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Fumigation Pest Control

Category 7C

Preface

This training manual provides you with the information you need to meet the minimum Environmental Protection Agency (EPA) standards for certification as commercial applicators in Category 7c, Fumigation Pest Control. Category 7c encompasses any tasks involving the use of fumigant materials for pest control. This manual primarily addresses the use of fumigants in various stored-product facilities, such as those used for grain storage and transportation, and the soil application of fumigants. It also prepares you for an examination, based on this manual, given by the Missouri Department of Agriculture. Those of you wishing to certify commercially in Category 7c should study ALL sections of this manual.

Manual 97 DOES NOT provide all of the information you need for safe and effective use of pesticides. Examine the label for each pesticide you use. Labels must list directions, precautions and health information — all of which are updated regularly when a pesticide is registered in Missouri. If you notice information on a current pesticide label that conflicts with the information in this manual, follow the label.

Manufacturers will supply additional information about products registered for use in controlling pests with fumigants. Information also is available from the Office of Pesticide Coordinator, 45 Agriculture Building, University of Missouri-Columbia, Columbia, MO 65211, (573) 884-6361.

Missouri's Pesticide Applicator Training Program is a cooperative effort. The Missouri Department of Agriculture is the state lead agency. University Extension, the University of Missouri-Columbia, is responsible for the content of the Pesticide Applicator Training Program. The Missouri Departments of Health, of Conservation, of Natural Resources and the EPA also contribute to the development of educational materials and participate in the training program.

(**A note on this manual:** Terms highlighted in bold type throughout the text are found in the glossary, on page 38.)

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Acknowledgments

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- Ray Nabors, University Extension, University of Missouri

The information given in this manual is supplied with the understanding that no endorsement is implied or discrimination intended.

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Coordinator of Pesticide Programs
University of Missouri
Spring 1995

Pesticide use laws

Worker Protection Standard

The Worker Protection Standard (WPS) covers most pesticide uses involved in the production of agricultural plants on farms and in forests, nurseries or greenhouses. This includes pesticides used on plants and on the soil or planting medium in which the plants are (or will be) grown. The WPS covers both general-use and restricted-use pesticides. You will know the product is covered by the WPS if you see the following statement in the "Directions for use" section of the pesticide labeling:

Agricultural Use Requirements — Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR Part 170 . This standard contains requirements for the protection of agricultural workers on farms, forests, nurseries and greenhouses, and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about personal protective equipment, notification of workers and restricted-entry intervals.

If you are using a pesticide product with labeling that refers to the WPS, you must comply with the standard. Otherwise, you will be in violation of federal law because it is illegal to use a pesticide product in a manner inconsistent with its labeling.

For more specific information, consult the EPA manual *The Worker Protection Standard for Agricultural Pesticides — How to Comply*. These manuals are available from several sources, including local University Extension centers and the Missouri Department of Agriculture.

Federal recordkeeping regulation

Certified commercial applicators, certified non-commercial applicators and certified public operators need to follow EPA's regulations implementing the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and Missouri pesticide recordkeeping regulations. Commercial applicators must provide a copy of the restricted-use pesticide application record, within 30 days, to the individual contracting the service. For more details about the contents of pesticide application records, consult the "Missouri Pesticide Use Act," which is available by contacting:

Missouri Department of Agriculture
Division of Plant Industries
Bureau of Pesticide Control
P.O. Box 630
Jefferson City, MO 65102

Storing and transporting grain

Introduction

Storing grain after harvest represents a substantial investment of time and money for farmers and grain dealers. It's important to protect this post-harvest investment by properly managing the grain while it's in storage.

Insects are the major cause of stored-grain deterioration. Some insect s are well adapted to exploit the stored-grain environment. Most stored-grain insects are highly prolific, producing large numbers of offspring in a year. A pair of insects can produce enough young within a couple of months to severely infest several tons of grain.

Most insects reproduce sexually. They develop either by **simple** or **complex metamorphosis** (see Figures 1 and 2). The more primitive insects undergo simple metamorphosis. A young nymph (immature) hatches from an egg and grows by a series of molts (shedding of skin); the fully formed adult emerges from the final molt. Examples include psocids, silver-fish and cockroaches. Beetles, weevils and moths undergo a complex metamorphosis in which the immature stages do not closely resemble the ad ult. A small **larva** hatches from the egg and begins to feed. As it grows, it molts on several occasions. The larva then molts into a nonmobile form known as a **pupa**. The adult emerges from the pupal case and seeks out

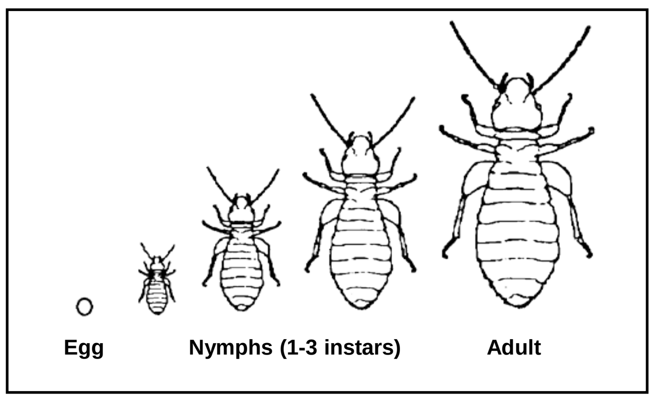

Figure 1. Simple metamorphosis — psocid.

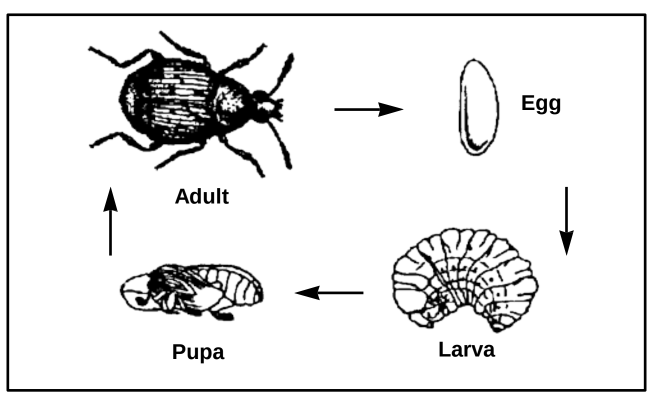

Figure 2. Complex metamorphosis — bean beetle.

a mate. Temperature is a critical factor in insect development. Cool conditions retard development, and warm temperatures enhance development.

Identifying pests

Many different insects inhabit stored grain. The small size and overall similarity of many stored-grain insects make their precise identification difficult. Although it is always wise to specifically identify any insects collected in stored grains, having a general knowledge of the types of insects that occur in storage often provides a start toward understanding the role of an unidentified insect. It's useful for you to be able to identify three major groups of stored insects: **primary (or internal) pests**, **secondary beetles** and **surface-feeding caterpillars**. Not all insects in grain are pests. Parasitic wasps, predacious fly larvae and predacious Hemiptera (true bugs) attack certain grain pests. In addition, many field insects inadvertently are transported to grain bins, where they cause no damage.

The following sections provide information about each of the three major stored-grain pest categories and some of their individual members that are of economic importance in Missouri.

Primary (or internal) pests

The most damaging stored-grain pests are those that develop within grain kernels. Adults deposit eggs on, or in, whole kernels, and larvae develop hidden within the kernels. Damage caused by internal pests makes grain more susceptible to infestation by insects that feed externally on grain or grain debris.

Although inspectors may designate grain as "weevily" when in fact other insects are present, **weevils** are a unique and recognizable group of stored- grain insects. Adults are small (between 1/16 inch and 1/8 inch long), but they are identifiable because the head has a prolonged snout. Once the weevil larva completes its development, the adult emerges from the damaged kernel and feeds, mates and deposits eggs as it moves about among kernels. You may identify an insect borer, the lesser grain borer and a primary pest, because its head projects down- ward, not forward, from the front section of the body. You'll find these insects in any part of a grain mass; they are not restricted to the grain surface.

Larval stages of the Angoumois grain moth also feed within grain kernels. This insect can infest grain in the field; storage infestations usually are limited to the surface layer of a grain mass. The following are some examples of primary grain-storage insects that are of economic importance in Missouri.

Granary weevil *Sitophilus granarius* (Linnaeus): The adult beetle has no wings under the wing covers and is no more than 3/16 inch long. Granary weevil adults look similar to rice weevils; however, they have no yellow markings on the back and no hind wings. Adults live approximately 7 to 8 months, and a female lays 50 to 250 eggs during this period. The development of the immature stages within the grain kernel requires about a month in warm weather. Granary weevils are extremely destructive grain pests. The larvae feed and develop within grain kernels. They can destroy grain in elevators or bins where conditions are favorable. Infested grain usually heats at the surface, and with proper moisture, sprouting occurs. Signs of infestation are eaten-out kernels containing small, white, legless larvae and small brown-to- black snout beetles.

Rice weevil *Sitophilus oryzae* (Linnaeus): The rice weevil is smaller than the granary weevil, averaging about 3/32 inch long. You can distinguish it from the granary weevil by four large light areas on the wing covers and fully developed wings under the wing covers. The adult rice weevil lives 4 to 5 months, and each female lays from 300 to 400 eggs in holes bored in kernels during this period. The larvae hatch inside the kernel and mature there. The period from egg to adult may be as short as 26 days. On a global basis, the rice weevil is considered to be the most destructive pest of stored grain.

Lesser grain borer *Rhyzopertha dominaca* (Fabricius): The lesser grain borer, like the weevils, attack sound kernels, causing weevil-type injury. A sweet, musty odor often is associated with lesser grain borer infestations. Large amounts of **frass** are produced by this pest, and fecal pellets may accumulate in the grain. Adults are approximately one-eighth inch in length, and their heads are tucked down under their shoulders. The body shape is cylindrical with numerous small pits on the elytra. Adults have antler-shaped antennae. Related to a group of beetles that normally attack trees, the grain borers have powerful jaws they use to bore into grain kernels.

Angoumois grain moth *Sitoroga cerealella* (Olivier): This pest flies to fields of ripening corn and wheat as both the pest and the crops near maturity and lays eggs on the wheat heads or corn kernels. Between crops, the moth breeds in stored grain. Females lay about 40 eggs, one egg per kernel. Larvae hatching from the eggs bore into the kernels, where they develop.

Surface-feeding caterpillars

Surface- feeding caterpillars make up the second major group of stored-grain insects. These insects commonly inhabit the outer parts of a grain mass (usually the surface, but also the bottom of the grain mass just above perforated drying floors or aeration ducts). The most common surface-feeding grain pest in Missouri is the Indian meal moth.

Indian meal moth *Plodia interpunctella* (Hubner): Infestations mostly occur in the upper 4 to 6 inches of grain in a bin. The larvae, which are dirty white with sometimes a greenish or pinkish tint, produce silken threads, which result in caking or crusting of the surface grain. Their frass, cast *exoskeletons* and silk contaminate grain. Adult Indian meal moths at rest, having wings folded over their backs, measure about 0.4-inch long. The wingspan is about 0.6 inch. The outer portion of the front pair of wings is bronzed to purple; however, this color is lost as the moth ages. The inner half of the wings near the body is light gray. The hind wings are gray and lack distinctive markings. Female moths deposit from 60 to 300 eggs over a three-week period within the grain mass's upper surface.

Secondary insects

A third group of stored-grain insects includes the secondary beetles that develop and feed outside grain kernels or within cracked or damaged kernels. In Missouri, most insects commonly collected in stored grain are beetles that range from 1/16 to 1/2 inch in length. Adults of most species are reddish-brown to black, and their **forewings** are hardened to form a "shell" over the body. Like the weevils, these beetles are not limited in distribution to the grain surface but instead inhabit any part of a grain mass. They feed on several different grains, but their buildup in any grain depends on bro- ken kernels (or other fine material) or fungal growth on moist grain. This dependence on grain that is already damaged explains the description of these insects as secondary pests, bran bugs or fungus feeders. Concentrations of stored-grain beetles raise grain temperature and moisture, and these altered conditions favor continued population growth. The following gives more detailed information for secondary grain-storage insect pests that are of economic importance in Missouri.

Red flour beetle *Tribolium castaneum* (Herbst): The adult beetles are flattened, reddish-brown in color and about 1/7 inch long. They may live for several years, and each female lays about 450 eggs. Larvae appear wiry, are about 3/16 inch long and are whitish, tinged with yellow. This insect causes dam- age by feeding but probably causes the most damage through contamination. Large numbers of dead bodies, cast skins, fecal pellets and liquids (quinones) produce extremely pun gent odors in the grain.

Sawtoothed grain beetle *Oryzaephilus surinamensis* (Linnaeus): Adults are small, slender, dark brown, flat insects about 0.1-inch long. The most distinguishing characteristic is the six sawlike teeth found on either edge of the thorax. Females may lay from 50 to 300 eggs in their six- to 10- month lifetimes. At temperatures of 80 degrees F to 85 degrees F, eggs hatch in 3 to 5 days, and the larvae move about and feed freely. Cooler temperatures prolong hatch. Larvae mature in about two weeks in the summer and construct "nests" of small grains and fragments stuck together with a sticky secretion. Along with the red flour beetle, this is a major pest in stored grains and processed cereals.

Flat grain beetle *Cryptolestes pusillus* (Schonherr): These insects usually are associated with mold, in high moisture and heating grain or both. Both adult and larvae feed on grain. The production of additional heat and moisture as well as their waste products may cause the most problems. When fully grown, larvae form cocoons; food particles stick to these cocoons. Several species of flat grain beetles exist, and most people cannot distinguish among them. Flat grain beetles are small, less than 0.1-inch long and reddish-brown. Antennae are long, often nearly the length of the body. Each wing cover has five ridges running its length. Larvae are elongate, slender and pale-colored. The head is black.

Cadelle *Tenebroides mauritanicus* (Linnaeus): A seemingly clean bin may harbor thousands of these pests. At times, this insect may burrow into the woodwork of empty bins and remain dormant until fresh grain is stored. Adults live for more than a year and some for two years. Females lay about 1,000 eggs, which hatch in seven to 10 days into white larvae with black heads and two black points at the end of their bodies.

Insect biology and grain infestations

Behavioral and biological characteristics of the groups of stored-grain insects are important to management decisions. For example, an insecticide treatment incorporated in the surface portion of the grain mass may provide adequate control of the Indian meal moth, but such an application will not control a secondary beetle or weevil problem that already exists in the core of the grain mass. Cleaning grain to remove fine material helps control infestations of several secondary beetles, but this action is of limited value for reducing infestations of weevils or other primary pests.

Some stored-grain insects may infest maturing grain crops in the field; however, this is not the primary means of stored-grain insect problems. Infestations more commonly develop when insects move to new grain from carry-over grain, from small amounts of grain not cleaned from empty bins, from feed-supply buildings and from grain debris beneath perforated floors of bins. Most pest species can fly at least short distances to reach new grain. Pest migration to, and development within, stored grain depends on suitable air and grain temperatures. Common drying and aeration practices usually produce moisture and temperature conditions that allow a fall-harvested crop such as corn to remain nearly insect-free during the first winter of storage. As air and grain temperatures increase during spring and summer, insects move into stored corn and reproduce rapidly. When corn remains in storage through additional seasons, normal winter cooling causes some insect mortality, but many individuals, although inactive, do survive. Insect density usually increases with each year of storage. The level of insect buildup for any du ration of storage varies among bins according to grain conditions (moisture, temperature, amount of fine material and mold), proximity of pest sources and the use of insecticides.

Pest-specific information presented previously provides details on the biology of several major stored-grain pests. Some generalizations provide an overall understanding of the population dynamics of these insects. First, reproductive potential is phenomenal. Females of the various species develop from egg to adult in approximately 4 to 6 weeks, but a few species are characterized by the development of only one generation per year.

Although temperatures for optimum development differ among species, the majority develop most rapidly and success fully at temperatures between 75 degrees F and 90 degrees F. At temperatures below 50 degrees F, stored-grain insects exhibit little or no activity. Cooling grain to temperatures below 50 degrees F for an extended period causes some mortality, and the percentage mortality is greatest at even lower temperatures. Some pest species can, however, survive extended exposure to temperatures at or below freezing.

Grain moisture also influences species composition and population density. Several pests, including foreign grain beetle, hairy fungus beetle and the mealworms, feed on fungi that develop in grain that is too wet. Others, such as the weevils and the larger black flour beetle, feed directly on grain that is high in moisture. Storage at moisture levels of 12 to 13 per - cent reduces insect proliferation, but some species will invade grain held at even such low moisture.

Owners of infested grains suffer losses several ways, including losses that occur prior to the sale, upon attempts to deliver grain and through dis- counts or **quarantines** if live insects are detected in grain samples. When discounts are assigned for insect infestation, important factors are insect numbers and type of grain. Federal Grain Inspection Service (FGIS) standards for grain-insect infestation are shown in Table 1.

Table 1. Number of live insects required for FGIS designation as "infested."

Grain	Insect density per kilogram of grain
Wheat, rye, triticale	• More than one live weevil, or • One live weevil plus any other live pest insect, or • No live weevils, but two or more other live pest insects
Corn, barley, oats, sorghum, soybeans	• More than one live weevil, or • One live weevil plus five or more other live pest insects, or • No live weevils, but ten or more other

Detecting insect problems

To manage stored-grain insects effectively, operators of grain-storage facilities must examine grain for insect infestation before it is unloaded and moved into storage, and operators must repeat inspections regularly throughout the subsequent storage period. Initial inspection may use manual or hydraulic probes that withdraw grain samples from incoming loads. Scree n these samples using an appropriate grain sieve, and examine the screenings (material that passes through the sieve) for the presence of insects. The size and shape of sieve openings vary for different grains. If the grain temperature is lower than 60 degrees F, allowing the screenings to warm to room temperature before examination will make active any insects that are present; their movement increases the likelihood that an inspector can detect their presence. Don't move infested loads into storage with noninfested grain; doing so promotes infestation of the entire storage.

Once grain is stored, regularly inspect it to measure grain temperature and moisture and to detect any insect infestations. The number of samples necessary to deter mine grain condition adequately is not well defined. The minim um number of samples suggested for round bins is given in Table 2.

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

	Temperature probes		Moisture & insect determination	
Bin diameter	Shallow	Deep	Shallow	Deep
< 24 feet	2	3	2	5
> 24 feet	2	5	3	10P

Source: H.J. Raney et al., University of Kentucky.

Increasing the number of sample sites increases the accuracy of the information obtained. If temperature measurements are unusually high at any sites, collect samples from these areas to deter mine moisture content and presence of insects. It also is especially important to check for insects in samples from the grain surface and from areas where fine material is concentrated. Infestations often begin in these locations.

Sampling grain

One standard sampling too l used to collect grain samples is the partitioned (or compartmentalized) grain trier. Insert it into grain at about a 10-degree angle from vertical, with the sampling compartments closed and facing slightly upward. Rotating the handle opens the compartments, and three quick, short, vertical strokes force grain into each compartment. After the trier is filled, close the compartments and remove the trier from the grain. You can use a grain canvas or eaves trough to catch the sample when the trier is opened. You also can use triers to collect surface samples by inserting the trier horizontally just below the grain surface with the compartments opening upward. Three-, five-, 10- and 12-foot triers are marketed by grain-industry suppliers.

You may use deep-bin or deep-cup probes to collect samples from greater depths within a grain mass. Attached the sample cup to the end of a metal probe and insert it closed into the grain mass. Extension sections added to the top of the metal probe allow insertion of the sample cup to the desired depth. Pulling up on the probe opens the sample cup, and it fills with grain. If grain has settled within a storage, it is usually difficult to insert a deep-bin cup beyond 10 to 15 feet below the surface.

Collecting samples from depths greater than 10 to 15 feet requires a vacuum sampler or power probe. Hydraulic or mechanically powered probes can collect samples from depths as great as 100 feet.

Traps

Several types of traps are available to monitor stored-grain insects. You may insert a plastic probe or pitfall trap into stored grain. This trap consists of a 14-inch long, 1-inch diameter clear plastic cylinder with perforations drilled through the upper part. The lower part of the cylinder is not perforated and contains a smaller plastic catch-tube capped with an open funnel. The top of the 14-inch cylinder is capped; the bottom is closed by a removable, tapered plug. Insects crawl through the perforations into the lower catch-tub e and cannot escape. Although you may use specific sex attractants, aggregation attractants or foo d attractants to lure insects into the trap, the random movement of insects within an infested grain mass produces substantial captures even in unbaited traps.

Place plastic probe or pitfall traps just below the grain surface or probe into grain to a depth of about 12 feet. To probe the traps into grain, screw a metal collar onto a probe extension section; this collar holds the trap in a vertical position as it is pushed into the grain. The top of the trap contains openings for the attachment of a rope for retrieving the trap from the grain mass.

Leave pitfall traps in place for one to four days. Increasing the trapping period increases the likelihood that you'll capture insects. Because these traps depend on insect movement, they are not effective in grain colder than approximately 50 degrees F where insects are inactive.

Another trap designed for monitoring stored-grain insects is a corrugated cardboard trap that holds an oil lure that attracts and kills insects active where the trap is placed. These traps might be used on the surface of a grain mass to detect insect presence. They also are effective around bagged seeds or feeds in warehouses.

Paper sticky traps baited with attractants also are available. Use these to monitor the flight activity of several insects in warehouses and processing plants.

Detection of insects also is possible through acoustical sensors. The idea of detecting storage insects by the sounds they make was thought of some years ago; however, due to development of inexpensive computers, better band-pass filters and high-gain, low-noise amplifiers, this type of technology now is available. Because the number of times that sounds are detected increases as the number of insects infesting grain increases, you can estimate insect infestation levels from the number of times that insect sounds are detected. The number of times that insects are detected also depends up on insect size. Large insects evidently produce more powerful sounds, can be detected from farther away and thus are detected more often than small insects. Previous research has shown that rice weevil and red flour beetle were detected almost twice as often as lesser grain borer. Rusty grain beetle and sawtoothed grain beetle are much smaller and more difficult to detect. An acoustical detect ion sys- tem should prove especially useful for detection of insects that feed internally on the grain.

Preventing insect infestation

It's often difficult to control established infestations of stored-grain insects. Usually, preventing infestations is more profitable and successful than eliminating existing problems. Preventive steps include thorough sanitation, applying an insecticide to the empty storage, properly cleaning and drying grain, applying protectant insecticides when extended storage is planned and adequately aerating for temperature and moisture management.

Sanitation

An important rule for successful grain storage is: Never store new grain on top of old, carry-over grain. When this rule is ignored, insects that infest old grain will readily move into the new grain placed in the same storage. Preventing insect carry-over within a bin also is the reason for thoroughly cleaning bins before adding new grain. Cleanup should include removal of all grain that may be caked or webbed on the bin walls and all grain and debris on the bin floor. Those doing cleanup work inside a dusty storage facility should always wear a dust-filtering mask. Although removing the perforated floor is impractical in most bins, cleanup practices that include the subfloor plenum are recommended where possible. Also remove grain and grain debris from combines, wagons, augers, etc. Piles of spilled grain near bins also are sources for insect infestations; remove these infestation sources before moving new grain into storage.

Bin sprays

Applying a registered insecticide to the walls and floor of empty bins supplements, BUT DOES NOT REPLACE, cleanup efforts. MU Publication M 160, *Insect and Disease Management: Field Crops, Forages and Livestock*, contains a list of approved insecticides and information regarding their use. Insecticide residues control insects that may have remained in hard-to-clean cracks and crevices or beneath the perforated floor. Apply sprays to the point of run-off; applicators should thoroughly treat all cracks and crevices and around doors. Applicators applying empty-bin sprays inside storage structures should wear a cartridge or canister respirator to prevent inhalation of insecticide vapors. Directing extra spray to and through perforated flooring provides some control of insects in the subfloor plenum, but maximum insect control in this space requires fumigation or the removal of the perforated floor and thorough cleanup.

Moisture and fine material

Whenever plans include storing grain during summer months, it's recommended that you dry to moisture levels of 12 to 13 percent. This range is drier than the preferred condition for stored-grain insects, and it slows their buildup. In addition, insecticides applied directly to grain persist longer on dry grain than on moist grain.

Fine material (in corn, called BCFM, or broken corn and foreign material) in stored grain is detrimental for several reasons. Broken kernels, weed seeds and other crop debris often spoil at moisture levels generally considered safe for whole-kernel storage. Concentrations of fine material reduce air flow and prevent uniform aeration of a grain mass. Extremely fine particles form aerosol dusts that can explode. In addition to these negative effects in grain, fine material also contributes directly or indirectly to most insect problems in stored grain. Many secondary beetles depend on fine material to survive and reproduce. These insects release metabolic heat and moisture that contribute to the survival and reproduction of additional secondary pests and weevils. Cleaning grain to remove fine material reduces the survival of some of the most common pests. Rotary cleaners and aspirators are more effective than perforated or screened sections of augers.

Protectant insecticides

Several grain **protectant** insecticides are available for use in Missouri. Because pesticide registrations constantly change, consult MU Publication M160, *Insect and Disease Management: Field Crops, forages and Livestock*, for currently registered materials and specific information. Remember that protectant insecticides are not fumigants. Their activity is limited to the grain on which they are applied directly. Unlike fumigants, these insecticides do not readily form a gas and will not kill insects present in untreated portions of the grain mass. Grain temperature and moisture determine the stability of stored grain insecticides and the duration of their effectiveness. Temperatures below 40 degrees F not only prevent insect activity, they also retard the degradation of insecticides. For example, at 60 degrees F and 12 percent moisture, a malathion residue of 6.2 parts per million (ppm) is present one year after application of the labeled rate of 10 ppm. A 3 ppm residue is considered effective in the absence of resistance. At 14 percent moisture and 60 degrees F, a residue of only 2.4 ppm remains one year after application at 10 ppm. The moisture- and temperature-related breakdown of malathion explains why storage at low temperatures and 12 to 13 percent moisture is recommended when you need long-term malathion efficacy.

Grain can be treated in several ways as it is augered into storage or transferred from bin to bin. One simple and effective device is the gravity flow applicator, which delivers an insecticide solution to grain as it flows into an auger, conveyor belt or similar grain-transfer equipment. It requires no electrical or mechanical power source. Its successful use does, however, require knowledge of the delivery rate of the auger, a value easily computed by determining the time required to move a known quantity of grain into storage.

Stored-grain insecticides are effective when applied in 5 gallons of water per 1,000 bushels of grain. Table 3 on page 10 lists grain delivery rates and flow rates for application of 5 gallons of solution per thousand bushels.

Table 3. Flow rates for applying 5 gallons of insecticide solution per 1,000 bushels of grain.

Auger delivery rate (bushels/hour)	Application rate for insecticide solution (fluid ounces/minute)
500	5.3
600	6.4
700	7.5
800	8.5
900	9.6
1,000	10.7
1,200	12.8
1,400	14.9
1,600	17.1
1,800	19.2
2,000	21.3
2,200	23.5
2,400	25.6
2,600	27.7
2,800	29.9
3,000	32.0
4,000	42.7

Aeration for pest management

Proper aeration practices can control insects in several ways. By preventing moisture migration, aeration helps limit mold growth; an absence of mold prevents the proliferation of fungus-feeding insects. Aeration also cools any hot spots, and this temperature reduction slows insect development and prolongs the effective ness of insecticide treatments.

Stored-product fumigation

Practical fumigation considerations

(From: Leesch, J.G. et al., in *Stored Product Management*, Oklahoma Cooperative Extension Service, Circular No. E-912.)

Fumigants are pesticides that kill in the gaseous form. As **toxic** gases, fumigants penetrate into cracks and crevices, the commodity and throughout the area to be treated. These characteristics also make fumigants the choice for disinfestation and a highly restricted pesticide.

Fumigation goal: To contain a toxic concentration of gas so that it is evenly distributed and in contact with the target pest long enough to obtain total kill.

A fumigant is a tool you may need to help preserve the stored commodity quality by keeping it free of insect pests. Only use fumigants when live insects are found in a commodity in large enough numbers to cause damage or the reduction of quality. Fumigation is the most hazardous type of pesticide treatment; it is expensive, provides no long-term residual protection and may cause resistance problems if conducted repeatedly. You need to fumigate when no other pesticide or control method can reach the insect infestation. If the insects are already inside the grain kernel, no spray or dust can reach them. The only other methods that will penetrate commodities to kill insects are cold, heat and radiation. Cooling and heating methods are energy inefficient and expensive, particularly for large bulk volumes of commodity. Radiation also is expensive and has the disadvantage of requiring that the commodity be moved to the radiation facility. In general, insects are tolerant of radiation and would need impractical dosages to be controlled effectively. Also, radiation is not an accepted method because the public doesn't accept irradiated products.

Fumigation decisions in stored-product management

Any treatment considerations should include the following factors:

- Time of year — temperature, humidity, wind.
- Type of problem — insect infestation, mold, etc.
- Probable cause — will the problem return?
- Magnitude of the problem — economic losses?
- Available alternatives — long-term effectiveness.
- Cost of alternatives.
- Management capabilities and time available.
- Market destination.

Fumigants exert their effect on pests only during the time in which the gas is present in the insects' environment. After the fumigant diffuses or is aerated out of the product, no residua l protection is left behind and the stored product is again susceptible to reinfestation. The objective of fumigation, therefore, is to introduce a killing concentration of gas into all parts of the stored product and to maintain that concentration long enough to kill all stages of insects present.

You may apply fumigants directly into the fumigated space as gases from pressurized cylinders. Some fumigants are stored as liquids under pressure but expand to a gaseous form when released or after passing through a heat exchanger, which is installed between the cylinders and the commodity. This method often is used with methyl bromide. Fumigants also can be generated from solids that react with moisture and heat from the air to release the fumigant. This is the way that phosphine is used as a fumigant. The formulation is a solid containing the **active ingredient**, such as aluminum or magnesium phosphide, that react s with moisture in the air to release phosphine. In addition, other solids may be present that produce a warning gas and a reaction stabilizer.

The EPA has initiated a "Label Improvement Program for Fumigants" to help minimize occupational exposure to fumigants. Changes on the label to better define user information, warnings and necessary precautionary measures will directly affect how fumigants are used and who uses them. Three features of the program are of prime importance:

- The revised label directs that at least two "trained persons" be present during the principal fumigation operation. You, as a licensed fumigator, now are required to be present during the application and aeration of the fumigant.
- The use of approved respirator protection devices is required during application of the fumigant when concentrations of fumigant exceed prescribed levels or if the concentrations are unknown.
- Specified direct-reading detector devices are required to monitor fumigant concentrations, ensuring that they remain at prescribed levels as a condition of re-entry or transfer of treated grain.

The selection of an appropriate fumigant is of utmost importance. Give special consideration to many factors, including toxicity to the pest, volatility, penetrability, corrosiveness, safety, flammability, residue tolerances, offensive odors, method of application, safety equipment required and economics.

Stored-product fumigant types

Only two fumigants remain for treating stored products — phosphine- producing materials and methyl bromide. Two other fumigants, chloropicrin and sulfuryl fluoride (Vikane®), are used for structural fumigation, but they are not allowed as fumigants for food or animal feed.

Phosphine fumigants. Phosphine- producing formulations have become the predominant fumigants used for the disinfestation of stored products throughout the world. They are available in solid formulations of aluminum phosphide or magnesium phosphide.

Phosphine has no adverse effects on seed **germination** when applied at labeled dosage rates and is the choice of fumigants for seeds or malting barley. It also is used widely in the fumigation of processed foods because fumigant residues are not usually a problem with phosphine. One disadvantage of phosphine is that it can react with certain metals. These include copper and its alloys (i.e., brass, bronze), as well as gold and silver, resulting in corrosion or discoloration of these metals. If the corrosion is extensive, electrical or mechanical systems using these metals may fail. Thus, damage to contact points, telephones, computers and other electronic equipment can occur. 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 you still need to be careful. In most stored-product situations, phosphine produces very little harm.

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 (sachets, blankets, ropes). 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 com- pounds, such as ammonium carbonate or aluminum stearate and calcium oxide, which control the release rate and lower the combustibility of the mixture. In formulations containing ammonium carbamate, carbon dioxide and ammonia are released along with the phosphine. These products serve both as a warning gas (garlic odor) and a retarding gas for the production of phosphine. Under certain circumstances where phosphine cannot diffuse out of a localized area, such as when the pellets are piled or emerged in water, its concentration can build up to 1.79 percent (17,900 ppm), which is the point of spontaneous ignition for phosphine. In most cases, a fire never results from phosphine fumigation. However, where the fumigant is applied poorly, situations can occur such as trays of formulation getting covered by the covering tarpaulin, causing high concentrations of phosphine to accumulate in the tray. Proper fumigation practices result in concentrations that are probably no more than one-fiftieth of the amount that would result in a fire.

Manufacturers of aluminum phosphide fumigants indicate that there is a delay before heavy concentrations of phosphine are released from commercial formulations. Usually, dangerous amounts of phosphine are released after one-half hour to 1.5 hours with tablets. The time required for phosphine release is much shorter on warm, humid days and much longer on dry, cold days. With grain temperatures above 70 degrees F, decomposition should be complete in three days. With low temperatures and low grain moisture (below 10 percent), appreciable amounts of gas may be evolved for five days or longer. At 40 to 53 degrees F, the manufacturer recommends a minimum exposure period of 10 days, although at 68 degrees F and above only three days are needed.

Phosphine is only slightly heavier than air (20 percent heavier); therefore, it will diffuse rapidly through the stored product because it is a small molecule and is not strongly absorbed by most commodities. This combination of the low absorption loss, great mixing capacity of phosphine and the exposure time of three to 10 days means that bins treated with this material must be gastight. Sealing is one of the most important aspects of fumigation, especially when using phosphine. If the facilities have holes for gas to leak out, the fumigation will fail. Even probing formulation into the grain does not hold sufficient gas to give proper results if the head space above the grain is not sealed. Gas simply will be evolved and swept out of the facility as it reaches the headspace area. Leaks in the areas covered by grain also will let gas escape and may well result in a fumigation failure. With an airtight structure, this gas loss is not a problem because the leaked gas is minimal during the fumigation. In Australia, some fumigations require that a structure pass a leak test before the structure and its contents can be fumigated. This has resulted in the construction of better facilities and a strong emphasis on sealing prior to fumigation. For further information on sealing, see Technical Release ESPC 073033 from the National Pest Control Association.

Methyl bromide. You can use methyl bromide for a variety of fumigations besides stored grain. It is used to fumigate raw and processed commodities, structures, soil and shipments under quarantine. In addition to being an all-purpose fumigant for the professional fumigator, it has some advantages, such as reduced fumigator exposure, economy, effectiveness and speed. In large bulk-storage facilities where methyl bromide is used, some type of recirculation system is usually used to achieve an even distribution of the fumigant after application. You can use fans to distribute methyl bromide in smaller facilities and under tarpaulins. Detection equipment and respiratory equipment are mandatory when using methyl bromide. You can detect methyl bromide by one of several methods. Tubes with chemicals that react with the methyl bromide are available and are used for determining when it is safe to re-enter a facility after aeration. During the fumigation, thermal conductivity devices are available for determining concentrations. In addition, infrared and gas chromatographic instruments are available. For further information, see the bulletin on fumigant detection, available from the National Pest Control Association (1983). Professional fumigators who have all the required equipment and use methyl bromide regularly enjoy its advantages.

Methyl bromide is a simple, small, active, naturally occurring molecule. It is odorless, nonflammable and will extinguish flames. It has a low boiling point of 38.5 degrees F, so it vaporizes rapidly. It evaporates quickly at lower temperatures but faster when the temperatures exceed 60 degrees F. Under ordinary conditions, methyl bromide boils to gas almost immediately. When you use methyl bromide in large fumigations and the application times must be short, use a heat exchanger to vaporize the fumigant as it is applied from the cylinders.

Methyl bromide gas is 3.27 times heavier than air. This means it tends to fall when it is first released. This is one reason that stored grain should be leveled. Otherwise, the fumigant will settle in the valleys and then diffuse through the grain. The high peaks in the grain may not get as much or enough fumigant to kill all the pests. It also is the reason that operators often recirculate methyl bromide with fans during and shortly after application.

You can use cans of methyl bromide to fumigate a small space, but they require a special “can opener” often called a “Jiffy” or “Star” opener. These openers puncture the can and allow the methyl bromide to escape through polyethylene tubing. Before opening the can, insert the tubing into a rail car, truck trailer, bin plenum or fan housing. It is important that the gasket on the puncturing knife be in good condition to prevent leaks.

You can fit steel cylinders with special metering devices to fumigate small places, such as rail cars, or you can measure the gas applied by loss of weight from a cylinder. For example, a full cylinder that weighs 118 pounds should weigh 93 pounds after applying 25 pounds of gas to a 10,000-bushel bin of corn (2 pounds per 1,000 cubic feet in a bin of 12,500 cubic feet).

In a simple fumigation of a small bin, place the cylinder on a scale. After removing the safety bonnet, remove the safety cap. You’ll probably need a crescent wrench. Attach a polyethylene shooting hose with brass fittings to the cylinder. Attach the far end of the hose firmly in the headspace of the bin. It is often wise to place a small piece of plastic or a tray below the end of the application tube to prevent liquid from coming into contact with the commodity. Then open the valve. After the correct number of pounds is in the bin, close the valve. Leave the sealed bin undisturbed for 24 hours, and then open to air it out. Turning on the bin fan helps remove the fumigant quickly from the bin. Don’t remove warning signs until gas levels are below 5 ppm. Have equipment on hand to determine when the concentration falls below 5 ppm (0.02g / m3) for re-entry into the facility.

Recirculation often is required with methyl bromide. Generally, circulation is not difficult and can be eased with existing fans or additional small, portable fans. Recirculating methyl bromide often requires significant air movement, compared to “closed loop” phosphine fumigation. Using the bin fan(s) means that circulation may be completed in a few minutes to an hour. Leave fans on until the fumigant has cycled approximately three times through the return ductwork. Determine the time by how long it takes to detect the gas passing through the grain mass once. For example, if it takes 12 minutes to detect the gas, then leave fans running for 24 more minutes for a total of 36 minutes.

Fumigation of railcars and trucks that carry grain can’t be done with methyl bromide unless the vehicle is stationary. Fumigation in transit is not allowed because of the difficulty in holding the gas when air is moving over the vehicle. Again, an advantage of methyl bromide is that the fumigation of the standing vehicle can be done in 24 hours or less so that demurrage is minimal. Often, railcars and truck trailers are so leaky that the only way to obtain a successful fumigation is to tarp the entire vehicle for fumigation.

Another advantage to using methyl bromide is that it won't harm electronic equipment and wiring. But at high doses and under certain conditions, it can harm seed germination. If rodents are the target, only one-fourth pound per 1,000 cubic feet is required for 12 to 24 hours. Phosphine and chloropicrin also kill rodents. This amount won't harm seed germination. Avoid higher rates of methyl bromide (for insects) for more than 24 hours at warm (85+ degrees F) temperatures and high moisture (12+ percent) for seeds. One disadvantage in using methyl bromide is that you shouldn't use it with certain materials. It imparts an odor to objects containing sulfur compound s, such as vulcanized rubber, feathers, hair, furs, woolens, full fat soy flour, sponge rubber, foam rubber, viscose rayons, photographic paper and cinder blocks.

Methyl bromide does require less time than phosphine to kill insects. Although phosphine requires from three to 10 days, depending on the temperature, methyl bromide exposure times usually range from a few hours to one day. This short exposure often is advantageous in treating commodities with quick turnover times in the marketing channel. When fumigating with methyl bromide at low temperatures (<60 degrees F), keep the exposure time constant and the dosage increased, although when fumigating with phosphine, keep the dosage the same and the exposure time lengthened.

Resistance

Concern has spread to the United States about resistance of stored-grain insects. The widespread and sometimes frequent use of phosphine-generating fumigants, especially when used improperly, can lead to resistance. Part of a plan to avoid or delay resistance is occasionally alternating fumigants. Of course, excellent fumigation technique that results in 100-percent kill prevents survival of insects that can lea d to the development of resistant populations. The major factor that contributes to the development of resistance to either phosphine or methyl bromide is poor sealing of fumigation facilities. Poor sealing results in insect exposure to sublethal doses of fumigant, which causes resistance through selection pressure. Poor sealing also is the most common cause of fumigation failures.

Safety

Safety is important when fumigating with methyl bromide or phosphine. For methyl bromide, wear loose clothing to avoid trapping the gas. Also, remove jewelry, watches, adhesive bandages or any article that may trap the fumigant when applying methyl bromide. Burns can result if a high concentration of vapors or liquid methyl bromide is trapped next to the skin. Wear a full-face shield when opening cans or cylinders to prevent fumigant injury. If phosphine levels are unknown du ring application or aeration, wear a self-contained breathing apparatus (SBCA). Don't allow anyone in the area until the gas concentration is below 5 ppm. Wear gloves when applying phosphine to keep the dust of the formulation off damp skin. However, when applying methyl bromide, do NOT wear gloves because they can trap liquid fumigant against the skin and cause burns. When applying or aerating either phosphine or methyl bromide, use gas detection devices to deter- mine whether or not the threshold limit value (TLV) is exceeded and respiratory protection is necessary.

Fumigation effectiveness

Understanding how fumigants react in commodities is an essential step in developing the knowledge to use fumigants effectively and safely.

Sorption. When a fumigant gas attaches itself to the surface of a commodity particle or kernel or penetrates into the kernel, it slows movement through the grain mass and disrupts penetration of the fumigant through the commodity mass. However, some **sorption** must occur if the fumigant is to reach all stages of pest insects, especially those that develop within the kernel. When sorbed into a kernel, some fumigants react with materials in the commodity to form other chemical compounds that may be permanent and form residues. Methyl bromide particularly is vulnerable to this type of chemical react ion. When this react ion takes place, the methyl group attaches to some molecules in the commodity while the bromine atom is released as bromide ion. Some of the intact methyl bromide molecules also remain in the commodity until they either react or are desorbed by diffusing out of the commodity. Thus, the amount of methyl bromide inside commodities is related to the amount of aeration that has taken place and the reaction rate with components of the commodity. This has required the establishment of residue limits or tolerances for the amount of bromide per mitted in grain and other commodities. Each time a commodity is fumigated with methyl bromide, it accumulates more bromide as residue. Therefore, be careful not to fumigate commodities more than necessary because eventually the residues of bromide may exceed the tolerance limit.

Residues of phosphine tend to be low compared to those resulting from methyl bromide fumigation. Phosphine react s to form phosphate, which is a natural component of living organisms. Furthermore, the amount of phosphate added by phosphine fumigation is negligible compared with the amount naturally occurring in living tissue. Therefore, tolerance for residues resulting from phosphine fumigation is measured as phosphine. Because the phosphine molecule is small and diffuses even faster than methyl bromide, residues of phosphine disappear from grain quickly after aeration begins. Residues of phosphine are measured in parts- per-billion (ppb) while those of methyl bromide are measured in quantities 10 times larger, namely parts-per-million (ppm).

Temperature. Temperature influences fumigation distribution in grain and affects its ability to kill insects. Temperature also influences the rate of phosphine and methyl bromide release and movement after application. Because for every 10-degree rise in temperature a reaction will double, it is easy to see how the temperature increases or decreases the reaction that releases phosphine from the formulation. At temperatures below 40 degrees F, activity of the fumigant molecule is reduced significantly, sorption of fumigant vapors into grain kernels increases and distribution is less uniform throughout the grain mass. At colder temperatures, gases move more slowly and insects breathe less. Thus, it takes longer for the fumigant vapors to reach insects in the grain, less gas is available for controlling the pests and, because 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, thus requiring prolonged ventilation periods.

Moisture. The moisture content of the stored-product environment also influences the penetration of fumigant gases by altering the rate of sorption. In general, high-moisture commodities require an increased dosage or an extended exposure to compensate for the reduced penetration and increased sorption. However, as previously mentioned, adequate moisture is necessary for the generation of phosphine from solid formulations. Although most grain that supports insect development contains sufficient moisture to start the chemical react ion, dry grain (less than 10-percent moisture) extends the time required for solid fumigant decomposition.

Grain type and condition. Various grains have different characteristics that can affect fumigations. The surface area of individual grain kernels is a factor influencing the dosage required to treat various commodities. For example, because of its smaller size and more spherical shape, sorghum has higher total surface area than wheat. Increased surface means greater sorption loss, which reduces the amount of fumigant left in the space between the grain kernels and further reduces the amount of fumigant available to penetrate the grain. To compensate for this increased loss, dose in higher rates in sorghum than in wheat, particularly when you use fumigants that are easily sorbed by the grain. The makeup of the outside coat on grain may change the sorption of the fumigant into the kernel.

Type and amount of dockage in grain. The type and amount of dockage in grain has a pronounced effect on the sorption, distribution of fumigants and potential failures. When the grain mass contains large amounts of dockage, such as crust, chaff or broken kernels, this material rapidly sorbs the fumigant vapors and impairs further penetration into the grain. You'll usually find dockage in the center of grain during storage because of the way facilities are filled. Unfortunately, these areas, such as the top center and the center of the grain mass, frequently are sites that attract the greatest number of insects. When isolated "pockets" of dockage occur within a grain mass, fumigant vapors may pass around such pockets and intergranular area of the grain. Sometimes probing phosphine formulation down into the center of the grain mass helps the gas better penetrate these areas where dockage pockets frequently occur. Fumigant distribution patterns may be affected adversely in grain that has settled or compacted unevenly during long storage periods or in storage vibrated by nearby traffic and railroads.

Insects. In the various developmental stages (egg, larva, pupa and adult), stored-product pests differ in their susceptibility and resistance to fumigants. Beetles and other insects that develop outside grain kernels usually are more susceptible to fumigants than certain moth and beetle species that develop inside grain kernels. The pupae and eggs that respire very little are the most difficult to kill, although the young larvae are relatively susceptible because they are active and heavily respiring.

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

Structure. A fumigant, whether applied initially as a gas, liquid or solid, eventually moves through space, penetrates the commodity and enters the insect in the form of a gas. The gastightness of the storage facility or grain bin greatly influences the retention of the fumigant. Metal bins with caulked or welded seams or concrete bins still lose some gas, but they generally are better suited for fumigation than loosely constructed wooden bins.

The size and shape of the storage structure affect both distribution and retention of fumigants. The height of a structure often deter mines the type of fumigant used and method of application. When grain depths exceed 40 feet, you may use special forced distribution techniques using circulation equipment or other methods to get satisfactory control.

Wind and heat expansion are major factors influencing gas loss. Winds around a structure create pressure gradients across its surface, resulting in rapid loss of fumigant concentrations on the surface and on the downwind side of the storage. The expansion of headspace air from solar heating of roofs and walls followed by nighttime cooling can result in a "pumping" of the fumigant from the bin. Large flat storage that contain more surface than grain depth are particularly susceptible to gas loss from wind and heat expansion. The greatest gas loss frequently occurs at the surface and in the headspace above the surface — a location that often contains the highest insect populations. Furthermore, when the grain surface is uneven, with large peaks and valleys, fumigant distribution through the grain also will be uneven. You must seal air access points, such as roof vents, grain surface, aeration fans and exhausters.

Dosage and exposure time. Because fumigants act in the gaseous state, the dosage necessary to kill an insect is related to the temperature, the concentration of gas surrounding the insect, the insect's respiration rate and the length of time an insect is exposed to that fumigant concentration. A general relationship for most fumigants exists between con- centration and time. High concentrations require shorter exposure time to achieve com parable kill. In phosphine fumigations, the length of time exposed often is more important than the concentration of gas. This is du e, in part, to the fact that the rate of phosphine up take by insects is somewhat time- dependent.

Variations in recommended dosages generally are based on sorption differences of commodities and the relative gastightness of storage structures. For example, dosage requirements for wooden bins are higher than those for steel or concrete bins. Because phosphine is less affected by sorption loss in various commodities, application rates for most commodities are virtually the same and depend primarily on the type of storage structure being treated and its gastightness. This contrasts with methyl bromide, where rates vary with commodity because of sorption differences between commodities.

Small-bin fumigation with aluminum phosphide

Most round bins usually found on farms can be fumigated safely and efficiently by two trained people. The process for fumigating typical round farm bins with phosphine is as follows:

Lay out all equipment you need to carry into the bin. Upon entering the bin, work without interruption. Take the following items inside the bin to complete the fumigation: probes for tablets 1.5 inch in diameter and for pellets 1 inch in diameter (see Figure 3); cotton gloves; fumigant sufficient to complete the job; tape for marking bin quad rants; measuring cup if you're using pellets; plastic, 4-6 mil, pre-cut to overlap at least a foot on all sides; rope, a piece long enough to extend through the hatch door from each sheet of plastic; an approved gas mask; self-contained breathing apparatus or canisters; and detection equipment.

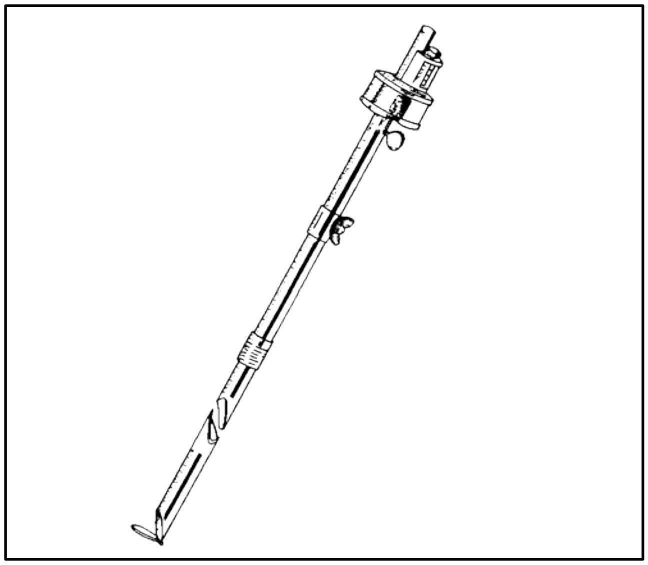

Figure 3. Commercial probe for applying aluminum phosphide.

You are responsible for reading and following the fumigant label. An instruction manual, which can provide more detailed information, is available from suppliers.

Determine the target pest. Determine the volume to be treated. Remember that aluminum phosphide gas is 1.21 times heavier than air (for all practical purposes, consider hydrogen phosphide to be equal in weight to air). As the gas fills the volume of the bin, it does not differentiate between grain mass and bin headspace.

Fumigation — Do not open the bin top and scatter fumigant on the surface. This is a common misuse of phosphine that results in a failed attempt to eliminate pests. The following steps explain how you can success fully fumigate a grain bin:

1. Always use at least two people to fumigate. Never fumigate alone!

2. Outside the bin, pre-cut a piece of poly sheeting to fit over the surface of the grain. Use the bin as a template to measure the poly, and allow for extra poly to tuck around the edges of the grain and for grain peaks (the grain should not have a peak).

3. You should be in the bin for a maximum of 15 minutes because the headspace of the bin can reach a temperature of 140 degrees F. Take precautions to protect against heat exhaustion.

4. One person should pull the poly sheeting to the farthest end of the bin and secure it by tucking it down in between the grain and the metal side walls.

5. The other person should probe the phosphine tablets or pellets on five-foot centers by starting at the farthest point from the escape hatch and working toward the ladder. Probe about 10 to 20 tablets or 50 to 100 pellets per probe. Push the probe in as fast as possible.

6. Open canisters outside of the bin.

7. Using detection equipment, take a gas reading if you suspect that the gas concentration level is approaching 0.1 ppm. If you detect a gas level of 0.3 ppm, wear a gas mask in the bin (everyone in the bin must wear one).

8. After you make the last probe, pull the poly sheeting toward the bin opening and secure it with a piece of cord or rope. Extend the cord out of the bin entry, and then seal the hatch. This allows for the removal of the poly without anyone having to climb into the bin after the fumigation is complete.

9. To finish the fumigation, place the fumigant into the aeration fans and cover the ends of the fans with 4 mil poly. The fans must be stopped during the entire fumigation. **Note:** Make sure the aeration duct is dry before adding phosphine fumigant.

10. Place **placard** signs on all doors and near ladders. Place signs where they will be visible to youths as well as adults.

11. Lock the bin securely after adding the gas. Double-check all possible entrances.

12. Spray the bin's perimeter at ground level with an approved insecticide. This helps prevent reinfestation. Also remove weeds and any obsolete equipment.

13. Following the fumigation, remove the poly sheeting from the surface of the grain and the aeration fans. The sheeting can be reused. Always remove placard signs after the gas has been monitored properly.

14. After you've vented the gas, no residual effect exists. This is why it is best to apply an approved protectant to the surface of the commodity after the fumigation.

Fumigating a flat storage of grain with phosphine fumigant

Fumigating flat storage is a physical, difficult, potentially dangerous, labor-intensive and hot job. The following directions outline the proper method of fumigating with phosphine to kill all stages of insect life:

Fumigant — Tablets are preferred over pellets. Tablets take one to two days longer to break down than pellets.

Labor — Use enough people to complete the job rapidly and easily. Walking in grain for 30 to 45 minutes in a zigzag manner is hard, physical work. Heat exhaustion is a hazard, along with working with a poisonous gas.

Dosage — Follow label instructions for flat storage and the type of formulation to be used.

You need the following materials to fumigate a 100,000 -bushel flat storage: phosphine-producing formulation; one PVC pipe (4 to 5 feet long) per fumigator; duffel bag (to carry the fumigant); approved respiratory equipment; gas-detection equipment; plenty of drinking water; 4 mil poly sheeting; masking tape; strapping tape; phosphine warning signs; and locks and chains for doors.

The following are steps to fumigating a flat storage of grain:

1. Leave all vents and end doors open.

2. At least two people should climb onto the roof and cover the roof vents with 4 mil poly sheeting or poly bags. Use strapping tape to secure the poly over the roof vents. Cut off any excess poly; otherwise, the wind will work it loose.

3. Seal the remaining doors and vents and any openings necessary to retain the gas.

4. One person (or more) should lag behind the probers and gather empty flasks and caps. Discard containers in duffel bags that are carried along.

5. Use two or more people to probe, depending on the size of the flat.

6. Check the gas concentration from time to time with a gas-detection device. If the concentration reaches 0.3 ppm, you must wear a gas mask.

7. After getting to the opposite end of the flat storage, exit and take a rest! Drink liquids and check each person for symptoms of heat exhaustion and poisoning. Heat exhaustion and heat strokes can be serious. Proper equipment can protect workers from the gas; common sense is the only protection from the heat.

8. Apply 150 to 250 pellets or 30 to 50 tablets into each aeration fan. The fumigant placed in the aeration system should penetrate the bottom five to 10 feet of the bin. **Note:** On larger flats, the vent duct is not perforated until 15 to 25 feet into the flat storage.

9. Lock all doors and place properly labeled warning signs on all four sides of the fumigated flat storage buildings. Allow the building to stay under gas for the full amount of time recommended on the label. The duration of the fumigation varies according to the temperature. Ventilate the bin until detection equipment shows that gas concentration is below 0.3 ppm.

Fumigating large metal grain bins and silos with phosphine

Fumigating large metal grain bins with phosphine is much easier than fumigating flat storage or small grain bins. The information in this section applies to bins that range from 25,000 to 250,000 bushels, with diameters of 36 to 50 feet. Any storage larger than this will require a different fumigation technique. The following materials are needed to fumigate large bins: phosphine-producing formulation; a watch; 4 mil poly sheeting; respiratory and detection equipment; masking and strapping tape; warning signs; and locks.

The best method is to fill an empty bin while intermittently metering in phosphine as the grain is loaded. If the grain in a bin is infested already and cannot be transferred to an empty bin, follow the following procedures:

1. Start with an inverted cone on the grain surface.
2. Probe the outer ring of the bin (along the wall) with a small portion of the dosage rate.
3. Pull the core out of the bin and turn it around on top of the inverted cone.
4. While rotating the core, periodically place phosphine in the top of the transfer system, preferably near the bin being fumigated. Avoid placing the fumigant in the bottom portion of the transfer system.

Warning: If phosphine is administered into the dump or bottom of the transfer system, the pellets / tablets can become lodged in voids and emit gas into the tunnel or other areas that can be occupied.

5. It is not necessary to turn the entire bin to effectively use solid fumigant. However, you need to pull down the center of the bin and rotate it so that the pellets/ tablets will be pulled to the bottom (within 20 to 30 feet of the bottom).
6. Three-fourths of the entire dosage rate goes into the core.
7. Find out the turning speed of the leg that transfers the grain (measured in bushels per hour).
8. Several ways exist to determine when the fumigant has been pulled to the bottom or near the bottom:
   - Take gas readings at the bottom of the grain-transfer system while applying the gas at the top of the bin.
   - Place a large amount of confetti or Ping-Pong balls in the bottom of the inverted cone, and start the coring process. When these materials exit the bin, they will quickly surface in the lower transfer system. Take careful notes on the exact time it takes to turn the bin.
9. How far will phosphine gas travel? A good rule to follow is 25 to 30 feet in any direction. Remember that phosphine is about the same weight as air.
10. If you've used the confetti/ ping-pong-ball method to determine the exact coring time, divide the length of time by the number of flasks required to fumigate the bin. The sum of these figures will provide the number of minutes between the dispensing of each flask.

For example:

TT ÷ NF = X
TT = Turning time
NF = Number of flasks being added to the core
X = Lapsed time between dispensing each flask

Note: If the coring time and time dose are unknown, use your best judgment. In most cases, if you have a center draw and a center drop, and you start with an inverted core, it usually takes 20 to 45 minutes to core the average-sized silo. For help in determining estimated rotation time, call a professional fumigator.

11. After everything is turned off, hold back a small portion of fumigant to be administered through the manway without entering the bin. Most gas is lost through leaks in the headspace. The additional gas compensates for this loss.
12. If the roof vents can be covered safely with poly tape, do so. Occasionally, this can be dangerous, and you must take other measures. One way to seal hard-to-reach vents is to seal them from the inside of the bin prior to administering the gas. If the grain level is down, use a ladder inside the bin. Thorough sealing is important, but it is not worth risking a life.
13. Consult the phosphine label to determine the required duration of the fumigation, according to the ambient temperature of the commodity.
14. Lock and secure the bin. Place proper warning signs on all entryways and ladders. Write the name of the bin's fumigant on chalkboards and bin charts in controller rooms and scale houses. Make sure every employee knows that the storage is under gas and the **hazards** involved with fumigation.
15. Aerate the bin until gas- detection equipment shows that gas levels are below 0.3 ppm.
16. Grain insects can immediately re-enter the bin after fumigation. Fumigants do not have any residual effect, so it is best to apply a top dress grain protectant to combat any reoccurrence.

Applying aluminum phosphide to a grain stream

You can use commercially available automatic dispensers to meter the application of pellets or tablets to moving grain carried by augers, conveyor belts or bucket elevators. The main benefit of applying aluminum phosphide to a moving grain stream is that it allows a uniform pellet or tablet distribution within the grain mass as the storage fills. This application method does not require that workers enter the actual fumigation atmosphere, and you avoid the difficulties associated with probing aluminum phosphide into the grain mass. It is not mandatory that two trained applicators be present when aluminum phosphide is applied without entering a confined space. Applying aluminum phosphide to a moving grain stream in non-contained or open-air spaces requires only one certified applicator.

Problems that complicate this type of application are related to gas release and escape during the filling process. Gas evolution from tablets normally begins within two hours and from pellets within one hour (sometimes faster) of application. Some gas escapes from the storage as grain is continuously added because (obviously) the storage is not sealed during filling. This problem may be insignificant where bins or tanks can be filled continuously and rapidly, but where filling is interrupted, gas escape means insufficient concentrations near the top of the grain mass. When you meter aluminum phosphide into the grain stream, it is important to monitor gas concentrations in confined work areas where hydro- gen phosphide may accumulate.

Most insect infestations that must be managed by fumigation involve grain that cannot be moved from one bin to another to allow metered application of aluminum phosphide. In these instances, probing tablets or pellets into the grain mass usually is necessary. Sprinkling pellets or tablets onto the grain surface or raking them into the top layer of grain won't provide adequate fumigation.

Applying methyl bromide to stored grain

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

When you use methyl bromide to fumigate enclosed spaces such as grain-storage facilities, two trained persons must be present at all times when worker exposure exceeds 5 ppm. Avoid wearing tight clothing, jewelry, gloves and boots. Methyl bromide may be trapped next to the body under these articles of clothing and cause severe injury to skin. Remove any contaminated clothing or boots and do not reuse until they are thoroughly cleaned and aerated. At any time when full-face respiratory protection is not required, 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 gas-detector tube and pump (from Draeger, Kitagawa, MSA or Sensidyne), does not exceed 5 parts per million, you don't need respiratory protection. If this concentration is exceeded at any time, everyone in the fumigation area must wear a NIOSH / MSHA-approved 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 methyl bromide application for control of insects in stored grain, take the following steps:

1. Thoroughly seal the storage, using tape for small openings and polyethylene sheeting secured with tape for large openings. Unsealed openings allow methyl bromide to escape du ring the recirculation application. Fumigant leaks reduce the effectiveness of the fumigation and present safety concerns around the storage.

2. 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. Anyone who transfers a treated commodity to another site is placarded until the commodity is aerated sufficiently to reduce methyl bromide concentration to below 5 ppm. Only a certified applicator may remove the placards and only after one or more gas readings have indicated that the methyl bromide concentration is below 5 ppm.

3. Apply methyl bromide 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 you can use the aeration system to force air through the grain mass and collect and recirculate that air back through the aeration fans. You can discharge methyl bromide into the duct system or into the storage headspace.

4. For most stored grains, methyl bromide recirculation should continue for 24 hours; check label directions for fumigation periods of specific commodities. This period of 24 hours or less is one benefit associated with methyl bromide fumigation. Under most conditions, other fumigants require an exposure period of 72 hours or longer. During the application period, it is important to use gas-detector tubes to check for methyl bromide leaks around the treated storage; leaks reduce fumigation success and may cause health hazards in the work area.

5. Once the fumigation period ends, aerate storage. To aerate, disconnect the return air flow from the recirculation system so exhaust air discharges out- side the storage. Continue aeration until gas-detection devices show methyl bromide levels have

dropped below 5 ppm. Take multiple readings in the elevator headspace, access pits and other areas to detect any pockets of methyl bromide gas.

6. As mentioned above, once fumigated grain is aerated, it is susceptible to reinfestation. Surface top-dress applications of protectant insecticides help limit reinfestation.

Don’t apply methyl bromide if the grain temperature is less than 40 degrees F, except in cold-storage fumigations specified in APHIS quarantine programs. Methyl bromide will retard or destroy the germination potential of seeds in many fumigation conditions. For grain to be used for seed, alternatives to methyl bromide fumigation usually are recommended.

Vacuum chamber fumigation

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 by 6 feet by 8 feet. Frequently they are equipped with fans or recirculating systems. By using a vacuum, you can reduce the fumigation time from 12 to 24 hours to 1.5 to 4.5 hours. The vacuum both denies the insect oxygen and allows the fumigant to rapidly penetrate the commodity. By adding an air-wash cycle (breaking the vacuum and drawing a second vacuum), aeration also is rapid. Vacuum fumigation chambers usually are found at port facilities and near large warehousing operations. Ethylene oxide-carbon dioxide mixture and methyl bromide are used most frequently in these facilities. Aluminum phosphide cannot be used as phosphine and is explosive under vacuum conditions and high phosphine concentrations.

Two main methods exist for conducting vacuum fumigation: sustained-vacuum fumigation and nearly complete pressure restoration. 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 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 fumigant discharge, 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 used widely 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, carry out air-washing. It consists of removing the fumigant/ air mixture and then pumping the chamber several times until it is considered safe to open the door for unloading. The effectiveness of the different methods is in the order presented.

The disadvantages of vacuum fumigation include: 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 that cannot withstand reduced pressure. The amount of fumigant dosage required usually is two or three times greater than at atmospheric pressure.

Atmospheric vaults or fumigation chambers

Usually, small buildings are 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, you can use it again and again. You can monitor gas concentrations through a permanent arrangement. Commodities are easily moved in and out of the vault without special preparation. You don’t have to compute the cube of the structure each time you fumigate. Special preparation of the commodity, such as padding corners, is not necessary. You can use almost any fumigant. Although you must take safety precautions, 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 use of the facility.

Trucks (stationary) and freight cars (stationary or in transit)

Stationary trucks and freight cars also are examples of “vault” fumigation. These vehicles must be well constructed and in good repair. If they are not, make them airtight or place a tarp over the entire vehicle so 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.

Fumigating wheeled carriers often is convenient and economical in both time and labor because you avoid 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. Fumigating incoming loads prevents the introduction of pests into clean areas.

Shipboard fumigation

Ship fumigations also are examples of vault fumigation but are highly specialized. You may need to treat products needing fumigation before you unload them. The extent of the area to be fumigated depends on the amount of cargo involved. Determine size and depth of space to be fumigated and cargo present. If proper provision is made, any full cargo space can be fumigated. Seal off all piping, bilge openings, ventilator openings and hatches. 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, the National Pest Control Association has prepared a technical release. Study *Good Practices in Ship Fumigation* prior to undertaking any ship fumigation.

Close cooperation with the responsible ship's officer, ship's agent and USDA inspector (if involved) is essential. Notify the Port Authority, fire and police departments, and arrange for guards, if necessary. If most of the cargo space is fumigated, account for the entire crew and evacuate the crew while fumigating. Allow no one to return until the ship is clear of fumigant and given a "Gas Free" certificate.

Building fumigation

This essentially is a modification of vault fumigation. The entire structure becomes a fumigation vault. If you use this method, you only need to move those building contents that would be damaged by the fumigant. You'll usually get incidental control of non-target pests. You need less material to make the structure airtight, but this advantage usually is offset by the labor required to find and seal gas leaks. It's usually easy to aerate the building. Usually, you won't have to move exterior shrubbery. Disadvantages do exist, however. Occupants must be moved from the structure, and items that may be damaged by the fumigant must be moved as well. Because 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 because the gas concentration may be too low to be effective. Run gas-concentration test leads throughout the structure. It may be difficult to compute the cube of the structure. It is easy to overlook vents, cracks, conduits, etc., that may permit gas to escape. In the past, NCH was the fumigant most commonly used in this type of fumigation.

Premises inspection. Once it app ears that fumigation will be required to control a pest problem, conduct a serious on-site inspection. Frequently, the success or failure of the fumigation depends upon what you learn, decisions you make and how well you plan the operation. Some questions of concern include:

- If the structure itself is not infested, could the infested items or commodity be moved from the building and fumigated elsewhere?
- Assuming that removal of the infested items from the building is not practical, can they be fumigated in place?
- Is there enough room between the commodity and walls or partitions so you can seal the tarp to the floor?
- What is the volume of the commodity?
- Can you make the structure itself reasonably air-tight, or will you need 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 require sealing?

A number of fumigations have failed because floor drains under stacked commodities went unnoticed. In one instance, the fumigant leaked into a telephone cable tunnel that led to an occupied building. No one died, but a number of people got sick.

- How will the air conditioning ducts and ventilation fans be handled? Are there fireplaces, flues, stove pipes?
- Will interior partitions interfere with fumigant circulation?
- Are the interior partitions gas tight so 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 the customer? Can you shut down these other operations during the fumigation?
- What are the building contents? Can any of them be damaged by the fumigant? Can such items be removed during the fumigation? If you cannot remove them, can you protect them?
- Where are the gas cutoffs? Where are the pilot lights? Where are the electrical outlets? Of what voltage are they? Will the circuits be live during fumigation? Can the outlets be used to operate the fumigant circulating fans?
- Inspect the outside of the building. If the entire structure is tarped, will there be a good, tight ground seal?
- Is there shrubbery next to the building that might be damaged either by the fumigant or by digging to make an airtight fumigation seal? Can this shrubbery be moved?
- How far is it to the nearest building? Does that building have air conditioning? Does it have air intakes that could draw the fumigant inside,

particularly during aeration?

- How will the structure be aerated following the 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 provisions be made for interrupting the fumigation and aerating the building within a certain time requirement?
- Is the structure to be fumigated located so that the operation may attract bystanders? If so, police assistance may be necessary.
- Where is the nearest medical facility? What is the telephone number of the nearest poison control center?

Once you have covered everything, prepare a checklist for the things to do and the materials needed. Finally, two more questions:

- Has anything been overlooked?
- Is fumigation still the best alternative for controlling the pest problem?

Tarpaulin fumigation

Tarpaulin fumigation involves the placement of a gas-tight 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. You can use impregnated nylon tarps again and again because they are strong and resist ripping. Many sections of impregnated nylon tarps can be clamped together, so there is no limit to the size of the stack or structure that may be covered. You can use polyethylene tarps in thicknesses from 1.5 mil up to 6 mil. Use the thinner material only once and for indoor work. Four and 6 mil material can be used outdoors, and with some luck, the 6 mil material can be reused. Because clear polyethylene breaks down in sunlight, use black polyethylene films outdoors. It is normal to use gas-impervious adhesive tape instead of clamps to join various sections of polyethylene film. In addition to considering the material to use for tarpaulin fumigation, consider the method of obtaining a ground seal. If they are smooth, concrete and asphalt surfaces are satisfactory. Wood surfaces are not. With wood, and frequently with soil surfaces, you'll need to place a section of the tarp material beneath the stack as well as over it.

You can get a good ground seal through several methods. Of course, allow enough tarp material to skirt out from the stack. This should extend outward at least 18 inches. Then use loose sand, sand snakes or water snakes to hold the skirt to the ground. Snakes are merely tubes of cloth or plastic filled about three-fourths full of sand or water. Don't fill them too full or there won't be enough ground contact to make a good seal. Be careful with water snakes in the event that the floor is not level. Water will run to one end, and the seal will be poor. The snakes should overlap each other about 1.5 feet. Sometimes it may be easier to use adhesive tape and make a direct seal to the floor. In this case, you don't need snakes. Occasionally, you may place a stack too close to a wall to get a good ground seal. If the wall is reasonably impervious, seal the tarp directly to the wall.

Indoor tarpaulin fumigation

If you determine that a stack of items is infested and requires fumigation, 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, then move the commodity to another indoor location rather than fumigating outdoors. Determine this during your first inspection of the structure. Place the commodity to be fumigated on pallets. With most fumigants, it will be necessary to keep all people not connected with the fumigation operation out of the fumigation area. If partition walls are not impervious to the fumigant, evacuate the entire building.

If you use aluminum phosphide, restrictions are not as rigid. After aluminum phosphide is introduced, work can continue in the area as long as there is no fumigant leakage. Of course, post warning signs on the stack. If you use any fumigant except aluminum phosphide, erect tarp supports that are 1 to 2 feet higher than the commodity. This is to make certain there will be adequate gas circulation during the initial stages of fumigation. Then, secure the gas-introduction tubes to the top of one of the supports. Place a pan or other device beneath the gas-introduction tube outlet to protect the commodity from any liquid fumigant.

Next, make sure all of the corners are well padded to prevent the tarp from tearing. The lighter the polyethylene tarp, the more chance for it to tear. If the stack is large, place non-springing fans so gas circulation is assured. Run these fans for one-half to 1 hour after introducing the fumigant. 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 the gas concentration will be sampled. After you've done all of this, place the tarp and seal it to the floor. Because of the molecular activity of hydrogen phosphide, the air dome and tubing, fans are not necessary if you are using aluminum phosphide. Of course, you'll have to determine the cubic area of the space beneath the tarp so you can calculate the amount of fumigant to be used.

Outdoor tarpaulin fumigation

The same principles as stated above apply to fumigation outdoors. The difference is that the fumigation tarpaulin must be of a stronger material. If you use polyethylene film, it must be at least 4 mil thick. Six mil material is better. Clear polyethylene tends to become brittle from ultraviolet rays of the sun. If you plan to keep the polyethylene in place after completing the fumigation, or if you plan to reuse the tarp, consider using black polyethylene. 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, or other voids, 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 get a good ground seal outdoors. It may be necessary to place a layer of loose sand on the skirt to get any sort of a goo d seal. Additionally, take steps to protect against unanticipated adverse weather; if you know that storms are in the forecast, delay fumigation. Place braces over the stack (but under the tarp) so 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, make workers aware of void locations between stacks because black polyethylene is not transparent.

Entire structure tarpaulin fumigation

This type of tarpaulin fumigation normally is reserved for the control of dry-wood termites or wood-boring beetles. The fumigants normally used are sulfuryl fluoride (Vikane) or methyl bromide.

Remove items that could be damaged by the fumigant. Evacuate building occupants for the entire fumigation and aeration period. Turn off all pilot lights, flames and electrical appliances. Place tubing for drawing air samples at several places within the structure. Introduce the fumigant into the structure at several locations. Place non-sparking electric fans so the fumigant will be circulated throughout the structure for one-half to 1 hour after introducing the fumigant.

If methyl bromide is used, it should be the formulation containing 2 percent chloropicrin. If sulfuryl fluoride is used, introduce chloropicrin into the structure 15 minutes before you introduce the sulfuryl fluoride. To introduce the chloropicrin, take 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 1 ounce of chloropicrin for each 10,000 -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, move the vegetation. Pad all edges of the structure that could puncture or tear the tarpaulin. For workers to be safe, they should wear shoes with nonskid surfaces, and all ladders should be strong and braced. Tarp sections then may be carried to the roof-top for further assembly. If you use impregnated nylon as the tarp material, join sections with special fumigation clamps. Roll together and clamp the edges of adjacent tarp sections. You may use clamps with polyethylene, but adhesive polyethylene tape may be better.

Once enough sections have been joined, drop the completed tarp over the side of the structure and complete any additional clamping or taping. If the building top is flat, use sand snakes to hold down the tarp. If the roof is peaked, throw weighted ropes over the tarp to prevent the tarp from billowing. Excessive billowing of the tarp can ruin a fumigation job, so take all possible measures to prevent this from occurring. Draw the tarp as close to the building as possible. If you place a high-capacity electric fan in one doorway and direct it outward, you'll create a partial vacuum, which 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 important. The ground should be level and devoid of vegetation. If the soil is porous, soak the soil around the perimeter of the building with water to prevent the fumigant from escaping through the soil. The tarp skirt must be at least 24 inches and weighted down by an ample amount of loose sand. If you use sand snakes, they should be doubled or tripled. The ground seal must be weighted enough to withstand any unexpected wind.

Spot or local fumigation

Fumigants, both spot and local, are used in many flour mills, mix plants and some packaging operations to prevent 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)

Make preparations before shutting down the plant. In the mills, cut the feed and allow the mill to run for a length of time to remove as much stock as possible. During this period, use rubber mallets to tap on spouting, elevator legs and sifters to loosen as much residual stock as possible. Check outlet channels in sifters at this time to be sure that none are blocked or choked. Do not clean out boot and other machinery containing static stock prior to the fumigation.

Place a notice on the plant bulletin board a few days before 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, seal all dust-collector vents with polyethylene sheeting or large plastic bags. On pneumatic mills, or where filters are used, locate a damper or a series of slide valves in the air-discharge system. Close dust collectors and filter vents to contain the fumigant within the machinery. Thermal currents and drafts can make fumigation a total failure because vapors may be discharged to the atmosphere before reaching a lethal concentration.

Close and seal all windows, close the fire doors between floors and close and seal all outside doors. Place warning signs on each exterior entry door. Doors that can be opened only from the inside must be fastened securely or locked. Local codes may require that you notify fire and police departments as well as any alarm services. Some labels now require a guard be posted.

When it is necessary during the winter months to check the operation of the boilers, use the outside entrance to the boiler room rather than a section of the plant under fumigation. Place warning signs on the doors that connect the boiler room to the plant.

The length of exposure time is important for an effective fumigation. Follow the label instructions on the 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 and opens the necessary windows and dust-collector vents to allow any remaining fumigant vapors to dissipate. Then, remove the warning signs from the exterior doors. Start exhaust fans. Do not clean the mill machinery prior to start-up.

Closed-loop fumigation systems

(From: Noyes, R. T., et al., Closed Loop Fumigation Systems in *Stored Product Management*, Oklahoma Cooperative Extension Service, Publication No. E-912)

Closed-loop fumigation (CLF) originally was developed as a recirculation process for methyl bromide fumigation in the United States and other major grain-producing countries. CLF uses low-pressure, low-volume centrifugal blowers to draw fumigant/air mixtures through pipes from the headspace and push the gas into the base of structures, forcing it to flow upward through the grain to the headspace in a closed-loop cycle. CLF offers an alternative to traditional probe-and-tarp fumigation of round and flat steel storage structures or fumigating concrete silos as grain is turned. CLF systems have been installed and teste d in grain-storage structures at several mid-west locations in the late 1980s. CLF reduces worker chemical exposure and improves fumigant distribution and efficacy, thus reducing the incidence of fumigation failures. CLF also reduces housekeeping while improving elevator facility safety. The cost of fumigant typically is reduced from 25 to 50 percent through CLF's efficient application technology.

CLF fumigation procedures — sealing structures. Sealing bin or silo openings is of primary importance in a successful CLF system operation (see Figure 4). Phosphine concentration levels of 100 to 150 ppm are needed for at least 72 hours to penetrate kernels and kill insect eggs and larvae. Welded steel and concrete tanks usually are sealed tighter than bolted steel tanks, unless bolted tanks were well-caulked during construction.

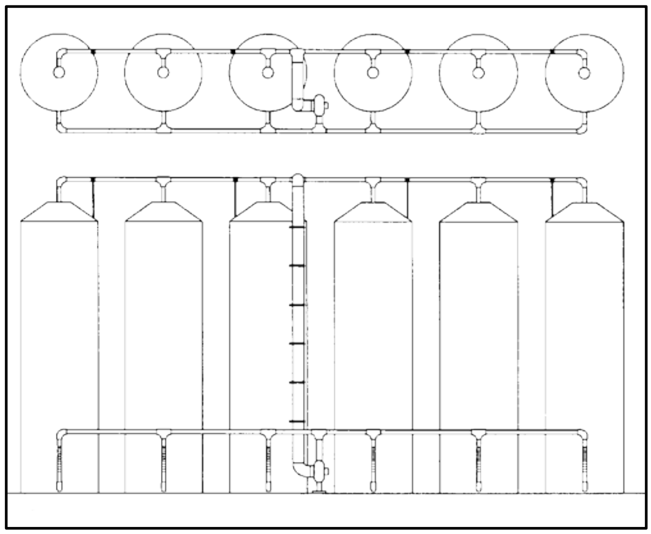

Figure 4. Concrete silos manifolded together using one CLF blower and one vertical pipe.

Critical sealing areas in corrugated steel tanks are roof to sidewall air gaps, mid-roof panel overlaps and exposed spaces between roof panel ridges and fill rings. Open roof panel ends under fill ring flashing collect grain dust and make natural insect breeding sites. Seal these openings with a foam sealer. For standard bolted tanks without intensive caulking, recirculation airflow rates should be higher (0.004 to 0.008 cfm / bu range) than for welded steel or concrete tanks.

Phosphine application. In CLF structures such as corrugated steel tanks that have leaks, phosphine tablets may be preferred over pellets because of slower gas release. In tightly sealed structures, such as welded steel and concrete tanks, pellets provide a faster, more uniform concentration buildup. Successful fumigation is based on maintaining an adequate minimum concentration of 100 ppm for at least three to five days.

After placing the phosphine pellets or tablets on the grain surface in the structure headspace and sealing the structure, turn on the CLF blower immediately or after a two- or three- hour delay. The air/gas mixture is pulled from the storage headspace through a 5- to 6-inch diameter duct (tube, pipe or hose) into the suction side of the blower, then pushed through a duct into the base of the storage, forcing it up through the grain back to the storage bin headspace. Blower operation options. You can operate the blower continuously, but if the structure is not tightly sealed, less gas loss occurs if you operate the blower until the gas distribution is uniform (two to three days) and then shut it off for two or three days. During shutoff periods, the fumigant remains in the grain and interstice air unless convection currents cause it to leak out of the structure. This is especially important in corrugated steel tanks and flat storage with poorly sealed roofs and sidewalls. Calculate total fumigation time based on grain moisture and temperature factors according to the fumigant label.

Gas level monitoring. While using a new CLF system for the first time, monitor gas concentration levels daily at key locations in the storage throughout the fumigant recirculation period to develop valuable management data. File and maintain these recorded gas-level monitoring data for future reference and comparison against future monitoring data.

Start by using high label rates (85 to 100 percent of maximum or normal probe dosages) during the first application of the new system, and then monitor to make sure gas levels are adequate. If initial gas readings are sufficiently high and stable for several days, reduce application levels by stages during future fumigations. If satisfactory gas levels and kill results warrant, reduce application to minimum label rates for the type of structure being fumigated.

Purging structures after fumigation. When possible, use aeration blowers to purge fumigant gas from structures. If aeration is not available, use CLF blowers to vent storage structures. CLF blowers that provide 0.002 to 0.01 cfm / bu air flow should be operated continuously for two to three days when venting storage because of nonuniform air distribution. Monitor air at access and entry points to be sure fumigant levels are well below the minimum worker re-entry threshold levels.

When CLF blowers are used for purging, disconnect the suction hose at the blower inlet, open the roof hatch or vents and turn on the blower. Open vents or hatches must be located away from fresh air supplies of blowers. If blowers are roof mounted, you may need a fresh air supply to be ducted to the blower from several feet away so exhaust air is not recirculated. Consider prevailing winds, and you may need standpipes to avoid dilution of fresh air.

If blowers are inside the storage, control the blower air supply from the outside to avoid the need for SCBA-equipped personnel to change the piping prior to venting or purging the fumigant (Noyes, 1993). On externally mounted blower and piping systems where the tank or silo has no aeration system, remove the suction return pipe and open roof exhaust vents or doors and operate the blower to purge the tank.

Regardless of the method used for venting the gas, monitor the air quality or gas level in each storage structure with appropriate gas-sampling equipment, preferably through remote sampling tubes, before entering the storage. You must take air samples inside the bin at entrances and in storage work areas and record them to confirm that the fumigant has been purged satisfactorily. Take work space air samples and record data before workers resume normal re-entry to ensure safe concentration levels of phosphine gas below 0.225 pp m (0.3 pp m x .75-phosphine gas monitoring tube accuracy ranges from about + 5 to 25 percent) for phosphine gas sampling tubes, depending on the tube range and the manufacturer.

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, always read and follow label instructions.

Factors affecting aeration time

In addition to the characteristics of the fumigant itself, several factors affect the rate of ventilation or aeration. 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, size and arrangement of area fumigated and the mixing of gases. When the conditions for mixing 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 one 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 stirring 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 slows down and requires longer aeration time. In some cases, it may be necessary to close up the area, reheat it to 76 degrees F and then repeat the aeration process to satisfactorily remove the fumigant. Sorption and desorption. The amount of fumigant sorbed by the materials in the area fumigated is referred to as the "load factor." This sorbed fumigant is not available to act as a fumigant, but it must be removed in the aeration process. Some commodities are much more sorptive than others just as some fumigants are more subject to sorption than others. The greater the sorptive capacity of the fumigant and 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, open machinery aerates much more rapidly than bagged flour. Because of the slow desorption rate of grain, hold it an additional 24 hours after the satisfactory aeration period. Pay particular attention to retention of fumigant gas by highly sorptive materials such as flour, meals and jute bags.

Aeration procedures

Procedures for aeration or ventilation vary with the fumigant and the area and items fumigated. Plan for the aeration before starting the fumigation.

Building ventilation. Plans for opening doors, windows and ventilators for the initial ventilation are particularly important. Whenever possible, open ground-floor windows and doors from the outside. Aerate 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, enter the building only for 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 previously have been opened from the outside. Don't open all windows on a particular floor at this time, but only those providing thorough cross ventilation. Then return to the outside. If ground-floor ventilation occurred before entry, work upward floor by floor, opening those windows necessary for cross ventilation. Do not remain in the building longer than 15 minutes. Turn on fans (non-sparking) and allow them 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 that indicates no fumigant vapors remain.

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

Test with detectors in closets, stacked commodities, etc., to be sure no gas remains. Usually after two or three hours aeration, the building can return to normal operation; however, check it first.

Tarpaulins. When aerating loads under tarps, in buildings or on still, humid days, make an opening by lifting the tar p on the end opposite the blower or source of air and discharging the fumigant with a blower near the outside opening. If you don't use blowers or strong cross ventilation, lift tarp at corners and raise as concentration is lowered prior to complete removal. Use respirators or gas masks. Occupants, other than fumigation operators, should vacate the building before tarps are aerated.

If aeration is in the open and the breeze is blowing, first lift the end or side of the tar p opposite the direction of wind movement, 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. Release free gas and aerate commodities immediately following fumigation. 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, provide intake and exhaust stacks. The exhaust stack must lea d outside the building. Open the intake and exhaust stacks after completing the fumigation exposure. The normal air-circulation equipment in a chamber can conduct air from the chamber to the outside.

When a chamber is outside a building, you can aerate it safely by opening the door slightly at the beginning of the aeration period and turning on the blower. Hold the door in the partially opened position so it cannot close accidentally. Vent air discharged from the blower to the outside of the chamber. If the door should accidentally close, the partial vacuum created by the blower may da mage the chamber.

No one should remain near the door or the exhaust when the blower is 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 then checked with a halide detector.

Soil fumigation

(From: Ramsay, et al., in *Soil Fumigation*, Cooperative Extension, Washington State University, Miscellaneous Publication O163)

Introduction

Soil fumigation is a chemical-control strategy used independently or in conjunction with cultural and physical control methods to reduce populations of soil organisms. Soil fumigants can effectively control **soil-borne** organisms, such as **nematodes**, **fungi**, **bacteria**, insects, weed seeds and **weeds**. Different fumigants have varying effects on the control of these pests. Some are pest specific while others are broad- spectrum biocides that kill most soil organisms. Soil fumigants are used in agriculture, nurseries, ornamental beddings, forest systems and other areas where soil-borne pests can harm or devastate desirable plants. Because of treatment costs, applicators use soil fumigants primarily on high-value crops, such as vegetables, fruits and ornamentals. Control of soil-borne pests will increase plant aesthetics, plant quality and vigor, crop yields and, ultimately, profitability.

Soil fumigation uses pesticide **formulations** that **volatilize** from a liquid or solid into a gas state. Soil fumigants are applied to the soil as liquefied gases, volatile liquids or granules. Because of the high volatility of these compounds, incorporate the fumigant into the soil during or immediately following application. At or shortly after application, these chemicals volatilize, allowing toxic molecules to move through the air pores in the soil. Some molecules dissolve in the water film surrounding the soil particles. Soil pests are killed when they come in con- tact with a toxic concentration for a long enough exposure period.

Fumigant formulations and descriptions

Liquefied gases are gaseous under normal temperatures and pressures. The gas is liquid when held in a pressurized container. When released from a container, the liquid immediately converts to gas.

Volatile liquids are liquid under normal temperatures but volatilize into a gas when in the soil.

Solids are granular under normal temperatures but volatilize into a gas when in the soil.

Fumigants diffuse in the soil. They ultimately dissipate into the atmosphere or decompose in the soil through chemical reactions or activity by soil microorganisms until their concentrations are negligible. To avoid toxic effects to subsequently planted crops or plants, allow a sufficient time interval to lapse for diffusion and decomposition of the fumigant. This preplant interval varies with the fumigant, its application rate and environmental conditions.

Most soil fumigants are registered for use only on a preplant basis due to their **phytotoxicity**.

Fumigation only controls those **target pests** present in the soil at the time of fumigation. Once applied, fumigants have no residual activity and will not control subsequent pest infestations.

Soil pests

Nematodes generally are microscopic. They are small, nonsegmented, threadlike round worms that attack and injure plants. Some develop into swollen adult females at maturity. Usually transparent, nematodes range in size from 1/64 to approximately 1 / 10 of an inch. A key feature used to identify nematodes that feed on plants is the presence of a hard, piercing spear or **stylet** in the anterior portion of the body. Plant parasitic nematodes use a stylet to puncture and feed on plant cells. Nematodes reproduce by laying eggs. Nematodes live either in the water film in and around soil particles and plant tissue or within plant tissues. **Ectoparasitic** plant nematodes remain on the outside of the plant. Most ectoparasitic nematodes migrate freely over the root surface although some more **sedentary** nematodes remain at one point to feed. **Endoparasitic** nematodes move into the plant tissue to feed. Endoparasitic nematodes either move in and out of roots or remain sedentary within the root. At certain life stages, nematodes are present in the soil.

Soil fungi also can destroy plants. Fungi (molds, mildews, *Pythium*) are plant-like organisms that lack **chlorophyll**; thus, they do not manufacture their own food. They must get nutrients from other sources, including plants. Most fungi reproduce by **spores**. Fungal spores germinate into thread-like filaments called **hyphae** that grow, secrete **enzymes**, absorb nutrients and release chemicals that induce plant diseases. Most soil fumigants can control soil fungi effectively.

A few species of soil bacteria cause plant diseases. Bacteria are small, one-celled organisms that reproduce by simple **fission**. They get nutrients from plant cells and generally need an injury or natural opening to enter plants.

Several insects and insect relatives that live in the soil are plant pests. The insects generally are immature stages of beetles and flies. These two groups of insects undergo complete metamorphosis, developing from egg to larva to pupa to adult. The larval stage (maggot, grub, worm) usually causes damage, though some adults also will feed on under-ground plant parts.

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

You may need to use a soil fumigant to control vertebrate pests, particularly moles. Moles feed on earthworms, white grubs, beetles, centipedes, millipedes and spiders. You usually can control them by eliminating their food supply, such as treatment for white grubs. Trapping and the use of toxic bait are other alternatives; consider them prior to soil fumigation.

Weeds also compete with plants. Some fumigants control weed seeds and germinating plants.

Factors influencing soil fumigation

Many factors affect soil fumigation and its effectiveness for pest control. The pest and its habits will affect fumigant selection, application rate, time of application, fumigant placement and necessary length of exposure. Soil factors also play a key role in fumigation. Soil texture, soil condition, debris, soil moisture and soil temperature may affect the volatility, movement and availability of the fumigant once applied. Fumigant dosage is both pest- and soil- dependent. The following section discusses some of these factors in greater detail.

Pest habits

Properly identifying the pest(s) is crucial. Once you identify the pest, you can understand its life cycles and habits. Understanding the pest's habits provides information for proper application timing to target the susceptible stage and for proper application depth to ensure adequate contact with the pest organisms. In Missouri, University Extension centers have information concerning pest identification.

Soil texture

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

Soil condition

Soil condition is a major factor in fumigant penetration and diffusion. Fumigants do not move uniformly through the soil. Compacted soil limits the amount of diffusion and penetration. Cultivating soil prior to fumigation is essential. Cultivate the soil to the level where the fumigant needs to diffuse. Break up or remove soil lumps, clods and nondecomposed organic matter. Pulverize and smooth the soil surface before fumigation to aid post- application sealing, if required. Sealing prevents fumigant vapor from escaping too quickly. Improper soil preparation is the major reason for fumigation failures. Fumigate soils before applying manure, sawdust or other organic matter.

Plant debris

Plant debris can pose problems to shank-type fumigation if excessive amounts of fresh or decaying plant material are present. Organic matter binds with the fumigant, making it unavailable for free movement. If a high concentration of organic matter is near the soil surface, it may impede proper diffusion of the fumigant and may create avenues (chimneys) for gas to escape. Work all vegetation into the soil thoroughly. Allow vegetation plenty of time to decompose before fumigation. Do not fumigate soils that contain excessive amounts of organic matter.

Soil moisture

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

Soil temperature

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

Application depth

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

Time of application

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

Dosage

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

Soil sealing

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

Exposure period

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

Soil aeration

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

Phytotoxicity

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

Application principles

Application techniques and equipment

Various types of soil-fumigant application equipment are available commercially. Appropriate soil-incorporation equipment and soil-sealing equipment should follow or be attached to the fumigant equipment. Good fumigation equipment is expensive to build and maintain. Sometimes it is necessary to buy custom-designed and custom-built equipment for specific purposes. Because fumigants are highly corrosive, equipment manufacturers must construct equipment from materials tolerant or resistant to these chemicals. Many fumigators either rent fumigation equipment or lease it from their fumigant supplier. Proper care of fumigation equipment is essential. Clean application equipment immediately after use, and cover or coat all parts with a lightweight fuel oil before storing.

Liquefied gas (example: methyl bromide)

Above-ground applications. Several devices are available commercially for applying liquefied gases to small areas, such as greenhouse growing media and nursery soil. Cover soil to be treated with plastic. Release fumigant through a plastic tube to an evaporation pan placed under the sealed plastic. The fumigant flows under pressure from the container to the soil to be fumigated. Large cylinders require valves and pressure regulators to control the delivery of the gas to the evaporation pan. Use a separate pressurized cylinder of nitrogen to maintain a constant pressure to the fumigant cylinder, ensuring a uniform application rate. The equipment you use with pressurized cylinders can be complex. You must be sure that the application systems are designed to deliver and withstand the pressurized fumigant.

Injection applications. For overall field application (broadcast) of liquefied gases, such as methyl bromide, apply the fumigant using a tractor with sufficient horsepower to pull shanks (chisels) through the soil at the required depth and speed. For shallow applications (6 to 12 inches), mount shanks 12 inches apart on a tool bar connected directly to a machine that lays a plastic tarp. For deep applications (18 to 30 inches), mount shanks up to 66 inches apart, depending up on fumigation conditions. Fumigant delivery rates depend on equipment speed and chemical flow rate.

The most commonly used machine to seal the soil with a plastic tarp consists of two discs that open small furrows immediately outside the area to be treated. These discs connect to a device that unrolls polyethylene plastic over the treated area. Small press wheels insert the plastic into the open furrows. Closing discs seal the plastic by throwing soil back into the furrow.

To treat a field on a broadcast basis, apply one strip as described above, then remove and replace one set of discs with an adhesive dispenser. Using the adhesive, seal one side of the second plastic sheet to the first plastic sheet, and seal the other side of the second plastic sheet in the furrow made by the remaining discs. Repeat to fumigate, and cover the entire field with plastic. The same type of fumigating equipment also is suitable for band applications (strip or row applications). For deep (18 to 30 inches) injections, you may not need to seal with a plastic tarp, depending on the target pests.

Auger applications. Use augers in perennial crops, such as deciduous fruits, nuts, vineyards, etc. Use them with either 1- or 1.5-pound seamless cans or with large cylinders of gaseous fumigants. After the auger digs a hole approximately 5 feet deep, release the fumigant into the hole at the proper dosage, and then fill the hole and compact for a soil seal.

Volatile liquids (examples: chloropicrin and metam-sodium)

Trench applications. To treat very small areas, such as ornamental planting beds, place the prescribed dosage of liquid fumigant in a small container. Pour the liquid into the bottom of a 6- to 8-inch-deep furrow. Cover and seal the trench. Form a water seal using a small amount of water.

Handgun applications. To treat small areas, such as experimental plots and nursery beds, use equipment with a holding tank connected to a hollow pointed base for penetrating the soil. A plunger device or drip device releases a known quantity of fumigant for each penetration.

Shank (chisel) applications. This method is the one most commonly used to treat large-scale areas, such as agricultural crops. Make field applications using tractors with sufficient horse power to pull the shanks through the soil at the required depth and speed. Narrow knifelike shanks (such as forward-swept shanks) inject fumigant. Metal delivery tubes attach to the trailing edges of the shanks. Delivery tubes release the fumigant in the bottom of the furrow that is made when you pull the shank through the soil. For **broadcast applications**, shank spacing usually equals the depth of injection. Maintain constant pressure to the metering pump, such as electrical or hydraulic pumps, power takeoff system (PTO), or ground -wheel drive. Regulate delivery rate using various combinations of pressure, nozzle orifice, shank spacing and speed of travel, depending on the pressure system serving the metering pump.

Shank equipment works for broadcast or **band applications**. For row applications, use equipment with either one or two shanks to treat only the soil where the crop will be planted. Seal the application with a plastic tarp or by mechanically compacting soil. If injection shank traces are present, disc soil to remove traces prior to sealing the soil.

Sweep or blade applications. Attach fan-shaped sweeps or blades equipped with evenly spaced fumigant outlets to the shanks and draw them through the soil. Seal the application with a plastic tarp or by mechanically compacting the soil. If blade shank traces are present, disc soil to remove traces prior to sealing the soil.

Drench application. Add the fumigant to water and drench the soil with this solution. This method is useful in nurseries, ornamental plantings and orchards.

Chemigation. To fumigate soil by chemigation, meter and inject a liquid fumigant into irrigation water. You can apply fumigant chemigation through several types of irrigation systems, most commonly center pivots. Equipment includes an injection pump and nurse-tank system. Proper setup includes check valves between the injection pump and both the fumigant supply and the water source. Keep all screens and filters clean. Use as large a droplet as possible to avoid loss of fumigant through volatilization in the air. Chemigation often requires irrigation to bring the field to the desired moisture level prior to fumigation. Moisture levels must be even throughout the field. Chemigation requires attention to detail, an understanding of the equipment used and constant monitoring during the application.

Volatile solids (example: dazomet)

Broadcast applications. Apply granules evenly over the soil and incorporate them, or inject the granules into the soil. For small-scale applications, use a shaker and apply over the area. Incorporate granules into the soil and seal. For large-scale applications, use a granule spreader to broadcast treat and then incorporate, or use a fertilizer drill or granule distributor that delivers the granules at the desired depth. Adjust application rate by changing the size of the opening from the hopper or by altering the speed of travel. Immediately after spreading, incorporate granules into soil to the proper depth using a rotary hoe or disc. Seal soil with a mechanical compactor.

Equipment calibration

Calibrate all applicators to deliver the desired rate of chemical. All commercially constructed applicators are designed to alter fumigant rates. Applicators use two basic methods for application-equipment calibration. The first method measures the amount of material applied over a known area. The second method collect s a volume of fumigant for a specified time period and measures the distance covered in the same time interval for a volume-to-area ratio. Table 4 gives you a number of useful figures for calibration.

Table 4. Useful figures for calibration.

1 acre = 43,560 square feet (ft^2)
1 gallon (gal) = 4 quarts (qts) = 8 pints (pts) = 128-fluid ounces
1 gal = 3,785 milliliters (ml)
1 fl oz = 29.57 ml
1 cubic foot (water) = 7.481 gals
1 acre inch (water) = 27,156 gals
1 pound (lb) = 16 oz = 453.6 grams (g)
1 mph = 88 feet per minute = 1.467 feet per second (ft/sec)
Circle circumference = $2\pi r$ (r = radius; _ = 3.1417)
Circle area = πr^2 (r = radius; π = 3.1417)

Application over a known area

This calibration method is useful for gravity flow and ground-driven metering systems. Apply fumigant over a small, known area. Measure or weigh the amount of fumigant used over that area. Measurement may include determining the amount delivered by calculating the difference from the volume or weight at the start and the residual volume or weight after the application to the known area, or simply by collecting the volume or weight delivered. Compute the amount per acre equivalent from the amount delivered (per small area). If necessary, adjust the equipment to approach more closely the desired amount, and repeat the process. Follow equipment operation instructions to alter flow rate; methods differ among equipment. Repeat calibration several times until the equipment delivers the exact amount required per acre.

To achieve the label application rate, use the following equation to determine the amount of fumigant that you should apply over the calibration test area.

For example, to calibrate a shank applicator with a liquid fumigant, measure the effective swath width, let us say 8 feet wide with seven shanks. The label rate for the application is 20 gallons of fumigant per acre. To calibrate, travel 100 feet with the application equipment and collect all the material released from one outlet. Multiply the amount collected by the number of shank outlets to get the total delivery rate of the equipment. How much material should the equipment deliver from all the outlets if the equipment is calibrated at 20 gallons per acre? The first step is to make sure that all nozzles deliver within 10 percent of each other to maintain a uniform application pattern. Replace nozzles that do not conform.

(8 ft x 100 ft x 20 gal) ÷ 43,560 ft² = 0.367 gal
0.367 gal x 128 oz/gal = 47 oz for the system
47 oz ÷ 7 nozzles = 6.7 oz per nozzle
0.367 gal/800 ft² is equivalent to 20 gal/acre

If the equipment delivered too much material (>6.7 oz per nozzle), it is over applying. If the equipment delivered too little material (<6.7 oz per nozzle), it is underapplying. Adjust the equipment until it delivers the proper amount of material. Follow equipment manufacturer's instructions for changes. Adjustments may include altering pressure, application speed or nozzle orifice.

Calculate flow rate per unit time

This is the common method for calibrating metering systems driven by PTO and electric or hydraulic pumps. For volatile liquids, measure fumigant flow rate for a specific time interval and then convert that measurement to an area basis dependent upon the application equipment speed. To alter the delivery rate, adjust the speed of travel, orifice size, shank spacing or pressure.

For liquefied gases, such as methyl bromide, the method differs slightly because the gas can't be collected. Before releasing gas, weigh the gas cylinder. Release gas for a set time. Re-weigh cylinders and calculate how much was released over the time interval. Calculate the distance the equipment travels for that time interval. You now know the amount of fumigant applied per unit area. Convert to an acre basis. Adjust the in-line valve to tune the flow rate to the proper level for the proper delivery rate.

For example, to calibrate a shank applicator with a liquefied gas fumigant, measure the effective swath width of the shank row. For this example, we'll use an 8-foot width. The label rate is 350 pounds per acre. Weigh the cylinder. Release material for 30 seconds. Re-weigh the cylinder. Calculate the amount used in 30 seconds.

Determine the application-equipment speed. Mark the start and finish of a 100-foot speed course. Time the equipment over the course, once each direction.

Example: 33 and 35 seconds

Conduct the speed test in the application area with the equipment loaded and the shanks at the application depth. Average the times determined across the speed course, and convert to feet per second.

(33 + 35) ÷ 2 = 34 seconds to travel the 100-foot course
100 feet ÷ 34 seconds = 2.94 feet per second

Calculate the distance covered in 30 seconds.

2.94 ft/sec x 30 sec = 88 ft

Now use the formula to determine the amount of material that should be delivered on the 8-foot by 88-foot area (or in 30 seconds).

(8 ft x 88 ft x 350 lb) ÷ 43,560 ft² = 5.66 lb

If the equipment delivered too much material (>5.66 lb in 30 seconds), it is overapplying; reduce the flow rate. If the equipment delivered too little material (<5.66 lb), it is underapplying; increase the flow rate. Adjust the flow rate until equipment delivers the proper rate in 30 seconds.

Chemigation

Fumigant application through irrigation requires great attention to calibration and operation details. Failure to calibrate accurately or to monitor the system continuously during the application can lead to costly mistakes. Poorly made applications may result in poor control or expensive and illegal excessive applications.

Check sprinkler system for proper operation and uniform water distribution. Check irrigation systems using catch cups to determine the speed of the irrigation system needed to provide at least 1-acre-inch of water delivery. Once the timer is set to deliver 1-acre-inch of water, do not reset it before making the application. If the timer is reset, for any reason, recalibrate the system to ensure an accurate level of water delivery.

Check the injection pump and nurse-tank system to ensure proper operation. Clean all screens and filters. Make sure check valves are in place between the injector pump and both the water source and the nurse tank.

Determine the revolution time of the center pivot. Place a flag or marker at the end wheel, and measure the distance traveled in a given time interval, such as 30 minutes. With a calculated circumference, calculate the revolution time. Once you know the revolution time (minutes per revolution), calculate the injection rate and calibrate the injection pump for proper delivery.

For example, the label rate for metam-sodium is 50 gallons per acre. The center pivot is 1,320 feet to the end wheel, and the end gun covers an additional 40 feet (radius = 1,360 ft), for a total of 133.3 acres. When running at 45 percent on the timer, the center pivot applies 1-acre-inch of water. The pivot moves 346 feet in 2 hours at the end wheel.

First, calculate how much metam-sodium is needed for the job:

50 gal/acre x 133.3 acres = 6,665 gal

Next, determine revolution time. It takes 2 hours (120 minutes) to travel 346 feet at the end wheel, so how long will it take to cover the entire circle?

End wheel circumference = 2 x 3.1417 x 1,320 ft = 8,294 ft

Set up a ratio calculation to determine end wheel revolution time:

120 minutes/346 ft = X/8,294 ft = (120 min x 8,294 ft)/346 ft = 2,876.5 min (47.9 hours)

This means that it takes 47.9 hours to cover the entire circle of 133.3 acres, needing 6,665 gallons of metam-sodium. Next calculate the amount of metam-sodium that must be injected, per minute, into the irrigation water to deliver 6,665 gallons per 2,876.5 minutes. A reduction in terms is all that is necessary: gallons to ounces or milliliters, depending up on how the injection system is set up.

(6,665 gal/2,876.5 min) x 128 oz/gal = 296.6 oz/min

or

296.6 oz/min x 29.57 ml/oz = 8,769.9 ml/min

To achieve a rate of 50 gallons per acre in a pivot moving 173 feet per hour, inject chemical at a rate of 296.6 ounces per minute (2.3 gallons per minute).

Another example: The center-pivot irrigation system covers 133.3 acres, with a radius of 1,360 feet (1,320 to the end wheel + 40 feet for end gun). In 1 hour, the end wheel travels 210 feet. At 50 percent on the timer, it is applying 1-acre-inch of water. To achieve the label rate for nematode control in potatoes of 75 gallons per acre, how many milliliters of chemical need to be injected each minute? Solution:

133.3 acres x 75 gal per acre = 9,997.5 gallons needed

End wheel circumference = 2 x 3.1417 x 1,320 ft = 8,294 ft

Revolution time at end wheel = 60 min/210 ft = X/8,294 ft

(60 min x 8,294 ft) ÷ 210 ft = 2,369.7 min (39.5 hours)

9,997.5 gal/2,369.7 min x 128 oz/gal x 29.57 ml/oz = 15,968.3 ml/min

Soil fumigant characteristics and uses

The following section discusses the major principles involved in handling and applying soil fumigants for safe, effective control of soil-borne organ- isms. Some of the factors differ consider ably among the fumigants. Prior to making an application, you must understand the following information:

- What pest(s) does the fumigant control effectively?
- How well does the fumigant diffuse through the soil?
- What are the requirements for soil condition, moisture levels and temperatures?
- What equipment do you need to apply the particular formulation?
- How deep do you need to place the fumigant?
- What application and soil sealing methods are best?
- In addition to the standard safety precautions, are there any special safety precautions for personal or environ mental safety?

Note: Following the application of any soil fumigant, regardless of the method, you must establish a soil surface seal. Covering the soil with a plastic tarp provides the near perfect seal. You can partially seal the soil surface to retard rapid loss of fumigant by light irrigation, by cultipacking the soil, by harrowing followed by roller, by rotary tillage and roller or by rotary tillage and power rolling. You'll have more success controlling pests in the upper 2 to 3 inches of soil when you seal the application with plastic since water or when soil compaction decreases the pore space into which the fumigant can diffuse.

Methyl bromide

Methyl bromide is a general soil biocide. It controls weeds, insects, nematode s and some soil-borne diseases. Methyl bromide, a liquefied gas, is stored under pressure in 1- to 1.5-pound cans or cylinders.

Highly volatile, it changes to an odorless gas when you open the can. It travels up to 36 inches in the soil. It has the greatest volatility, thus the widest range of diffusion of all the soil fumigants. Methyl bromide is extremely toxic to mammals, including humans. Do not risk exposure to levels higher than 5 ppm without the proper protective equipment. Inhalation can be fatal; wear appropriate respirators at all times.

Preapplication. Till soil to below the level of desired control. Work soil surface to seedbed condition. Soil moisture levels may range from 30 to 70 percent field capacity, depending on other soil conditions; check label recommendations. For deep injection, it is preferable to have soil moisture below 50 percent field capacity at a depth of 18 to 24 inches. Soil temperatures, at the target depth, can range from 40 degrees F to 90 degrees F with an optimum range of 50 degrees F to 85 degrees F.

Application. Apply methyl bromide by application to or by injection into the soil. For surface application, cover surface with a plastic tarp, and release the chemical through tubing directly from the cylinder to evaporation pans placed underneath the cover. For shallow applications, use shanks to inject the fumigant 8 to 10 inches deep. For applications less than 10 inches, cover application area with plastic tarp.

Use deep applications (greater than 12 inches, usually 18 to 30 inches deep) only for nematode and insect control. For applications greater than 18 inches deep, cultivate and pack soil surface to destroy injection shank traces and to com pact the soil surface; sealing with a plastic tarp is not necessary.

Chloropicrin

Chloropicrin has general biocidal activity. It is most active against soil fungi and insects with limited activity on weed seeds and nematodes. Chloropicrin generally is manufactured combined with other fumigants, such as methyl bromide, to increase the range of pests to be controlled and as a warning agent when added to odorless methyl bromide. Commonly known as "tear gas," it has the odor of garlic. Chloropicrin, a liquid, moves 6 to 12 inches from point of injection. Chloropicrin is extremely toxic; handle it accordingly. In its liquid form, it can damage skin and eyes, even during short exposures. The vapor irritates the eyes, skin and nose.

Preapplication. Till soil to below the level of desired control. Work soil surface to seedbed condition. Soil moisture levels may range from 30 to 70 percent field capacity, depending on other soil conditions. Soil temperatures, at injection depth, can range from 40 degrees F to 85 degrees F with optimum range of 50 degrees F to 80 degrees F. Check the label for moisture and temperature requirements; they vary for combined fumigant formulations (methyl

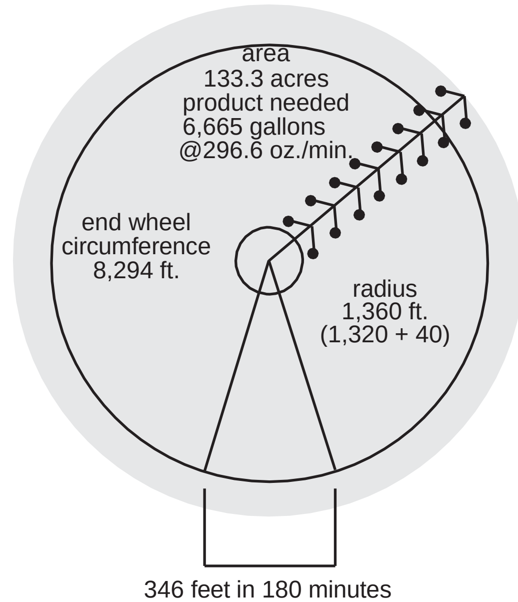

Figure 5. Center pivot calculations.

bromide + chloropicrin).

Application methods. Chloropicrin generally is used in combination with other fumigants; thus, the application methods vary. When you inject 6 to 10 inches deep, alone or in combination with methyl bromide, use a plastic tarp because of chloropicrin's high volatility. Sealing bed applications with a plastic tarp is not necessary for plant disease control under special conditions. Use no-tarp applications only under specific conditions.

Metam-sodium

Metam-sodium is a general soil biocide. It is active on some weeds, weed seeds, insects, nematodes and soil-inhabiting fungi. In contact with soil, metam-sodium breaks down into MITC (methyl isothiocyanate). Metam-sodium, soluble in water, is used in chemigation. This material is moderately toxic to mammals, including humans.

Preapplication. Site preparation will, in part, depend up on the application method. Soil moisture requirements (generally above 75 percent field capacity) depend on the application method. Refer to the pesticide label. Soil temperatures can range from 40 degrees F to 90 degrees F at a 3-inch depth (optimum 50 degrees F to 80 degrees F).

Application. You can apply metam-sodium to the soil through irrigation systems, including overhead, drip and flood; by injection; by band or sweep applications; or by broadcast to the soil surface followed by mechanical incorporation. The control to be achieved and the depth of control you desire determine the method or combination of methods. Refer to the pesticide label. Soil sealing may be required, depending on the application method. Seal soil by incorporation, follow by laying a plastic tarp, compacting with a power driven roller or applying water.

Nursery personnel commonly use metam-sodium in potting soils and container growing media. For this use, apply the label rate of metam-sodium by sprinkling the soil with dilute metam-sodium and then incorporating metam-sodium into the soil with a mixer or through a soil shredder. After applying metam-sodium, cover soil with a plastic tarp. A preplant test using the germination of radish seeds in the medium will indicate any phytotoxic effects. If seeds germinate and seedlings grow normally, metam-sodium has dissipated from the soil.

Dazomet

Dazomet is a general soil biocide used in ornamental seed beds and turf seed beds. It is active on some weeds, weed seeds, insects, nematodes and soil-inhabiting fungi. Dazomet, a solid, is sold as a granular formulation. The major fumigant fraction of dazomet in the soil is MITC (methyl isothiocyanate).

Preapplication. Work soil to a depth of 12 to 18 inches. Soil surface should be relatively free of clods and moisture at 50 to 80 percent field capacity. Soil temperature, at the target depth, should range from 40 degrees F to 90 degrees F with the preferable range of 50 degrees F to 80 degrees F.

Application. Spread dazomet, a dry formulation, on the soil surface and incorporate into the soil to the depth the control is needed, or inject with drills to the proper depth. After application, compact or water seal the soil surface. Use a plastic tarp for water seal after treating small limited areas or if you want nearly total weed control.

General instructions for all fumigants

Preceding sections included detailed discussions of specific fumigants and fumigation procedures. The following sections discuss important issues that affect all fumigants.

Many of the regulations stressed in this manual were established only recently. Suspensions of registrations for ethylene dibromide (EDB), ethylene dichloride (EDC), carbon bisulfide and carbon tetra- chloride were enacted from 1984 through 1986. Some products may possess a federal registration (such as dichloropropene); however, they are not registered for use in Missouri. In 1986 and 1987, several new regulations addressed application and worker-safety concerns for fumigants that remain registered. Also, the new Worker Protection Standard was fully implemented in 1995 (see page 4 of this manual). These regulations officially required that two applicators be present for most fumigant applications and mandated important changes in gas-monitoring practices, respiratory protection equipment and placard requirements. These regulations are presented as part of the use directions on fumigant labels and supplemental instructional material (legally considered part of the label). Label instructions are considered law. Violation of label instructions makes the applicator liable to criminal and civil proceedings.

Two trained applicators

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

Gas-detection devices

Revised labels for fumigants require the use of sensitive gas-monitoring devices during fumigant application and before warning placards can be removed from fumigated storage. Devices that provide adequate sensitivity include gas-detector tubes and matching pumps manufactured by Auer, Draeger, Matheson-Kitagawa, MSA and Sensidyne. Detector tubes are sealed glass tubes filled with a specific reactive solid. Break off both ends of a tube just before use, and attach one end to a calibrated pump. Available pumps use a bellows, bulb or piston-type syringe to draw a precise volume of air through the detector tube. Discoloration of the solid material within the tube indicates fumigant presence, and the gas concentration can be read directly from the scale on the glass tube. Although tubes and pumps manufactured by different companies may be similar, accurate readings require matching detector tubes and pumps from the same manufacturer. **Do not mix separate brands of equipment.**

"Low-range" detector tubes that accurately indicate low levels of fumigant concentrations are required for label-specified monitoring practices that provide information for worker safety. "High-range" tubes may be useful for detecting fumigant leaks. These tubes are scaled for measuring much higher concentrations of fumigants, and they are especially useful for monitoring gas concentrations within storage during fumigation to determine whether you've reached necessary fumigant levels. You may use other gas-monitoring devices, such as halide leak detectors and thermal conductivity meters, to detect leaks or determine internal concentrations of gas during fumigation, but these devices do not provide label required sensitivity levels necessary to determine safety needs such as respiratory protection.

Detector tubes are specific for a single fumigant. Auer, Draeger, Matheson-Kitagawa, MSA and Sensidyne manufacture detectors that offer adequate sensitivity for label- required monitoring of hydrogen phosphide and methyl bromide. The only currently available chloropicrin detector is produced by Matheson-Kitagawa. Several manufacturers offer tubes for measuring CO^2 concentrations.

Respiratory protection

Fumigant labels require the use of specific respiratory protection equipment during most fumigant applications. Labels also state maximum fumigant concentrations in which applicators can work with-out respiratory protection. Gas concentrations greater than specified levels indicate that exposed workers must use respiratory protection equipment. Workers exposed to hydrogen phosphide must wear a canister-type gas mask or SCBA if hydrogen phosphide concentrations in the work area exceed 0.3 ppm. Workers must wear a SCBA at concentrations greater than 15 ppm or when hydrogen phosphide gas concentrations are not measured. Workers exposed to chloropicrin concentrations greater than 1.1 ppm must wear a canister-type respirator, a SCBA or a combination air-supplied-SCBA respirator. Workers exposed to methyl bromide levels greater than 5 ppm must wear a SCBA or a combination air-supplied-SCBA respirator. A SCBA or combination air-supplied-SCBA respirator is required when CO^2 concentrations in work areas exceed 1.0 percent.

Canister and cartridge-type gas masks or respirators use a replaceable canister or cartridge containing chemical components that absorb specific gases. Use full-face, canister respirators (not half-face cartridge respirators) when this type of respiratory protection meets label specifications.

The effective life of an individual canister varies according to fumigant concentration and the respiratory rate of the applicator. Each canister lists its maximum limits. Under NIOSH / MSHA regulations, canisters are color-coded according to fumigant absorbency. Canisters approved to provide protection from hydrogen phosphide are coded yellow with an orange stripe; canisters effective for protection against chloropicrin are color-coded black. No canisters currently are approved for protection against methyl bromide. In addition to checking color-coding, you must be sure that written specifications indicate that a canister is effective against the fumigant you plan to use.

When a canister is no longer effective, it becomes hot. Some canisters have a color gauge or “window” that shows when they are about to become ineffective. Breathing hot air or meeting with high resistance to breathing also are warnings that the canister is about to become ineffective. When this occurs, or when you smell or taste the fumigant or become nauseous or dizzy, exit the fumigated area immediately. Crush an expired canister before you discard it so that no one will mistakenly use it in the future.

Canister respirators are inadequate for use in oxygen-deficient environments such as those produced during CO^2 fumigations. Although the canister may absorb the toxic fumigant in this environment, it cannot supply necessary oxygen. In these situations, you need a SCBA or a combination air-supplied- SCBA respirator.

The SCBA commonly used for fumigation is the air pack. Air packs consist of a full-face mask attached to a tank of air carried on the applicator’s back. An air pack supplies up to 25 to 30 minutes of air and allows work in an oxygen-deficient environment. This time period may be considerably shorter if overexertion increases your respiration rate. You can set a warning bell to signal the depletion of the air supply.

In a fumigant-laden storage, safe exit may require uninterrupted respiratory protection. For this reason, carry an approved canister respirator when using an air pack for situations where oxygen concentrations remain adequate. The canister respirator allows emergency escape if the SCBA expires or mal- functions.

Methyl bromide and chloropicrin label directions concerning respiratory protection include reference to combination air-supplied-SCBA respirators. Air-supplied respirators use an outside air source pumped to the applicator through an air line. The air-line system’s major advantage is that the air supply does not expire in a short time. Disadvantages, however, include: you must tow the air line throughout the storage; air-pump failure or a constriction of the air line can shut off the air supply; and you must locate the air pump in a fumigant-free area. In combination with a SCBA, an air-supplied respirator DOES NOT offer an unlimited work period with backup respiratory protection provided by the SCBA if for any reason the outside air supply is cut off.

One final topic regarding respiratory protection concerns the fit of face masks. A face mask that does not seal tightly against the face cannot provide protection from a fumigant gas. You must select a mask that fits your face; cleanly shave facial hair for a tight fit. Test the fit by closing off the breathing tube and trying to breath in or blow out air. Passage of air between the mask and the face indicates an unsatisfactory fit. Another test involves the release of an irritant gas in front of the mask. If the gas leaks into the mask, you will experience eye or respiratory irritation or nausea.

A direct correlation exists between comfort and user acceptance. If workers have comfortable respirators, they are less likely to remove or adjust them. An important comfort consideration is the type of material used in the mask's construction. Common materials include silicone rubber, neoprene, EPDM, nitrile, natural rubber and PVC. Most safety professionals prefer silicone because of its chemical resistance, durability, elasticity and comfort. For example, silicone rubber is unaffected by ozone-containing environments in which organic materials such as nitrile, natural rubber and neoprene slowly deteriorate.

Materials should be hypoallergenic to reduce skin irritation, especially in hot, humid environments.

Warning placards

Labels specify the wording and content that must appear on warning placards (including the presentation of some information in both English and Spanish). These requirements represent no major changes in a fumigator's procedures.

Regulations do specify an important step concerning the removal of warning placards. Following aeration, you may not remove warning placards, and the commodity may not be processed or fed until a certified applicator uses an appropriate gas-detection device to determine that gas concentrations have dropped below levels specified for each fumigant. Such followup monitoring was not previously conducted by many applicators.

Special considerations for fumigant container disposal

Fumigants are hazardous materials; you must handle appropriately all empty containers and excess or unused fumigant. The correct method of handling containers differs among fumigant products. To refill, return empty canisters or tanks used to hold methyl bromide or CO^2 under pressure through the original shipper to the manufacturer. Some chloropicrin containers should be handled in the same manner although others should be triple-rinsed and disposed of in approved landfills. Consult specific container labels for instructions.

Dispose of unused aluminum phosphide pellets or tablets in opened flasks. If flasks are resealed, safely store these tablets or pellets for future use as long as the label remains intact. Do not store flasks at sub-zero temperatures because doing so will increase the likelihood of ignition when they are opened.

If aluminum phosphide tablets or pellets are spilled or flasks are punctured, hydrogen phosphide gas is released. People cleaning up the spill or working in the contaminated area must wear a SCBA unless they use gas- detection equipment. If gas concentrations are measured, they should use a canister respirator if hydrogen phosphide concentrations range between 0.3 and 15 ppm. At higher concentrations, a SCBA is required. Technically, the full-face canister respirator can be used in concentrations up to 1,500 ppm for emergency escape purposes, but do not use them to re-enter an area where concentrations exceed 15 ppm. Cleanup personnel should wear cotton or neoprene gloves while handling spilled material. If you can clean up a spill, immediately use spilled pellets or tablets or transfer to an empty flask with an intact label. If such a container is not available, place tablets or pellets in a sound, dry metal container, which should be sealed and labeled as aluminum phosphide. Keep the original product label with the substitute container.

If spilled material has begun to react and decompose or if other substances contaminate it so it cannot be safely stored, gather it and place it into open-top, perforated gallon cans and process immediately. Do not use water to clean up an aluminum phosphide spill. Water rapidly reacts with tablets or pellets to release hydrogen phosphide gas, and the rapid gas production can cause spontaneous ignition and explosion.

To deactivate unreacted or partially reacted pellets, transport them by hand or in an open vehicle to open air away from occupied structures. Fill a drum two-thirds full with water and add one-quarter cup of low-sudsing liquid detergent or surfactant for each gallon of water. Mix each flask of tablets or pellets with no less than 1 gallon of the water-detergent mixture. Wear respiratory protection equipment and slowly add the aluminum phosphide product to the drum while stirring. Stir occasionally thereafter for at least 36 hours.

This wet method of deactivation is preferred when you must deactivate five or more flasks of material. Dispose of the resulting slurry at an approved landfill or burial site.

An alternative to slurry deactivation is dry deactivation (for quantities not exceeding five flasks). Spread out pellets or tablets in an open, secure area away from occupied buildings and deactivate by atmospheric moisture.

Disposal of residual dust from reacted pellets or tablets is necessary following a space fumigation. Residual dust is grayish white, and it contains a small amount of unreacted aluminum phosphide. Tablets or pellets that are only partially reacted remain slightly greenish in color; dispose of them in the manners described above for spills. Residual dust from up to five flasks can be disposed of by on-site burial or by spreading over the land surface in a secure area away from inhabited buildings. This amount of dust also may be disposed of at a sanitary landfill or approved pesticide incinerator. For larger amounts of residual dust, use a detergent slurry disposal method similar to that described above. See product labels for additional directions.

Residual dust from up to three flasks can be held in an open 1-gallon bucket pending disposal. Larger amounts of dust should be held in a porous cloth bag during any storage or transport before disposal. Do not put the residual dust from more than eight flasks of tablets or ten flasks of pellets in any one bag before disposal. Greater amounts may generate enough gas that a risk of explosion exists. Do not pile these bags or leave them exposed to rain. Do not confine, dispose of or store residual dust in closed containers such as dumpsters, drums or plastic bags. Do not dispose of dust in toilets.

You may recycle or dispose of in sanitary landfills empty flasks that contained aluminum phosphide after you have properly processed them. To clean flasks adequately prior to disposal, triple-rinse and puncture flasks and stoppers, or puncture a small number of empty flasks and place outdoors in an open and secure area away from occupied buildngs to allow complete reaction of aluminum phosphide. If you use triple-rinsing, dispose of rinsate in a sanitary landfill.

Common sense

It is essential that fumigators understand and follow the technical instructions that promote safe and effective fumigation pest control. It is just as important that fumigators remember to use good common sense when planning and carrying out a fumigation. Although it may be impossible to teach good common sense by writing instructions in study materials, the following comments are offered as reminders to exercise good judgment and think ahead:

- Read and understand label directions. Demand information from the manufacturer, distributor and other information resources. Do not use a fumigant without adequate training and confidence in your ability to do the job properly.
- Supply local medical personnel with fumigant and poison-treatment information before using the fumigant.
- Preplan the entire job. Think through every step, and plan your reactions to possible problems and emergencies.
- Always work in pairs.
- Use or have available proper safety equipment. Make sure all equipment fits well and that all applicators are trained in and familiar with the use of necessary safety equipment.
- Do not take short cuts; follow through with well-planned and thorough application practices.
- Do not become complacent. Each job is a new challenge and a new situation in which an emergency may require rapid and proper reaction.
- One phrase may be appropriate: “Do not be the fastest fumigator; be the oldest.”

Glossary

Active ingredient. The chemical in a pesticide formulation primarily responsible for its activity against pests. It is identified on the ingredients statement of the product label.

Adsorption. Holding or binding to a surface.

Bacteria. Very small, one-celled organisms that reproduce by simple fission.

Band application. Placement of a pesticide in a strip either over or along the crop row.

Biocide. Substance that has action to kill all organisms, including plants, animals, fungi, etc.

Broadcast application. Application made uniformly over an entire area rather than only over rows, beds or small spots within a general area.

Chemigation. Injecting agricultural chemicals (fertilizers, pesticides) into an irrigation system.

Chlorophyll. Pigment in plants that gives them their green color.

Complex metamorphosis. Development from egg to larva to pupa to adult.

Diffuse. Move in all directions.

Ectoparasitic. Live outside of the organism on which they feed.

Endoparasitic. Live within the organism on which they feed.

Enzyme. Proteins that initiate or speed up specific chemical reactions.

Exoskeleton. The hard outer skeleton.

Fission. Division of one-celled organisms into two-progeny cells.

Forewings. Front pair of an insect's wings.

Formulation. The active and inert ingredients that make up a pesticide product (i.e., an emulsifiable concentrate or a granule).

Frass. Excrement.

Fumigant. Penetrating gas.

Fungi. Plant-like organisms that lack chlorophyll and conductive tissues; reproduce by spores.

Germination. Sprouting or developing of a seed, bud or spore.

Hazard. Degree of danger, risk.

Hyphae. Vegetative growth portion of fungi.

Insect. An animal with an exoskeleton and jointed appendages that has three body segments, three pair of legs and sometimes wings.

Larva. An immature stage of an insect that undergoes complete metamorphosis.

Nematode. Generally a microscopic, nonsegmented threadlike round worm.

Organic matter. Remains of plant and animal debris found in the soil in all stages of decay.

Phytotoxicity. An effect that is injurious or lethal to plants.

Placard. A poster or notice giving information.

Pore space. Area between soil particles that is filled with air or water.

Primary pest. Pest that attacks undamaged grain kernels.

Protectant. Chemical placed on grain to guard against a possible infestation.

Pupa. A stage in insect development between the larva and adult.

Quarantine. Isolation or restriction imposed to keep pests from spreading.

Secondary beetle. Beetle that can attack only previously damaged grain kernels.

Sedentary. Relatively immobile, moves very little.

Simple metamorphosis. Development from egg to nymph (looks like adult with no wings) to adult.

Soil-borne. Lives in the soil.

Sorption. Absorption or adsorption.

Spore. Reproductive unit of fungi.

Stylet. A piercing instrument of nematodes used to puncture cells and feed on cell contents.

Surface-feeding caterpillar. Insect that commonly inhabits the outer parts of a grain mass.

Symphylan. An animal with an exoskeleton and jointed appendages that has many body segments and legs, looks like a centipede.

Target pest. Pest at which a control is directed.

Toxic. Injurious to plant or animal or both, poisonous.

Volatilize. To evaporate, change from liquid to gas.

Weed. A plant that grows out of place.

Weevil. Beetles with mouthparts at the end of an extended snout.

Emergency Telephone Numbers

Missouri Regional Poison Control Center — 1-800-366-8888

For pesticide poisoning emergencies, the Missouri Poison Control Center is accessible through a toll free number. The center is located and administered by Cardinal Glennon Memorial Hospital in St. Louis. It is staffed 24 hours daily with medical professionals. The center is equipped to refer poisoning accident victims to a local poison control emergency facility.

Missouri Emergency Response Team — (573) 634-2436

For pesticide spill emergencies, the Emergency Response Team handles pesticide spills any where in Missouri. For information, call (314) 751-7929. Contact: Environmental Emergency Response Coordinator, Missouri Department of Natural Resources, Division of Environmental Quality, P.O. Box 176, Jefferson City, MO 65102.

National Pesticide Safety Team Network (Chemtrec) — 1-800-424-9300

The National Agricultural Chemicals Association has a telephone network. This network can tell the applicator the correct contamination procedures to use to send a local safety team to clean up the spill. An applicator can call the network toll free and any time.

National Pesticide Tele-Communications Network — 1-800-858-PEST

Call the NPTN network toll free.

U.S. Environmental Protection Agency (EPA) — (913) 551-7000

All major pesticide spills are required by law to be reported immediately to the U.S. Environmental Protection Agency, Region VII Office, 726 Minnesota Avenue, Kansas City, KS 66101. The following information should be reported:

1. Name, address, and telephone number of person reporting
2. Exact location of spill
3. Name of company involved and location
4. Specific pesticide spilled
5. Estimated quantity of pesticide spilled
6. Source of spill
7. Cause of spill
8. Name of body of water involved, or nearest body of water to the spill area
9. Action taken for containment and cleanup.

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