain temperatures

The grain temperature should be maintained within 20°F of average outdoor temperatures. Cool the stored grain using aeration to about 25°F for storage during winter and warm the grain to about 50°F for storage during summer. This will reduce mold growth, limit insect activity and reduce moisture migration.

INSECT CONTROL OPTIONS

If the preventive measures discussed have been utilized, there is a good chance that additional controls will not be necessary. However, under long-term storage situations (beyond one year) the grain protectants will eventually lose their killing power and subsequent insect infestation can occur. Or perhaps none of the suggested preventive measures were used, in which case insect infestations may develop in first-year stored grain.

Whatever the circumstance might be, just about any grain producer, at some time or another, is likely to encounter stored grain insect problems. When this occurs, the producer has control options that should be considered.

The presence of insects or their damage in stored grain represents some loss in value of the grain. The first decision to make when you find insects is whether the grain is worth treating. Remember that the damaged grain, odor, webbing and dead insects will remain after the insects are killed Some estimate of the value of the grain after treatment and the cost of control must be made. The best decision may be to immediately sell the grain at a discount or to feed it as soon as possible.

The type of insects found, their location in the bin and the time of year that an infestation is discovered all have a significant bearing on the control option to be utilized.

Cooling stored grain with aeration equipment will stop insect activity. The grain should be cooled to about 25°F.

If the bin is not equipped for aeration, moving or turning the grain may cool it enough to stop insect activity.

Turning the grain or moving it slowly into an adjacent bin or truck box on a cold day in winter will often cool it sufficiently and break up pockets of insect infestation, thereby decreasing insect activity, at least until the grain temperature becomes high enough to allow for successful fumigation. Keep in mind that a single turning or transfer of the grain will only lower the temperature a few degrees. Grain temperature reduction is related to the difference between the temperature of the grain and the outside air as well as the time of exposure to the cold air. Slowing down grain movement should allow the cold air to reduce the grain temperature sufficiently to minimize or stop insect activity

Insects found only on the surface grain, such as Indian meal moth larvae, should not normally require fumigation. In such a situation, a surface application of BT (as previously described) is all that should be necessary. On the other hand, an insect infestation found to be occurring throughout a large portion of the grain mass can only be successfully controlled by effective fumigation.

FUMIGATION

Fumigants are gases that penetrate the grain mass to kill insects. The term fumigation is sometimes used for smokes, mists or aerosols and even the fumes from "pest strips." These are fine solid or liquid particles that are suspended in the air but, unlike the true fumigant gases, they cannot penetrate surfaces. It is the ability to penetrate that gives fumigants their big advantage in controlling stored grain insects. This same ability creates the greatest problems with their use: bins must be sealed tightly enough to hold a toxic concentration of the gas for the time that it takes to kill the insects, and the gases that escape from the bin during fumigation are lethal to humans, livestock and other animals. Every step in the use of fumigants must be done properly if the fumigation is to be effective and safe.

Because all fumigants are highly toxic and hazardous to use, they are classified by the EPA as restricted use pesticides. This means that they should only be applied by or under the direct supervision of persons trained to properly use them.

Due to the large size of many on-farm grain bins and the specialized equipment and training necessary to conduct a successful and safe fumigation job, it is often safer, less expensive, and more effective for farmers to have their stored grain fumigated by a licensed and certified professional fumigator. The most important factor to consider when deciding whether to hire a professional to do a fumigation job is the personal risk involved in the handling and application of these highly toxic chemicals. A professional fumigator will have the knowledge and experience required to conduct effective treatment and will also have the special equipment needed to apply fumigants properly. In addition, professionals will have safety equipment such as gas masks or other respiratory protection which is expensive but necessary when applying any fumigant.

Recognizing that professional fumigators are not always available to service farm-stored grains and that many farmers still prefer to handle this phase of pest management themselves, the following information is designed to help the farmer better understand the properties of grain fumigants, the factors that influence their effectiveness, and the methods used to properly apply and distribute them into bulk stored grain.

Types of fumigants (Summarized in Table 1.)

Liquids - For many years there were four general formulas for liquid fumigant mixtures: 1) those in which carbon tetrachloride was the major constituent, 2) those in which ethylene dichloride was the predominant compound, and 3) the group containing ethylene dibromide (EDB). As of this writing (late 1990), carbon tetrachloride, ethylene dichloride and ethylene dibromide have all been phased out by EPA. The compound in the last group 4) is chloropicrin, and this chemical is the only liquid grain fumigant with continuing registration for use in grain bins (empty bin treatment only).

Table 1. Some common fumigants registered for use in stored grains.

Fumigant**	State	Trade names	Common uses
aluminum phosphide*	solid	Fumitoxin Phostoxin Phostek	Wheat, barley, rye, oats, corn, sorghum, safflower, sunflower, soybeans, millet.
chloropicrin*	liquid	Chlor-O-Pic	Perforated floors in empty grain bins.
methyl bromide*	gas	Meth-O-Gas Brom-O-Gas	Wheat (similar small grains), shelled corn, milo (grain sorghum). May affect seed germination at high moisture levels and high dosages.

*EPA has classified this fumigant as a restricted use pesticide.
**Dosage rates for the fumigants listed will vary depending upon the commodity and type of storage structure to be treated. Read and follow label directions.

The chemicals that comprise the various liquid fumigant mixtures share a common property: the fumigant gas they form is heavier than air. When these fumigants are released on the grain surface, the "pull of gravity" starts the gas moving down through the grain mass.

Other properties of liquid fumigant components differ greatly from one chemical to another and these differences are often the reason why certain chemicals were combined together in a particular formulation. For example, carbon disulfide (CS_2) could not be used alone safely because of its high flammability and, therefore, it was generally mixed with carbon tetrachloride (CCl_4), which is a fire retardant. Carbon tetrachloride has a relatively low toxicity to insects. It requires very high dosages and long exposure periods unless it is combined with other more toxic chemicals.

Most chemicals used in liquid fumigant mixtures are strongly sorbed by the grain, so they sometimes were preferred over other fumigants by commercial applicators for the treatment of small lots of grain, grain that is moldy or "out of condition," and grain stored in loosely constructed bins. Longer periods of ventilation or "airing" are required to remove the fumigant vapors after treatment than are required with less sorptive fumigants. This is especially true if the grain temperature is 60° or lower.

Liquid fumigants are supplied "ready to use" and do not require the addition of water, oil or other diluents. They are generally marketed in unit sizes of 1, 5, 30 and 55-gallon cans or drums and in bulk tank lots of 1,000 gallons or more. Liquid fumigants are most expensive when purchased in small quantities. The chemicals in liquid fumigant mixtures are excellent organic solvents and improper use will damage some types of plastic and rubber products.

Chloropicrin is a nonflammable yellowish liquid fumigant marketed in pressurized and nonpressurized containers as a space and soil fumigant as well as a warning agent for methyl bromide. Chloropicrin vaporizes to a gas when exposed to air. This gas is heavily sorbed by grain and may require long periods of ventilation or aeration to remove the odor and resulting "tear gas" effect following fumigation. Chloropicrin is marketed in cans of 1 to 32 pounds and in cylinders of 70 to 375 pounds each.

Chloropicrin is highly corrosive to most metals and may adversely affect the germination of most seeds. It should not be used to fumigate seed grains. Chloropicrin is particularly effective against immature stages of grain pests and is especially toxic to the Indian meal moth.

Chloropicrin is highly toxic to man. The established threshold limit is 0.1 ppm. Concentrations as low as 1 ppm produce an intense smarting of the eyes and the immediate reactions to leave in haste. Continuous exposure may cause serious lung injury. If it is necessary to enter a treated area, a gas mask with black canister should be worn.

Chloropicrin treated commodities are often unpleasant to handle as they may be extremely irritating from even low quantities diffusing from the treated material.

Its primary use other than acting as a "warning gas" is as a soil fumigant. Chloropicrin cannot be used on any processed foods, in dairy, cheese, or meat plants or where there are living plants, or on fresh fruits or vegetables. Labeling for the application of chloropicrin was changed in 1987. As the new product is distributed, it will no longer be legal to apply chloropicrin to stored grain. It will still be legal to use chloropicrin as a space fumigant to treat empty storage facilities. Chloropicrin is particularly effective for fumigation beneath the perforated floor of empty grain bins.

NOTE: Chloropicrin is no longer registered for direct application to stored grain. However, the fumigant can still be used for treating the perforated floors in empty bins in order to control insects in the sub-floor area prior to bin filling.

Solid - Phosphine-producing fumigants have become one of the predominant fumigants used for the treatment of bulk-stored grain throughout the world. They are available in solid formulations of aluminum phosphide or magnesium phosphide.

Phosphine has no adverse effects on germination of seeds when applied at normal dosage rates and is the choice of fumigants for seeds or malting barley. It is also widely used in the fumigation of processed foods since excessive fumigant residues have not been a problem with phosphine.

Hydrogen phosphide is a colorless gas with an odor that is perceived differently by different individuals. Its odor is often described as similar to garlic, commercial carbide, or decaying fish. Although the odor of hydrogen phosphide gas can be very distinctive, fumigators must not rely only on their sense of smell to detect potentially harmful gas concentrations. Gas detector tubes should be used throughout all stages of a fumigation to monitor gas concentrators.

Phosphine can react with copper and copper-containing alloys such as brass, gold and silver, resulting in corrosion and discoloration of exposed surfaces. This can result in damage to contact points, telephones, computers and other electronic equipment. This problem is rare and apparently only occurs when there is a high concentration of phosphine in combination with high humidity and high temperature, but care still needs to be exercised. In the normal farm grain bin, there is little that could be harmed by phosphine.

Solid aluminum phosphide formulations, which release hydrogen phosphide (phosphine) gas when exposed to moisture and heat, are available in tablets, pellets and powder packed in paper packets. If the liberation of hydrogen phosphide occurs too rapidly in a confined area, an explosion or fire can occur. To control the rate of release, aluminum phosphide is formulated with other compounds such as ammonium carbonate or aluminum stearate and calcium oxide which control the release rate and lower the combustibility of the mixture. In some formulations, carbon dioxide is given off in the reaction to help retard this problem. Good practice in fumigation will result in concentrations that are probably no more than 1/50 of the amount that would result in fire.

Manufacturers of aluminum phosphide fumigants indicate that there is a delay before phosphine is evolved in large quantities from commercial formulations. There is usually one to two hours with pellets or two to four hours with tablets before dangerous amounts of phosphine are released. The time required for release is much shorter on warm, humid days and much longer on dry, cold days. With grain temperatures above 60°F, decomposition should be nearly complete in three days. With low temperatures and grain moisture below 10 percent, there may still be appreciable gas evolved for at least five days.

Phosphine is only slightly heavier than air (20 percent heavier) but will diffuse rapidly through the grain mass because it is not strongly sorbed by grain. This combination of the low sorption loss and the great penetration capacity of phosphine means that bins treated with this material must be fairly gas tight. The gas loss problem is partially solved because the leaked gas can be replaced constantly during the fumigation.

The formula for the various aluminum phosphide products varies somewhat among manufacturers, but this fumigant is usually packaged in 3-gram tablets or 0.6 gram pellets. Each tablet produces 1 gram of phosphine and each pellet 0.2 grams. Formulations packaged in packets contain 34 grams of material and produce 11 grams of phosphine.

Magnesium phosphide is a new material that has been developed to release phosphine gas. It is formulated in cloth-covered plates sealed in special plastic envelopes and in series of plates (strips) which are also sealed in plastic envelopes and then packed in metal cans. These formulations dispense the same hydrogen phosphide gas (phosphine) but release it more rapidly. Present distribution is limited to professional fumigators until more experience and data in the use of this material have been accumulated.

Hydrogen phosphide is highly toxic to all forms of animal life. Early symptoms of hydrogen phosphide poisoning can be severe, but these symptoms are clearly recognizable and reversible if exposure is ended. Initial symptoms of over-exposure include "tightness" in the chest, faintness, dizziness, nausea, vomiting, and diarrhea. Severe poisoning leads to coma and death. Hydrogen phosphide is not absorbed through the skin, and it is not stored in body tissues. Any gas entering the body will be completely eliminated within 48 hours. Hydrogen phosphide is very toxic to humans. The threshold limit is only 0.3 ppm (8 hour time weighted average). Mathematically, this would indicate that the gas is about 45 times as toxic as methyl bromide. However, because of the manner in which hydrogen phosphide is liberated and because of the odor characteristics, this material can be used safely.

Gas - Methyl bromide is a colorless, odorless, tasteless, gaseous fumigant marketed as compressed, liquefied gas packed in special 1 or 1.5 pound cans or in cylinders of 50, 100 or 200-pound capacity. As with other fumigants, the cost is lower when purchased in larger containers. However, farmers should not try to store fumigants but should buy only enough fumigant for each fumigation. Compressed liquid methyl bromide readily changes into a gas when the container is opened at temperatures above 39°F. The gas is odorless at fumigation concentrations and has no irritating qualities to indicate its presence. For fumigation, methyl bromide is formulated as either 100 percent methyl bromide or with a mixture with ½ to 2 percent chloropicrin that serves as a warning agent.

Methyl bromide is nonflammable, penetrates grain well and provides a very rapid kill of insect pests. It is over three times the weight of air, and recirculation or other techniques may be needed to ensure even distribution. These distribution problems and the extreme hazard of methyl bromide are reasons why this product should only be used by trained professional fumigators. The established threshold limit of methyl bromide exposure is 15 ppm.

Early symptoms of methyl bromide over-exposure include dizziness, headache, nausea, vomiting, and weakness. Lung edema and cardiac irregularities may develop within 24-48 hours and are often fatal. Repeated exposure to low dosages allows methyl bromide to accumulate in body tissues and may eventually cause chronic symptoms including blurred vision, dizziness and staggering, and mental imbalance.

Methyl bromide will not corrode most metals. However, it can react with aluminum or magnesium in the absence of oxygen to form an explosive mixture. Therefore, aluminum or magnesium tubing should never be connected to a methyl bromide cylinder.

Methyl bromide can affect seed viability by reducing germination of sorghum, grain and grass seeds, particularly at high moisture levels or high dosages. Phosphine is a safer choice when seed germination is a concern .

Undesirable odors can result when certain materials are exposed to methyl bromide. The pesticide distributor can furnish you a list of potentially affected materials. The list would include full fat soya flour, iodized salt, some sponge and foam rubbers, cinder blocks formed from cinders from high sulfur coal and any other materials containing reactive sulfur compounds.

Factors which influence the effectiveness of fumigation

Understanding how fumigants react in grain and what influences their behavior is an essential step in developing the "know-how" to effectively and safely use grain fumigants.

Sorption - When a fumigant gas attaches itself to the surface of a grain kernel or penetrates into the kernel, it slows diffusion and disrupts penetration of the fumigant through the grain mass. However, some sorption must occur if the fumigant is to reach all stages of pest insects, especially those that develop within the kernel. The degree of sorption of individual components is the basis for selection of many of the liquid fumigant mixtures. These mixtures include chemicals which are sorbed at different rates, permitting some fumigant vapors to penetrate a grain mass readily, while others are held near the surface of the grain mass. Some fumigants react with materials in the grain to form other chemical compounds that may be permanent, thus forming residues. Methyl bromide fumigants are particularly subject to this type of chemical reaction which has necessitated the establishment of residue limits or tolerances for the amount of bromide permitted in grain.

Temperature - Temperature influences the distribution of fumigants in grain and affects their ability to kill insects. At temperatures below 60°F, volatility of a fumigant is reduced significantly, sorption of fumigant vapors into the grain is increased, and distribution is less uniform throughout the grain mass. Gases move more slowly and insects breathe less at colder temperatures. It takes longer for the fumigant vapors to reach insects in the grain, less gas is actually available for controlling the pests, and since the insects are less active, less gas enters their bodies. Desorption may take longer at cold temperatures because grain retains more fumigants longer at low temperatures, requiring prolonged ventilation periods.

Grain Moisture - The moisture content of grain also influences the penetration of fumigant gases by altering the rate of sorption. In general, moist grain requires an increase in dosage or an extended exposure to compensate for the reduced penetration and increased sorption. However, as previously mentioned, moisture is necessary for the generation of phosphine from solid formulations. Although most grain that will support insect development will also contain sufficient moisture to start the chemical reaction, grain below 10 percent moisture will slow solid fumigant decomposition.

Grain Type and Condition - Various grains have different characteristics that can affect fumigations. The surface area of individual grain kernels is an influencing factor in the dosage required to treat various commodities. For example, sorghum, because of its smaller size and more spherical shape, has higher total surface area than wheat. Increased surface means greater sorption loss, which reduces the amount of fumigants left in the space between the grain kernels and further reduces the amount of fumigant available to penetrate throughout the grain. To compensate for this increased sorptive loss, higher dosage rates are required in sorghum than in wheat, particularly with the high sorption fumigants.

The type and amount of dockage in grain has a pronounced effect on the sorption and distribution of fumigants. When the grain mass contains large amounts of dockage such as chaff or broken kernels, the fumigant vapors are rapidly sorbed by this material and further penetration into the grain is impaired. Unfortunately, such areas are frequently sites that attract the greatest number of insects. When isolated "pockets" of dockage occur within a grain mass, such as below grain spouts, fumigant vapors may pass around such pockets and follow the path of least resistance down through the intergranular area of the grain. Similar changes in fumigant distribution patterns may be obtained in grain that has settled or compacted unevenly during long storage periods or in storage vibrated by nearby traffic such as a railroad.

Insects - Grain insect pests and their various developmental stages (egg, larva, pupa and adult) vary in their susceptibility and resistance to fumigants. Beetles and other insects that develop outside grain kernels are usually more susceptible to fumigants than certain moth and beetle species that develop inside grain kernels. The pupae and eggs are the hardest developmental stages to kill while the young larvae are relatively susceptible.

Heavy infestations in which large amounts of dust, damaged grain, webbing and cast skins have accumulated are more difficult to control because of the effect these materials have on the penetration and diffusion of grain fumigants.

Storage Facility - A fumigant, whether applied initially as a gas, liquid or solid, penetrates the grain and enters the insect in the form of a gas. The "gas tightness" of the storage bin, therefore, greatly influences the retention of the fumigant. Metal bins with caulked or welded seams or concrete bins will lose some gas but are generally better suited for fumigation than wooden bins.

Although there are often label recommendations for fumigation of grain in wooden bins, the high dosages and poor control usually achieved normally make this type of fumigation uneconomical.

The size and shape of the storage structure affect both distribution and retention of fumigants. The height of a storage bin often determines the type of fumigant used and its method of application. Some liquid fumigants will readily penetrate substantial depths of grain, but solid fumigants may be more effective if mixed with the grain during transfer into the bins. Commercial applicators may use special techniques to achieve control that would be difficult for a farmer to apply.

Winds and thermal or heat expansion are major factors influencing gas loss. Winds around a grain storage structure create pressure gradients across its surface resulting in rapid loss of fumigant concentrations at the grain surface and on the downwind side of the storage. The expansion of head space air due to solar heating of roofs and walls followed by nighttime cooling can result in a "pumping" of the fumigant from the bin. Large flat storages that contain more grain surface than grain depth are particularly susceptible to gas loss due to wind and heat expansion. The greatest gas loss frequently occurs at the grain surface, a location that often contains the highest insect populations. Furthermore, when the grain surface is uneven with large peaks and valleys, the distribution of fumigants through the grain will also be uneven.

Air Movement - Successful fumigation of stored grain requires an understanding of air movement within the grain mass. It is easy to think that the air in between the kernels of grain in a bin is as immobile as the grain itself. This is not true and is one of the reasons that fumigation sometimes fails even when done by professional fumigators.

Air moves along the path of least resistance, with warm air moving upward and cold air moving downward. In a bin, there is usually air movement both up and down because of temperature difference between the well insulated middle and the grain near the perimeter that is affected by the outside temperature. Air movement upward can carry moisture (moisture migration) that can condense on the surface and cause crusting. The resulting crust can also interfere with air and gas movement. Air will move more easily through a grain mass composed of larger kernels, such as corn, and more slowly through those composed of smaller grains, such as grain sorghum. Air may move around a hot spot and carry a fumigant gas away from the critical area. Fumigant gases can penetrate these areas better than normal air but the air movement can affect how much gas reaches and stays at these critical areas.

Gas movement in a grain mass is affected by other forces such as gravity, sorption, temperature and moisture content, but an understanding of the air movement is the first step in understanding the many forces that determine gas dispersion.

Dosage and time of exposure - Because fumigants act in the gaseous state, the dosage necessary to kill an insect is related to the concentration of gas surrounding the insect, the insect's respiration rate, which is related partially to temperature, and the time of exposure of the insect to the specific concentration of fumigant. For most fumigants there is a general relationship between concentration and time: high concentrations require shorter exposure time and low concentrations require long exposure to achieve comparable kill. In phosphine fumigations, time of exposure is often more important than the concentration of gas. This situation is partly due to the increased time necessary for release of the gas from the solid material and also because the rate of uptake of phosphine by insects is somewhat time dependent.

With liquid fumigant mixtures, the concentration-time relationship depends on the concentration of the individual chemicals in the mixture that actually reach the insect. When the more toxic compounds in a fumigant mixture are separated due to sorption loss during penetration, the remaining chemicals may require longer exposure or higher concentrations to be as effective as the original mixture.

Variations in recommended dosages are generally based on sorption differences of commodities and the relative gas tightness of different storage structures. For example, dosage requirements for sorghum are generally higher than for less sorptive commodities such as wheat, and dosages in wooden bins are higher than in steel or concrete bins. Application rates for phosphine-producing fumigants are based primarily on the type of storage structure being treated and its gas tightness. Because phosphine is less affected by sorption loss in grain, the rates of application for most commodities are virtually the same.

Dosage rates for methyl bromide are usually based on the amount of total space within a storage rather than the amount of grain present. Dosage rates are frequently in the range of 2 to 4 pounds per 1,000 cubic feet of space, which is equivalent to about 2.5 to 5 pounds per 1,000 bushels. In general, higher dosage rates of methyl bromide are required for cool grain, higher sorptive commodities and less tight storage structures.

Application and distribution

Aluminum Phosphide - Tablets or pellets of aluminum phosphide may be added manually to the grain stream when moving infested grain to new storage. The rate of grain loading will determine the intervals at which the pellets should be added to achieve the appropriate dosage per 1,000 bushels of grain. As noted previously with liquid fumigants, treatment during turning of the grain is not generally feasible in on-farm storage and alternative methods must be used to treat the grain in place. In shallow grain bins, tablets may be probed into the grain using a 5-foot hollow tube designed for this purpose. These tubes can be purchased from the supplier or made from electrical conduit or from plastic pipe according to the distributor's recommendation.

A typical probe treatment of a circular steel bin is described below:

1) Determine the number of tablets required to treat the volume of grain in the bin and the head space. Start with a dosage rate of 90 tablets per 1,000 bushels. Allow extra pellets for the head space unless the grain is going to be covered with a plastic sheet.

2) Increase this rate up to as many as 180 tablets per 1,000 bushels if the bin cannot be adequately sealed or if the temperature of most of the grain is below 68°F.

3) Decrease the dosage to as few as 60 tablets per 1,000 bushels if the bin is exceptionally gaslight, contains clean dry grain, or if the grain temperature throughout the bin is above 80°F.

4) Determine the probable natural air flow in the grain. Divide the tablets by four to place in each pie-shaped quarter of the bin. Typically the number would then be divided by five (the number of tablets per probe) to determine the number of probes needed per quarter. For example, if the total number of tablets required for the surface area is 280, the number for each quarter is 280 divided by four which equals 70 per quarter section. Each section would be probed 14 times 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 it 1 foot and place the next tablet in the probe. Continue until all tablets are used. The last tablet should be about 6 inches from the surface.

A gas mask with canister labeled for use with phosphine should be available and applicators should work in pairs. Normally the application of aluminum phosphide tablets can be finished before reaching a dangerous concentration of phosphine. Therefore, it is not necessary for the applicator to wear the mask unless the work is unduly prolonged .

5) After all sections of the bin have been probed, close the bin and seal the access point as described under liquid fumigant procedures. Gas loss can be reduced by placing a polyethylene sheet cut to size over the grain before sealing the door. It is a good idea to fasten a rope to this sheet so it can be removed easily after the fumigation to prevent condensation problems. The rest of the bin still needs to be well-sealed for best results.

6) Never place aluminum phosphide on a wet surface since it would evolve the gas too fast and could possibly ignite. When the grain temperature is considerably warmer than the outside air, the professional fumigator may use as many as 40 percent of the tablets in the aeration system. Tablets or pellets should never be stacked on top of each other.

7) Leave the bin sealed for at least five days after application of the tablets. Never leave plastic on the grain surface more than seven days.

8) Following fumigation, the commodity should be ventilated before anyone enters the bin. It is much safer to check the gas concentration with detector tubes.

At the end of a phosphine fumigation, the powdery residue of tablets or pellets still contains a small amount of undecomposed aluminum phosphide for a number of days. Under normal circumstances of grain handling, these residues do not present a hazard, but inhalation of the powder should naturally be avoided.

Recent changes in aluminum phosphide labels call for mandatory monitoring of phosphine levels whenever workers are inside a structure while fumigation is in process. The current law calls for monitoring of each fumigation procedure and documentation of phosphine levels throughout the time workers are present in the building. Once a particular fumigation procedure within a particular structure has been monitored often enough to form a clear pattern of phosphine levels, it is no longer necessary to monitor during each subsequent fumigation. You should still monitor periodically to insure that nothing has changed. When monitoring reveals that phosphine concentration never exceed 0.3 ppm, no protective breathing equipment is required. If phosphine gas concentrations exceed 0.3 ppm but remain lower than 15.0 ppm, a full-faced, NIOSH/MSHA approved canister type gas mask with the appropriate yellow canister must be worn by each person in the affected area. If phosphine concentrations exceed 15 ppm, a NIOSH/MSHA approved self contained breathing system (SCBA) must be worn. Regardless of the phosphine levels achieved during fumigation, a full-faced gas mask and yellow canister must be available on location during every fumigation. A SCBA must be available on location or locally through a fire department, rescue squad or similar source.

The law also requires that following fumigation the fumigated commodity be monitored until phosphine levels fall below 0.3 ppm. Until such time it is illegal to remove warning placards or move the commodity. Workers entering a structure under fumigation to monitor gas levels must wear the appropriate gas masks.

Methyl bromide - All persons who work with methyl bromide must be aware of the hazards associated with this fumigant. They should understand the use of gas detection devices and respiratory protection equipment, and they should be trained in proper application methods and emergency procedures.

When methyl bromide is used to fumigate enclosed spaces such as grain storage facilities, two trained persons must be present at all times when worker exposure exceeds 5 ppm. Applicators should avoid wearing tight clothing, jewelry, gloves, and boots when applying methyl bromide. Methyl bromide may be trapped next to the body under these articles of clothing and cause severe injury to skin. Any contaminated clothing or boots must be removed and not reused until thoroughly cleaned and aerated. At any time when full-face respiratory protection is not required, applicators should wear goggles or a full-face shield for eye protection when handling methyl bromide liquid.

If the concentration of methyl bromide in the work area, as measured by a pump and detector tube (from Draeger, Kitagawa, MSA, or Sensidyne), does not exceed 5 ppm, no respiratory protection is required. If this concentration is exceeded at any time, al persons in the fumigation area must wear a NIOSH/MSHA approved self-contained breathing apparatus (SCBA) or combination air-supplied/SCBA respirator. Canister-type gas masks with air-filtering cartridges are not adequate for use with methyl bromide.

For recirculating application of methyl bromide for control of insects in stored grain, the following steps should be followed:

1. The storage should be sealed thoroughly, using masking tape for small openings and polyethylene sheeting secured with masking tape for large openings. Unsealed openings allow the escape of methyl bromide during the recirculation application. Fumigant leaks reduce the effectiveness of the fumigation and can present safety concerns around the storage.
2. Applicators must post warning placards at all entrances to the fumigated storage. Placards must present the words DANGER/PELIGRO and the skull and crossbones symbol. Warnings also must state "Area under Fumigation, DO NOT ENTER/NO ENTRE." Placards should state the date of the fumigation, the name of the fumigant applied, and the name, address, and telephone number of the applicator. Any person who transfers a treated commodity to another site without aeration must ensure that the new site is placarded until the commodity is aerated sufficiently to reduce methyl bromide concentrations to below 5 ppm. Only a certified applicator may remove the placards, and only after he has taken one or more gas readings that indicate the methyl bromide concentration is below 5 ppm.
3. Methyl bromide should be applied at a rate of 1.5 to 6.0 pounds per 1,000 cubic feet. Follow label instructions to determine the rate for the specific commodity to be fumigated. A duct system should be constructed so that the aeration system can be used to force air through the grain mass and collect and recirculate that air back through the aeration fans. Methyl bromide can be discharged into the duct system or into the head space of the storage.
4. For most stored grains, methyl bromide recirculation should continue for 24 hours; check label directions for fumigation periods for specific commodities. This fumigation period of 24 hours or less is one benefit associated with methyl bromide fumigation; other fumigations require a 72 hour (or longer) exposure period under most conditions. During the application period it is important to use gas detector tubes to check for methyl bromide leaks around the treated storage; leaks will reduce fumigation success and may cause health hazards in the work area.
5. Once the fumigation period has ended, storage must be aerated. To aerate, disconnect the return air flow from the recirculation system so that exhaust air discharges outside the storage. Aeration should continue until gas detection devices show methyl bromide levels have dropped to below 5 ppm. Take multiple readings in the elevator head space to detect any possible pockets of methyl bromide gas.
6. As mentioned before, once fumigated grain is aerated, it is susceptible to reinfestation. Surface topdress applications of protectant insecticides and the use of Vapona strips will help to limit reinfestation.

Methyl bromide is not to be applied if grain temperature is less than 40˚F except in cold storage fumigations specified in APHIS quarantine programs. Methyl bromide will retard or destroy germination potential of seeds in many fumigation conditions. Where grain is to be used for seed, alternatives to methyl bromide fumigation are usually recommended.

Checklist of equipment needed for fumigation

! "Man in Bin" Sign - placed near the control panel

! Tape Measure - to calculate volume treated

! Polyethylene Film - cut to size of grain to be covered and with rope attached for easy removal if using phosphine

! Cotton Gloves - if using phosphine

! Two Gas Masks with Canisters - labeled for the fumigant being used

! Probes - made from plastic pipe if using phosphine

! Safety Rope - if anyone is going to climb down into a bin

! Shovels - to level grain mass

! Grain Thermometer - to measure grain temperature top and bottom

! Warning Signs - for the fumigant used to be posted on the outside of the bin

! Lock - for building

! Monitoring Equipment - if the building will be entered

! 2 or 3-inch Wide Masking or Duct Tape, Spray Can of Glue, Glue for Poly Sheets

! Instruction Manual and Label

! Dosage Chart

! Sufficient Fumigant

! Grain Sampling Probe

! Sprayer and Wand - if using liquid fumigants

! Plastic Hose and Openers - if methyl bromide is used ! Plastic Hose Fitting and Scale if cylinders of methyl bromide are used

Bin preparation prior to fumigation

Proper sealing of grain bins prior to fumigation will often make the difference between success or failure of the treatment. A high degree of gas tightness is essential to achieve the required combination of gas concentration and time of exposure necessary to kill grain pests.

Metal storage bins are not gas tight since they were originally designed to hold and aerate grain. They can be used for fumigation with proper sealing. It is important to recognize that the bins will vary in tightness depending on their design and construction. If the corrugated sections were caulked when put together and then bolted tight, they will be more effective in holding fumigants when sealed. Loosely constructed wooden bins may have to be covered totally with a gas tight tarpaulin to retain enough fumigant to be effective.

Remember, the goal is to try to confine a gas for a sufficient length of time at a proper concentration to be lethal to the target pests. Sealing is extremely important and demands study and work but there are techniques that can make the job more effective.

There are a number of places in a bin where gas can escape. The roof-wall juncture looks tight from the outside, but examination from the inside will show a gap around the perimeter in many bins. 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. It is necessary to clean the dust from the surface before it can be taped or sealed with any other material.

Professionals will first clean the surface and then spray it with an adhesive dispensed from a pressurized can. The gap is then sealed with duct or furnace cloth tape since this is more effective here than masking tape. Use at least 2-inch and preferably 3-inch tape when sealing these cracks.

Polyurethane foams can be used to seal this gap but they are expensive and difficult to remove if the gap is needed for grain aeration. Insects can burrow into the foams and destroy their effectiveness, but they can provide a good seal for several years.

Another key area to seal 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 sealing materials have been used including one made with polyurethane impregnated with asphalt. Plain asphalt has also been used but does not have as much elasticity.

We have seen some use of foam-in-place plastics applied after the bins were built that seemed to give a good seal but still would be subject to problems discussed previously.

Roof ventilators can be covered with plastic bags. The bags are less likely to tear against sharp edges if a burlap bag is placed over the ventilator first. The plastic bag should be gathered in at the base and then taped in place. Be careful in this work to avoid falling.

Bin doors are not gas tight when merely closed. They can be cleaned and sealed with duct tape or masking tape, or if not used regularly, they can be sealed with foam-in-place plastic.

Aeration fans and their housings must be sealed to avoid gas loss. Normally, polyethylene glued to the air intake will be sufficient. However, the unit should be examined for other potential leaks.

An expensive but useful tool is the pressurized can of tape primer. This can be obtained from the fumigant distributor or sometimes from an auto paint store. These materials give the surface a tacky feeling and help the tape hold much better. They can be applied to the adhesive surface of a piece of tape to improve its sticking power. Although taping of a damp surface is not recommended, it can sometimes be done with this material.

Another useful material is called Bondmaster. It is painted onto a surface and then the plastic tarp is pressed into the tacky area. This will normally hold the plastic on, even in a high wind. Bondmaster can be removed from the hands with mineral spirits since the application is a messy job that will usually leave some on the hands and maybe on the clothing. It can leave a stain on the building but the improved seal is probably worth the effort and mess.

Another alternative to taping the eaves is to cover the entire roof with a plastic sheet formed into a bonnet or cap which drapes over the top of the bin and extends down past the roof joint. An adhesive sprayed or painted in a horizontal band around the outside bin wall will provide a point of attachment for the plastic sheet. The bonnet can then be secured by rope using the corrugated grooves on the bin to reduce slippage. Obviously, this sealing method can only be partially completed before application of the fumigant in order to provide access to the grain surface.

Level the grain surface 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 and 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 up these areas 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.

Calculating dosage

All fumigant labels provide information on the recommended dosages required to effectively treat stored grain. Using less fumigant than is recommended can result in too low a concentration of gas to be effective. Using more fumigant than recommended is illegal, adds cost and may not increase efficiency.

Dosages found on most liquid fumigant labels are expressed in gallons of fumigant to be applied per 1,000 bushels of grain. The recommended dosage varies with formulation. Once the dosage recommended for the conditions of your fumigation has been identified from the label chart, you need only calculate the number of bushels to be treated to determine the total fumigant dosage. The number of bushels in a bin may be calculated using one of the following formulas:

If the bin is round: Bushels = 0.6283 x diameter (ft) x diameter (ft) x grain depth (ft).

Example: An 18-foot diameter bin containing 15 feet of grain would equal 0.6283 x 18 x 18 x 15 = 3,053.5 bushels. If the recommended dosage is 3 gallons per 1,000 bushels, the total dosage required would be (3,053.5 divided by 1,000) x 3 = 9.2 gallons. If the recommended dosage was 4 gallons per 1,000 bushels, the total dosage required would be (3,053.5 divided by 1,000) x 4 = 12.2 gallons.

Dosages recommended for the various phosphine producing fumigant formulations are fairly similar. However, the actual amount of phosphine involved in specific fumigations will vary depending on the type of structure to be treated and whether tablets or pellets are utilized. Because phosphine distribution is not materially affected by sorption or differences in grains, application rates are based primarily on the gas tightness of the storage, grain temperature and the method of application. Dosages for aluminum phosphide formulations are expressed in terms of tablets or pellets per 1,000 bushels.

A typical dosage chart for aluminum phosphide tablets is as follows:

Type of Storage	**Grain Temp. °F**	**Dosage tables for 1,000 bushels**
Concrete elevators or steel tanks with turning facilities	over 68	60 as grain is being turned
Round steel bins	60-68 over 68	120 90
Flat stores in tight building not over 30 feet in depth	60-68 over 68	150 120

Example: Find the number of tablets required to treat a circular steel bin containing 3,000 bushels with temperatures ranging from 92°F on the surface to 75°F at the bottom of the bin. From the dosage chart, the treatment rate for round steel bins containing grain above 68°F is 90 tablets per 1,000 bushels. The total number of tablets required is 3,000 divided by 1,000 x 90= 270 tablets.

Determining concentrations

It is very important to monitor the fumigant concentration to determine the loss 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 plus time combination. After the fumigation is over, it is equally important to be able to know that the gas has been reduced to a level below its threshold limit value (TLV) to ensure worker safety upon reentry.

There is no single device that can economically and efficiently measure all fumigants at all normal levels. A variety of 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 TLV after the fumigation is needed.

Detection tubes for fumigation

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. They are sufficiently accurate for most gases.

The disadvantages to using these tubes is that they are designed for a single use on a single type of fumigant. Their cost of over $2 per tube can be burdensome when many readings are necessary. They are not available for both high and low readings for all fumigants so other detection tools may be needed. The tubes have a limited shelf life and are not reliable after the expiration date. In addition they have limited accuracy on some gases.

When a given quantity of air/gas mixture is drawn through the tube, a color change occurs in the reagents inside the tubes. This change can be easily read in parts per million.

To take a reading, it is necessary to first break the tips off the ends of the tube so that air/gas mixture can be drawn through the tube. With some gases, it is necessary to break the tube in a second place and to mix two ingredients or to attach another tube containing different ingredients to the first tube.

The glass tips removed from the tubes should be disposed of properly to avoid any chance of food contamination or personal injury. If the tubes are to be retained, the tips should be covered with tape to mask.

After the tips are removed, the tube is inserted into the pump according to the directional arrows. Instructions on the tube give the number of pump strokes required (example: n=3 means three strokes) for a sample. Each stroke draws one-tenth liter of air through the tube. Workers can learn to take accurate readings with a minimum of time and instruction.

If the air/gas sample is taken from a long monitoring hose, the hose line must be purged to give an accurate gas reading. Vacuum pumps that will speed up the purging operations are available. To ensure accuracy, it is better to purge too much than not enough. Naturally, readings should be taken in open air or other precautions taken to ensure that the purged air/gas mixture will not cause health problems.

With the Draeger methyl bromide tube, it is extremely important that the tube is held in a vertical position when reading the ppm or an improper gas reading may be obtained.

Most manufacturers have equipment called grab samplers that will take a single reading of the present concentration of toxic gases or vapors a worker is exposed to over several hours.

Halide leak detectors

Halide leak detectors have found uses in several industries. They are used to detect leaks of halogenated refrigerant gases and they have been used to give reasonably accurate estimates of the concentration of methyl bromide related halogenated fumigant gases.

The propane fueled halide leak detector is the lowest cost fumigant detection instrument both in terms of initial purchase and in terms of cost per use. The gas is turned on and ignited and then adjusted so that the tip of the flame just pierces the copper ring. Air/gas mixtures are siphoned through the flexible tube and a blue or green halo above the copper ring will indicate the presence of halogenated gas. It is important to keep the copper ring clean and to replace it periodically.

People vary in their ability to recognize shades of blue and green but 25 ppm is the lowest concentration anyone could consistently recognize. This is adequate for spotting leaks in a structure but not for detecting 5 ppm which is the present recommended TLV for methyl bromide. Naturally, this instrument should never be used in an atmosphere where an open flame would be a hazard.

Summary of requirements for successful grain fumigation

! Do not attempt fumigating grain unless the grain temperature is 60 degrees or higher. Fumigating cool grain will be ineffective and increases the risk of chemical residue in the treated grain.

! Before applying fumigants, level the surface of the grain and break up any "caking" on the surface.

! Seal bins as tightly as possible. The fumigant should be retained in the grain and not allowed to "leak" out. Use building paper or other material to cover all holes and cracks. Cover the grain with a tarpaulin if there is a large air space above the grain.

! All fumigants should be handled with extreme care as the fumes are toxic. Apply the fumigant from the outside of the bin whenever possible. Always have a second person nearby while fumigating. Use a recommended gas mask with canister.

! Always use the recommended dosage.

! Keep all persons and animals out of the building for at least 72 hours.

Reasons for fumigation failures

! **Insufficient Fumigant:** Because the efficiency of a fumigant depends on the maintenance of a killing concentration in the grain, any factor that affects gas concentration is important. You cannot get satisfactory results by applying less than the recommended dosage. Be sure to use the amount of fumigant required for the capacity of the bin, not the amount of grain contained in the bin.

! **Storage Structure:** A loosely constructed, leaky bin may not retain fumigants long enough to kill the insects while a tight concrete or metal bin may hold the fumigant in killing concentrations for several days. The depth of the grain in relation to its surface area also affects the efficiency of a fumigant. In general, the greater the surface area of the grain in proportion to the bulk, the greater the difficulties encountered in fumigation. This is why flat storage require higher dosages than round silo-type bins. Storage structures with a large amount of space over the grain are also difficult to fumigate effectively, as large amounts of gas escape into the head space.

! **Type of Grain and Dockage:** The kind of grain affects the efficiency of a fumigant in accordance with its sorption quality. For example, shelled corn and grain sorghum appear to be much more sorptive than wheat. The amount of dockage also affects the diffusion of the fumigant. Wheat with dockage exceeding 3 percent requires nearly twice the dosage than wheat with less than 1 percent dockage requires.

! **Moisture:** The moisture content of the grain has a profound effect on the efficiency of a fumigant (the higher the moisture content the higher the dosage required). As the moisture content increases above 12 percent, a proportionally higher dosage is required. Generally you cannot satisfactorily fumigate grain having a surface moisture content of 15 to 20 percent because the fumigant vapors will not penetrate the moist layer.

! **Temperature:** During fumigation the gas quickly assumes the temperature of the grain. An increase in temperature results in greater molecular activity of gases, which facilitates the diffusion and penetration of the fumigant. However, there are limiting factors for both extremes of high or low temperatures. If grain temperature reaches 115°F, the fumigants vaporize very rapidly and may escape from the bin before lethal gas concentrations can be obtained. Most stored grain insects cannot survive in grain at 115°F or above, eliminating the need for fumigating. You need not fumigate stored grain with a temperature of 60°F or below as the insects are inactive below this temperature.

FUMIGATION OF STRUCTURES INCLUDING BUILDINGS, SHIPS & RAILCARS

INTRODUCTION

All methods by which fumigation may be accomplished have one factor in common - some means to hold an adequate concentration of fumigant for the time necessary to obtain pest kill. These various methods of fumigating within structures are: vault fumigation including vacuum chambers; atmospheric chambers, trucks, railway cars, ships and buildings; tarpaulin fumigation which may be accomplished under a tarp indoors, outdoors, or by covering the entire structure; and spot or local fumigation.

VAULT FUMIGATION

Vault fumigation is referred to in this manual as including any structure of a permanent nature in which fumigation may occur as opposed to specialized vaults such as vacuum or atmospheric chambers used only for fumigation.

Vacuum chamber

Vacuum chambers differ from other forms of vault fumigation in that the fumigation is conducted under vacuum rather than at atmospheric pressure. Vacuum chambers are large steel structures. One common chamber is built in sets of two, each 50 feet x 6 feet x 8 feet. Frequently they are equipped with fans or recirculating systems. By using a vacuum, the fumigation time can be reduced from 12 to 24 hours to 1 ½ to 4 ½ hours. The vacuum both denies the insects oxygen and facilitates rapid penetration of the commodity by the fumigant. By adding an air-wash cycle (breaking the vacuum and drawing a second vacuum), aeration is also rapid. Vacuum fumigation chambers are usually found at port facilities and near large warehousing operation. Ethylene oxide-carbon dioxide mixture and methyl bromide are most frequently used though HCN and acrylonitrile are also used. Aluminum phosphide cannot be used as phosphine is explosive under vacuum conditions and high phosphine concentrations .

There are two main methods of conducting vacuum fumigation: sustained-vacuum fumigation and nearly complete restoration of pressure. In the sustained vacuum method, the pressure is reduced, the fumigant introduced and the slightly reduced pressure or vacuum held until the end of the fumigation period. In the restored pressure method, the pressure is lowered and restored in one of several ways.

1. Gradual restoration of atmospheric pressure. The fumigant is released and air then is slowly introduced until after 2 or 3 hours it is just below atmospheric pressure.

2. Delayed restoration with the vacuum being held for about 45 minutes following discharge of the fumigant, after which air is allowed to enter the chamber rapidly.

3. Immediate restoration following introduction of the fumigant by letting air rapidly into the chamber by opening one or more valves. This method has been widely used in this country for baled cotton.

4. Simultaneous introduction of air and fumigant in which special metering equipment meters a mixture of air and fumigant into the chamber.

At the end of any of the methods, air-washing is carried out. It consists of removal of the fumigant/air mixture and the chamber is then pumped several times until it is considered safe to open the door for unloading. The effectiveness of the different methods is in the order presented with the sustained vacuum method following between methods 2 and 3 of the restored pressure methods.

The disadvantages of vacuum fumigation include: the very expensive initial investment, and the need to move the commodities into and out of the chambers. It cannot be used with certain tender plants fruits and vegetables which cannot withstand reduced pressure. The amount or dosage of fumigant required is usually 2 or 3 times greater than at atmospheric pressure.

ATMOSPHERIC VAULTS OR FUMIGATION CHAMBERS

These are usually small buildings located well apart from other structures. Some are specially built for fumigation, others are modified from other structures. Once an atmospheric vault has been built or modified for fumigation, it can be used again and again. Gas concentrations can be monitored through a permanent arrangement. Commodities are easily moved in and out of the vault without special preparation. The fumigator does not have to compute the cube of the structure each time the fumigation will take place. Special preparation of the commodity, such as padding corners, is not necessary. Almost any fumigant can be used. And while safety precautions can be observed, fewer considerations are necessary. In addition to the initial cost of setting up a fumigation vault, the disadvantages include: cost of moving the commodity to and from the chamber, the limited quantity of items that most vaults will hold, and the economical utilization of the facility.

TRUCKS (STATIONARY) AND FREIGHT CARS (STATIONARY OR IN TRANSIT)

Stationary trucks and freight cars are also examples of “vault” fumigation. These vehicles must be well constructed and in good repair. If they are not, they must be made air-tight or the entire vehicle must be tarped in order that the fumigant can be retained for the fumigation period. Movement of the freight car or truck during the fumigation usually results in loss of the fumigant. An exception to this is in-transit fumigation of rail cars using aluminum phosphide. As hydrogen phosphide continues to be generated, a low gas concentration is maintained.

Fumigation of wheeled carriers is often convenient and economical in both time and labor by avoiding extra loading and unloading. It not only kills the pests in the commodity, but also in the vehicle so that live pests do not remain behind after unloading. Fumigation of incoming loads, prevents the introduction of pests into clean areas.

SHIPBOARD FUMIGATION

Ship fumigations are also examples of vault fumigation but are highly specialized. Products needing fumigation may need to be treated before they can be loaded. The extent of the area to be fumigated will depend on the amount of cargo involved. Size and depth of space to be fumigated and cargo present must be determined. If proper provision is made, any full cargo space can be fumigated. All piping, bilge openings, ventilator openings, and hatches must be sealed off. Heating and ventilator systems may be helpful in bringing the cargo to optimum temperature and for aeration.

Because of the specialized nature and problems of ship fumigation, you should be thoroughly familiar with the Technical Release from the National Pest Control Association, No. 18-72, Good Practices in Ship Fumigation, before undertaking any ship fumigation. In many instances, firms specializing in ship fumigation may be engaged.

Close cooperation with the responsible ship's officer, ship's agent, and USDA inspector (if involved) is essential. The Port Authority, fire and police departments should be notified, and guards arranged for if necessary. If most of the cargo space is fumigated, the entire crew should be accounted for and evacuated while fumigation is in progress. No one should be allowed to return until the ship is clear of fumigant and given a "Gas Free" certificate.

BUILDING FUMIGATION (BY SEALING)

This essentially is a modification of vault fumigation. The entire structure becomes a fumigation vault. By using this method, only those building contents which would be damaged by the fumigant need to be moved. Incidental control of non-target pests is usually obtained. Less material is needed to make the structure air-tight, but this advantage is usually offset by the labor required to find and seal gas leaks. The building is usually easily aerated. Exterior shrubbery usually does not need to be moved.

There are also many disadvantages. The occupants must be moved from the structure. Items that may be damaged by the fumigant must be moved from the structure. As the fumigant may diffuse through the walls, it may be difficult to maintain the required gas concentration. Insects in the exterior walls may not be killed as the gas concentration may be too low to be effective. Gas concentration gas leads must be run throughout the structure. It may be difficult to compute the cube of the structure. It is very easy to overlook vents, cracks, conduits, etc., that may permit the escape of gas. In the past, HCN was the fumigant most commonly used in this type of fumigation.

PREMISES INSPECTION

Once it appears to you that fumigation will be required to control a pest problem, you must make a serious on-site inspection. You must ask yourself a number of questions and make a number of decisions. Frequently, the success or failure of the fumigation operation will depend upon what you learn, what you decide, and how you plan. Some of the questions should include: If the structure itself is not infested, could the infested items or commodity be moved from the building and be fumigated elsewhere? Assuming that removal of the infested items from the building is not practical, can you fumigant them in place? Is there enough room between the commodity and walls or partitions so that you can seal the tarp to the floor? What is the volume of the commodity? What is the volume of the building? Can the structure itself be made reasonably airtight, or will it be necessary to tarp the entire building?

From what construction materials is the structure built? (Fumigants will pass through cinder block with no difficulty). Are there broken windows that must be replaced? Are there cracks in the ceiling, walls or floors that must be sealed? Are there floor drains, sewer pipes or cable conduits that will require sealing? There have been a number of fumigation failures because floor drains under stacked commodities went unnoticed. In once instance, the fumigant leaked into a telephone cable tunnel which lead to an occupied building. No loss of life occurred, but a number of people were made ill.
How are you going to handle air conditioning ducts and ventilation fans. Are there fireplaces, flues, stove pipes? Will interior partitions interfere with fumigant circulation? Are the interior partitions gaslight so that they can be relied upon to keep the fumigant from entering other parts of the structure?

Are there parts of the building not under the control of your customer? Can these other operations be shut down during the fumigation? What are the building contents? Can any of them be damaged by the fumigant? Can such items be removed during fumigation? If they cannot be removed, can they be otherwise protected?

Where are the gas cut-offs? Where are the pilot lights? Where are the electrical outlets? Of what voltage are they? Will the circuits be live during fumigation? Can the outlets be used to operate your fumigant circulating fans?

Look outside the building. If you tarp the entire structure, can you make a good, tight ground seal? Is there shrubbery next to the building that might be damaged either by the fumigant, or by your digging to make an airtight fumigation seal? Can this shrubbery be moved? How far is it to the nearest building? Does that building have air conditioning? Does it have air intakes that could draw the fumigation inside - particularly during aeration?

How are you going to aerate your structure after fumigation? Are there exhaust fans, and where are the fan switches? Are there windows and doors that can be opened for cross ventilation? Does the building contain any high priority items that may have to be shipped within a few hours notice? If so, can you make provisions for interrupting the fumigation and aerating the building within a certain time requirement?

Is the structure to be fumigated located so that your operations may attract bystanders? (If so, you should consider asking for police assistance to augment your own guards.) Where is the nearest medical facility? What is the telephone number of the nearest poison control center?

Once you are convinced that you have covered everything, prepare a checklist of things to do and of materials needed. Don't rely upon your memory. Then finally, two questions: What have I overlooked? Is fumigation still the best method of controlling the pest problem?

TARPAULIN FUMIGATION

Tarpaulin fumigation involves the placement of a gaslight material over the commodity or structure to be fumigated. The tarps may be specially made for fumigation, such as impregnated nylon, or they may be sheet polyethylene. Impregnated nylon tarps may be used again and again as they are very strong and resist ripping. Many sections of impregnated nylon tarps can be clamped together, so there is no limit as to the size of the stack or structure that may be covered. Polyethylene tarps can be used in thicknesses from 1 ½ mil up to 6 mil. The thinner material can be used but once, and is for indoor work. Four and six mil material can be used outdoors, and if you are lucky, the 6 mil material can be reused. As clear polyethylene breaks down in sunlight, black polyethylene films may be used outdoors. It is normal to use gas impervious adhesive tape instead of clamps to join various sections of polyethylene film together. In addition to considering the material for use for tarpaulin fumigation, consideration must be given to the method of obtaining a ground seal. If they are smooth, concrete and asphaltic surfaces are satisfactory. Wood surfaces are not. With wood, and frequently with soil surfaces, it is necessary to place a section of the tarp material beneath the stack as well as over it.

There are several methods of obtaining a good ground seal. Of course, you must allow enough tarp material to skirt out from the stack. This should extend outward at least 18 inches. Then loose sand, sand snakes, or water snakes are used to hold the skirt to the ground surface. Snakes are merely tubes of cloth or plastic filled about 3/4 full with sand or water. Don't fill them too full or there will not be enough ground contact to make a good seal. A word of caution about using water snakes. If the floor is not level, the water will run to one end and the seal will be poor. The snakes should overlap each other by about 1 ½ feet. Sometimes it is easier to use adhesive tape and make a direct seal to the floor. In this case, snakes are not needed. Occasionally, you may find a stack placed too close to a wall to obtain a good ground seal. If the wall is reasonably impervious, the tarp may be sealed directly to the wall.

Indoors

If it is determined that a stack of items is infested and requires fumigation, it is best to conduct the operation indoors. Indoors, the stack is protected from wind and rain. If, for safety or other reasons, the storage area is not suited for fumigation, it is better to move the commodity to another indoor location rather than to fumigate outdoors. This you will have determined when you first inspected the structure. The commodity to be fumigated should be on pallets. With most fumigants, it will be necessary to keep all persons not connected with the fumigation operation out of the area where the fumigation is being conducted. If partition walls are not impervious to the fumigant, the entire building will have to be evacuated. If you are using aluminum phosphide, these restrictions are not so rigid. With aluminum phosphide, after the fumigant is introduced, work can continue in the area as long as you are sure that there is no fumigant leakage. Of course, warning signs will be posted on the stack.

If you are using any fumigant except aluminum phosphide, you will have to erect tarp supports which are one to two feet higher than the stacked commodity. This is to make certain that there will be adequate circulation of the gas during the initial stages of the fumigation. The gas introduction tubes should then be secured to the top of one of the supports. A pan or other device should then be placed beneath the gas introduction outlet to protect the commodity from any liquid fumigant. Next, all of the corners must be well padded to prevent the tarp from tearing. The lighter the polyethylene tarp, the more chance there is for tears. If the stack is large, non-springing fans must be so placed that gas circulation will be assured. These fans must be run for one-half to one hour after the introduction of the fumigant. You must also run tubing from various positions in the stack (usually, one located high in the stack, one at an intermediate location, and one at a low location) to the position where you will be sampling the gas concentration. After all of this is done, the tarp can be placed and sealed to the floor. Because of the molecular activity of hydrogen phosphide, the air dome, tubing and fans are not necessary if you are using aluminum phosphide. Of course, you will have to obtain the cube of the space beneath the tarp so that you can calculate the amount of fumigant to use.

Outdoors

The same principles as stated above apply to fumigation outdoors. The difference is that the fumigation tarpaulin must be of a stronger material. If polyethylene film is used, it must be at least four mil thick. Six mil material is better. Clear polyethylene tends to become brittle from ultraviolet rays of the sun. If the polyethylene tarp is to be kept in place after the fumigation is completed, or if it is planned to reuse the tarp, black polyethylene should be considered for use. Black polyethylene is more resistant to the effects of sunlight. There is, however, some danger in using black polyethylene. If the tarp spans several stacks, it may conceal gaps between stacks, or other voids, and personnel working on top of the tarp may fall through. If fumigation has begun, such a fall could be fatal.

It is more difficult to obtain a good ground seal outdoors. It may even be necessary to place a layer of loose sand on the skirt to obtain any sort of a good seal. Additional, steps will have to be taken to protect against unanticipated bad weather (if you know that the weather will be stormy, delay fumigation). Place braces over the stack (but under the tarp) so that rain will not accumulate in any low spot. Also place weighted ropes (sandbags make good weights) over the tarp as protection against wind. If the tarp bridges stacks, workers will have to be very careful not to fall through the void while they are working atop the stacks. The black polyethylene is not transparent.

Entire structure

This type of tarpaulin fumigation is normally reserved for the control of dry-wood termites or wood-boring beetles. The fumigants normally used are sulfuryl fluoride (Vikane) or methyl bromide. HCN is also registered for this purpose, but because of better penetration and increased safety, sulfuryl fluoride or methyl bromide is preferred.

Items which could be damaged by the fumigant must be removed. Building occupants will have to be evacuated for the entire fumigation and aeration period. All pilot lights, flames, and electrical appliances will have to be turned off. Tubing for drawing air samples will have to be placed at several places within the structure. It is well to introduce the fumigant into the structure at several locations. Non-sparking electric fans should be placed so the fumigant will be circulated throughout the structure for one-half to one hour after the introduction of the fumigant.

If methyl bromide is used, it should be the formulation containing 2 percent chloropicrin. If sulfuryl fluoride is used, chloropicrin should be introduced into the structure 15 minutes before the sulfuryl fluoride is introduced. (To introduce the chloropicrin, place a handful of cotton in a shallow dish and set the dish in the air stream of one of the electric fans. Pour chloropicrin over the cotton. Use one ounce of chloropicrin for each 10,000 to 15,000 cubic feet of space to be fumigated.)

If ornamental vegetation is too close to the structure to permit the tarpaulin to be sealed to the ground, the vegetation will have to be moved. All edges of the structure which could puncture or tear the tarpaulin will have to be well padded. From a worker safety standpoint, they should wear shoes with non-skid surfaces, and all ladders should be strong and braced. Tarp sections then may be carried to the roof top for further assembly.

The edges of adjacent tarp sections are rolled together and clamped. Clamps can be used with polyethylene, but adhesive polyethylene tape may be better. Once enough sections have been joined, the completed tarp can be dropped over the side of the structure and any additional clamping or taping completed. If the building top is flat, sand snakes should be used to hold down the tarps. If the roof is peaked, weighted ropes should be thrown over the tarp to prevent the tarp from billowing. Excessive billowing of the tarp can ruin a fumigation job, and all possible measures should be taken to prevent this from occurring. The tarp should be drawn as close to the building as possible. If a high capacity electric fan is placed in one doorway and directed outward, a partial vacuum will be created and will draw the tarp against the structure. The excess tarp material at the corners of the structure then can be drawn together and taped down. As in any fumigation, the ground seal is very important. The ground should be level and devoid of vegetation. If the soil is porous, the soil around the perimeter of the building should be soaked with water to prevent escape of the fumigant through the soil. The tarp skirt must be at least 24 inches and weighed down by an ample amount of loose sand. If sand snakes are used, they should be doubled or tripled. The ground seal must be weighted down enough to withstand any unexpected wind.

! A sample checklist for fumigation preparation is given under the section on **PREMISES INSPECTION**.
! A sample checklist for clearing a building after fumigation is given under the section on **AERATION PROCEDURES**.

SPOT OR LOCAL FUMIGATION

Fumigants, both spot and local, are used in many flour mills, mix plants, and some packaging operations for the prevention of insect development inside processing equipment. Spot and local fumigants are highly toxic and must be handled with extreme care. Magnesium phosphide converts rapidly to Phosphine gas and may be used for spot or local fumigation. This material must be applied to mill equipment by trained, certified personnel. Application requirements and equipment required for magnesium phosphide are the same as those for aluminum phosphide.

GENERAL FUMIGATIONS (MILLS)

Preparations must be made before the plant is shut down. In the mills, the feed should be cut and the mill allowed to run for 30 to 45 minutes to remove as much stock as possible. During the period, rubber mallets should be used to tap on spouting, elevator legs, and sifters to loosen as much residual stock as possible. Outlet channels in sifters should be checked at this time to make sure none are blocked or choked. Boots and other machinery containing stack stock are not cleaned out prior to the fumigation.

A notice is placed on the plant bulletin board a few days in advance of the fumigation to advise employees of the date, time and length of fumigation, and to advise them that they are not to enter the plant under any circumstances while it is under fumigation.

After shut-down, all dust collector vents should be sealed using polyethylene sheeting or large plastic bags. On pneumatic mills, or where filters are used, a damper or a series of slide values are usually located in the air discharge system. It is important to close dust collectors and filter vents to contain the fumigant within the machinery. Thermal currents and drafts can make fumigation a total failure as vapors may be discharged to the atmosphere before reaching a killing concentration.

All windows must be closed and sealed, the fire doors between floors sealed, and all outside doors must be closed and sealed. Warning signs must be placed on each exterior entry door. Other doors, which can only be opened from the inside must be securely fastened or locked. Local codes may require you to notify fire and police departments, as well as any alarm services. Some labels now require a guard to be posted.

When it is necessary during the winter months to check the operation of the boilers, the outside entrance to the boiler room must be used rather than entering through a section of the plant under fumigation. Warning signs must be place on the doors which connect the boiler room to the plant.

The length of exposure time is important for an effective fumigation. Follow the label instructions on your fumigant container. Exposure periods of less than label instructions are not effective. At least two hours before any employee is allowed to enter the plant, an employee wearing a gas mask opens the doors, opens the necessary windows and dust collector vents to allow any remaining fumigant to dissipate. The warning signs are then removed from the exterior doors. Exhaust fans are then started. The mill machinery is not cleaned prior to startup.

These are a few basic rules that must be followed in carrying out a fumigation:

! At least two certified employees must be present; never attempt to do a fumigation alone.

! The applicators must wear gas masks fitted with correct vapor canisters specified for the fumigant used.

! The applicators must remain on the same floor at the same time or be within sight or hearing distance of each other.

Before anyone uses a gas mask, the mask inspection log must be checked. This will tell you when the mask was last cleaned, inspected, and the canister installation date. The tape on the bottom of the mask canister protects the canister while it is in storage. The date that this canister was first used has been entered in the space provided on the reverse label.

Remember, your safety is of prime importance to you, your family and your employer. Be sure to follow these instructions on every fumigation, so that it is both safe and effective.

AERATION OR VENTILATION OF FUMIGANTS

Aeration procedures vary according to the fumigant being used, the type of installation being fumigated and the items being fumigated. Because of these factors, one should always read and follow the label instructions for the fumigant and situation for which it is being used.

FACTORS AFFECTING AERATION TIME

In addition to the characteristics of the fumigant itself, the rate of ventilation or aeration is affected by several factors. The more important of these are the rate of air exchange, the temperature, the amount of sorption and the rate of desorption.

Rate of air exchange

The rate of air exchange within the structure or area fumigated is the most important factor affecting aeration. The exchange rate will be proportional to wind velocity through the area and size and arrangement of the gasses. When the conditions for mixing the old gas with new air are good, the exchange of one volume of air will reduce the fumigant concentration by one-half. The time for this reduction to occur is referred to as "half loss time" (HLT). In atmospheric chambers an exchange time of 1 air change per minute is desirable. In other areas, the most effective practical method is to increase cross ventilation. Fans (non-sparking) are useful for this purpose as well as to stir up the air in "pockets" or "dead spaces." Loaded areas aerate much more slowly than empty areas.

Temperature

Temperature affects the clearance rate of a fumigant because higher temperatures favor the diffusion of the fumigant and the rate of desorption. In aeration of areas using cold outside air in the colder months of the year the rate of diffusion and desorption is slowed down requiring longer aeration time. In some cases it may be necessary to close up the area and reheat it to 76° F (24° C) and then to repeat the aeration process in order to satisfactorily remove the fumigant.

Sorption and desorption

The amount of fumigant absorbed by the materials in the area fumigated is referred to as the "load factor." This absorbed fumigant is not available to act as a fumigant, but must be removed in the aeration process. Some commodities are much more sorptive that others just as some fumigants are much more subject to sorption than others. The greater the sorptive capacity of the fumigant and the item fumigated, the longer the desorption process and the greater the aeration time needed.

Also, the greater the surface area of the items being fumigated the greater the sorption rate and the longer the aeration period needed for desorption. For example, sulfuryl fluoride aerates much more rapidly than HCN and open machinery much faster than bagged flour. Because of the slow desorption rate of grain, it is usually advisable to hold it an additional 24 hours after the satisfactory aeration period. Particular attention must be given to retention of fumigant gas by highly sorptive materials such as flour, meals and jute bags.

AERATION PROCEDURES

Procedures for aeration or ventilation will vary with the fumigant and the area and items fumigated. Plans for aeration should be made before starting the fumigation.

Building ventilation

Plans for opening doors, windows and ventilators for the initial ventilation are of particular importance. Whenever possible, ground floor windows and doors should be opened form the outside. Aeration should take place for at least 30 minutes to 1 hour before entry and until detectors indicate safe working levels with gas masks.

At the beginning of the aeration, the building should be entered for only short periods of time. At least two fumigators, wearing previously tested air supply respirators or (SCBA) should enter. Doors and windows on the first floor should be opened first, particularly if none have previously been opened from the outside. All windows should not be opened on a particular floor at the time, but only those providing thorough cross ventilation. The fumigators should then return to the outside. If ground floor ventilation occurred before entry, they should work upward floor by floor, opening those windows necessary for cross ventilation. They should not remain in the building longer than 15 minutes. Fans (non-sparking) should be turned on and allowed to run until aeration is complete.

After the building has been partially aerated, two fumigators in gas masks should open as many of the remaining windows as needed to complete the aeration. They should leave every 15 minutes or so for fresh air and ventilate the basement.

No one should be allowed inside without a gas mask until all parts of the building have been checked with a detector indication no fumigant vapors remain.

Flush toilets, dispose of any quantities of fluid such as fire pails.

Test with detectors in closets, stacked commodities, etc. to make certain no gas remains. Usually after 2 or 3 hours aeration, the building can return to normal operation. Check it first.

Tarpaulins

When aerating loads under tarps, in buildings, or on still, humid days, an opening should be made be lifting the tarp on the end opposite the blower or source of air and discharging the fumigant with a blower near the outside opening. If blowers or strong cross ventilation is not used, lift tarp at corners and raise as concentration is lowered and finally they can be completely removed. Respirators or gas masks should be used. Occupants, other then fumigation operators, should vacate the building before tarps are aerated.

If aeration is in the open and the breeze is blowing, the end or side of the tarp opposite the direction of wind movement should be lifted first, then the portion of the tarp on the windward side may be opened safely. If the first opening is on the windward side, fumigant vapors will be forced backward and may endanger operators.

Fumigation chambers

Free gas should be released and commodities aerated immediately following fumigation. It is important to consider and protect human health at all times. When a fumigation chamber is inside a packing house or any other enclosure where employees are likely to be present, intake and exhaust stacks should be provided.

The exhaust stack must lead outside the building. The intake and exhaust stacks should be opened after the fumigation exposure is completed. The normal air circulation equipment in a chamber can be made to conduct air from the chamber to the outside.

When a chamber is outside a building, it may be aerated safely by opening the door slightly at the beginning of the aeration period and turning the blower on. The door should be held in the partially opened position so it cannot accidentally close. Air discharged from the blower should be vented to the outside of the chamber. If the door should accidentally close, the partial vacuum created by the blower may damage the chamber.

No one should remain near the door or the exhaust when the blower is turned on. The doors may be fully opened after about 15 minutes, but employees should not enter the chamber until it has been aerated for at least 30 minutes and checked with a halide detector.